Contra Costa Community College District
Applied Arts Building
HVAC and Controls Evaluation

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1 Executive Summary

1.1 Introduction

Taylor Engineering was engaged to evaluate the existing HVAC and control systems at the Applied Arts building and provide recommendations for upgrades to improve system operation and energy efficiency. This report summarizes our observations and recommendations.

1.2 HVAC System Description

The Applied Arts building is served by a central chilled water system with a single 120-ton air cooled chiller that was installed in 2017. Heating hot water is provided by a single 2000 kBH condensing boiler that was installed in 2018. A review of the central plant is not included in this report.

The building is served by six rooftop air handling units and one air handling unit in the Boiler Room on the first floor that were all installed in 1979, as well as four rooftop packaged AC units with gas heat that were installed in 2018. The air handling units are beyond their expected service life of 20-30 years, and facility staff reported and we observed many operational and mechanical issues with the units as described below. The chilled water and hot water piping that serves the air handling units is in very poor condition on the roof, with piping insulation tattered, wet or missing throughout, and with severe corrosion easily visible on the exposed piping.

The first floor of the building is served by induction VAV boxes that were installed in 1979. The second floor is served by standard VAV boxes, some with reheat coils, some with 4-pipe cooling and heating coils, and some cooling-only. About half the second-floor VAV boxes are from 1979 and half were installed in the 2011 and 2018 retrofits.

1.3 Control System

The building has a mix of HVAC control system types. The HVAC system was originally installed with all pneumatic controls in 1979. The chilled water and boiler plants have ALC DDC controls that were installed in 2017 and 2018, respectively.

All seven air handling units have primarily Reliable DDC controls that were installed in 2011, though they have pneumatic chilled water and hot water valves from 1979. Facility staff report and we observed many operational issues with the air handling unit controls as described in detail below.

Most terminal units have pneumatic controls, though roughly 25% of the units have ALC DDC controls that were installed in 2018 and several VAV boxes have Reliable DDC controls that were installed in 2011.

1.4 Recommendations

In the table below we summarize our recommendations along with estimated rough-order-of-magnitude costs to implement each item. These costs are based on past experience and have not been verified by a contractor or cost estimator. We strongly recommend that they be verified by a contractor or professional cost estimator. Recommendations in italic font are alternative options to the recommendation directly above.

Each recommendation is assigned a "high", "medium", or "low" priority based on the maintenance, energy, and comfort implications of maintaining the status quo.

Table 1: Recommended Retrofit Measures

Recommendation (click on name to jump to associated section)	**Priority**	**ROM Cost**
HVAC System		
Replace Rooftop Chilled Water and Hot Water Piping	High	$100,000
Drain and Abandon Chilled Water Distribution and Coils on Second Floor	Medium	$5,000
Replace Air Handling Units	High	$350,000
Alternate Option: Refurbish All Existing Air Handling Units	*High*	*$200,000*
Install Sheet Metal Covers on Rooftop Ductwork	Low	$10,000
Install New ALC DDC controls on Existing Terminal Units	Medium	$100,000
Alternative Option: Install New VAV Reheat Boxes	*Medium*	*$200,000*
Control System		
Install New ALC DDC Controls on the New Air Handling Units	High	Included in AHU replacement cost above
Alternate Option: Install New ALC DDC Controllers on Existing Air Handling Units	*High*	*Included in AHU refurbishment cost above*
Install ALC DDC Controls on All Terminal Units	Medium	See costs above

2 Introduction

The two-story, 55,000 ft^2 Applied Arts Building is located on the Contra Costa College campus in San Pablo, CA and is part of the Contra Costa Community College District. This academic building was constructed in 1979 and consists of classrooms, offices and support areas such as janitor closets, IDF rooms and a Loading Dock and a Boiler Room on the first floor. The building houses the Nursing, Math, Speech, and Journalism Departments, as well as the Gateway and Middle College Programs.

Taylor Engineering was engaged to evaluate and provide recommendations for the existing HVAC system including air handling units, duct distribution, rooftop chilled and hot water piping, and controls.

The observations and recommendations in this study are based on a detailed review of mechanical and controls drawings and the Building Automation System interface, discussions with energy management and facilities engineering staff, and a site visit. The site visit was performed on February 6, 2019, accompanied by Bruce King and Reggie (last name unknown).

3 HVAC System Description

3.1 Central Plant

A. *Chilled Water Plant*

The Applied Arts building was originally constructed in 1979. It is served by a primary-secondary central chilled water plant with a 120-ton Carrier Aquasnap 30RB air-cooled chiller installed in 2017. The system has one 7.5 HP pump dedicated a chilled water supply line that serves the air handling units and one 3 HP pump dedicated to a separate chilled water supply line that serves branch and zone cooling coils on the 2nd floor. Both the air handling supply line and the 2nd floor supply lines share a single chilled water return riser.

B. *Hot Water Plant*

Heating hot water is provided by an Aerco Benchmark 2000 condensing boiler installed in 2018. The system is piped primary-only with 3-way valves at coils to maintain boiler minimum flow. The hot water plant serves heating coils in the air handling units, reheat coils in the induction VAV boxes on the first floor, and reheat and 4-pipe coils on second floor.

