Summary of Performance Analyses of a Santa Clara County Facility by CEE 243 Student Groups

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Abstract

In recent years, much attention has been given to the gap between predicted and actual performance in buildings. Attempts to design energy efficient buildings have often led to underperforming buildings, oftentimes far below code. Existing buildings can veer away from their functional intents with varying impacts on energy consumption. In the spring of 2010, four groups of students in Stanford University's CEE 243 class studied and analyzed multiple HVAC systems within a Santa Clara County facility. These groups analyzed a large amount of sensor data from these systems to determine whether the individual systems were performing well and meeting their functional intents. After graphically analyzing data, trends were noted, problems diagnosed, and hypotheses formulated. Analysis was based graphs generated by Stanford Energy Efficient Information Tool (SEE IT). The *SCC Facility Data Manual, Version 1.4* gave set points and descriptions of intended system behavior. Anomalies were noted by comparing measured data from the intent described in the *Manual*. Hypotheses were then tested through further analysis, and informed recommendations were provided. Students without prior experience were able to draw conclusions and recommendations for the facility's operation. This information was then relayed to Santa Clara County for use in retrocommissioning efforts to reduce energy consumption and ensure restoration of functional intent.

This document summarizes these findings with most content directly from the groups' final reports. Contributors for each section are noted at the end of the document.

Key words:

BIM, building, energy analysis, energy monitoring, energy use, energy prediction, measurement

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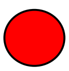
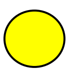
Introduction

In the spring of 2010, four groups of students in Stanford University's CEE 243 class studied and analyzed multiple HVAC systems within a Santa Clara County facility. This document is a summary of their work. These groups analyzed a large amount of sensor data from these systems to determine whether the individual systems were performing well and meeting their functional intents. After graphically analyzing data, trends were noted, problems diagnosed, and hypotheses formulated. Analysis was based graphs generated by Stanford Energy Efficient Information Tool (SEE IT). The *SCC Facility Data Manual, Version 1.4* gave set points and descriptions of intended system behavior. Anomalies were noted by comparing measured data from the intent described in the *Manual*. Hypotheses were then tested through further analysis, and informed recommendations were provided.

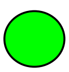
Each of the systems was given a traffic light symbol to indicate the functional performance of the system. This traffic light signifies the degree to which the system's behavior is believed to align with functional intent, based on the functional intent communicated to the team and the team's best interpretation of the available data. The following describes the meaning of each color of traffic light:



System operation does not align with functional intent. Major system operational and/or control issues are present and thus, system requires immediate attention. Operational improvement will likely yield significant energy savings.



System operation does not appear to align with functional intent, but operation and/or control schemes are unclear and require additional investigation. Systems have some potential for operational improvement and energy savings. SCC Facility manager should be consulted.



System operation aligns with functional intent.

System Descriptions

Below are short summaries of the systems for reference. More detailed descriptions can be found in the *Manual*.

SF1/SF2/SF3

Supply fans SF1, SF2, and SF3 provide ventilation and temperature control to the holding cells. Outdoor air is drawn in and passed through a heat exchanger and then conditioned by heating and cooling coils before being provided to the cells. The return air is exhausted and not mixed with the supply air stream.

AH1/2

AH01 and AH02 are variable air volume air handlers both located on the third floor and serve the basement; AH01 controls the cold deck temperature, and AH02 controls the hot deck temperature. Sensors provided data at various points within each of the systems, including temperature, static pressure, heating and cooling valve positions, fan speeds, and fan on/off statuses. Primary components were heating and cooling coils, supply and return fans, and an economizer.

AH11/12

AH11 and 12 are VAV air-handling units providing conditioning to the first floor offices. AH11 has a cooling coil and post-heat coil and the supply fan while AH12 only has a heating coil. The air streams are mixed with a damper to provide proper temperature control to the offices.

AH13/14/15

AH13, AH14, and AH15 are identical CAV air handling units serving the kitchen facilities. The air handlers provide both heating and cooling. Return air is actively exhausted and mixed with outside air in the economizer.

AH21

AH21 is a constant air volume, dual duct system serving the 2nd floor. Conditioned air is supplied through parallel ducts and returned in a single duct. An economizer handles both the return air and outside air.

AH41/51/61/71/81

AH41, AH51, AH61, AH71, and AH81 are constant air volume air handlers are located on floors four, five, six, seven, and eight, respectively, in one of the three towers of the SCC facility and serve two rooms on their respective floors: a day room and a multi purpose room. Each system diagram has an identical layout. An economizer mixes incoming fresh air with air from the return fan. A supply fan sends the air to just a cooling coil for the multi-purpose room and both a heating coil and a cooling coil for the day room.

AH42/52/62/72/82

AH42, AH52, AH62, AH72, and AH82 are constant air volume air handlers are located on floors four, five, six, seven, and eight, respectively, in one of the three towers of the SCC facility and serve two rooms on their respective floors: a day room and a multi purpose room. Each system diagram has an identical layout. An economizer mixes incoming fresh air with air from the return fan. A supply fan sends the air to just a cooling coil for the multi-purpose room and both a heating coil and a cooling coil for the day room.

AH43/53/63/73/83

AH43, AH53, AH63, AH73, and AH83 are constant air volume air handlers are located on floors four, five, six, seven, and eight, respectively, in one of the three towers of the SCC facility and serve two rooms on their respective floors: a day room and a multi purpose room. Each system diagram has an identical layout. An economizer mixes incoming fresh air with air from the return fan. A supply fan sends the air to just a cooling coil for the multi-purpose room and both a heating coil and a cooling coil for the day room.

AH44/54/64/74/84

AH44, AH54, AH64, AH74, and AH84 are constant volume air handlers serving the core and lobby spaces on floors four, five, six, seven, and eight, respectively. An economizer mixes incoming fresh air with air from the return fan. A supply fan sends the air to just a cooling coil for the core space and both a heating coil and a cooling coil for the lobby space.

AH91/92

AH91/92 are CAV air handling units providing cooling only to the mechanical penthouse. Outside air is provided through an economizer. There is no return fan.

AH92

AH92 is a smaller cooling-only system servicing the penthouse mechanical room.

Small Chilled Water Loop

This smaller chilled water loop serves only the computer room air conditioner. Water from tank 3 is mixed with water in the existing loop. This flow is sent to one of two pumps operating on a lead/lag schedule and then the pump's respective evaporative water cooler. Both coolers feed the air conditioning unit. Return water is mixed with fresh water from the tank.

Chilled Water Loop

The chilled water loop provides cold water to cooling coils in air handlers and the supply fan system. Two chillers and their associated sets of primary and secondary pumps provide the chilled water to the loop.

Condenser Loop

The condenser loop serves the chillers that are a part of the main cold water loop. Two cooling towers supply a mixed flow of chilled water that is split among two chillers, each with its own pump. The return water is mixed and redirected to the two cooling towers.

Hot Water Loop

The hot water loop supplies heated water to all of the building's heating coils including air handlers and heating coils in the supply fan system. Hot water originates from three boilers.

Findings

Summaries of the findings of the student groups are below. Information has been significantly condensed for accessibility and brevity. Additional details, background information, and analysis can be found in the individual student group reports. The information is the work of the student groups and only word changes and other small edits have been made for the summaries. The analyses and conclusions are those of the original student groups. Additional commentary has been added and will be clearly identified as an "editors' note".

The table below provides a brief summary of the major problems and recommendations identified for each system, in order by functional status priority.

Table 1: Summary of Findings

System	Functional Status	Area Served	Major Problem(s)
AH21	🔴	2nd Floor	Improper component function
AH52	🔴	5th floor day room & multi-purpose room, tower two	Space air temperatures 3-5°F below *Manual* set point and barely cross into functional intent dead band.

AH64		6th floor, core and lobby	Core and lobby space experience 11°F of variation Observed set point band of 72°F to 74°F in lobby space seems to cause cyclical heating and cooling
AH74		7th floor, core and lobby	Core and lobby space experience 17°F of variation Observed set point band of 69°F to 74°F in lobby space seems to cause cyclical heating and cooling
AH82		8th floor day room & multi-purpose room, tower two	Space air temperatures 2 to 3 °F below *Manual* set point No heating/cooling is occurring according to heating/cooling coil valve position data.
SF1		Holding cells, tower one	Cooling/heating coil position fluctuates significantly & almost instantaneously Huge variation in supply air temperature
Small Chilled Water Loop		Ground floor server room	Positive correlation between supply water temperature and OAT.
AH01		Basement	Supply air temperature outside the 51-53 degree F set point range. Basement static pressure is less than the prescribed .25 inwc set point.
AH02		Basement	Hot deck temperature does not adhere to the set point for OAT below 52°F and OAT above 75°F. Static pressure drops below the set point for a large OAT range and shows significant variation.
AH13		Ground Floor – Kitchen	Internal Loads
AH15		Ground Floor - Kitchen	Internal Loads
AH42		4th floor day room & multi-purpose room, tower two	Day room and multi-purpose room temperatures average 2 to 3 degrees below the set point and vary by 2 to 6 degrees around this value.
AH44		4th floor, core and lobby	Space air temperature data may not correctly correspond to spaces listed for AH44 Some heating and/or cooling occurs out of season
AH51/61/71/81		5th – 8th floor day room & multi-purpose room, tower one	Provides consistent air, but many data points are missing and the coil valve positions are concerning.
AH54		5th floor, core and lobby	Core and lobby exceed assumed set point Observed set point band of 69°F to 74°F Heat/cool at unexpected time of day/year and OAT
AH62		6th floor day room & multi-purpose room, tower two	Space air temperatures are slightly below *Manual* set point and fluctuate. Damper valve periodically closes.
AH72		7th floor day room & multi-purpose room, tower two	Multi-purpose room space air temperature 3 degrees lower than set point and positively correlates with OAT. Damper frequently opens and closes.
AH84		8th floor, core and lobby	Core and lobby exceed assumed set point Observed set point band of 69°F to 74°F Heat/cool at unexpected time of day/year and OAT
AH92		Mechanical Penthouse	Mixed air and supply air temperature positively correlate with OAT for colder temperatures. Damper position remains open for very cold and very warm temperatures and oscillates during mild temperatures.
SF2		Holding cells, tower two	Zone 5 shows significant cooling, but also has highest average temperatures Only discrete heating/cooling coil valve positions are observed (0%, 50%, and 100%) Supply air temperature not available

