



HVAC READINESS

A CASE STUDY IN DENVER PUBLIC SCHOOLS // 2020



published June 2021



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SECTION 1
Overview

PROJECT GOALS

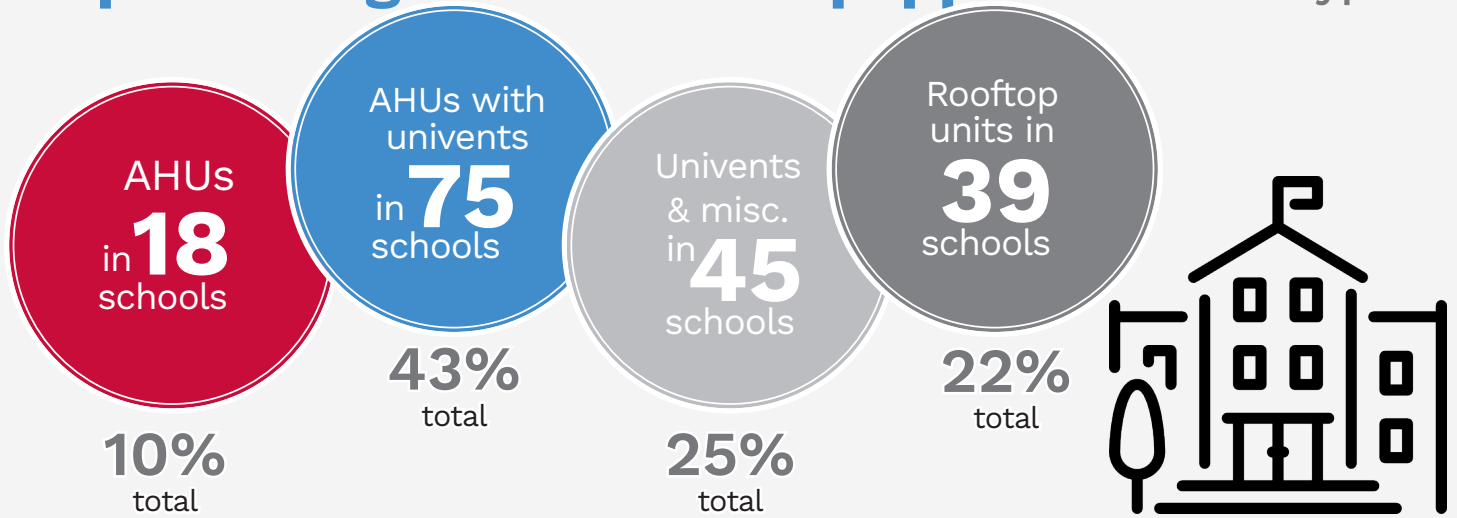
The DPS Operations team has been working throughout the COVID-19 pandemic to maintain all DPS buildings and to implement extensive safety measures in buildings across the district.

These measures include a \$5 million district-wide investment in HVAC systems, improved filtration, air ventilation and ventilation controls. These were our project goals.

- **HVAC systems:** Assess and repair heating and ventilation equipment to ensure proper operation.
- **Improved Filtration:** Increase filtration to maximum filtration allowed by the equipment manufacturer.
- **Air Ventilation:** Increase outside air flow by opening dampers to 30% during the heating months. Remove obstructions. Clean louvers.
- **Ventilation Controls:** Adjust HVAC controls to run systems for two hours after occupancy to flush the building.



4 major **types of HVAC systems** assessed in **177** buildings & the **percentage of schools equipped** with each type:



PROJECT GOALS (CONTINUED)

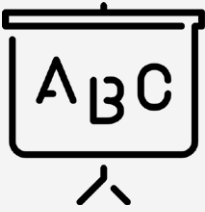
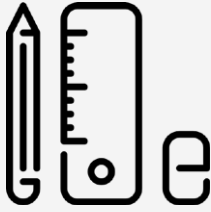
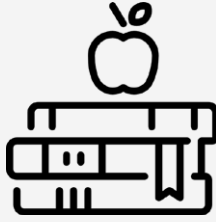

The team achieved our goal of improving air quality in DPS’s buildings to improve the safety of students, staff and community members.

Knowing the building controls and mechanical systems were tested and repaired to ensure proper operation, filtration was at the maximum allowable amount, and the increased amount of outside air gave DPS staff and families peace of mind, so they could focus on the needs of our over 92,000 students.

