Multiple Failures in Roosevelt High School HVAC System

March 30, 2023

A report by RSM US LLP for the Office of the D.C. Auditor

Audit Team
RSM US LLP

Office of the District of Columbia Auditor

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ODCA Office of the District of Columbia Auditor

March 30, 2023

The Hon. Phil Mendelson
Chairman, Council of the District of Columbia
The John A. Wilson Building
Washington, DC 20004

Dear Chairman Mendelson and Councilmembers:

I write to present the report, Multiple Failures in Roosevelt High School HVAC System, prepared for the Office of the DC Auditor (ODCA) by RSM US LLP, in response to the D.C. Code §38-2973 requirement to report on the Department of General Services (DGS) management of school modernization on behalf of D.C.Public Schools.

The report describes DGS' efforts to maintain, repair, and determine likely causes for multiple failures in the heating and cooling system (HVAC) at Roosevelt Senior High School. In 2016, a $136 million modernization was completed at Roosevelt, including a modernized variable refrigerant flow (VRF) system and subsystem. HVAC failures occurred each year since the modernization, resulting in frequent system outages and heating and cooling loss throughout the facility. Auditors found that the District accepted a non-functioning heating and cooling system in the modernized building. They found that DGS initiated several assessments and engaged multiple 3rd party vendors to determine the likely causes of the continual issues and spent over $2 million to repair and maintain the VRF system following installation.

Despite DGS' efforts to remediate issues related to Roosevelt's modernized HVAC system, including major equipment and component replacements, consultation with the VRF system manufacturer, and other 3rd party experts, problems with the VRF system continue through the date of this report. The parties evaluating these issues noted multiple potential origins of failure with a combination of contributing factors outlined in the following report including the use of mechanical fittings instead of welded materials contrary to manufacturer's specifications

The audit team documented shortcomings in DGS' management of the HVAC issues at Roosevelt. The team noted "a general theme of untimely action by both 3rd party vendors and DGS" with "several months/years [elapsing] between the identification of issues and the actions performed to assess or remediate those issues." Examples included issuing a Latent Defect Notice 16 months after the 1-year warranty period ended.

They found documentation not accessible or not available, including one key document, the Certificate of Substantial Completion typically signed by the project manager which in the case of Roosevelt was an employee of McKissack and McKissack. The auditors recommend assessing whether legal action is warranted and compiling, following, and reporting on an action plan with completion dates for steps already recommended by third party consultants. For future modernizations, we recommend that DGS develop procedures for sharing potential warranty issues with agency leadership and general counsel before the end of the warranty period and confirm all systems are installed according to manufacturer requirements before building turnover and project completion.

ODCA appreciates the partnership with and professionalism of the RSM team and appreciates the cooperation of DGS Leadership and officials. We hope this report gives the Council insight into how the District can avoid a repetition of the issues encountered at Roosevelt Senior High School.

Sincerely yours,

Kathy Patterson

Kathleen Patterson
District of Columbia Auditor

cc: D.C. Councilmembers

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TRANSMITTAL LETTER

March 30, 2023

Kathleen Patterson, D.C. Auditor
Office of the D.C. Auditor
1331 Pennsylvania Avenue, N.W.
Washington D.C. 20005

Pursuant to our Consulting Services Agreement, dated March 10, 2022, we hereby present our internal audit report of the Roosevelt High School Modernization project.

Our report is organized in the following sections:

Executive Summary	This provides a high-level overview and summary of the conclusions noted as part of our internal audit.
Background	This section includes an overview of the Roosevelt High School Modernization project.
Conclusions	This section includes a description of the conclusions and key takeaways noted during our internal audit and recommended actions.
Objectives and Approach	The objectives and approach of the internal audit are explained in this section.
Appendix A	This section includes data analytics related to HVAC work orders.
Appendix B	This section includes a listing of key warranty and turnover contract provisions.
Appendices C - H	This section includes the various third-party reports and other supplemental documents referenced throughout the report.

We would like to thank the staff and all those involved in assisting us with this internal audit.

Respectfully Submitted,

RSM US LLP

Executive Summary

Theodore Roosevelt High School ("Roosevelt" or "Roosevelt High School") was originally constructed between 1930 and 1932. Roosevelt underwent a major addition and renovation between 1977 and 1980, which expanded the school's academic, athletic, arts, and dining facilities. Currently, the facilities are shared between Roosevelt High School and Roosevelt S.T.A.Y., an alternative education program for adults.

In 2016, a $136 million modernization was completed to transform the school into a 21st century educational facility. The scope of the Modernization included, but was not limited to building renovations, restoration of historical building components, removal of 1970's additions, replacement of mechanical, electrical, and plumbing systems, and various technology enhancements.

The Modernization was designed by Perkins Eastman DC, in conjunction with the Design-Builder Smoot-Gilbane (a joint venture between Smoot Construction and Gilbane Building Company). The "Owner" of the project was the Department of General Services ("DGS"), who oversees capital construction and facilities management of existing District-owned properties.

Roosevelt High School has experienced a multitude of issues related to the heating, ventilation, and air-conditioning ("HVAC") system installed as part of the modernization, most notably the variable refrigerant flow ("VRF") system.

HVAC failures have occurred each year since the Modernization, resulting in frequent system outages, and the loss of heating and cooling functionality throughout the facilities. These system failures have persisted through 2022, leading to costly repairs, component replacements, and emergency contracting to provide temporary heating and cooling solutions for students and staff. According to an October 2021 DGS case study, over $2 million has been expended to repair and maintain the VRF system following its initial installation.

Approach

Our audit approach consisted of the following:

- Obtained the design-build agreement and mechanical (HVAC) subcontractor agreement to identify and assess contract articles related to warranties, as-builts, equipment manuals, and other relevant provisions
- Conducted interviews with relevant members of the District's facilities management team to gain an understanding of key events, the construction turnover process, and testing / commissioning of equipment
- Conducted interviews with the District's legal team to gain an understanding of potential legal action related to the Modernization
- Obtained a population of work orders and performed data analytics

Through our work, RSM endeavored to obtain an understanding of the history of the Roosevelt High School Modernization project and the HVAC issues that have persisted since completion of the project. The information and conclusions presented within this report are limited to the interviews and documentation made available to us. Several potential sources of failure related to the HVAC system have been noted by various parties since project completion; however, evaluation of the technical aspects of these potential failures falls outside of our expertise and the scope of our engagement.