SF3		Holding cells, tower three	Only discrete heating/cooling coil valve positions are observed from data (0%, 50%, and 100%) Inconsistent control schemes among zones Supply air temperature not available
Hot Water Loop		Whole Building	Pumps 9 & 10 are operating even when the outside air temperature is greater than 70 °F Behavior of pump 10 changes dramatically at the beginning of the month of January, 2010 There is a sustained increase in return water temperature starting in September 2009 Investigate the operation of pumps 9 & 10 to determine if they should be initiated by the OAT alone or other factors as well
Chilled Water Loop		Whole Building	High peak energy consumption, variable supply water temperature
Building Gas Consumption		Whole Building	Additional analysis is required to determine if the sum of the heating loads of each system equals the total facility gas consumption
Building Electricity Consumption		Whole Building	Large plunge in electricity consumption during winter should be explored and determined whether similar efforts can be used during other parts of the year. Main meter includes several facilities; usage needs to be determined on a per building basis. Submeters should be analyzed once loads are known.
AH11		1st floor offices	Add occupant sensors; reduce the internal loads.
AH12		1st floor offices	Add occupant sensors; reduce the internal loads.
AH14		Ground Floor – Kitchen	Internal Loads
AH41		4th floor day room & multi-purpose room, tower one	Check system schedule to operate only when necessary.
AH43		4th floor day room & multi-purpose room, tower three	
AH53		5th floor day room & multi-purpose room, tower three	
AH63		6th floor day room & multi-purpose room, tower three	
AH73		7th floor day room & multi-purpose room, tower three	
AH83		8th floor day room & multi-purpose room, tower three	
AH91		Mechanical penthouse	
Condenser Loop		Whole Building	Check Variability

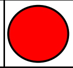
The detailed analyses of each system are provided below, organized by priority.

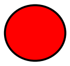
High Priority Systems

System	AH21
Group	3
Functional Status	System: Hot Deck: Cold Deck:
Functional Intent	Maintain space temperatures to 73°F. Hot Deck – heat the air to the desired temperature, without exceeding 115°F.

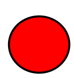
	Temperatures should decrease with increasing OATs. Cold Deck – maintain temperature above 55°F. Temperatures should decrease with increasing OATs. Enter lockout mode when OAT drops below 55°F.
Functional Areas	Hot Deck During specific data set (April 4, 2010 through May 1, 2010) Hot Deck got colder as OATs increased. Cold Deck During low OATs (below 55°F), the cold deck is hotter, and correlated to OAT linearly, presumably because the cooling coil is off. Looking at the difference between the cold deck and OAT, the amount of cooling increases as OAT increases.
Problem Areas	Hot Deck Hot deck temperature reaches a ceiling of close to 140°F, in excess of the intended 115°F. Hot deck generally warms as the OAT increases, which is the opposite of the intention. The heating coil valve is at 100% open for the majority of the time. The valve should respond to OAT and close more during the summer and open more during the winter. Because the valve position does not adjust properly to the OAT, the hot deck reaches temperatures higher than the functional intent. There is no correlation between the cold deck, hot deck, and space temperatures. Cold Deck The variance in cold deck temperatures for a given OAT is larger than we might expect. The variance in the cooling coil valve position is great, especially in OATs slightly above 55°F. On June 3, 2009, a tremendous amount of cooling coil valve swings was recorded – 58 major swings within only 2 hours. The variation is immense, with positions varying from 15% to 80%.
Recommendations	Hot Deck A further investigation of the space air temperature and its need to be at a constant temperature would provide additional insight to the Hot Deck. The valve for the heating coil might be affected by the space air temperature, thus resulting in the valve staying open for long periods of time. The hot deck may be getting so hot due to the heating coil valve malfunctioning. A properly functioning valve would close when the OAT reached a certain temperature. The mechanical servo for the valve itself must be determined to function properly. If the servo is simply not responding to control signals, then it is an easy fix. If the servo does respond to control signals, the control system should be inspected and potentially reconfigured for more efficient operation. Cold Deck The loop gain (rate at which the valve is calibrated to change given the difference between the measured temperature and the set point) may be too high. Lowering the gain sufficiently should allow the control loop to “lock on” to the proper valve position rather than oscillating around it. The rapid oscillations could have a significant effect on components which are not currently monitored. For example, the individual zone mixing boxes may also need to rapidly adjust the amount of cold and hot deck air that is mixed to maintain a constant room temperature.

	System While the system as a whole is meeting the functional intent, the component areas have opportunity for improvement. Monitor interlinked systems, such as the hot and chilled water loops. *Editor's note: Comparison of hot docket and cold deck would help determine whether overcompensation of heating/cooling is taking place due to poor controls.*

System	AH52
Group	1
Functional Status	
Functional Intent	Day room and multi-purpose rooms are maintained at 74±2°F.
Functional Areas	Both space temperature dead bands are within ±2°F.
Problem Areas	Day room 3°F and multi-purpose room 5°F below functional intent, barely cross dead band.
Recommendations	Determine why cooling coil is providing too much cooling. Cooling coil and damper not open, so inconclusive why spaces are below functional intent. Determine whether cooling coil is ever fully open. Determine actual set points for both spaces and rewrite manual if different than manual set point.

System	AH64
Group	2
Functional Status	
Functional Intent	Core and lobby maintained at 74±2°F. Damper position should be 100% open for 100% air replacement.
Functional Areas	Lobby Space air temperature remains fairly constant despite OA temperature variations Heating/cooling valve seems to be operating at correct times Core Slight upward trend in space temperature with OAT consistent with cooling-only functional intent Cooling appears to operate predominately during summer
Problem Areas	Lobby Space temperature varies between 66°F and 76.5°F from March through May, exceeding set point range. Heating occurs even when OAT is greater than 80°F Cooling occurs even when OAT is as low as 47°F Maximum space air temperatures occurred when OAT was near its low During beginning of 2009, space air temperature changes by 4°F within a minute Core Space temperature varies between 63°F and 82°F from March through May, exceeding set point range.

	Widest variation in valve position and space air temperature than other core/lobby systems. Cooling valve control mostly at 50% regardless of OAT No visible pattern correlating space air temperature and valve position System Heating in the summer months and cooling in the winter months Some of the summer heating happens during extreme drop in space air temperature to 0°F and a period without OAT data. Supply and return fans should be fixed on. However, there are periods of off status (perhaps during maintenance). There are also sensor readings of 0.5 and 0.33 although the systems are supposed to be binary. OA damper should be fixed on but is primarily closed. Mixed air temperature has large variation from -38°F to 92°F.
Recommendations	Set point range does not seem to be 74±2°F. Investigate what set point is intended and/or acceptable for these spaces. Consider wider band to improve efficiency. Investigate whether maintenance to any portion of the sensor or physical system (particularly in August 2009) was performed to explain change in observed behavior of lobby space. Investigate whether wide variation in core cooling valve position is physically plausible or indicate of a data collection system error or a faulty valve Consider installing fan sensors with constant monitoring to determine whether there is missing data or the system was unchanged. Confirm whether sensors that should output binary signals (supply and return fan sensors) are truly binary; otherwise determine what would cause non-binary readings. Check, recalibrate, or replace mixed air temperature sensor which has unrealistic readings. A redundant sensor could be used for confirmation.

System	AH74
Group	2
Functional Status	
Functional Intent	Core and lobby maintained at 74±2°F. Damper position should be 100% open for 100% air replacement.
Functional Areas	Lobby Relatively constant space air temperature with varying OAT Core Slight upward trend in space temperature with OAT consistent with cooling-only functional intent Cooling appears to operate predominately during summer
Problem Areas	Lobby Space temperature varies between 69°F and 78°F, exceeding set point range. Cooling control set to full open when OAT is between 52°F 80°F with no cooling between 80°F and 90°F OAT. Heating control set to open during some days in the summer and for range of OAT up to 82°F.

On the evening of August 25, 2009, control valve alternated between 100% open heating and 0% activity in response to a drop in space air temperature from 72°F to 69°F. While in line with functional intent, perhaps dead band should be widened to reduce need for summer heating.

On August 26, 2009, hottest OAT occurs (96°F) and only 10 minutes of cooling required to maintain tolerance levels. However, heating was called for in the evening.