Project Goals Source:

DPS Website. Keeping School Buildings & Classrooms Safe. Preparing DPS Buildings. <https://www.dpsk12.org/coronavirus/return-2020/health-and-safety/#buildings>

HVAC Readiness by the numbers

				
	95 elementary schools	22 K-8 schools	14 middle schools	46 high schools
Average sq feet	65,236	82,495	112,725	116,546
Total sq ft	6.2M ~	1.8M ~	1.6M ~	5.4M ~
Controls	*Hybrid: 31 DDC schools: 64	*Hybrid: 3 DDC schools: 19	*Hybrid: 3 DDC schools: 11	*Hybrid: 9 DDC schools: 37

*Pneumatic and DDC controls

ASHRAE RECOMMENDATIONS FOR VENTILATION

When the project was started COVID-19 strategies for HVAC systems were still emerging and changing. We closely followed ASHRAE and other research organizations as new information became available and as it evolved.

As the team reviewed emerging information, we adopted a foundational rubric for HVAC equipment:

- **Increase ventilation** by increasing outdoor air.
- **Improve filtration** to the maximum allowed by the manufacturer.
- **Analyze and repair airside HVAC systems** to ensure proper operation.

Source: ASHRAE Epidemic Task Force Building Readiness. <https://www.ashrae.org/about/news/2020/ashrae-epidemic-task-force-releases-updated-building-readiness-guide>



PROJECT TEAM ROLES & RESPONSIBILITIES

A large, diverse team from multiple agencies came together to tackle this project. This section identifies those team members and provides a brief description of their contribution to the outcome.



PROJECT CHAMPION

Communicated progress to the Senior Leadership team and Board of Education and addressed concerns.

PROJECT MANAGERS

Lead Project Manager: coordinated all DPS and Contractor teams, lead team meetings, and facilitated issue and decision resolution.

Sr. Construction Project Manager: aligned work with active Construction Projects.

Construction Project Manager: contracted, scheduled, and monitored vendor activity for cleaning grills and coils.

MAINTENANCE TEAMS

Provided support for contractors, assistance with troubleshooting, and completed assigned repairs (including assessments in non-academic/admin buildings).

Shops: HVAC, BAS, Electrical and Structural.

PREVENTATIVE MAINTENANCE TEAMS

Changed all filters to higher filtration levels and cleaned uninvents.

ENVIRONMENTAL SERVICES

Reviewed emerging data, made recommendations, and documented decisions.

FACILITY MANAGERS

Supported contractors by providing access and insight on mechanical systems.

<https://www.dpsk12.org/>



PROJECT MANAGERS

Provided Mechanical Engineering / Controls expertise and helped guide technical decisions, particularly related to COVID-19.

Coordinated teams assessing equipment and assigned issues for appropriate team to address.

COMMISSIONING ENGINEERS

Executed remote testing and provided recommendations on potential deficiencies.

Performed on-site testing to verify remote testing results.

Verified mechanical system performance after repairs were made.

<http://www.mckinstry.com/>



U.S. ENGINEERING

PROJECT MANAGERS

Coordinated U.S. Engineering and subcontractor repair teams.

PROJECT COORDINATOR

Tracked and provided status reports on progress made by the U.S. Engineering/subcontractor teams.