Aside from the rooftop chilled water and hot water distribution, a detailed review of the central plant is not included in this report.

C. *Chilled Water and Hot Water Distribution*

The rooftop chilled water and hot water piping was installed in 1979. As observed during our site visit, both the weather jacket covering the piping insulation and the piping insulation itself have failed. The jackets and the fiberglass piping insulation are tattered and missing throughout and the piping insulation was wet throughout, which means that it has permanently lost almost all its insulation value. The exposed piping is very rusted and corroded, see photos in Appendix A. Building staff did not report any leaks but is likely that leaks will become regular and require more frequent maintenance as the piping continues to corrode.

The poor condition of the exterior of the rooftop piping raises concerns about the inside of the piping as well. But facility staff did not mention any issues with piping leaks inside or outside of the building, and a recent water treatment report from February 2019 shows good protection, indicating that the water quality is being maintained to prevent internal piping corrosion.

The interior piping we observed at terminal units was still in good condition. Insulation was intact with limited signs of wear. Reheat valves did however show signs of minor leakage in the form of rust; see Figure 4.

3.2 Air Systems

A. *Air Handling Units*

The six rooftop air handling units and one air handling unit in the first-floor Boiler Room serve the building. All seven units have full economizers, and chilled water and hot water coils with three-way valves. All seven units have constant speed supply and return fans with discharge dampers on both supply and return to modulate airflow. Using a discharge damper to modulate airflow is much less efficient than using a variable frequency drive for that purpose.

Table 2. Air Handling Unit Airflow Summary

Equipment Tag	Location	Year Installed	Supply Fan CFM	Return Fan CFM
AHU 1-1	Boiler Room	1979	10350	7800
AHU 1-2	Rooftop	1979	8460	6350
AHU 1-3	Rooftop	1979	9024	6800
AHU 2-1	Rooftop	1979	10350	7800
AHU 2-2	Rooftop	1979	10350	7800
AHU 2-3	Rooftop	1979	10350	7800
AHU 2-4	Rooftop	1980's?*	8000?*	7000?*

**We were not provided with design drawings for AHU 2-4 so the year of installation and airflows listed above are an estimate based on air handling unit appearance and size*

At 35-40 years old, the units are all past their expected service life of 20-30 years, based on the ASHRAE Expected Equipment Service Life Database. We present the following operational observations from our site visit.

- Unit Casing
  - There were water stains on the floor and minor rust throughout most of the units, indicating minor rain leaks.
  - There was no standing water inside any of the units.
  - The exterior paint is chipping and peeling on most of the units, with rust clearly visible in the exposed locations.
  - Some seams on the units are beginning to peel apart.
  - Overall the unit casing is in acceptable condition, but we believe that the housings are not very air tight.
- Supply and Return Fans
  - Several of the fans were making very loud humming/whining noises during our site visit, especially the supply fan for AH 1-2.
  - Several of the fan housings and support rails had some rust indicating exposure to moisture, likely due to leaky unit casings.
  - The flex connectors for several of the supply and return fans were torn or were compressed to the point of being squished against the air handler housing.
  - The fans are past their expected service life of 25 years
- Dampers

  - Most of the outdoor air dampers and relief dampers had a significant amount of rust on the blades and linkages.
  - When tested, roughly 10 to 20% of dampers failed to move either due to bound linkages or failed actuators.
  - The dampers are past their expected service life of 20 years.
- Ductwork
  - Several sections of rectangular rooftop ductwork had some standing water on top, indicating that the ductwork was not installed at a slight slant, which is best practice for preventing rust and corrosion.
  - The ductwork is in good condition with very little visible rust.
- Noise
  - Facility staff noted frequent rumbling noises above rooms 137 and 140, both served by induction VAV units with DDC controls installed in 2018 and both served by AHU 1-2, the unit that we observed making a loud whining noise.

B. *Terminal Units*

The building has a mix of terminal unit types as summarized in Table 3. The first floor has all induction VAV boxes, all but one of which are Barber-Colman model HFP boxes installed in 1979. One new induction box was added for Classroom 140 in 2018; the make and model of this new box is unknown. The induction VAV boxes are designed to provide semi-constant discharge airflow over a wide range of VAV damper positions and minimize reheat energy, but the boxes have a relatively high pressure drop because of the venturi nozzle that creates the induced air. This results in higher central fan energy.

The second floor is served by VAV reheat and VAV cooling-only boxes. There are 24 Barber-Colman model HUP boxes installed in 1979, 4 Titus PESV boxes installed in 2011 and 5 Titus DESV boxes installed in 2018. The second floor has both hot water and chilled water distribution piping. The hot water piping serves both reheat coils and 4-pipe "reheat-and-cool" coils. The chilled water piping serves both 2-pipe cooling coils and 4-pipe reheat-and-cool coils. Some of the 4-pipe coils serve multiple VAV boxes, just like in a conventional variable volume and temperature (VVT) system.

Classrooms 201A and 201B and Real Study 201C have 3 VAV cooling only boxes that were installed in 2018. All three boxes are served by a single 4-pipe coil. The coil did not appear to get new controls in 2018 and it is not clear how the coil is being controlled.