Period of October and November 2009 required more frequent cooling than summer months. On November 13, 2009, system quickly alternated between heating and cooling.

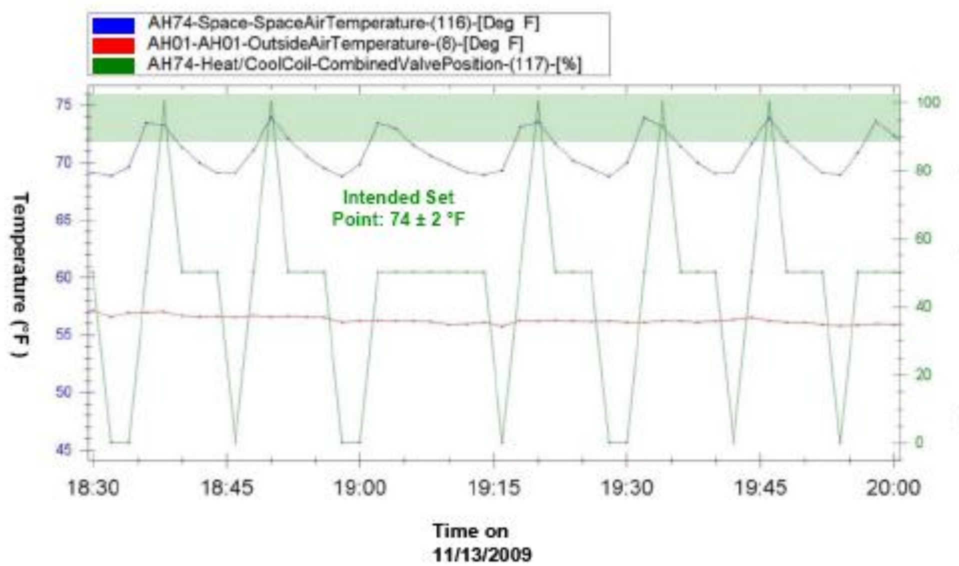


Figure 1: AH74 lobby space air temperature, heating/cooling valve position, and OAT on November 13, 2009, showing heating and cooling cycles

On March 23, 2010, excessive cooling (possibly due to abnormal space usage) causes a brief usage of heating.

Core

Space temperature varies between 63°F and 80°F, exceeding set point range.

Cooling coil operational at 100% for OATs as low as 48°F.

January data indicates set points may be different than assumed.

0% cooling for space air temperature below 69°F

50% cooling for space air temperature 69°F to 74°F

100% cooling for space air temperature above 74°F

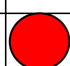
System

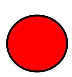
Along with other AH-X4 systems, a period in August shows the valve control and space air temperature going to 0% and 0°F respectively.

Supply and return fans should be fixed on. However, there are periods of off status (perhaps during maintenance). There are also sensor readings of 0.5 although the systems are supposed to be binary.

OA damper should be fixed on but is primarily closed. The instances when it is does open does not correlate to OATs and occur even when temperatures are above 80°F.

Recommendations	Set point range does not seem to be 74±2°F. Investigate what set point is intended and/or acceptable for these spaces. Investigate whether a wider dead band would be tolerable to prevent summer heating, winter cooling, and frequent cycling between heating and cooling. Investigate when these spaces are occupied and whether the dead band can be increased during times of vacancy. System neither heats nor cools for a majority of the time, which in conjunction with the wide space air temperature could indicate a malfunctioning valve or sensor. Physically investigate to determine whether the valves are functioning properly. Occupancy sensors would help explain abnormal spikes or temperature decreases. Consider installing fan sensors with constant monitoring to determine whether there is missing data or the system was unchanged. Confirm whether sensors that should output binary signals (supply and return fan sensors) are truly binary; otherwise determine what would cause non-binary readings.

System	AH82
Group	1
Functional Status	
Functional Intent	Day room and multi-purpose room maintained at 74±2°F. 100% outside air replacement.
Functional Areas	Day room and multi-purpose room temperatures stay fairly constant. Mixed air temperature positively correlates with OAT.
Problem Areas	Temperature for each room is maintained at a temperature lower than expected. Day room averages 71°F and multi-purpose room averages 72°F. Heating/cooling coil valve position data shows that no heating/cooling is occurring.
Recommendations	Check set points for consistency across manual and physical system. Physically verify if heating/cooling coils are functioning Confirm whether the sensors are measuring actual position.

System	SF1
Group	2
Functional Status	
Functional Intent	Maintain space air temperature in Zones 1-4 between 66°F and 72°F and in Zones 5-6 between 66°F and 70°F.
Functional Areas	Zones 1- 4 Space air temperature nearly constantly at 72°F, which is within the set point range. Heat Exchanger

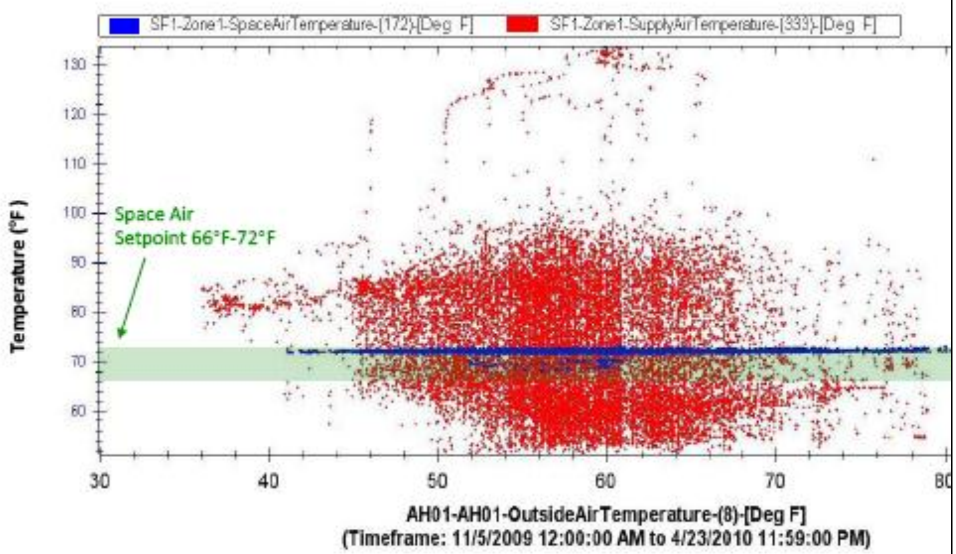
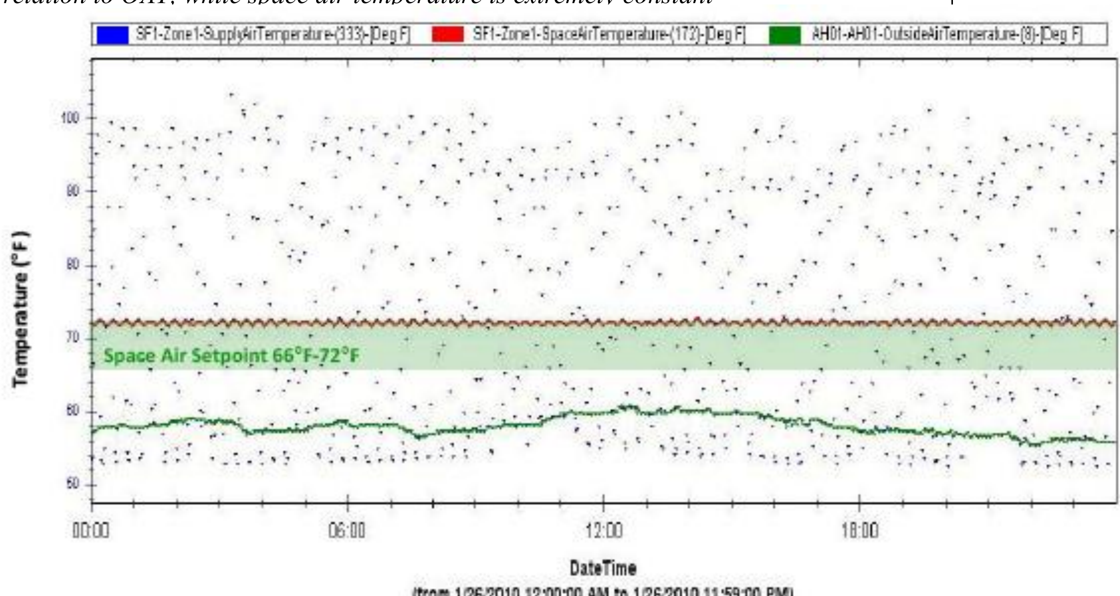
	Winter exhaust heat recovery seemed to be operational with an estimated effectiveness of 68%-70%. Summer data was not available, so pre-cooling effectiveness could not be evaluated. 100% Fresh Air Supply fan draws in 100% fresh air as required.
Problem Areas	Zones 1-6 Space air temperature only within the intended set point range during a brief period in December 2009. No correlation between decrease in space air temperature and OAT. Zones 1-4 Supply air temperatures for zones 1 through 4 fluctuate radically from about 50°F to 130°F for almost all OATs. The difference between supply and space air temperature is +60°F and -20°F for a given OAT, while the space air temperature remains very constant. Cooling and heating are occurring almost simultaneously resulting in a clear indication of energy waste. Heating is occurring during warmer spring months and cooling is occurring during cooler winter months.  *Figure 2: Supply air temperature for Zone 1 of SF1 as OAT varies from November 4, 2009 through April 22, 2010. Note the extreme fluctuation in supply air temperature and lack of correlation to OAT, while space air temperature is extremely constant* 