MECHANICAL SERVICE TECHNICIANS

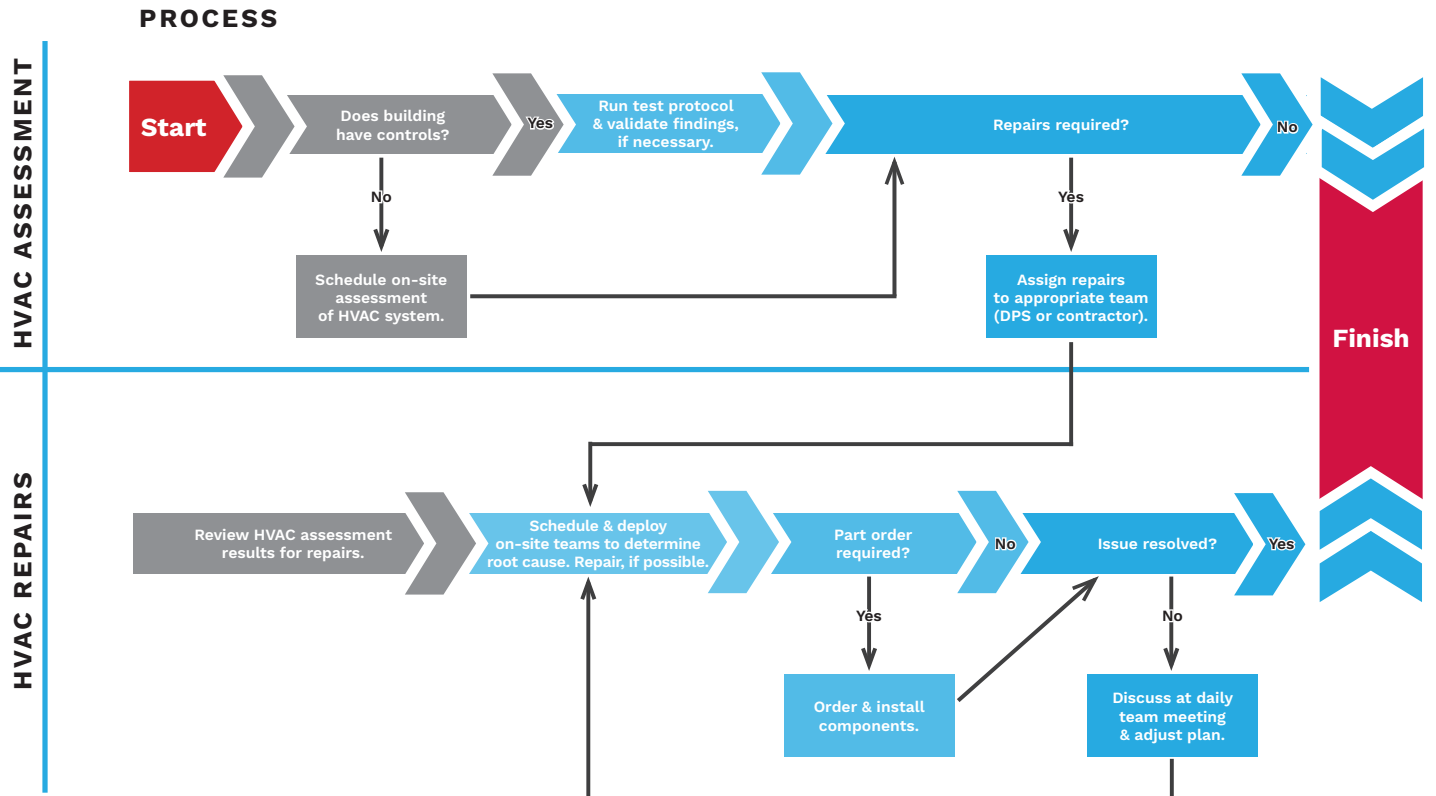
Assessed and repaired mechanical issues.

CONTROLS CONTRACTORS

Assessed and repaired controls issues.

<https://www.usengineering.com/>

SECTION 3
Process



PROJECT APPROACH

The team used the above workflow to assess and repair HVAC equipment for the DPS school facilities.

Commissioning engineers performed HVAC assessments in order to discover possible issues in multiple buildings. The issues they found were assigned to service teams for verification in the field, and ultimately, for repair.

The following pages break down our two-step assessment and repair process, offering a detailed look at the work our team performed, with examples.

STEP 1**USE REMOTE BAS ANALYSIS PROCESS FOR HVAC ASSESSMENTS**

McKinstry assessed approximately **4,800 pieces of equipment** by reviewing operation through the building automation system (BAS).

For each piece of HVAC equipment, the Cx Engineer reviewed the status of fans, dampers, and control valves in order to answer the following questions:

- Is the outside air damper/mixed air damper able to modulate properly?
- Does the fan turn on/off as commanded?
- Does the heating water/heating valve modulate as commanded?
- Does the chilled water/cooling valve modulate as commanded?
- Do all CO2 sensors read with the expected range (no lower than 325 ppm and no greater than 600 ppm for unoccupied buildings)?