At the conclusion of our audit, we summarized our findings into a written report, which was reviewed with the Office of the D.C. Auditor and the Department of General Services in January and February 2023.

Conclusions

Despite DGS' efforts to remediate issues related to Roosevelt's modernized HVAC system, including major equipment and component replacements, solicitation of third-party assessments and repairs, and oversight from the VRF system manufacturer, problems with the VRF system continue through the date of this report. Multiple potential origins of failure were noted by the various parties engaged to evaluate these issues, and the persistent malfunction of the HVAC system without resolution over the past six (6) years indicates that no single identifiable source of failure exists, but rather that a combination of factors contribute. Detailed conclusions and recommendations identified during our assessment are summarized on page 16.

BACKGROUND

Project Overview

Theodore Roosevelt High School ("Roosevelt" or "Roosevelt High School") was originally constructed between 1930 and 1932. Roosevelt underwent a major addition and renovation between 1977 and 1980, which expanded the school's academic, athletic, arts, and dining facilities. Currently, the facilities are shared between Roosevelt High School and Roosevelt S.T.A.Y., an alternative education program for adults.

In 2016, a $136 million modernization was completed to transform the school into a 21st century educational facility. The scope of the Modernization included, but was not limited to building renovations, restoration of historical building components, removal of 1970's additions, replacement of mechanical, electrical, and plumbing systems, and various technology enhancements. Roosevelt was designed and constructed to meet a minimum of the United States Green Building Council's ("USGBC") Leadership in Energy and Environmental Design ("LEED") for Schools 2009 gold certification level.

The design featured the addition of an enclosed atrium, which serves as the "heart" of the building, a new pavilion and public entrance for the S.T.A.Y. program and community use, renovation of the historic main entrance and cupola, and various sustainable design initiatives (i.e., stormwater management, on-site power generation, geothermal systems, etc.). According to the architectural / engineering agreement, the design was developed to serve approximately one thousand thirty (1,030) daytime students and up to six hundred (600) part-time evening students.

The Modernization was designed by Perkins Eastman DC, in conjunction with the Design-Builder Smoot-Gilbane (a joint venture between Smoot Construction and Gilbane Building Company). The "Owner" of the project was the Department of General Services ("DGS"), who oversees capital construction and facilities management of existing District-owned properties. Perkins Eastman was originally engaged by DGS to develop the design development ("DD") documents. The architectural / engineering agreement was structured so that the Design-Builder would assume the architect's contract and manage the completion of the design after a GMP ("guaranteed maximum price") had been established. A change order was executed to expand Perkins Eastman's scope of work to include a portion of the construction documents.

The project was turned over to DGS in August 2016 for DCPS' 2016-2017 instructional year, and substantially completed in November 2016.

Project Information	
Architect	Perkins Eastman DC
Design-Builder	Smoot-Gilbane
Overall Project Budget	$136.1M
Substantial Completion – Original	July 15, 2015
Substantial Completion – Revised	November 4, 2016 [1]
School Opening	August 2016

[1] Substantial completion date according to the Design-Builder's final payment application. A Certificate of Substantial Completion was not available per DGS.

BACKGROUND

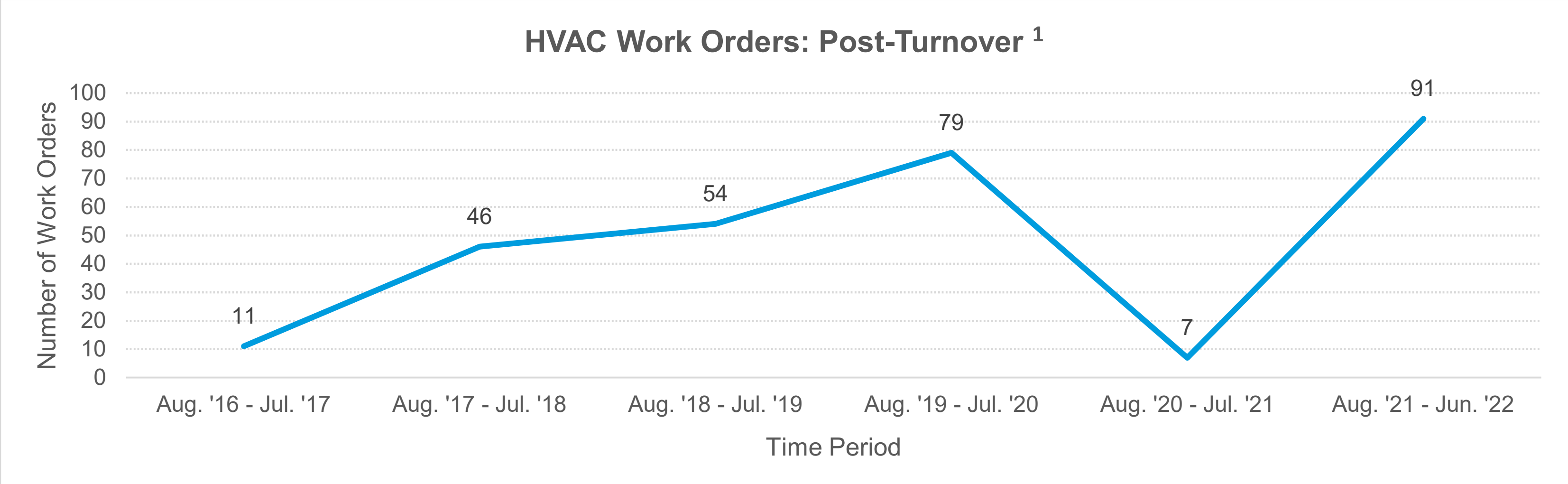
HVAC Issues: Summary

Roosevelt High School has experienced a multitude of issues related to the heating, ventilation, and air-conditioning ("HVAC") system installed as part of the Modernization, most notably the variable refrigerant flow ("VRF") system and its subsystems.

HVAC failures have occurred each year since the Modernization, resulting in frequent system outages, and the loss of heating and cooling functionality throughout the facility. These system failures have persisted through 2022, leading to costly repairs, component replacements, and emergency contracting to provide temporary heating and cooling solutions for students and staff. According to an October 2021 DGS case study **[Appendix C]**, over $2 million has been expended to repair and maintain the VRF system following its initial installation.