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Figure 3: An illustrative example of space 1 on January 26, 2010, showing the near simultaneous temperature fluctuation of supply air temperature as OAT and space air temperature remain fairly constant

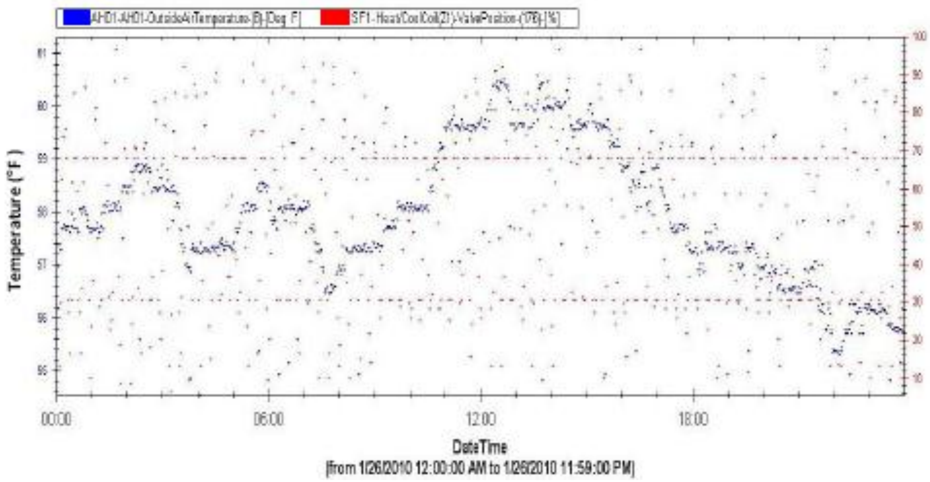

Figure 4: An illustrative example of space 1 valve position on January 26, 2010 (0% being full heating, 50% being neither heating nor cooling, and 100% being full cooling), showing the near simultaneous heating and cooling. Also note that cooling is occurring on a winter day when the OAT is less than 60 °F

Zones 5-6
Space air temperature range for zones 5-6 about 67.3°F-74.3°F from November 2009 through May 2010. This higher than intended space air temperature leads to unnecessary heating coil operation and wasted energy usage.
Supply air temperatures experience large fluctuations on the order of 50°F within very short time frames (though less extreme than Zones 1-4). Near simultaneous heating and cooling has been observed indicating significant energy waste. On an early morning in March, the valve was controlled to cool when the OAT was below 55°F.
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<td>Recommendations</td>
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Discuss the heating/cooling valve operation and control logic with facility manager. Determine how heating/cooling coil valves are controlled, i.e. by the supply and/or space temperature set point.
Physically assess valve operation and accuracy of binary valve signals. In particular, the valves for Zones 1-4 demonstrate alternate blasts of hot and cold supply air.
Install sensors at each of the valves to evaluate the accuracy of the readings and the operation.
Consider installing individual permanent sensors on each coil, as opposed to a single sensor for both that outputs a binary signal.
Install redundant sensors to check supply temperature for each zone.
Take spot measurements at diffusers.
Investigate and determine cause of the variation in space air temperature in mid-December. Consult with facility manager and check data for other building
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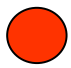
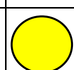
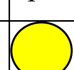
	subsystems. Determine why space air temperature was allowed to fluctuate within the appropriate set point range during this period, but remains constant at 72°F during all other times. Modify controls so space air temperature can fluctuate within larger range as allowable for each zone. Consider retrofitting entire control system if financial analysis is attractive.

System	Small Chilled Water Loop
Group	1
Functional Status	
Functional Intent	Maintain supply water temperature at 75ºF +/- 2 degrees.
Functional Areas	None
Problem Areas	Positive correlation between supply water temperature and OAT
Recommendations	Check if coolers are turned on/leaking.

Medium Priority Systems

System	AH01
Group	1
Functional Status	
Functional Intent	Maintain supply air temperature between 51-53 °F Static pressure is set at 2 inwc. Basement static pressure is set at 0.25 inwc.
Functional Areas	Figure 4 shows the supply temperature range is within 51-53 °F for part of the OAT. Static pressure is 2 inwc.
Problem Areas	Supply air temperature drops below and rises above the 51-53 °F range. Also, a cluster of points exists above the fit line and outside the 51-53 °F range. Basement static pressure is less than .25 inwc.
Recommendations	Better control of heating/cooling coil valves to ensure valves are opening/closing at the proper settings Compare set point in manual with actual set point Investigate fan speeds.

System	AH02
Group	1
Functional Status	
Functional Intent	For OAT range of 52-75°F, corresponding hot deck temperature range is 110-75°F. For OAT below 52°F, hot deck temperature stays at 110°F. For OAT above 75°F, hot deck temperature stays at 75°F.

	Static pressure is set at 2 inwc.
Functional Areas	Hot deck temperature is consistent for OAT range of 52-75°F. Some static pressure data points are clustered at 2 inwc.
Problem Areas	Hot deck temperature does not match set point for OAT below 52°F and above 75°F. Static pressure drops below 2 inwc for a large OAT range. Static pressure shows significant variation from 1.3 to 2.0 inwc.
Recommendations	Check set point temperatures to ensure hot deck temperature is correct outside of 52-75°F OAT range. Keep fan speed constant to stabilize static pressure. Replace fan if speed cannot be kept constant.

System	AH13
Group	3
Functional Status	
Functional Intent	Cool kitchen to a space air temperature of 68°F while running continuously.
Functional Areas	Space air temperature follows the supply air temperature and heating/cooling coil valve trends. Small variance between 68°F and 74°F.
Problem Areas	Supply air temperature has major fluctuations to meet intended space air temperature. *Editors' note: Although the temperatures do vary significantly from the functional intent, these temperatures are more realistic and energy efficient than the 68°F* setting.
Recommendations	Supply air temperature variances can cause energy efficiency issues. Installing several sensors in the kitchen can help determine the average kitchen temperature more easily, as the sensor readings can be influenced tremendously by nearby equipment.

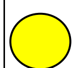
System	AH15
Group	3
Functional Status	
Functional Intent	Cool kitchen to a space air temperature of 68°F while running continuously.
Functional Areas	Temperature variation is relatively low, although it clusters around a temperature different from the functional intent. The space air temperature, supply air temperature, and combined valve position operate together as expected.
Problem Areas	Large variation in space temperature far exceeding the functional intent. The temperature varies between 72°F and 87°F. Spikes in temperature up to 87°F occur at specific times of day.

Recommendations	The control system seems to functioning as designed, but the cooling coil cannot handle added internal gains from 1pm-4pm and 1am-4am. Although there are significant temperature fluctuations, it may prevent too much energy from being wasted to keep such a space consistently cool. If the spiking phenomenon is caused by a poorly placed thermostat sensor, this should be inspected and the location should be changed. If the spiking is due to heating loads exceeding the systems capacity, this would be saving energy and not be a major concern. A log of major appliances and their hours of operation would be helpful in understanding potentially problematic internal loads.

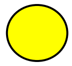
System	AH42
Group	1
Functional Status	
Functional Intent	Day room and multi-purpose rooms are maintained at 74±2°F.
Functional Areas	Day room and multi-purpose room temperatures stay fairly constant.
Problem Areas	Day room ranges from 69-73°F and averages 72°F. Multi-purpose room ranges from 65-78° and averages 71°F. Supply air temperature is too cold and range is too great.
Recommendations	Space temperature does not align with Manual set point. Supply temperature and cooling coil position work together as expected. Cooling coil is open too much in cold weather. Determine whether cooling coil is malfunctioning. Determine whether actual set point is correct or if manual gives correct set point. Rewrite manual set point if incorrect.

System	AH44
Group	2
Functional Status	
Functional Intent	Core and lobby maintained at 74±2°F. Damper position should be 100% open for 100% air replacement.
Functional Areas	Lobby Space air temperature remains fairly constant despite OA temperature variations Heating/cooling valve seems to be operating at correct times Core Cooling valve operational and responsive to OA and space air temperature Space air temperature relatively constant throughout the year
Problem Areas	Lobby Dramatic spikes in measured supply air temperature during several points in cooler winter months (up to 120ºF) Core Slight dips in supply air temperature not reflected in mixed or space air temperature

	System OA damper primarily closed even when OA temperatures may be advantageous for economizer
Recommendations	Explore set point ranges for both spaces to determine expectations for occupancy comfort and current operation settings. Investigate whether a wider set point band would be acceptable and whether it should vary with time of year or time of day Determine whether lobby heating/coil coil is malfunctioning sporadically during cooler winter months Check supply air temperature and cooling coil valve sensors Installation of redundant sensors for heating/cooling control valve and supply air temperature could held determine root cause of anomalous supply air temperature behavior Recalibrate and test sensor for OA damper position. If sensor is operating correctly, adjust operation to allow more OA during appropriate times