In 2011 two VAV reheat boxes were installed downstream of a branch 4-pipe coil, which puts 3 sets of coils in series and could potentially be wasting energy. For example, the supply air could be heated by the heating coil in the air handling unit, cooled by the 4-pipe cooling coil and then heated again by the VAV box reheat coil.

The air handling units serving the second floor have enough capacity to meet the cooling loads, as estimated using rules of thumb and engineering judgment, so we believe that the cooling coils could be removed without impacting the system's ability to meeting cooling loads. We believe that cooling coils were installed as an energy efficiency measure: they allow the air handling units to provide supply air at a higher supply air temperature, reducing cooling and reheat energy during certain weather conditions. However, the ability of the zone cooling coils to save energy was reduced in previous retrofits, likely as an oversight, when they demolished several of the cooling coils, forcing the air handling units to provide air at a lower temperature for the zones without cooling coils.

At 40 years old, many of the induction VAV and standard VAV boxes are past their expected service life of 20 years, based on the ASHRAE Equipment Expected Service Life Database.

Table 3. Terminal Unit Summary

Box Type	Estimated Count
First Floor	
Cooling-Only Induction Box	9
Induction Reheat Box	16
Total First-Floor Boxes	25
Second Floor	
VAV Reheat Boxes	8
VAV Box with Shared 4-Pipe "Reheat and Cool" Coil	7
VAV Box with Dedicated 4-Pipe "Reheat and Cool" Coil	8
VAV Box with Dedicated 2-Pipe Cooling Coil	8
Cooling-Only VAV Box	2
Total Second-Floor Boxes	33
Total Boxes	**58**

C. *Exhaust Fans*

Five centrifugal downblast rooftop exhaust fans with EC motors and one constant speed centrifugal inline exhaust fan were installed in 2018, see Table 4. No issues were report by facility staff. The fans are well under their expected service life of 20-25 years.

Table 4. Exhaust Fan Summary

Equipment Tag	Serving	HP	Manufacturer	Model
EFR-2	Hallway	1/4	Greenheck	G-060-VG-4
EFR-3	Toilets and Offices	1/6	Greenheck	G-090-VG-6
EFR-7	Women's Toilet	1/4	Greenheck	G-090-VG-4
EFR-8	Medical Assisting	1/4	Greenheck	G-099-VG-4
EFR-10	Men's and Women's Toilet	1/6	Greenheck	G-090-VG-6
EF-117D	Custodial Storage 117D	285 Watts	Greenheck	SP-A900

D. *Rooftop Packaged Air Conditioning Units*

Four rooftop packaged air conditioning units with gas heat were installed in 2018, see Table 5. This type of unit has an expected service life of 15 years. A review of the units was not included in this study.

Table 5. Rooftop Packaged Air Conditioning Unit Summary

Equipment Tag	Manuf.	Model	Serves	Nominal Tons	Design Cooling Airflow (CFM)
AC 2-1	Carrier	48CL004	Offices 237	3	1200
AC 2-2	Carrier	48CL005	Skills Lab 239A	4	1700
AC 2-3	Carrier	48CL004	Lobby 239 & Lab Prep 239C	3	1200
AC 2-4	Carrier	48CL006	Math Lab 202	5	2000

3.3 Recommendations

A. *Chilled and Hot Water Piping*

1. Replace Rooftop Chilled Water and Hot Water Piping

All of the chilled water and hot water piping and pipe insulation on the roof needs to be replaced. Replacing the piping will prevent the added water and energy waste and maintenance costs associated with future leaks.

We estimate replacing the rooftop chilled water and hot water piping to cost roughly $100,000.

2. Drain and Abandon Chilled Water Distribution and Coils on Second Floor

We recommend that the chilled water piping distribution and coils on the second floor be drained and abandoned in place to avoid the high first cost and control complexity associated with conversion to DDC. We see two options for draining the system. The first option is to drain the entire chilled water system using the existing drain on the chilled water return line in Room 117F.1 (the room where the VFDs for the chilled water pumps are located), cut and cap the chilled water return line where it connects to the riser on the second floor, see Figure 1, and decommission the dedicated second floor chilled water pump. The chilled water system would then need to be re-filled and water treatment chemicals reapplied. The second option is to hot tap a drain into the dedicated chilled water supply pipe for the second floor coils at a low point in the system, freeze or line-stop the chilled water return line in the same location where indicated to cut and cap in Figure 1 , drain that portion, then cut and cap the chilled water return line where indicated in Figure 1 and decommission the dedicated second floor chilled water pump same as the first option. The second option avoids having to drain, refill and re-apply chemicals to the entire chilled water system.

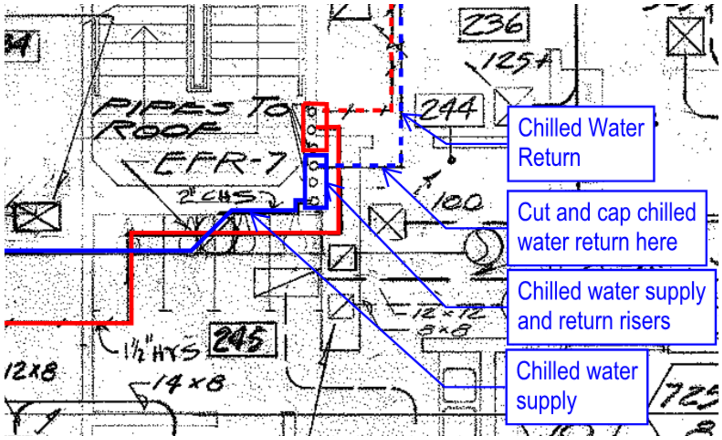

Figure 1. Chilled Water and Hot Water Risers at Second Floor

Unused chilled water coils could be removed in the future as part of TI work requiring the rerouting of terminal units and zonal distribution; until that point the coils would be a minor additional pressure drop.