Several investigations and assessments have been conducted by the Department of General Services and third-party vendors to determine the root cause of the issues. According to DGS personnel, several causes have been identified as a result of these investigations, including refrigerant leaks within the VRF system's distribution piping and compressor failures. Due to the extensive repairs and maintenance required for the modernized HVAC system, DGS has permanently excluded the VRF system manufacturer from the design specifications.

Between August 2016 (school opening after the Modernization) and June 30,2022, two hundred eighty-eight (288) HVAC work orders were requested within the District's Computerized Maintenance Management System ("CMMS"). As shown in the graphic below, the number of work orders requested for HVAC-related repairs and/or maintenance has increased year-over-year, excluding the period when the facility was temporarily unoccupied due to COVID-19.



[1] *Includes twenty (20) "cancelled" work orders and seven (7) "rejected" work orders. Refer to **Appendix A** for breakdown of requested work orders.*

BACKGROUND

HVAC Issues: System Overview

Roosevelt High School has a large and complex HVAC system comprised of five hundred seventy-seven (577) pieces of mechanical equipment, according to the final commissioning report. A core feature of Roosevelt's HVAC system is the ground-coupled geothermal loop system, which serves as the main water source for many of the building's HVAC systems and subsystems.

This geothermal loop system continuously circulates water through a network of underground pipes located in a large geothermal field at the north end of the site. In total, two hundred fifty-three (253) wells make up the geothermal field. The geothermal system uses the earth's natural year-round temperature to provide energy-efficient heating and cooling.

Most of the facility's mechanical equipment is connected to the geothermal loop, including VRF systems and equipment. This loop may also be referred to as the "condenser water loop". According to the final commissioning report, the following systems and/or equipment are connected to this loop:

- Variable Refrigerant Flow ("VRF") systems
- Heat pumps
- Air Handler Units ("AHU")
- Dedicated Outside Air Systems ("DOAS")
- Condensing boilers
- Cooling tower

Quick Facts
VRF Manufacturer
LG
Design-Builder
Smoot-Gilbane (Joint Venture)
Mechanical Subcontractor
Limbach
HVAC Installer
RSC Electrical and Mechanical Contractors (Limbach Subcontractor)

Variable Refrigerant Flow ("VRF") System:

Roosevelt's VRF systems are the main source of heating and cooling for classrooms, offices, and support spaces. In total, there are eleven (11) VRF systems or "trees" throughout the facility, and twenty-one (21) VRF condensers supporting the VRF systems. Heating and cooling are provided through a combination of fan coil units ("FCU") and indoor ceiling cassettes within these spaces. At the completion of the Modernization, the system consisted of thirty-three (33) FCU's and one hundred sixty-six (166) ceiling cassettes. The FCU's and ceiling cassettes are connected to the VRF system through a series of refrigerant piping. Each VRF system may serve a particular zone, area, or cluster of rooms within the building. If a VRF unit fails, this may result in a loss of heating and cooling to several classrooms and offices.

The VRF system was manufactured by LG and installed by Limbach, a building systems solutions company that specializes in the design, installation, and maintenance of HVAC, mechanical, electrical, plumbing and control systems. Limbach was subcontracted by Smoot-Gilbane in June 2014 to provide a "complete functional system of all HVAC/Plumbing/Geothermal Work". Limbach subcontracted with RSC Electrical and Mechanical Contractors to assist with the installation of the VRF systems and equipment.

BACKGROUND

HVAC Issues: Commissioning

Commissioning is the ongoing process of verifying that all building systems and components are designed, installed, tested, and capable of being operated and maintained to perform according to the operational requirements of the Owner (Department of General Services). Commissioning is typically performed by an independent third-party called a "Commissioning Authority" ("CxA") or "Commissioning Agent". The commissioning process often begins during pre-design or the design phase, and continues through occupancy and a project's warranty phase. During the design phase, the commissioning agent functions as a consultant to the Owner, providing input and review on key project documents such as the Owner's Project Requirements ("OPR"), Basis of Design ("BOD"), and the design drawings.

After the design is approved and the construction phase begins, the commissioning agent continues to serve as a consultant to the Owner, working closely with both the Design Team, Design-Builder, and their subcontractors. During construction, the commissioning agent's objective is to verify that the building's systems and equipment are installed and operate as intended by the Owner in the OPR and BOD specifications, and the approved design. Commissioning responsibilities during construction may include, but are not limited to:

- Reviewing subcontractor submittals for systems and equipment to be commissioned by the CxA
- Conducting commissioning meetings and regular site visits
- Developing construction checklists for commissioned systems (completed by installing subcontractors)
- Functional testing of equipment
- Tracking of issues and deficiencies through an issues log