System	AH51/61/71/81
Group	4
Functional Status	
Functional Intent	Maintain constant temperature range of 74°F±2°F in the day room and multi-purpose room
Functional Areas	Space temperatures are fairly consistent throughout the year. Mixed air temperature exhibits a consistent horizontal pattern. Multi-purpose room is slightly cooler because it has no heating coil.
Problem Areas	1. Space temperatures for the multi-purpose and day room range from 64°F-75°F and 69°F-75°F, which has temperatures lower than the functional intent. Damper pattern shows a surprising vertical pattern. A diagonal line would be expected, showing a proportionality of the OAT and mixed air temperature. Damper data unavailable for AH71. Cooling/heating valve positions fluctuate rapidly from 100%, 50%, and 0% positions. *Editors' Note: the valve positions were not plotted on a time graph, so this doesn't seem quite accurate. Perhaps the intended analysis is that the values are in these positions for a wide range of OATs.*
Recommendations	Check controls for changes from program/set point Note when damper controls are not recording. Add more sensors to see that components function properly. For multi-purpose room, see if there are distinct uses of room. Determine why fan status changes are sometimes intermediary

System	AH54
Group	2

Functional Status	
Functional Intent	Core and lobby maintained at 74±2°F. Damper position should be 100% open for 100% air replacement.
Functional Areas	Lobby Space air temperature remains fairly constant despite OA temperature variations Heating/cooling valve seems to be operating at correct times Core Slight upward trend in space temperature with OAT consistent with cooling-only functional intent Cooling control set to 0% for extremely low OAT as expected System Mixed air temperature agrees with expected behavior of economizer. Mixed air temperature constant below 58°F and increases slightly with OAT
Problem Areas	Lobby Space temperature varies between 69°F and 77°F from March through May, exceeding set point range. Heating occurring during summer months and for OAT of about 80°F 100% cooling control observed when space air temperature is at set point Core Space temperature varies between 68°F and 77°F from March through May, exceeding set point range. Cooling valve control mostly at 50% regardless of OAT 100% cooling control for OATs as low as 58°F System Both spaces show occasional drops in temperature to 0°F during the summer and a period without OAT temperature data suggesting a possible sensor malfunction. Supply and return fans should be fixed on. However, there are periods of off status (perhaps during maintenance). There are also sensor readings of 0.5 although the systems are supposed to be binary. OA damper should be fixed on but is primarily closed. Only four periods indicate 100% damper position with no regard to OAT.
Recommendations	Explore set point ranges for both spaces to determine expectations for occupancy comfort and current operation settings. Investigate whether a wider set point band would be acceptable and whether it should vary with time of year or time of day Determine occupancy schedules. Install occupancy and window/door open sensors and/or survey building users to determine level and time of space use to help modify set points. Visitor and core space systems neither heats nor cools for a majority of the time, which in conjunction with the wide space air temperature range could indicate malfunctioning valve or sensor. Sensors for supply and return fan only detect change in status, so there is no way to determine when there is missing data. Install sensors with constant monitoring for all data points. Confirm whether supply and return sensors are binary

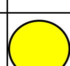
System	AH62

Group	1
Functional Status	
Functional Intent	Day room and multi-purpose rooms are set at 74±2°F. Rooms should receive 100% air replacement.
Functional Areas	Mixed air temperature positively correlates with OAT.
Problem Areas	Space temperatures fluctuate. Space temperatures average slightly lower than set point: 73°F ±5°F. Damper valve periodically closes.
Recommendations	Investigate the occupancy levels of the day room and multi-purpose room. Investigate damper valve, which is open all the time and cools the space below the dead band.

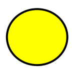
System	AH72
Group	1
Functional Status	
Functional Intent	Day room and multi-purpose rooms maintained at 74±2°F. Damper position should be 100% open for 100% air replacement.
Functional Areas	Day room and multi-purpose room temperatures stay fairly constant. Mixed air temperature positively correlates with OAT.
Problem Areas	Multi-purpose room temperatures are low with the average at about 72°F; they positively correlate with OAT. The damper position frequently opens and closes.
Recommendations	Check set points for consistency across manual and physical system. Check whether the damper is working or not.

System	AH84
Group	2
Functional Status	
Functional Intent	Core and lobby maintained at 74±2°F. Damper position should be 100% open for 100% air replacement.
Functional Areas	Lobby Relatively constant space air temperature with varying OAT Core Slight upward trend in space temperature with OAT consistent with cooling-only functional intent Cooling appears to operate predominately during summer
Problem Areas	Lobby Space temperature varies between 66°F and 74.5°F, exceeding set point range. Coil valve position control does not align with expected OAT and time of year behavior.

	Cooling control set to 100% when OAT is as low as 52°F. Heating control set to 100% when OAT is as high as 90°F. Data from March 9, 2009 through May 15, 2009 indicates rapid cycling between cooling and heating and an implied dead band of 69°F to 74°F. Minimum space air temperature of 66°F occurs when OAT was 50°F, which is not extreme, while control valve set to 100% heating. Could be a problem with the building hot water loop, an unusually low occupancy/internal load, or open window. Core Space temperature varies between 62°F and 81°F, exceeding set point range. Cooling coil operational at 100% for OATs as low as 44°F. Cooling coil operational at 50% for all OATs. Set point range seems to be between 69°F and 74°F. Sudden drop in space temperature to minimum of 62°F while OAT increases suggests change in space use or excessive cooling beforehand. System Along with other AH-X4 systems, a period in August shows the valve control and space air temperature going to 0% and 0°F respectively. Supply and return fans should be fixed on. However, there are periods of off status (perhaps during maintenance). There are also sensor readings of 0.5 although the systems are supposed to be binary. OA damper should be fixed on but the damper position is split about evenly between 0% and 100% for a wide range of OAT. There is a period in early 2010 with an unexplained scatter of damper position. This is likely due to system maintenance or malfunction, because it does not seem to be due to a relationship with OAT or mixed air temperature.
Recommendations	Set point range does not seem to be 74±2°F. Investigate whether set point band is actually intended to be 69°F to 74°F and update documentation to reflect changes. Investigate whether a wider dead band would be tolerable to prevent summer heating, winter cooling, and frequent cycling between heating and cooling. Investigate when these spaces are occupied and whether the dead band can be increased during times of vacancy. Occupancy, window, and/or door sensors would help explain abnormal spikes or decreases in temperatures. Consider installing fan sensors with constant monitoring to determine whether there is missing data or the system was unchanged. Confirm whether sensors that should output binary signals (supply and return fan sensors) are truly binary; otherwise determine what would cause non-binary readings. Investigate why coils operating at full cooling or heating for long periods of time did not seem to provide adequate space conditioning (perhaps due to maintenance, low capacity, ventilation levels, or occupancy schedules)

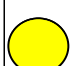
System	AH92
Group	1
Functional Status	
Functional Intent	Penthouse mechanical room supply temperature is maintained at 75±2°F. Mixed air temperature is maintained at 65±2°F.

Functional Areas	Mechanical room is 75°F when OAT is 65°F and above.
Problem Areas	For OAT 35-65°F, mechanical room space temperature positively correlates with OAT, increasing until the room reaches 70°F. Mixed air temperature positively correlates with OAT. Outside air damper position remains fully open when OAT is very hot and very cold, but oscillates for OAT between 56-72°F.
Recommendations	Mixed air temperature positively correlates with OAT. Verify mixed air temperature set point. Space air temperature is below functional intent when OAT is below 65°F. Check if valve is physically opening at extreme OAT temperatures. Investigate outside air damper position remaining open except for temperatures near assumed mixed air temperature set point range.

<table>
<tr><td>System</td><td>SF2</td></tr>
<tr><td>Group</td><td>2</td></tr>
<tr><td>Functional Status</td><td></td></tr>
<tr><td>Functional Intent</td><td>Maintain space air temperature in Zones 1, 2, 4 between 66°F and 72°F, in Zone 3 at 73°F and in Zones 5-6 between 66°F and 70°F.</td></tr>
<tr><td>Functional Areas</td><td>There are no distinct patterns that indicate any of the zones are always performing consistently with the functional intent of the system.</td></tr>
<tr><td>Problem Areas</td><td>Zones 1-4 and 6
Zone 1 space air temperature frequently exceeds the intended set point.
The entire month of July 2009 shows the Zone 1 heating/cooling coil valve remaining at 50% (no heating or cooling) with only a few outlier points which are not at 50%. However, the space air temperature is still being maintained near the set points while the OAT is fluctuating above and below the set point range.
December 2009 operation for Zone 1 reveals space air temperature exceeds upper set point limit at times if OAT is greater than 44°F. The lower limit of the intended set point range is 66°F, but the recorded space air temperature rarely dips below 70°F. Space air temperature varies between 70°F and 73°F.
December 2009 data for Zone 1 shows the heating/cooling valve remains off for nearly the entire month. It is unclear how the space air temperature is being maintained while the OAT is always significantly colder.
Similar patterns for Zone 1 are found in Zones 2, 3, 4, and 6. Average temperatures for each zone are shown below.
Table 2: Average temperature in each zone for July 2009 and December 2009
<table>
<tr><td rowspan="2">SF2 Zone</td><td colspan="2">Average Space Temp. (°F)</td></tr>
<tr><td>Jul 2009</td><td>Dec 2009</td></tr>
<tr><td>Zone 1</td><td>72.1</td><td>71.5</td></tr>
<tr><td>Zone 2</td><td>72.2</td><td>72.1</td></tr>
<tr><td>Zone 3</td><td>72.5</td><td>70.5</td></tr>
<tr><td>Zone 4</td><td>72.6</td><td>70.9</td></tr>
<tr><td>Zone 5</td><td>73.5</td><td>71.7</td></tr>
</table></td></tr>
</table>