We considered and eliminated two other options. First, we considered retaining and reusing the cooling coils, but eliminated it due to the high first cost of converting the valves to DDC, added controls complexity, and low expected energy savings. Given that the campus has limited facilities staff to maintain the growing building stock, any added controls complexity is unwarranted unless it pays back financially in the near term.

Second, we considered converting the cooling coils in the 4-pipe terminal to heating coils by modifying the piping at the coils, effectively converting the two-row reheat coils to six-row reheat coils, which would reduce heating and hot water pump energy. But we eliminated this option due to high first cost of the piping modification relative to the expected energy savings.

We estimate draining and abandoning the chilled water piping to cost roughly $5,000.

B. *Air Handling Units*

1. Replace Air Handling Units

The seven air handling units serving the building are past their expected service life and have many mechanical and operational issues. We recommend replacing the air handling units with new custom or semi-custom air handling units with variable speed supply and return fans, outside air economizer, chilled water coil, hot water coil and new ALC DDC controls. Installing variable speed supply and return fans will allow the units to modulate fan speed based on a static pressure reset control sequences, saving significant fan energy.

The hot water coil may be eliminated to save first cost on some or all of the units if either (1) all zones served by a given unit have preheat or reheat coils or (2) minimum outside air requirements on a heating design day would not drive the supply air temperature below 50°F for air handlers serving any cooling-only zones. One of these conditions is likely to be true of most AA building air handlers and should be evaluated for each unit.

The six new rooftop air handling units should have the same footprint and rough weight as the existing units to avoid triggering costly structural seismic upgrades for the building and so that the existing roof curbs can be reused. A lower unit weight of the same footprint would also be acceptable. Weight and dimensional considerations will dictate whether the College can proceed with less expensive semi-custom units, or must instead install custom air handlers.

Replacing AHU 1-1 in the Boiler Room will not be as straightforward as replacing the rooftop units because AHU 1-1 is mounted overhead in the crowded Boiler Room with limited access. Demolition of the unit would be difficult; the unit would need to be broken down, cut up, etc. and removed from the room in pieces. Installing a new unit in the Boiler Room would be even more difficult and may not even be practical. We see four options to consider for AHU 1-1: (1) install a new custom AHU in Vacant Cooling Tower Well, (2) install new AHU on the Boiler Room roof, (3) Replace with New AHU in Same Location and (4) refurbish existing unit in place.

The matrix below compares the options by weighting the importance of each attribute and providing a ranking of each option on a scale from 0 (low) to 10 (high) with respect to each attribute. The products of the attribute weight times the rank for each attribute are summed and compared by option. The higher the total score, the better the option. Figure 2 shows a schematic of Option 1.

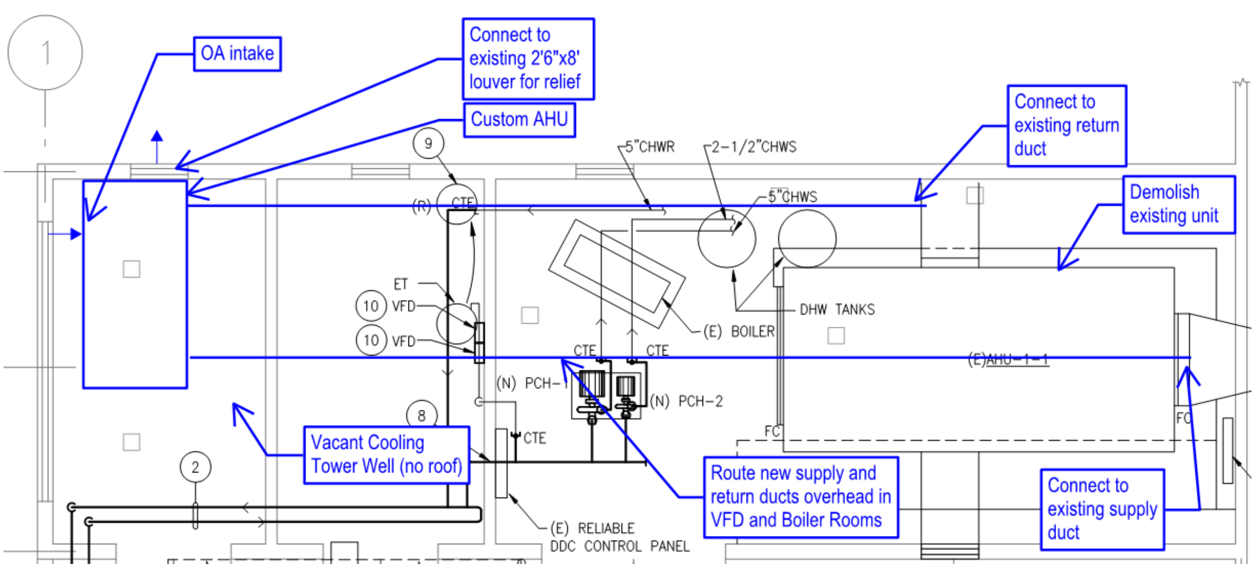

Figure 2. Schematic of Option 1: Install a New Unit in Vacant Cooling Tower Well

We estimate replacing all seven air handling units to cost roughly $350,000.