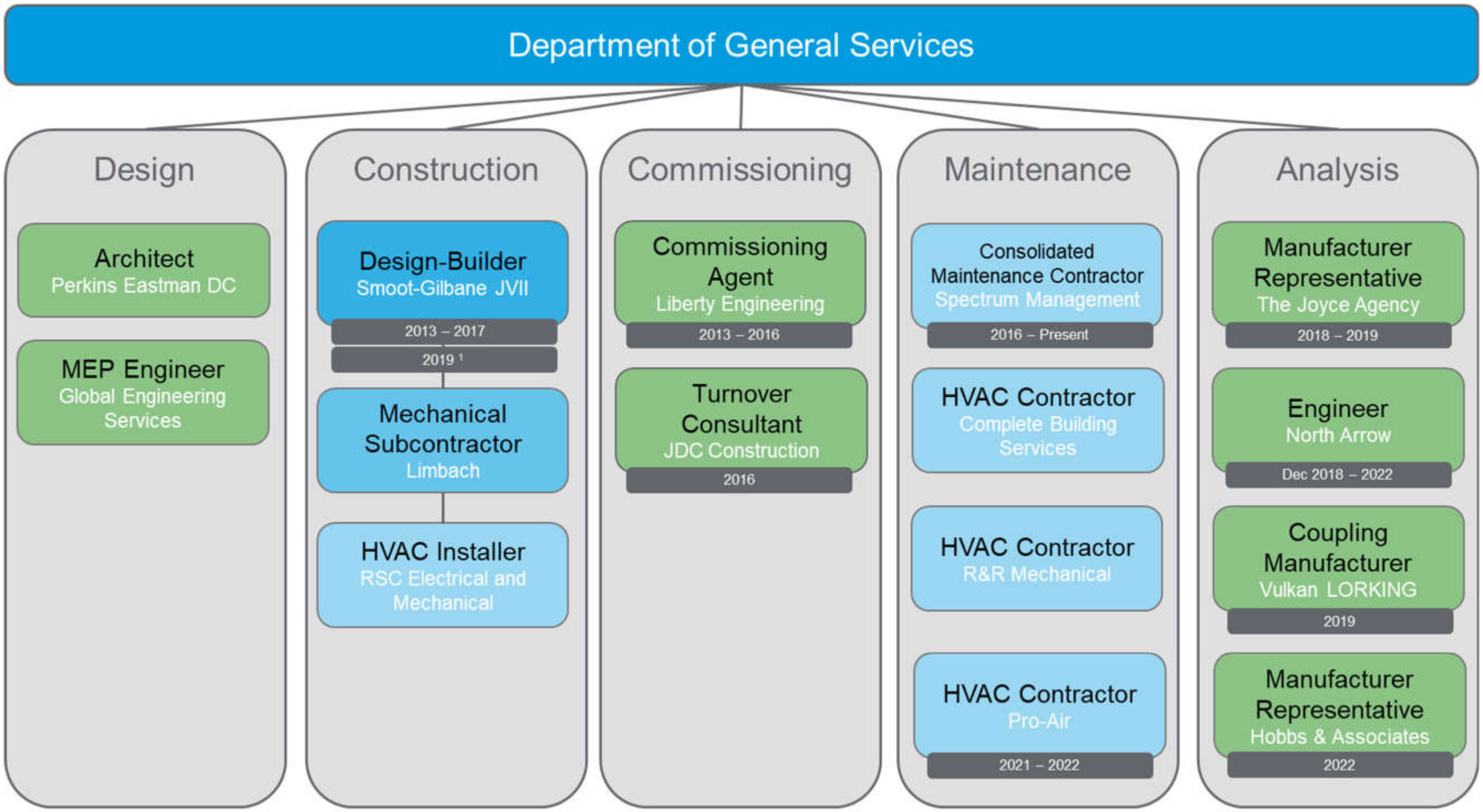
The Roosevelt High School Modernization was commissioned by a third-party commissioning agent, Liberty Engineering, LLP, who was contracted by the Department of General Services to provide commissioning services and the corresponding documentation for the building systems and equipment included in their scope of work. According to Liberty's Commissioning Plan, the objective of the commissioning process is to:

> *"Verify for the Owner that the mechanical, plumbing, electrical, and controls systems function interactively in compliance with the project intent, and to facilitate the orderly and efficient transfer of the systems to the Operations and Maintenance personnel. Commissioning also documents system performance parameters for fine-tuning control sequences and operational procedures, and to facilitate future troubleshooting. Commissioning is not intended to be a testing or inspection function that is redundant with respect to the installing contractor's obligations for testing and proof of performance."*

BACKGROUND

HVAC Issues: Key Parties

The following graphic includes some of the key parties involved in the installation, maintenance, repair, and assessment of Roosevelt's HVAC system.

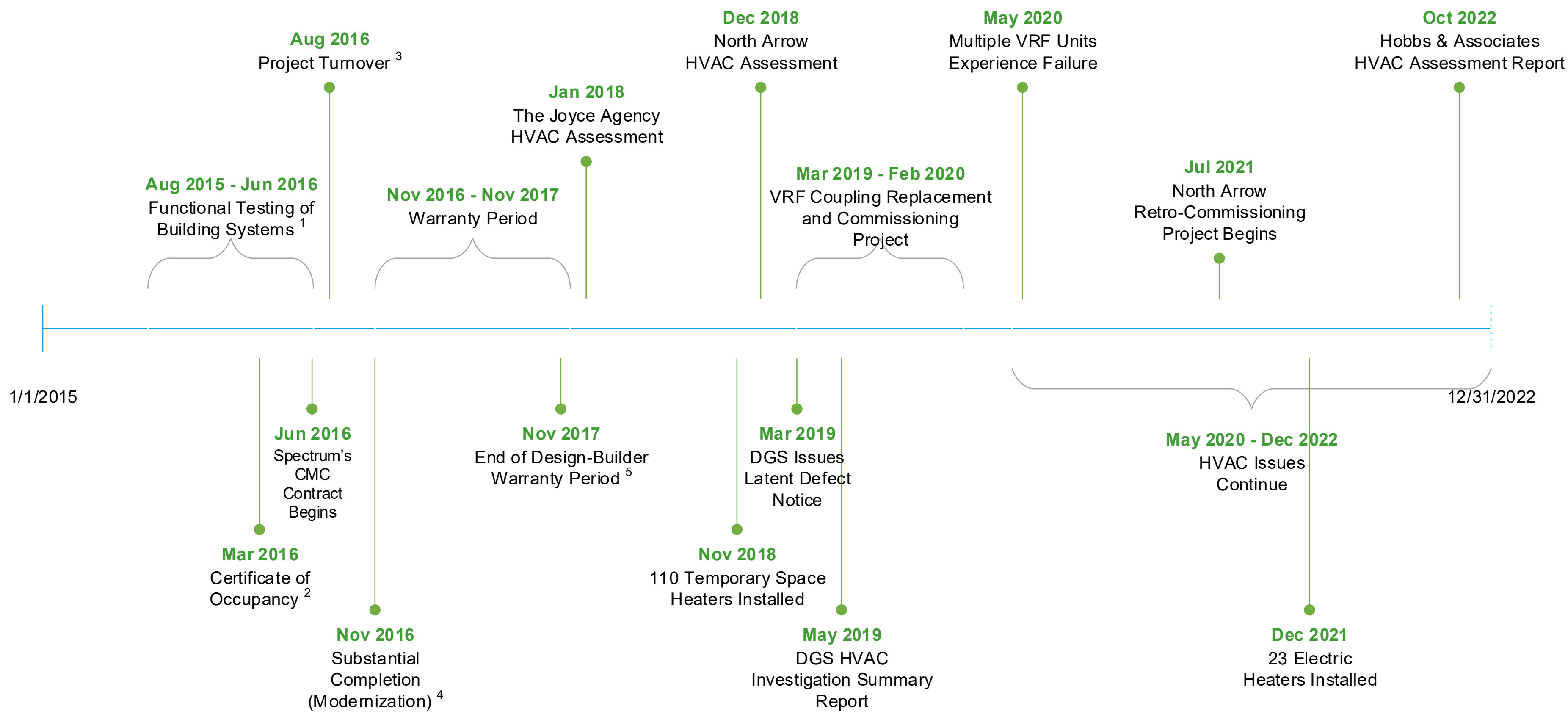


[1] Smoot-Gilbane was re-engaged in 2019 following DGS' latent defect notice (refer to report page 13 and 14 for additional information)

BACKGROUND

HVAC Issues: Timeline of Events

The following timeline includes key events, milestones, and deliverables related to the HVAC issues experienced at Roosevelt High School. Definitions of key terms and a summary of these events are detailed on the pages that follow. The information included within this report was compiled through stakeholder interviews and review of documentation made available by the Department of General Services.