COMMON ISSUES**Summary of Common Issues Identified during HVAC Assessment**

There was a large variety of issues, but also a commonly re-occurring theme. Specifically, McKinstry pinpointed three issues, which made up roughly two-thirds of the total discovered during the investigation. We detail those issues and their root causes in the following pages.

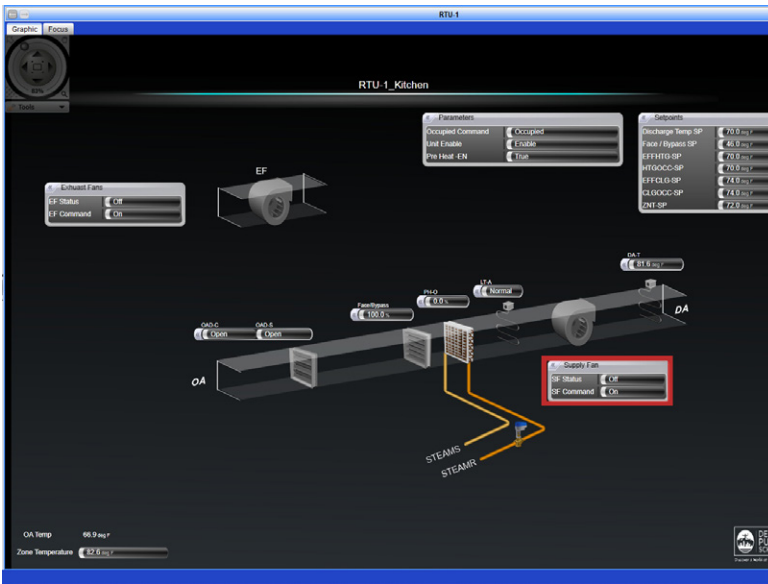
COMMON ISSUE 1

The supply fan did not enable when commanded in occupied mode.

Number of Occurrences: 332 (20% of total issues)

Issue Resolutions:

- Replace fan motor.
- Replace fan capacitor.
- Turn fan switch to high. Our teams discovered that some fans do not operate at low speed due to low speed resistor coil burnout.
- Repair motor. The bearing rubber was binding the shaft and keeping the motor from spinning.



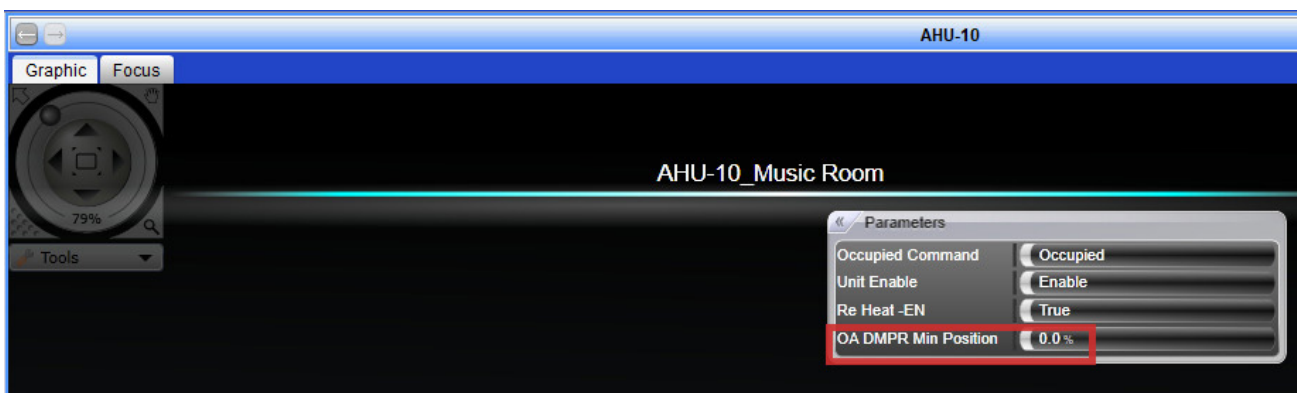
Status	Item	Value	Description
Occupied	STPLTN_K-8.HP-79.Occupied	Occupied	
Out of Ser...	STPLTN_K-8.HP-79.Room	95.0 deg F	
	STPLTN_K-8.HP-79.DA-T	57.0 deg F	
	STPLTN_K-8.HP-79.Filter-S	Clean	
	STPLTN_K-8.HP-79.Heat SP	70.0 deg F	
	STPLTN_K-8.HP-79.Cool SP	73.0 deg F	
	STPLTN_K-8.HP-79.SBHeatSP	70.0 deg F	
	STPLTN_K-8.HP-79.SBCoolSP	80.0 deg F	
	STPLTN_K-8.HP-79.MinHt SP	40.0 deg F	
	STPLTN_K-8.HP-79.MaxHt SP	90.0 deg F	
	STPLTN_K-8.HP-79.MinCL SP	54.0 deg F	
	STPLTN_K-8.HP-79.MaxCL SP	70.0 deg...	
	STPLTN_K-8.HP-79.HP-S	Off	
	STPLTN_K-8.HP-79.HPump	On	
	STPLTN_K-8.HP-79.Y1Cool1	On	
	STPLTN_K-8.HP-79.Y2Cool2	On	
	STPLTN_K-8.HP-79.G Fan St	On	
	STPLTN_K-8.HP-79.Temp Unit	On	
	STPLTN_K-8.HP-79.OccOvrd	Off	
	STPLTN_K-8.HP-79.Mode	Cool	