		Recommended Option		Option 2		Option 3		Option 4	
Consideration	**Weight**	**Install a New Custom AHU in Vacant Cooling Tower Well**	**Rank**	**Install New AHU on the Roof of the Boiler Room**	**Rank**	**Replace with New Custom AHU in Same Location**	**Rank**	**Refurbish Existing Unit in Place (see refurbishment Description below)**	**Rank**
First Cost	50	Lowest expected first cost since structural work is not triggered	10	Structural upgrades to the Boiler Room roof are expected. A semi-custom unit could be used and the existing AHU can be left in place.	7	Modifications to existing piping, electrical, walls, structure, etc. are expected	3	Modifications to existing piping, electrical, walls, structure, etc. are expected	4
Maintenance Cost	30	New unit requires limited maintenance	10	New unit requires limited maintenance	10	New unit requires limited maintenance	10	Certain components, for example dampers or fans, might be impossible to replace. Re-used components will require more maintenance than new.	3
Visual Appearance	15	No unsightly AHU or ductwork on the Boiler Room roof	10	New AHU and ductwork on the Boiler Room roof	1	No unsightly AHU or ductwork on the Boiler Room roof	10	No unsightly AHU or ductwork on the Boiler Room roof	10
Future Space Utility	5	Frees up some space in the Boiler room due to demolishing the existing AHU, but the Cooling Tower Well would no longer be vacant for potential future uses	5	Leaves the Cooling Tower Well vacant for other uses	10	Leaves the Cooling Tower Well vacant for other uses	10	Leaves the Cooling Tower Well vacant for other uses	10
Total	**100**		**975**		**715**		**650**		**490**

2. Alternate Option: Refurbish All Existing Air Handling Units

If financial constraints preclude the rooftop air handling units from being replaced in the next ten years, instead consider refurbishing the rooftop units per the following:

- Refurbish existing air handling units
  - Install new belts and bearings on supply and return fans and rebalance
  - Install new VFDs on supply and return fans
  - Install new ALC DDC controllers
  - Install new DDC hot water and chilled water valves
  - Install new outside, return and relief air dampers with new DDC actuators
  - Retain all other sensors (supply air temperature sensor, building pressure sensor, duct pressure sensor, etc.)
  - Remove supply and return fan discharge air dampers
  - Consider wirebrushing, resealing and painting unit casing and replacing gaskets on access doors. This would reduce air leakage and may prolong the life of the casing somewhat but is unlikely to be cost effective.

We estimate refurbishing the existing air handling units to cost roughly $200,000.

3. Install Sheet Metal Covers on Rooftop Ductwork

The rooftop ductwork is in good condition with minimal signs of rust, but we did witness puddles on top of several segments of ductwork. Consider installing sheet metal covers at a slight angle over the ductwork to shed water and prevent future rust and corrosion.

We estimate installing sheet metal covers to cost roughly $10,000.

C. *Terminal Units*

1. Install New ALC DDC controls on Existing Terminal Units

See detailed controls discussion in Section 4.6B.1 below. Although the majority of the terminal units are past their expected service life, we received no reports from facility staff of widespread issues with damper operation and our experience shows terminal units to last well beyond their expected service life. For these reasons, we recommend retaining the existing boxes, including both standard VAV and induction boxes.

We estimate installing new DDC controls on all existing terminal units to cost roughly $100,000.

2. Alternative Option: Install New VAV Reheat Boxes with ALC DDC Controls

If the existing terminal units from 1979 are not in good condition (e.g. failing dampers and airflow crosses) and if funds allow, consider replacing all terminal units from 1979. We strongly recommend doing this on only a selective basis though since dampers and flow crosses have long service lives in our experience.

We estimate replacing all the terminal units, including new DDC controls, to cost roughly $200,000.

4 Control System

4.1 Overview

The building has pneumatic controls that were installed in 1979, Reliable DDC controls that were installed in 2011 and ALC DDC controls that were installed in 2018. ALC is the campus standard and we have based our study around converting to ALC.

Facility staff noted many issues with the pneumatic system including the following:

- Lack of pneumatic pressure at AHU 1-1. This means the chilled water and hot water valves have to be operated manually, resulting in both wasted energy and poor thermal comfort for occupants.
- Oil in pneumatic lines.
- Loss of pneumatic pressure during recent construction projects.
- Frequent “too hot” complaints in many zones including the Math Department (served by AHU 2-1), room 216 (served by AHU 2-2), and room 219 (served by AHU 2-1).