BACKGROUND

HVAC Issues: Timeline of Events (continued)

Timeline Definitions		
Index	**Term**	**Description**
1	**Functional Testing**	Functional testing is a critical component of the commissioning process that involves performance testing the building's systems and equipment to verify proper installation and operation. For certain equipment types, testing may be performed on a sample basis, depending on the number of units. Refer to the "Commissioning" section of the report on page 6 for additional information.
2	**Certificate of Occupancy**	A Certificate of Occupancy was issued by the Department of Consumer and Regulatory Affairs on March 15, 2016. In the District of Columbia, a Certificate of Occupancy ("COO") is required before a building, structure, or land can be used for any purpose other than a single-family dwelling.
3	**Project Turnover**	The turnover phase is the period of transition from construction or renovation to owner occupancy and use. Roosevelt High School was effectively "turned over" from the Contractor (Design-Builder) and DGS' Capital Construction Division ("CCD") to DGS' Facilities Management Division ("FMD") when classes began in August 2016 for DCPS' 2016-2017 instructional year.
4	**Substantial Completion**	According to Smoot-Gilbane's final payment application, substantial completion was achieved on November 4, 2016. The substantial completed date could not be verified, as a Certificate of Substantial Completion was not available per DGS. According to the Design-Build Agreement, substantial completion is achieved when the following criteria have been met: *"Substantial Completion shall mean that all of the following have occurred: (1) the construction and installation work have been completed with only minor punch list items remaining to be completed; (2) a permanent certificate of occupancy and all other required permits or approvals have been obtained; (3) all operating and maintenance manuals, training videotapes and warranties required by the Contract have been delivered to the Department; (4) any supplemental training session required by the Contract for operating or maintenance personnel have been completed; (5) all clean-up required by the Contract has been completed; and (6) the Project is ready for the Department to use it for its intended purpose…"*
5	**Design-Builder Warranty Period**	The Design-Builder's warranty period ended in November 2017, according to the substantial completion date provided in Smoot-Gilbane's final payment application. Section 2.14 of the Design-Builder Agreement ("Design-Builder Warranty of Construction Work") defines the warranty period as one (1) year following date of substantial completion. Refer to **Appendix B** on page 23 for further detail.

Background

HVAC Issues: Timeline of Events (continued)

Commissioning & Functional Testing of HVAC System (August 2015 – June 2016)

Issues with the HVAC system were first observed and documented during construction as part of the commissioning and turnover process (refer to page 6 for additional information regarding commissioning). According to the final commissioning report, problems with the HVAC system were first identified during functional testing conducted between July 2015 and June 2016. During testing, the Commissioning Authority identified leaks and compressor issues, and problems with Building Automation System ("BAS") integration. Through our analysis of third-party HVAC assessments and interviews with stakeholders, we understand that these issues persisted through 2022. Liberty issued their "DGS Roosevelt High School Commissioning Final Report" on September 20, 2016, which identified several issues and challenges experienced during construction. According to the report, most issues were remediated prior to issuance of the final report, apart from four (4) key issues. The report states:

> *"The completion of the required commissioning verified that the systems are installed and operating correctly per the Owner Project Requirements, the Basis of Design, and as directed by the Engineer of Record. All issues that were identified during the commissioning process have been corrected with the exception of the following issues:*
>
> - *Communication issues between the equipment and the BAS.*
> - *The discrepancies between the Solar Heating System actual operation and the designed operation.*
> - *The installation issues with the Solar Heating System preventing continuous operation.*
> - *The relocation of OS-W-2 to an area with a clear field of vision."*

Consolidated Maintenance Contractor ("CMC") Contract Begins (June 2016)

In June 2016, DGS contracted with a full-service property, asset, and facility management company, Spectrum Management to provide consolidated maintenance services at Roosevelt High School. DGS utilizes Consolidated Maintenance Contracts ("CMC") to maintain the District's most critical facilities. The CMC Program was originally implemented to provide on-site maintenance resources for specific District facilities that posed the greatest operational risk in the event of facility shutdown or system failure. Following their onboarding, Spectrum submitted an Initial Deficiency List ("IDL") to DGS which identified ongoing critical issues related to the newly installed HVAC system (refer to "Warranty Period" below for further detail).

Project Turnover (August 2016)

Issues with the VRF system were still ongoing and pending remediation when the building became occupied in August 2016. The facilities were turned over to DGS' Facilities Management Division ("FMD") and Spectrum Management when classes began in August 2016 for DCPS' 2016-2017 instructional year. According to logs generated by Spectrum, over ten (10) VRF units experienced issues between June 2016 and December 2016. During this time, multiple VRF systems experienced failures leaving several classrooms without heat. Various components were replaced by the mechanical contractor, Limbach, including fan coil unit ("FCU") motors, valves, compressors, and a thermostat.

Warranty Period (November 2016 – November 2017)

Prior to December 2017, maintenance and repair of the HVAC system was the responsibility of the mechanical contractor, Limbach. According to their "Maintenance Agreement for Environmental Systems", effective November 1, 2016, Limbach entered into a one (1) year "full coverage" maintenance agreement, which included monthly operational inspections and maintenance visits, preventative maintenance, priority response to service calls, and all labor and parts for repairs.

BACKGROUND

HVAC Issues: Timeline of Events (continued)

Warranty Period (continued)

During the warranty period, Limbach was responsible for addressing the items on Spectrum's Initial Deficiency List and responding to maintenance and repair requests. RSM reviewed Spectrum's "Monthly Deliverable Reports", which included monthly updates regarding the status of the issues identified in the IDL. We noted that Limbach was still addressing critical IDL items, in addition to new HVAC issues through the end of the warranty period. It is unclear based on the narratives in the monthly reports whether the open IDL items were ever resolved. After the initial warranty period ended, maintenance and repair responsibilities for the HVAC system were turned over to DGS and Spectrum Management. Due to the nature and complexity of the issues experienced at Roosevelt, DGS solicited third-party vendors to perform repairs and install replacement components associated with the VRF system.