Zone 6	72.1	71.4

	Zone 3 Zone 3 operation should be further investigated. The purpose of its unique set point of 73°F with no tolerance band is unclear and would lead to a significant amount of wasted energy. Zone 5 Space air temperature exceeds the intended set point range for the data set. Heating/cooling coil primarily operates at 50% (neither heating nor cooling) or 100% (cooling). During the data set of noon to midnight on July 8, 2009, when the space air temperature reaches about 74.3°F, the valve changes to 100% cooling until the space air drops to 72.8°F. The controls seem to be preventing the intended cooling from occurring and bringing the space air temperature into the set point range. During December 2009, the space air temperature experiences the largest variation and highest temperatures at lower OATs, which is opposite of what is expected. Space air temperature remains warm in the months even though the heating/cooling coil valve is almost always at 50% (neither heating nor cooling). It is unclear how the space air remains warm with no apparent heating. *Editors' note: High internal loads and heat recovery could provide some explanation.* During a three day period from December 7 through December 10, 2009, alternating heating and cooling appeared to be occurring for short periods of time.
Recommendations	Investigate the binary valve control signal to determine if the signal aligns with the actual operation of the valve. Check the space air temperature control to verify that it aligns with what is intended. Allow the space air temperature to vary within the entire temperature range. In the winter, heating energy can be saved by allowing the space air to vary to the lower limit of the set point range. Investigate the intended set point and operation of Zone 3, which appears to be 73°F with no tolerance. A dead band would greatly improve energy performance. The control logic for Zone 5 may be faulty, leading the cooling valve to turn on and off at inappropriate temperatures in July. Consider installing additional measurement instrumentation, as installed on SF1. Installing supply air temperature sensors would be particularly useful.

System	SF3
Group	2
Functional Status	
Functional Intent	Maintain space air temperature in Zones 1-6 between 66°F and 70°F.
Functional Areas	There are no distinct patterns that indicate any of the zones are always performing consistently with the functional intent of the system.
Problem Areas	Zones 1,2,5, and 6 (all year) and Zone 4 (through Oct 2009) Space Air Temperature and Heating/Cooling Coil Position

	Zone 1 space air temperature almost always exceeds set point range, with the temperatures primarily clustered within 72°F to 74°F. Zone 1 heating/cooling coil valve position signal fluctuates only from 50% (neither heating nor cooling) to 100% (full cooling) with very few signs of heating. The Zone 1 system typically cools the air when the space air temperature reaches about 74.1°F and is idle when the space air temperature decreases to 72.6°F. Similar patterns to those observed in Zone 1 were evident in Zones 2, 5, and 6 for most of the data set (except December 2009) and for Zone 4 (from February 2009 through October 2009).

Table 3: Observed cooling trigger points for Zones 1, 2, 4-6 with two main exceptions: (1) heating occurred in all zones during December 2009, (2) Zone 4 operational patterns changed after October 2009, discussed later.

SF3 Zone	Observed temperature that triggers valve to change to:	
	(a) 100% (cooling)	(b) 50% (neither heating/cooling)
Zone 1	74.1°F	72.6°F
Zone 2	74.2°F	72.7°F
Zone 3	n/a	n/a
Zone 4	74.1°F	73.1°F
Zone 5	74.2°F	72.9°F
Zone 6	74.2°F	72.9°F

December 2009 is the only month when some heating occurs in Zone 1, 2, 5, and 6. Heating occurs when the space air temperature drops to about 70°F and continues until temperature rises to 70.8°F.

Zone 4 Space Air Temperature and Heating/Cooling Coil Position beginning November 2009

Beginning in November 2009, the control scheme governing Zone 4 operation appeared to change as the coil position data showed a significant amount of heating between November 2009 and April 2010. This makes sense as it corresponds with decreasing OAT.

During a three day time period from December 7, 2009 through December 10, 2009, the set point band was between 68°F and 72°F. This meets the tolerance band magnitude but is two degrees above the intended range.

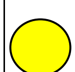
On March 17, 2010, the operation of Zone 4 changes again and the space temperatures greatly exceed set point reaching 74°F.

Zone 3 Space Air Temperature and Heating/Cooling Coil Position

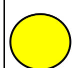
From February 23, 2009 to April 28, 2009, Zone 3 operated like the other zones, as described earlier, and the average space air temperature for this period was 73°F. A clear change in operation occurred on April 29 when the heating/cooling coil valve began to read positions in between 100% cooling and no conditioning. The result is a 4°F average drop in space air temperature to 69°F.

Data from July 8 and 9, 2009 indicates the cooling coil valve position fluctuating

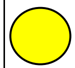
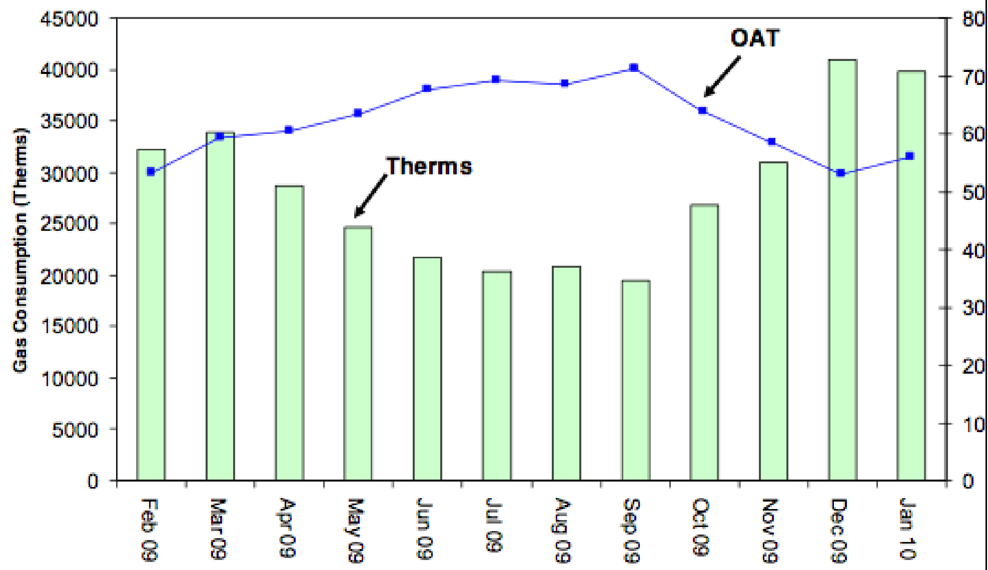
	along with the OAT. Significant internal loads appear to be in the space as cooling is required even when the OAT is well below the space air temperature set point range. Even on December 8, the heating/cooling coil valve position fluctuated primarily within the cooling realm loosely following the OAT. Heating was minimal even though OAT was lower than the space temperature, indicating large internal loads. Zone 6 Space Air Temperature Spike on June 28, 2009 Zone 6 showed a large spike in space air temperature on June 28, 2009 reaching a temperature of 77.7°F. Although space air temperature increases were also seen in other zones on this day, the rise in Zone 6 was most severe. While this large increase in space air temperature correlated to the observed rise in OAT, it seems that OAT cannot alone explain the rise; high OAT at other times during the year did not yield such high space air temperatures. Thus it appears that outside air may have been entering the space without the desired conditioning being achieved.
Recommendations	Check the space air temperature control scheme to verify that it aligns with what is intended. Allow the space air temperature to vary within the entire temperature range. In the winter, heating energy can be saved by allowing the space air to vary to the lower limit of the set point range. Explore the coil valve controls. Any value from 0% to 100% should be allowed on the valves, but only three discrete coil positions (0%, 50%, and 100%) are observed in all but Zone 3. Determine why and how the control scheme governing Zone 3 was changed on April 29, 2009 Investigate the intended set point and operation of Zone 3, which appears to be 73°F with no tolerance. A dead band would greatly improve energy performance. Consider installing additional measurement instrumentation, as installed on SF1. Installing supply air temperature sensors would be particularly useful.

System	Hot Water Loop
Group	2
Functional Status	
Functional Intent	Deliver hot water as required to the hot water coils throughout the facility
Functional Areas	System is heating supply water to temperatures within a relatively consistent range (160-190°F) throughout the year.
Problem Areas	Pumps 9&10 are intended to initiate when OAT drops below 70°F, but the data set indicates the pumps are operational even when the OATs exceed 70°F. Hot water loop supply temperature experienced anomalies during May and July of 2009. Both instances involved a sustained drop in temperature, however, there are many other increases in OAT that did not have a corresponding drop in hot water loop supply temperatures. The difference in temperature between supply and return water temperature should remain relatively constant. The difference between supply and return water temperature is dramatically reduced in September of 2009 and remains at that reduced level due to an increase in return water temperature.

Cross-System Analysis	The function of the hot water loop affects all of the heating and cooling units in the SCC Facility. If hot water is delivered to the heating coils at incorrect temperatures, every system could potentially overcompensate by opening the cooling valves more. This would continue to signal to the hot water system that the temperature needed to be increased, and the domino effect would result in wasted energy and intermittent blasts from the heating and cooling valves. There may be a connection between the performance of the hot water loop and the operation of the heating and cooling valves in the SF1 system.
Recommendations	If pumps 9&10 should shut off for OATs above 70°F, their continued operation could be a source of major energy loss. Heating coils may still be active during warm summer time temperatures, and any air that passes over the heating coils would need to be cooled beyond what was originally intended. This is a high priority for testing and control system calibration Sensors should be installed as the return water leaves each heating coil in order to pinpoint locations of heat gain in the return water system.