4.2 Air Handling Units

All seven air handlers are controlled by Reliable DDC controllers installed in 2011. The air handlers’ have three-way pneumatically actuated hot and chilled water valves that receive DDC signals via electronic to pneumatic (E-to-P) transducers. All dampers are electronically actuated with Belimo actuators. The Reliable controllers have been integrated in the main campus ALC interface; see a typical air handling unit graphic from the ALC interface in Figure 3 below. Note that both the supply and return fans have discharge dampers, though the return fan discharge dampers appear to be missing on the BAS graphic.

The pneumatic valves are well past their expected service life of 20 years. The Reliable controllers are below their expected service life of 15-20 years, but the controllers have very limited capacity for additional inputs or outputs, which eliminates the possibility of some control measures, for example, adding VFDs to modulate supply and return fan speed.

During our site visit, we noticed many issues with the control logic implementation for the air handling units including:

- AHU 1-2
  - Return fan deadheaded due to return air and exhaust air dampers shut
  - Potential mis-mapping of exhaust and return air dampers
- AHU 1-3
  - Supply fan deadheaded due to closed return fan discharge damper
  - Outside air being pulled in through relief path due to return fan discharge damper being mostly shut
- AHU 2-1
  - Duct static pressure very high at 3.6” (2” or less is typical)
  - Ambient static pressure sensor tip exposed to wind without wind shield

- AHU 2-2
  - Return fan recirculating on itself due to the return fan discharge damper being mostly shut with bypass door between the return and return fan discharge plenum fully open
  - Building pressure slightly negative at -0.039”
  - Duct static pressure high at 2.32”
- AHU 2-3
  - Outside air being pulled in through relief path due to return fan discharge damper being mostly shut
  - Incorrect exhaust air damper operation: it closes when OA damper opens

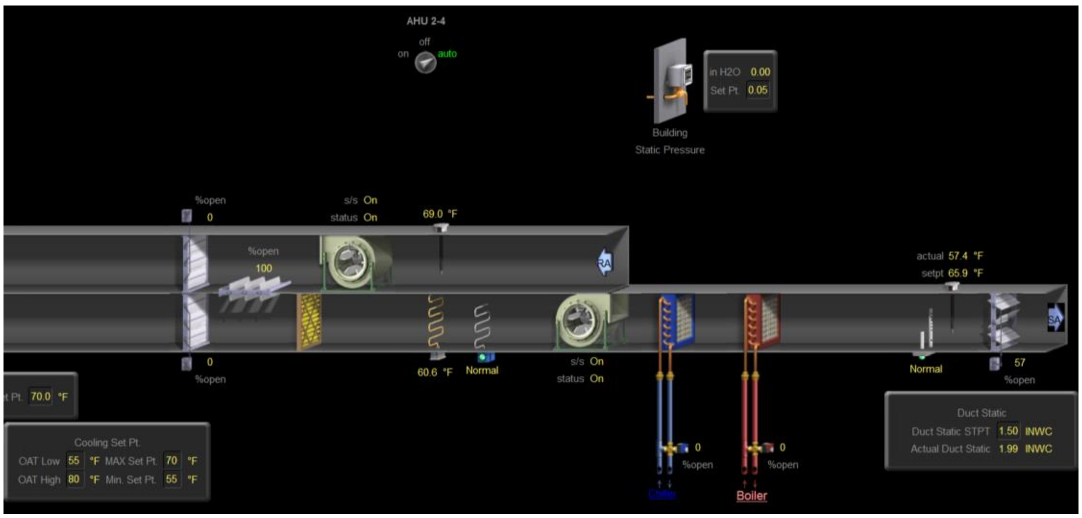

Figure 3. AHU 2-4 ALC Graphic

4.3 Terminal Units

The building has a mix of terminal unit control types, as shown in Table 6. The pneumatic controls are well past the end of their expected service life of 20 years. Both the Reliable and ALC controls are well below their expected service life of 15-20 years. The ALC and Reliable terminal units have been integrated into the ALC interface for monitoring and trending. The pneumatic controls do not allow for monitoring or trending and are incompatible with many of the advanced VAV control strategies outlined in ASHRAE Guideline 36 that minimize energy use. None of the terminal units have CO_2 sensors for demand-controlled ventilation.

Table 6. Terminal Unit Control Type Summary

Control Type	Estimated Count	Year Installed
Pneumatic	39	1979
DDC - Reliable	4	2011
DDC - ALC	15	2018
Total	58	-

4.4 Packaged Rooftop Air Conditioning Units

The four Carrier packaged units installed in 2018 have self-contained controls and have been integrated into the ALC interface. A review of the controls for these units was not included in this study, though we did incidentally discover that the AC-2-3 thermostat is incorrectly located in a hallway instead of the primary room it serves, 239B. As a result, the compressor and transformer in 239B overheated in February, 2019, triggering a heat sensor and causing room temperatures in excess of 90°F.

4.5 Exhaust Fans

Two of the six exhaust fans already have DDC controls for enabling and monitoring the fan. The other four fans do not have DDC controls and are assumed to run 24/7. We did a simple payback analysis for installing DDC controls to allow the fans to be scheduled on and off and found that the payback time would be roughly 20-30 years for the four small motor fans. Adding DDC controls is therefore not a cost effective measure, but would reduce energy use somewhat and would allow for fan monitoring.