The Joyce Agency Assessment (January 2018)

In January 2018, a third-party vendor performing HVAC repairs at Roosevelt contacted LG to send a representative to assess a problem with one of the VRF units. LG's representative, The Joyce Agency, performed an onsite assessment of the failed VRF condenser unit on January 9th. The Joyce Agency provided a written report following their onsite visit **[Appendix D]**, which included the following conclusion:

> *"Although we were unable to clearly identify what caused the failure or exactly why the heat exchanger would have frozen and/or ruptured, we believe key application and maintenance items may require exploration. In fact, it may be advantageous to initiate discovery on all VRF systems at this site to confirm operating conditions and reduce additional failures."*

The report included a listing of the most critical items identified during the onsite assessment, which are summarized below:

- A strainer "screen" was missing from the failed unit, indicating that the heat exchanger was operating without protection from particulate. The Joyce Agency noted that the strainer may not have been serviced since its initial installation.
- The control valve did not appear to be "stroking" properly when it was manually reset.
- Through inquiry, The Joyce Agency found that a condenser water boiler had recently failed, which may have been critical to keeping the condenser water loop above the required operating temperatures.
- There was significant water contamination within the VRF system's refrigerant piping *"to the point water was migrating throughout the conditioned zones and leaking out of VRF "heat recovery boxes" and even some of the indoor units".* According to The Joyce Agency, this may have permanently contaminated all of the VRF devices connected to that system.
- Refrigerant leaks were discovered at some of the mechanical fittings used throughout building (refer to "North Arrow HVAC Assessment" and "Mechanical Coupling Failure Analysis" below for further detail). The Joyce Agency noted that failures, such as seized compressors or frozen coils or heat exchangers may occur if the piping network loses charge and refrigerant is not distributed properly.

The Joyce Agency provided ten (10) total recommendations as a result of their assessment. Their recommendations included verifying that the refrigerant piping and other components were installed per the manufacturer's guidelines, and that general maintenance was sufficient. Notably, The Joyce Agency also provided the recommendation to confirm that manufacturer water quality requirements were adhered to. A separate assessment performed by North Arrow in December 2018 found that the water within the condenser water loop was being maintained at a pH above the manufacturer's requirement.

BACKGROUND

HVAC Issues: Timeline of Events (continued)

Spectrum Issues Letter to DGS COTR Detailing VRF issues (February 2018 – November 2018)

Shortly after taking over HVAC maintenance responsibilities from Limbach, Spectrum Management issued a letter to the DGS Contracting Officer's Technical Representative ("COTR") chronicling the various issues and system outages experienced between June 2016 and January 2018. The letter, issued on February 7, 2018, included a month-by-month accounting of VRF failures, equipment replacements, and actions taken by Limbach during the warranty period. The letter was updated on December 10, 2018 to include events that occurred between February and November 2018.

Temporary Space Heaters Installed (November 2018)

In November 2018, one hundred ten (110) space heaters were installed to provide temporary heating to classrooms. RSM requested contract documentation to determine the cost of this installation, however, documentation has not been provided to date. Further, we noted that a work order for the "purchase of heaters" was submitted on December 4, 2018, but an invoice or quote was not provided within the CMMS as evidence of actual cost ($0.01 recorded in the District's CMMS).

North Arrow HVAC Assessment (December 2018)

System failures, equipment replacements, and repairs continued through December 2018. On December 14, 2018, the Department of General Services engaged DC-based design and engineering firm, North Arrow through an emergency procurement process to assess the HVAC issues at Roosevelt. North Arrow issued an "HVAC Assessment" report on December 19th detailing the findings and recommendations identified as part of their assessment **[Appendix E]**. The assessment revealed that most of the HVAC issues were related to "compressor failures and refrigerant leaks in the water source for heat pump subsystems". The report states that the issues could have originated during construction, startup, and/or during operation of the system. The report included several key findings related to the LG VRF system, which are summarized below:

- Insufficient and/or incomplete documentation was provided to validate that the installer followed the manufacturer's recommended startup requirements during the initial commissioning of the system. One (1) or more construction checklists provided as part of the commissioning process were incomplete and missing information in required fields.
- There was a lack of documentation available to confirm the installer performed an initial flushing and testing of the condenser water loop. North Arrow noted in their assessment that if this process was not performed or executed effectively, debris could be left in the piping, leading to further damage and failure of heat exchangers connected to the condenser water loop.
- North Arrow noted that documentation was not available to verify that the refrigerant piping held the appropriate vacuum pressure required by the manufacturer.
- Water within the condenser water loop was being maintained at a pH between 10.0 and 10.5, compared to the manufacturer's required range of 7.0 to 8.0. North Arrow noted that documentation was not available to verify the condition of the water at the time of start-up. Further, North Arrow noted that while the installation manual for the LG VRF units included water quality requirements, the water treatment specialist performing this function at Roosevelt may not have been provided the requisite information.

During their onsite visit, North Arrow identified a leak in the refrigerant piping after visual inspection of an oil spot on the acoustical ceiling tile. North Arrow did not identify a cause at the time of inspection, but reviewed documentation to determine if the manufacturer's requirements for testing and cleaning refrigerant piping occurred.