System	Chilled Water Loop
Group	3
Functional Status	
Functional Intent	Provide chilled water to cooling coils in air handler systems and supply fans.
Functional Areas	Supply temperature is cooled to roughly 5-10°F below the return water temperature. Beginning in mid-June, the return water temperature increases relative to the supply water temperature, as expected. The SCC Data Manual does not indicate the temperature set point for the supply temperature, so it is difficult to evaluate relative to the functional intent. The pumps maintain a very constant pressure differential of about 20 inWC, which appears to be the set point. Calculated cooling capacity tracks OAT trending very well.
Problem Areas	Flow rate drops to nearly 0 gpm during the summer. Because the other systems do not indicate a diminished capacity to cool the space, the problem is likely with the sensor rather than the pumps themselves The database shows the flow rate as a percentage, although the Data Manual lists the data point as gpm. Also, the data consistently exceeds 100, so the analysis assumes this is indeed gpm.
Recommendations	The chilled water loop is very logically equipped with sensors. Similar data, particularly Delta T and water flow for the individual cooling coils would enable an inspection into which building systems are consuming more or less energy than others. The inaccuracy of the flow rate data from June to August could be checked against other building records. The calculated capacity could be translated to the actual power consumed by the chiller by recording the chiller power consumption. This information can be used to determine actual operating efficiency.

System	Whole Building Gas Consumption

Group	2
Functional Status	
Functional Intent	Combust natural gas to provide space heating, through the hot water loop system, and domestic hot water
Functional Areas	 Monthly natural gas consumption data (therms) for the SCC facility was available from February 2009 through January 2010. The total gas consumption for this 12-month period was 340,170 therms. The average OAT for each month was overlaid on monthly gas usage, as shown in the figure below. As expected, the therm usage is negatively correlated to the average OAT; the monthly therm usage is greater for months with a lower average OAT, and vice versa. *Figure 5: Whole Building Natural Gas Consumption* Monthly therm usage increases when OAT decreases because space heating is likely the largest therm end-use in the facility. The hot water loop system, which heats the air, thus has the largest impact on therm usage of the building.
Problem Areas	*Editor's Note: Summer natural gas usage is substantial and must be explored.*
Recommendations	As the performance of the hot water loop is improved and simultaneous heating and cooling in the facility is eliminated using better control schemes, gas consumption is expected to decrease, potentially yielding significant financial savings Domestic hot water is also on the same gas meter, but the domestic hot water demand is not known from the data available, and thus the therms usage attributed to domestic hot water cannot be estimated. The natural gas loads for each subsystem can be determined through a detailed analysis of the subsystem. However, this was not carried out in this project due to the complexity of operation observed and the number of zones. In the future, this load calculation could be carried out to determine if the sum of the heating loads for each subsystem equal the total gas consumption of the facility.

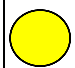
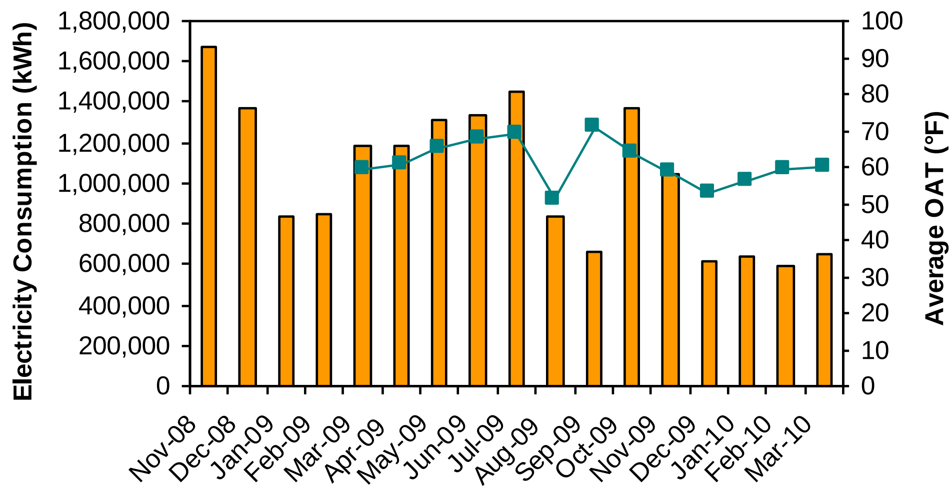
<table>
<tr><td></td><td>Editors' Note: The baseline natural gas consumption is approximately 70% of the annual usage. This indicates a high proportion of natural gas usage is from summer/shoulder season heating and/or domestic hot water. Further analysis should be done to break down the natural gas usage.</td></tr>
<tr><td>System</td><td>Whole Building Electricity Consumption</td></tr>
<tr><td>Group</td><td>Editor</td></tr>
<tr><td>Functional Status</td><td></td></tr>
<tr><td>Functional Intent</td><td>Provide electricity to power the chillers, fans, computers, and other electric equipment.</td></tr>
<tr><td>Functional Areas</td><td>Main electricity consumption data was available between November 2008 and March 2010. Annual electricity consumption (measured between April 2009 and March 2010) was 11,694,142. However, the main meter measures several additional facilities. As anticipated, the electricity consumption has a strong positive correlation to the OAT.


Figure 6: Whole Building Monthly Electricity Consumption</td></tr>
<tr><td>Problem Areas</td><td>During the second half of August 2009 and the first half of September 2009, the electricity data was unavailable.
There is a significant drop in measured electricity consumption between 1/16/2009 and 2/10/2009. A similar drop occurs from 11/23/2009 through 3/31/2009. Electricity is expected to decrease during time periods, but the drops are sharp. Perhaps large pieces of electric equipment, such as chillers, are turned off during these time periods. If so, there may be major energy conservation opportunities in these pieces of equipment when they are in operation, especially on either side of the scheduled outages.</td></tr>
</table>

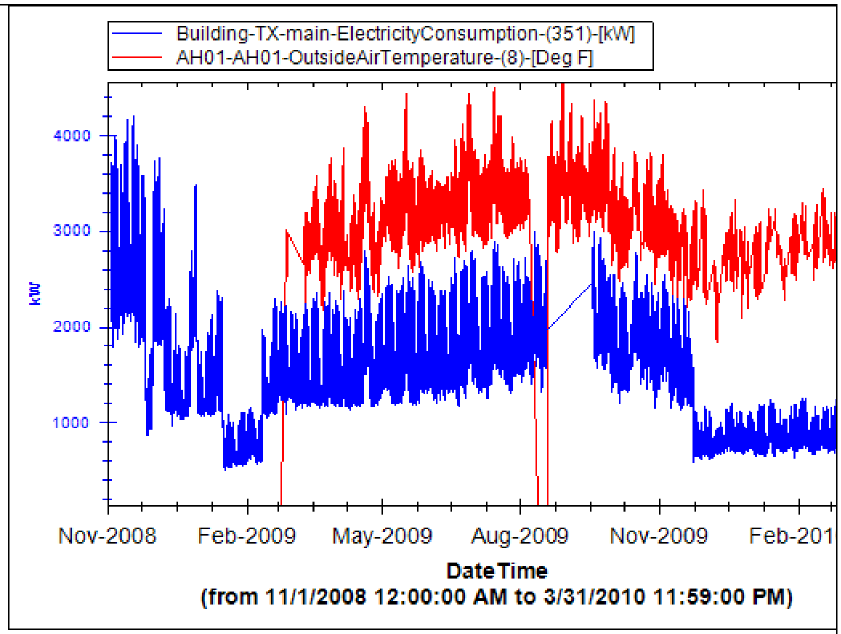


Figure 7: Whole Building Hourly Electricity Consumption

Since this meter measured several facilities, it is difficult to determine what portion is actually associated this facility.

Submetered data was available, but it is unknown which pieces of equipment are on each submeter. Electricity consumption on the submeters was relatively small and fairly constant throughout the year. There were evident daily patterns in the submeters, but their meanings were not intuitive. For example, meter TX-38 would oftentimes peak in the early morning.