These graphics represent examples of feedback from the BAS analysis. Supply fan status is off while other components appear to be running.

COMMON
ISSUE 2**The outside air damper was 0% open with the unit commanded on.****Number of Occurrences: 510 (32% of total issues)**

Issue Resolutions:

- Open outside air damper when found to be closed.
- Readjust outside air damper linkage or reprogram damper signal. The outside air damper linkage was not adjusted correctly, or the damper signal was programmed incorrectly (0-10V rather than 2-10V.)
- Replace economizer controller.
- Address pneumatic leak that caused the damper actuator to fail closed.
- Replace damper actuator and linkage. Linkage had loose/broken parts and/or stuck due to rust. Actuator was past its life or was faulty.
- Replace bad stat, which originally was not letting air pass through. Issues included faulty calibration screw, plugged restrictor, dirty nozzle at the bleed port, and broken plastic nipple in the back of the mounting base.



Graphic: An example of the outside air damper position shown as 0% (fully closed) in the BAS while the unit is running (enabled).

**COMMON
 ISSUE 3**

The CO2 level read significantly below normal atmospheric conditions.

Number of Occurrences: 181 (11% of total issues)

Issue Resolutions:

- Replace CO2 sensor. The sensor was damaged or missing an output voltage jumper.
- Recalibrate CO2 sensor. The CO2 jumper was set to 0-5 VDC, when it should be 0-10 VDC.

Status	Item	Value	Description
	ZN-T	80.4 deg F	Zone Temperature
	DPR-O	100.0 %	Supply Air Damper Output
	DA-VP	0.13 in wc	Discharge Air Velocity Pressure
	ZN-CO2	2,101 ppm	Zone Quality
	ZNT-SP	72.0 deg F	Common Setpoint
	OCC-SCHEDULE	Occupied	Occupancy Schedule
	SAFLOW-SP	1,275.0 cfm	Flow Setpoint
	SA-F	673 cfm	
	CLGOCC-SP	74.0 deg F	
	CLGUNOCC-SP	82.0 deg F	
	HTGOCC-SP	70.0 deg F	
	HTGUNOCC-SP	61.0 deg F	
	EFFCLG-SP	74.0 deg F	
	EFFHTG-SP	70.0 deg F	
	SA-AREA	0.79 sq ft	Supply Area
	SA-KFACTOR	3.00	Supply Pickup Gain
	CLG-MAXFLOW	1,275.0 cfm	Cooling Max Flow
	CLGOCC-MINFLOW	320.0 cfm	Occ Cooling Min Flow
	HTGOCC-MINFLOW	320.0 cfm	Occ Heating Min Flow