4.6 Recommendations

A. *Air Handling Units*

1. Install New ALC DDC Controls on the New Air Handling Units

See discussion above for replacing the air handling units. Installing ALC DDC controls with the new air handling units will:

- Align the building with the campus standard for ALC controls;
- Provide improved comfort due to tighter climate control and monitoring; and
- Reduce energy use by allowing the implementation of best practice VAV control sequences, including demand based resets of duct static pressure, supply air temperature, and chilled water supply temperature.

The cost of new ALC DDC controls for the air handling units is included in the cost for replacing the air handling units listed above.

2. Alternate Option: Install New ALC DDC Controllers on Existing Air Handling Units

See discussion above; the benefits are identical to those provided by installing new controls on new air handling units. The cost is included in the cost for refurbishing the air handling units above.

B. *Terminal Units*

1. Install ALC DDC Controls on All Terminal Units with Pneumatic or Reliable Controls

Replacing the pneumatic terminal unit controls with DDC, as was done for roughly ¼ of the terminal units in 2018, will provide improved comfort and energy efficiency by allowing implementation of dual maximum VAV logic. Dual max logic minimizes reheat energy and minimizes the risk of driving low load zones unnecessarily into heating mode—a common issue with the single maximum logic inherent to pneumatic controls.

Converting the four VAV boxes with Reliable DDC controllers to ALC will eliminate any complications with integrating these four boxes into the control logic and will align the building with the campus standard for ALC controls. Involving a Reliable Controls contractor to reprogram the four existing VAV controllers with Dual Max logic—which would be necessary for air handler demand based resets—is likely to be more expensive than just swapping out the controllers.

Note that, as required by code, this measure will include thermostats with CO_2 sensors for all densely-occupied zones, e.g. example classrooms and conference rooms, to allow demand control ventilation. We also recommend that the control retrofit include a review and reduction of the minimum airflow setpoints for each terminal unit to the minimum ventilation rates allowed by Title 24. Reducing zone minimum airflows will reduce fan, cooling and reheat energy. Demand control ventilation would also eliminate the need for the induced airflow of induction VAV boxes, allowing the induction air dampers to be closed permanently, decreasing the box pressure drop (required to induce air) and in doing so reducing central fan energy.

We estimate the cost of converting all the terminal units to ALC to be roughly $100,000.

2. Add CO_2 Sensors to Existing DDC Terminal Units

Roughly ten of the DDC terminal units that were installed in 2011 and 2018 serve densely occupied zones such as classrooms and conference rooms, but do not have CO_2 sensors. The thermostats could be converted to combination temperature-CO_2 sensors, or a separate CO_2 sensor could be added, to allow for demand-controlled ventilation.

We estimate adding CO_2 sensors to the ten terminal units to cost roughly $12,000.

C. *Exhaust Fans*

1. Consider Installing DDC Controls on Exhaust Fans

Consider installing DDC controls on the four exhaust fans without DDC controls to reduce energy use and allow for fan monitoring.

We estimate installing DDC controls on the four exhaust fans to cost roughly $7,000.

D. *Packaged Rooftop Units*

1. Move AC-2-3's Thermostat

Move AC-2-3's thermostat into room 239B to prevent overheating.

5 Measure Prioritization

Most of the measures we identified work in concert. For instance, to maximize the energy and thermal comfort impacts of air handler replacement using demand based resets, DCC retrofit work is required at the zone level. That being said, we prioritized measures in Table 1 largely based on the operations and maintenance criticality of the retrofit work.

Replacing the rooftop piping should be the first priority. The extreme corrosion observed on all of the hot and chilled water pipes predisposes the distribution systems to a catastrophic leak. Additionally, the tattered state of the pipe insulation results in substantial energy waste.

Air handler replacement (or refurbishment) and associated controls replacement should be the second priority, and ideally executed concurrently with piping replacement such that new pipe routing can be optimally coordinated with the air handlers. We cannot stress enough that the current operational state of the air handlers is grossly inadequate: deadheaded fans, ducts pressurized in excess of 4", air traveling the wrong way through relief dampers, and mis-mapped and/or failed dampers all go well beyond the typical inefficiencies expected of older systems.

Following air handler replacement, zonal work should be pursued in order to eliminate pneumatics from the building, improving serviceability, energy efficiency, and thermal comfort in the process. Thermal comfort and energy performance will improve from the air handler replacements alone, but continued occupant complaints and less than optimized energy performance should be expected until DDC retrofit work is completed throughout the building.