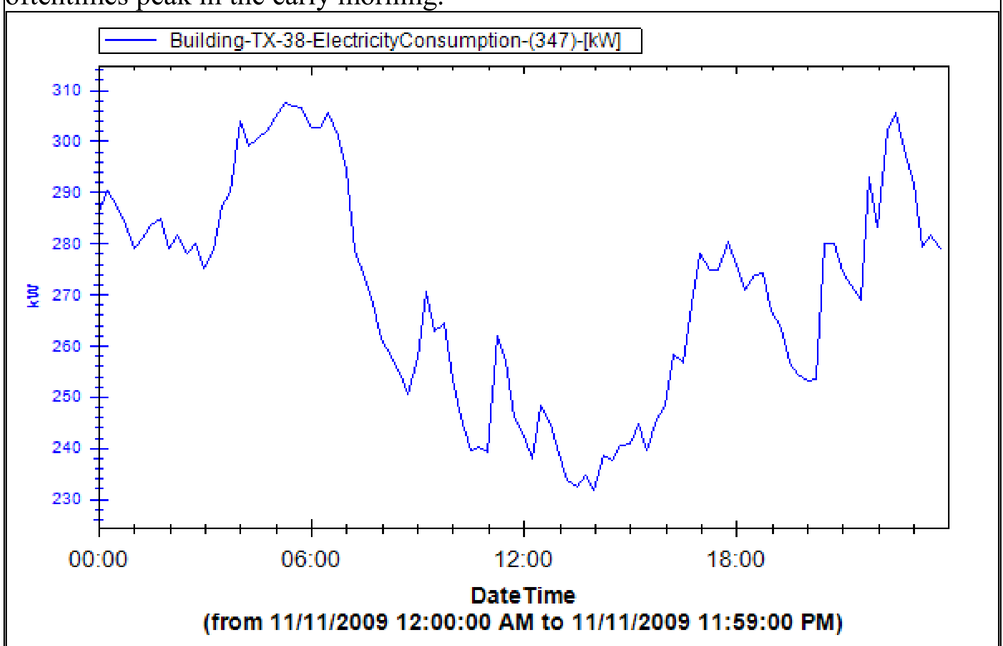
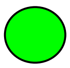
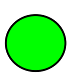


Figure 8: Submeter TX-238 Electricity Consumption on 11/11/09

Recommendations	Install a separate meter to measure the electricity consumption just in this facility. Confirm whether major pieces of equipment are being shut down during the winter season. If so, it appears that these units have major energy conservation potential while in operation. Determine the specific systems on the submeters for additional analysis. It would be useful to submeter specific areas or systems, such as the chillers, lights, and fans.

Low Priority Systems

System	AH11
Group	4
Functional Status	
Functional Intent	Provide an average temperature between 60°F and 70°F.
Functional Areas	System does not provide cooling during the winter Dead band between heating and cooling temperatures Difference between supply air temperature and OAT increases when OAT gets warmer to provide cooling and increases when OAT gets colder to provide heating.
Problem Areas	Temperature is fairly consistent at 53°F which is outside the range of functional intent. Supply air and cold deck temperatures range between 50°F and 60°F which is 10°F lower than the intended temperature range. Temperatures decrease after going through the post-heat coil. Gaps in data prevalent Difference between supply and OAT shows very cold temperatures in April, perhaps due to a malfunctioning heating coil or people using space heaters.
Recommendations	Check the ventilation systems and cooling coil to determine why the temperature is above functional intent. Add occupant sensors. Check whether space heaters are utilized in the offices. Address comfort issues through the air handler system to avoid space heaters.

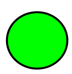
System	AH12
Group	4
Functional Status	
Functional Intent	Provide an average temperature between 60°F and 70°F. *Editors' note: The data manual indicates functional intent of supply air between 125° and 85°.*
Functional Areas	System follows the general expected pattern and is within the expected temperature range during brief periods of time.

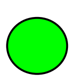
Problem Areas	The difference between supply air temperature and OAT should be between 60°F and 70°F, but is concentrated on lower temperature values. *Editors' note: This delta seems to be within the expected range based on the data manual values of 8° to 79°.* There are periods with significant data gaps. There are various periods with low supply air temperatures, perhaps the heating coil to be malfunctioning or turned off.
Recommendations	Check heating coil. Temperature tends to be below functional intent.

System	AH14
Group	3
Functional Status	
Functional Intent	Cool kitchen to a space air temperature of 68°F while running continuously.
Functional Areas	System is operating relatively consistent to functional intent. When space air temperatures spike, supply air temperatures react by getting colder and the valve position sensor reads 100% (full cooling). When the OAT gets hotter, the space air temperature stays relatively constant.
Problem Areas	Unusually large spikes in space air temperature, on the order of 15°F, quickly and briefly appear.
Recommendations	Study of the kitchen and how it used could be valuable to this analysis. Additional sensors in the kitchen could lead to more accurate data. Specific internal loads from cooking, appliances, and people from the kitchen along with sensor location would definitely help future analysis. The system quickly responds to space air temperatures. Large temperature spikes do occur but do not affect the proper operation of the system. This system should not be considered a major concern for inefficient energy usage, as there are more systems with higher potential.

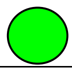
System	AH41
Group	4
Functional Status	
Functional Intent	Maintain constant temperature range of 74°F±2°F in the day room and multi-purpose room
Functional Areas	System seems to maintain a constant temperature in the multi-purpose room with a reasonable range Only cooling is being provided to the multi-purpose room and the supply temperatures get colder as the OAT rises. Day room temperature generally stays within a reasonable, though wider, temperature range of 70°F to 76°F. Multi-purpose room supply air and fan exhaust differential generally follows expectations. System only provides cooling with a small amount of temperature

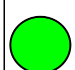
	increase likely due to periods when no cooling is needed and small gains happen inside the system. Day room supply air and fan exhaust differential demonstrates the system both heats and cools. Carpet graphs show the system maintains a constant temperature in both rooms at all times, even if nobody is present.
Problem Areas	Space air temperature range is about 2°F lower than the functional intent. Day room minimum space air temperature seems to be 2°F lower than the functional intent. The space air temperature in the day room exceeds the observed temperature range during periods of extreme OAT and during other unknown periods. Shape of the multi-purpose supply air and fan exhaust differential in relation to the OAT does not follow predictable usage pattern. This may be explained by different uses of the room during the week and its core location. Day room supply air and fan exhaust differential lacks a clear pattern in relation to the OAT.
Recommendations	Internal schedules and usage of the rooms would assist future analysis. Check set points of rooms since both are a couple of degrees below functional intent. Determine new, smart operating schedules based on time of day and occupancy sensors.

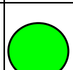
System	AH43
Group	3
Functional Status	
Functional Intent	Maintain space air temperature in the Day Room and the Multi-Purpose Room at 74°F
Functional Areas	Space air temperatures are consistently within a degree of the desired temperature in the Multi-Purpose room The space air temperatures for the space are within 2°F for most of the year.
Problem Areas	None
Recommendations	Determine why the sensor for the valve position is reading between 30%-80% and not the presumed 0%-100%. *Editors' note: This does not agree with the percentages shown in the figure from the report.*

System	AH53
Group	3
Functional Status	
Functional Intent	Maintain space air temperature in the Day Room and the Multi-Purpose Room at 74°F
Functional Areas	Space air temperatures are within the desired range year round, consistently

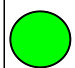
	remaining between 69°F and 74°F. Predictable relationship between the cooling/heating coil valve and the space air temperature is evident.
Problem Areas	None
Recommendations	None

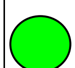
System	AH63
Group	3
Functional Status	
Functional Intent	Maintain space air temperature in the Day Room and the Multi-Purpose Room at 74°F
Functional Areas	Space air temperatures generally meet functional intent by ranging from 70°F to 72°F.
Problem Areas	The multi-purpose room cooling coil does not seem to have a strong effect on the space air temperature.
Recommendations	The multi-purpose room may have a connection problem between the space and supply duct, as the cooling coil does not seem to have a significant impact on space air temperature. Utilizing the economizer more efficiently could reduce the cooling/heating coil usage.

System	AH73
Group	3
Functional Status	
Functional Intent	Maintain space air temperature in the Day Room and the Multi-Purpose Room at 74°F
Functional Areas	Space air temperatures generally meet functional intent by consistently from 71°F to 75°F. The predictable relationship between the cooling and heating coil valve and corresponding room temperature is evident.
Problem Areas	None
Recommendations	None

System	AH83
Group	3
Functional Status	
Functional Intent	Maintain space air temperature in the Day Room and the Multi-Purpose Room at 74°F

Functional Areas	Space air temperatures generally meet functional intent by consistently from 71°F to 75°F. The predictable relationship between the cooling and heating coil valve and corresponding room temperature is evident.
Problem Areas	None
Recommendations	None

System	AH91
Group	4
Functional Status	
Functional Intent	Maintain constant temperature range of 72°F±2°F in the mechanical penthouse room.
Functional Areas	The system performs tolerably well to maintain the temperature range. The system starts to cool the air when the outside air temperature rises above 60°F. Outdoor damper highly correlates to OAT. Extra loads increase the internal temperature, and more external fresh air is required from the damper. Cooling coil valve position responds well to OAT and internal loads.
Problem Areas	Outdoor air damper fluctuates during the night, perhaps due to fresh air requirements.
Recommendations	None

System	Condenser Water Loop
Group	4
Functional Status	
Functional Intent	Provide cooled water to the chillers at a temperature of 85°F or below.
Functional Areas	Supply water temperature averages 80°F and generally stays below 85°F. Supply water temperature has a small positive slope relative to the OAT. Return water temperature follows expected patterns, with return temperatures increasing along with OATs. A zone of cooler than average return temperatures correlates to cold days when the chillers are turned off. Delta T between the supply and return water temperature follows expected patterns in relation to the OAT.
Problem Areas	Supply water temperatures far above the functional intent occurred on one day, likely due to maintenance or isolated malfunction. This inconsistency is reflected in other comparisons as well, such as a temperature increase from return to supply water temperature on the same day.
Recommendations	Check the normal behavior of the cooling tower.

Contributors

The analysis within this report was done by the Spring 2010 CEE 243 class. Below are the group members and the systems they analyzed.

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Summary report compiled by Tom Abram