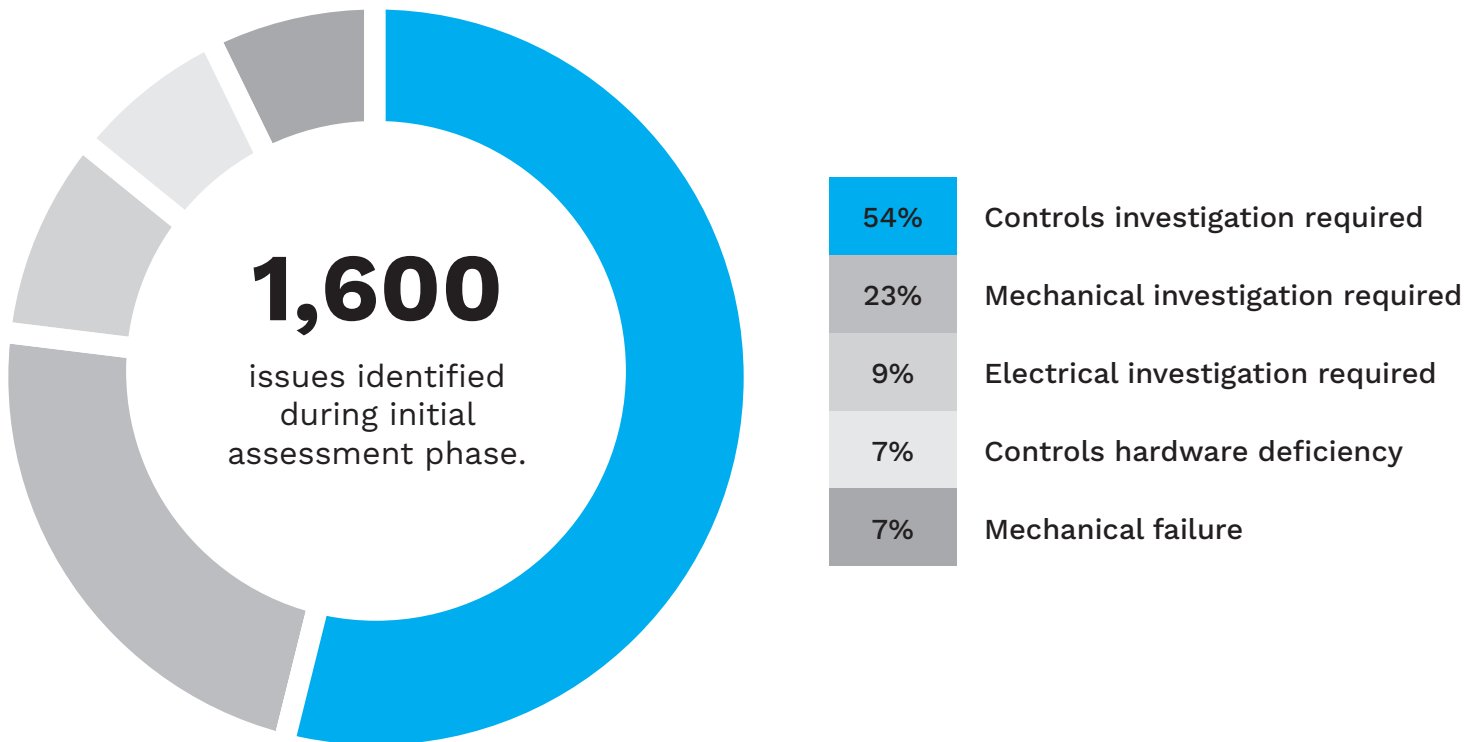
Graphic: Zone CO2 values were significantly higher expected in normal occupied conditions.

COMMON ISSUES

Root-cause breakdown.

Based on the BAS Analysis, McKinstry identified **over 1,600 issues** remotely. The majority of the analysis was performed within a 70-day window.

The issues were categorized according to the following potential root causes:



STEP 2**USE SERVICE TEAMS
TO VERIFY ISSUES**

As McKinstry teams identified potential issues at each facility, they provided a list of those issues to the implementation team for verification. The issues were assigned to the DPS maintenance teams, U.S. Engineering mechanical service technicians, electrical contractors, or to controls contractors, depending upon the the anticipated root cause.

The group dispatched individual service teams to perform visual inspections. Those service teams confirmed and clarified the issues and ordered parts, if necessary. Those teams then scheduled follow-up site visits to perform the repairs. Once completed, the Cx teams again verified proper operation through BAS analysis.

The implementation team addressed **over 1,600 issues in a 4-month period.**

The following pages provide examples of typical repairs that were made by the service teams and controls subcontractors.