Appendix A: Photos from Site Visit

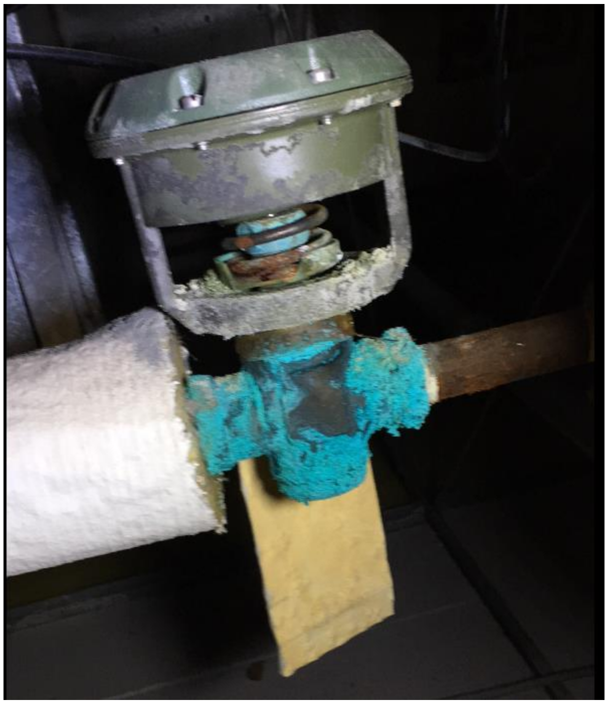

Figure 4. Pneumatic Hot Water Valve

Figure 6. Rooftop Piping

Figure 5. Rooftop Piping

Figure 7. Rooftop Piping

Figure 8. Rooftop Piping

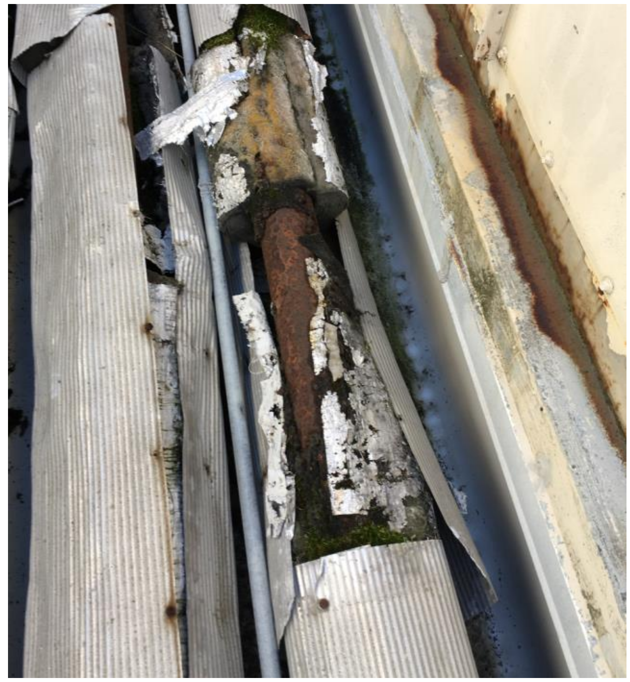

Figure 10. Rooftop Piping

Figure 9. Rooftop Piping

Figure 11. Rooftop Piping

Figure 12. AHU 1-2

Figure 14 AHU 2-4 Ductwork

Figure 13. AH 1-2

Figure 15. Rooftop Ductwork

Figure 16 AHU 1-2 Outdoor Air Damper

Figure 18. E/P Transducers for AHU 1-3 Chilled and Hot Water Pneumatic Valve Actuators

Figure 17. Pneumatic Valve Actuator for AHU 2-3 Chilled Water Valve

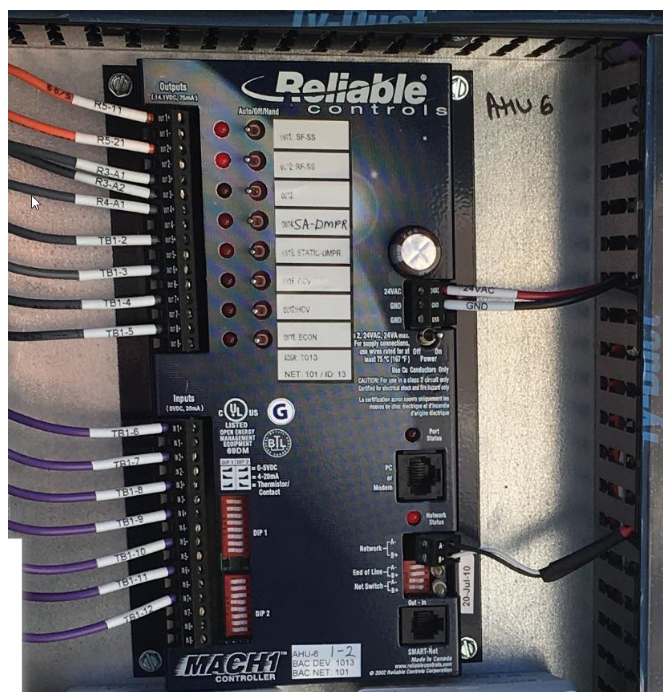

Figure 19. Reliable Controller for AHU 1-2

Figure 20. AHU 2-3

Appendix B: References

The following documents were referenced in creating this report and can be accessed via the following link: https://taylor-engineering.box.com/s/ui9mn8119tsn5c5was6xypt2816ogjd9

- 1979 As-Built Mechanical Drawings
- 2011 As-Built Mechanical Drawings
- 2017 Chiller Replacement Mechanical As-Builts
- 2017 Chiller Replacement BAS Drawings
- 2018 As-Built Mechanical Drawings
- 2018 As-Built Architectural Drawings
- 2018 Boiler Replacement Close-Out Transmittal
- 2019 Chilled and Hot Water Treatment Report