BACKGROUND

HVAC Issues: Timeline of Events (continued)

North Arrow HVAC Assessment (continued)

While reviewing the documentation provided, North Arrow noted that Limbach substituted brazed joints for mechanical couplings as the method for joining the piping connected to the VRF systems. RSM reviewed Limbach's equipment and material submittal for refrigerant piping and noted that the submittal was initially rejected by the Design Team. The following comments were provided regarding Limbach's proposal to use Vulkan's LOKRING solder-free connection system:

> *"The mechanical joining system that was listed for Aluminum tubing to be employed with Daiken only installations (and backed by Daiken) is a substantial joining process that exceeds the submitted copper crimping system in expected durability. The specification calls for brazing of copper tubing, fittings and joints, and is the expected level of joining. A mechanical joining process that is not enumerated within the specification is a variation that the owner must take under consideration for its suitability as a substitution since it is a matter of durability."*

Within their next submittal package, Limbach included a letter from LG, who concluded that Vulkan LOKRING mechanical fittings were acceptable for piping for LG VRF systems. The submittal was ultimately approved with the following comments:

> *"Refrigerant pipe connection system: The manufacturer shall be responsible to train and certify the system installers and provide periodic spot checks of the installation. The contractor shall be responsible to certify the installation."*

In total, North Arrow provided thirteen (13) recommendations based on a phased approach to limit interruptions during the school year. The recommendations included immediate actions, actions for the remainder of the school year, and actions to be carried out during the summer when the system could be taken offline. North Arrow recommended DGS commission each of the eleven (11) VRF systems during the summer of 2019 and test the Vulkan LOKRING mechanical couplings to confirm installation (refer to "VRF Coupling Replacement and HVAC Commissioning Project" and "Mechanical Coupling Failure Analysis" below for additional information).

Mechanical Coupling Failure Analysis (March 14, 2019)

As recommended by North Arrow in their December 2018 report, Smoot-Gilbane engaged Vulkan, the manufacturer of LOKRING, to perform a failure analysis on the mechanical couplings used to connect the refrigerant piping for the VRF systems. Vulkan issued a written report on March 14, 2019 including results of their analysis **[Appendix F]**. Based on visual inspection and leak tests performed on a sample of couplings, Vulkan concluded that leaks may have been the result of improper installation and application of sealant.

DGS Issues Latent Defect Notice to Design-Builder (March 26, 2019)

A latent defect notice was issued to the Design-Builder by DGS' Chief Procurement Officer on March 26, 2019. The Notice cited Section 2.14 and 13.6.2 of the Design-Build Agreement (refer to **Appendix B** for contract provisions) to direct Smoot-Gilbane to "*replace any material and correct any workmanship and latent defects in the refrigerant piping system found by the District that does not conform to the contract requirements"*. The letter summarized the events that occurred during the submittal review process in 2014, and Limbach's use of "LOKRING" mechanical fittings instead of "brazing for copper tubing" as the expected method for joining refrigerant pipes, per the specifications. DGS noted that "the *mechanical joining process was not enumerated in the specification and is a variation of the Contract that District of Columbia is required to approve as a substitution."*

BACKGROUND

HVAC Issues: Timeline of Events (continued)

VRF Coupling Replacement and HVAC Commissioning Project (March 2019 – February 2020)

Following issuance of the latent defect notice, DGS embarked on a major HVAC project to replace the mechanical couplings throughout the VRF system and commission each of the eleven (11) VRF systems. According to DGS personnel, Roosevelt High School was shut down in the summer of 2019 to take the systems offline, and Limbach, the original mechanical contractor was re-engaged to remove and replace the mechanical couplings and remediate other piping issues. Between July 2019 and October 2019, The Joyce Agency, LG's representative performed site evaluations and start up procedures for the VRF systems.

The project achieved partial substantial completion on November 20, 2019. A two (2) year workmanship warranty for the couplings was issued by Limbach. According to Limbach's November 20, 2019 warranty letter, a different contractor performed the work on one (1) or more of the VRF systems. The work performed on the remaining VRF system(s) was completed on February 3, 2020, per the Certificate of Substantial Completion.

DGS Issues HVAC Investigation Summary Report (May 2019)

On May 3, 2019, DGS issued an "HVAC Issues Investigation Summary Report" **[Appendix G]** detailing the various problems experienced with Roosevelt's HVAC system following the Modernization. The report provided a summary of the events preceding the issuance of the latent defect notice and subsequent VRF coupling replacement and HVAC commissioning project, an analysis of preventative maintenance records, results of various third-party assessments and testing, and recommendations for actions moving forward.

Issues Continue Following 2019 HVAC Project (May 2020)

According to Spectrum Management's May 2020 monthly report, several VRF units experienced failures around May 2020. Between May and September 2020, DGS engaged third-party contractor, Complete Building Services ("CBS") to replace various system components, including, but not limited to, compressors, pumps, and invertor boards.

North Arrow Retro Commissioning Project (July 2021)

In July 2021, the Department of General Services entered into an agreement with North Arrow for HVAC retro-commissioning services, effective between July 2021 and July 2022. The contract included a not-to-exceed fee of $316,634, and an additional cost reimbursable component for repairs in the amount of $283,366. A modification to the original contract was executed in June 2022 which extended the performance period through September 2022, and increased the reimbursable portion of the contract by $226,625.

According to DGS personnel, the retro-commissioning involved several parties, including Hobbs & Associates, an LG representative, and North Arrow's subcontractor, Pro-Air, who performed HVAC repairs. DGS noted that the retro-commissioning was split into two separate rounds, the second of which is underway as of the date of this report (refer to "Hobbs & Associates Issues Site Assessment Report [October 2022])" below for additional information).

Additional Temporary Heaters Installed (December 2021)

In December 2021, an emergency purchase order agreement in the amount of $79,340 was executed with RSC Electrical & Mechanical to install twenty-three (23) electric heaters throughout the school.

BACKGROUND

HVAC Issues: Timeline of Events (continued)

Hobbs & Associates Issues Assessment Report (October 2022)

In October 2022, Hobbs & Associates, an LG representative, issued a “Site Visit Report Summary” **[Appendix H]** summarizing the results of their operational assessment of the LG VRF systems at Roosevelt. According to the report, a team consisting of North Arrow, Pro-Air, and Hobbs & Associates was engaged to perform HVAC repairs and post-repair operational analysis. Several site visits and assessments were performed in April and May 2022. As a result, Hobbs noted the following key observations:

- A “significant number” of systems had active refrigerant leaks which impacted system performance and resulted in compressor failures
- Several systems were undercharged and were found to have improper amounts of refrigerant
- Evidence suggested that routine maintenance had not been performed
- Condensing unit control boards had been improperly replaced or switched with adjacent units resulting in communication and capacity errors
- There was at least one (1) instance where a refrigerant pipe was improperly installed from a heat recovery box to its non-respective indoor unit

Hobbs & Associates provided three (3) final recommendations in their October 2022 report, as detailed below:

- Address remaining items identified in initial site assessments
- Perform a “thorough controls analysis and overhaul”
- Implement a preventative maintenance program to regularly evaluate system operation and verify that routine maintenance is being performed. RSM previously reported a finding related to preventative maintenance in the September 2022 *Districtwide Work Order Process Analysis Internal Audit Report* (Observation #3).