PHOTOS

Examples of Specific Repairs



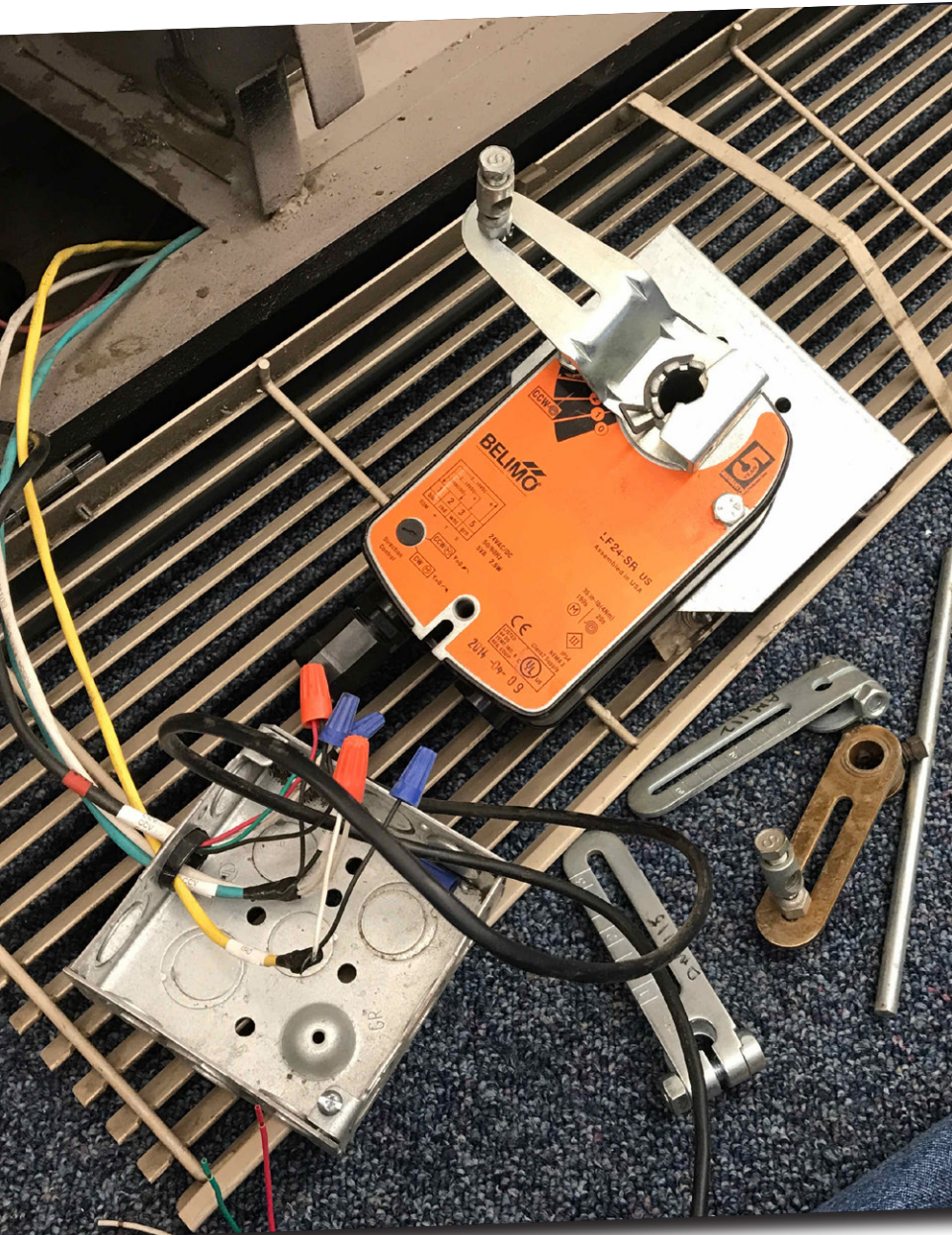
Controls. Outside air damper adjustment.

A completely closed damper (top) adjusted to the minimum outside air damper position (bottom).



PHOTOS

Examples of Specific Repairs



Controls. Uninvent outside air damper repair (left).

Other controls repairs included

- Tighten Damper/ Louver Blades
- Repair/Replace On/ Off HOA Switch
- Economizer Controller Replacement
- Actuator Settings
- Freezestats Tripped
- Sensor Replacement/ Recalibration
- VFD Reset
- Pneumatic controls air supply leak.

PHOTOS

Examples of Specific Repairs



Electrical. Uninvent temperature controller test (top).

This test addressed wiring issues, blown fuses, and other electrical malfunctions.



Equipment. Old equipment component (bottom) replacement, including

- Motors
- Shaft bearings
- Belts
- Motor starters
- Capacitors
- Compressors.



WHAT DID WE LEARN?

In a large project like this one, consisting of a significantly wide scope and a giant mechanism of moving parts, everyone involved is presented with opportunities for growth.

The following pages outline elements of the project that contributed to its success and some of the challenges that we faced along the way. We offer these lessons learned to improve future endeavors with similar scope.

LESSONS**WHAT CONTRIBUTED TO PROJECT SUCCESS?****Communication**

- Verbal communication in the form of daily meetings and focus on rapid decision making was a key to success.
- Calls to owner for troubleshooting HVAC and BAS resolved issues quickly.
- BIM 360 was used as a central software platform for communicating status of issues to the team.
- Procore was used for central document management (drawings, photos, progress reports) and internal issue documentation.

Interaction with DPS Facilities Personnel

Champions within owner administration, HVAC and controls shops are critical.

- Administration and project managers were very responsive to facility access and scheduling questions.
- Controls and HVAC shops were extremely responsive to questions about equipment operation and maintenance issues.
- Immediate communication with DPS was essential to identify and diagnose BAS issues.
- All impacted departments were assigned to the team which facilitated better coordination and understanding of decisions made.

Interaction with DPS Facility Managers (FMs)

- Most facility managers had extensive knowledge of their buildings.
- FMs were the primary points of contact for understanding changes in building occupancy and use.

Partnerships between DPS and Contractors

- The strong partnerships DPS has with both US Engineering and McKinstry were critical in order to quickly build a skilled team, determine roles and responsibilities, and meet project goals in a very short time frame.

Using the Commissioning (Cx) Process

- Using remote assessments allowed McKinstry to rapidly deploy a large number of Cx engineering resources from around the country. The first assessments were started, in multiple offices around the US, within hours of the initial conversations with the client.
- Remote BAS functional testing provided a detailed list of equipment to inspect for possible repairs.
- Provided a repair list early in the project so USE could deploy resources quickly.
- Saved significant time in the field. Repairs and verification were focused on specific equipment and issues instead of inspecting all equipment on-site.

LESSONS**WHAT CHALLENGES DID WE FACE?****COVID-19 Challenges**

- There were some issues with building access due to limited staff and limited hours.
- Longer working hours occasionally spilled over into building unoccupied hours, which resulted in some access issues.
- There were inefficiencies due to personnel safety, quarantine requirements, building sanitation and social distancing.

Interaction with DPS Facility Managers (FMs)

- Training issues with FMs that didn't understand the scope of the HVAC readiness project.
- Training issues where FMs didn't know HVAC equipment or locations.
- Some FMs were inexperienced with their particular facilities.

Documentation Issues

- There were out-dated as-built drawings and architectural plans with changed room numbers or equipment ID.
- Some equipment did not have equipment ID tags or the tags were incorrect.
- Coordination with new construction projects.

Supply Chain

- There were challenges with suppliers matching very old parts, motors etc. with new parts and motors.
- Some parts were obsolete, which required additional work to address.
- Some parts were not readily available, and had to be shipped from out of town.
- One of the keys was to use suppliers that are very good at getting these old parts and are knowledgeable in the equipment and installations we are working with.

Temperature Controls

Multiple types of temperature controls systems

- Some of the preapproved vendors and former vendors did not have the staffing or structure to support a project like this.
- It was challenging to get several of the companies scheduled and their work completed.

Pneumatic Systems

- Assessing pneumatic systems required substantially higher labor for fully in person evaluations.
- Working on the pneumatic systems was challenging in terms of having the proper diagnostics tools and knowledge.
- The parts for the pneumatic systems were very difficult to source and procure.

Thank you to the teams at DPS, McKinstry and U.S. Engineering for contributing to and creating “HVAC Readiness.” In particular, thank you to DPS’s Heather Bock, McKinstry’s Erik Greensfelder and Karen Johnson and U.S. Engineering’s Greg Italiano, Sr., Victoria Palmer, Tom Poeling and Jason Schneider for authoring and compiling the report. Thanks also to U.S. Engineering’s Diana Murphy and Monte Holman for editorial production.