CONCLUSIONS

Summary

While responsibility for the success of the project is shared by both the Owner and third-party vendors, DGS relied on the expertise of qualified professionals to design, construct, and commission a functioning HVAC system. Although the Modernization project is reported as completed in November 2016, based on discussions with stakeholders and review of turnover, maintenance, and work order documentation, we understand the HVAC system has never consistently functioned as specified in the Owner's Project Requirements and Basis of Design.

Multiple potential origins of failure were noted by the various parties engaged by DGS to evaluate these issues, and the persistent malfunction of the HVAC system without resolution over the past six (6) years indicates that no single identifiable source of failure exists, but rather that a combination of factors contribute. Potential origins of failure include, but are not limited to:

- Leaks within the VRF system's refrigerant piping
- The use of mechanical fittings to join refrigerant piping instead of "brazing of copper tubes" as required by the specifications
- Water contamination within the VRF system's refrigerant piping
- Improper operation and maintenance of the VRF system, including monitoring of water conditions within the condenser water loop

As part of our analysis, we noted the following key takeaways, which are further expanded upon below:

- **Warranty Provisions**: DGS' Design-Build Agreement included industry-standard provisions for warranty and turnover, as well as flow-through provisions that applied to subcontracts. Although available, these provisions may not have been utilized to the fullest extent available.
- **Timeliness:** Through interviews with stakeholders and review of documents, we identified instances in which months/years elapsed between the identification of issues and the actions performed to assess or remediate those issues.
- **Documentation:** Throughout our engagement, we noted that documentation was either not readily accessible or was not available.

Contract Warranty Provisions

Through review of contract documents, we noted that DGS' Design-Build Agreement includes industry-standard provisions for warranty and turnover. Specifically, the applicable provisions included language consistent with the American Institute of Architect's ("AIA") Standard Form of Agreement Between Owner and Design-Builder. The design-build agreement also included flow-down provisions, applicable to the subcontracts executed by the Design-Builder.

Based on interviews with stakeholders and review of documentation, we noted that HVAC issues were identified and documented prior to turnover of the building to DGS. While remediation measures were taken during the one-year warranty period, the issues persisted and were still ongoing through the end of the warranty period. After the warranty period ended and the mechanical contractor stopped performing repairs, DGS solicited third-party vendors to avoid further failures and service disruptions, which resulted in additional costs to repair and maintain the VRF system.

In discussions with DGS' General Counsel, we were informed that legal personnel present during the initial turnover, warranty period, and subsequent latent defect notice were no longer with DGS. However, Counsel noted that legal action had not been proposed by DGS since the initial latent defect notice in 2019.

CONCLUSIONS

Timeliness of Action

During our analysis, we noted a general theme of untimely action by both third-party vendors and the Department of General Services. Through interviews with stakeholders and review of documents, we identified instances in which several months/years elapsed between the identification of issues and the actions performed to assess or remediate those issues. Examples include:

- **Repairs During Warranty Period:** According to the timeline of issues included in Spectrum's letter to DGS (**Appendix G**, page 102), the lead time on repairs and component replacements performed by Limbach often exceeded a month. Examples include:
  - In June 2016, two (2) VRF units experienced problems related to leaks and compressor issues. The units were not fixed until September 2016.
  - On November 23, 2016, a VRF unit went down which left several rooms without heat. The system remained down through January 26, 2017.
  - On December 9, 2016, a VRF unit went down and remained down until January 27, 2017.
- **Issuance of Latent Defect Notice:** Although HVAC issues were still occurring through the end of the warranty period, DGS did not issue a latent defect notice to the Design-Builder until sixteen (16) months after the initial warranty period had ended.
- **The Joyce Agency Recommendations:** The Joyce Agency assessment performed in January 2018 resulted in several recommendations, including the recommendation to initiate discovery on all VRF systems to confirm operating conditions and reduce additional failures. Based on the information provided, it does not appear that discovery was conducted until North Arrow's HVAC Assessment in December 2018.
- **North Arrow Recommendations:** The HVAC assessment performed by North Arrow in December 2018 resulted in thirteen (13) total recommendations. RSM inquired with DGS to determine what corrective actions took place as a result of North Arrow's recommendations. Based on responses provided by DGS, we noted that four (4) of thirteen (13) recommended actions were completed; however, the remaining nine (9) recommendations had not been addressed to date, are currently ongoing, or could not be confirmed by DGS.
- **HVAC Work Order Data:** For two hundred thirty-five (235) HVAC-related work orders that were completed and/or closed between August 2016 and June 2022, the average duration between the work order request date and completion of the work order within the CMMS was thirty-three (33) days. Sixty (60) work orders were completed in fifty (50) days or more, and thirty-one (31) were completed in one hundred (100) days or more. Several factors may contribute to the overall duration of work orders, including the complexity of the work order, lead times for parts/components, third-party contracting/procurement requirements, etc.

Document Retention and Confirmation of Manufacturer Requirements

Throughout our engagement, we noted that documentation was either not readily accessible or was not available. The following documents were requested, but were not provided:

- Certificate of Substantial Completion (2016 Modernization)
- Deliverables specific to HVAC, as issued by JDC Construction during the turnover process
- Contract or agreement with HVAC contractor Pro Air
- Several monthly deliverable reports issued by the Consolidated Maintenance Contractor, Spectrum Management
- Contract documentation related to the temporary heating and cooling solutions between 2016 and 2022

Conclusions

Document Retention and Confirmation of Manufacturer Requirements (continued)

In addition to the missing documentation noted above, we also noted that the 2018 report issued by North Arrow included findings related to missing or incomplete documentation:

- Anecdotally, staff shared that multiple strainer screens were missing; however, maintenance logs did not reference the missing screens
- Operations and maintenance manuals included various manufacturer "checkout and startup procedures"; however, completed versions of those documents could not be located. The following were also specifically referenced:
  - No documentation could be located as evidence of initial flushing and testing of the condenser water loop
  - No documentation could be located as evidence of refrigerant line vacuum pressure testing
  - No documentation could be located as evidence that water pH level at time of startup was within manufacturer's specified range

Moving Forward – Roosevelt High School

As described in the timeline section and throughout this report, several third parties have been contracted to conduct analyses, identify causes of the system failure, and/or assist with performance of repairs. Recommendations have been provided within the deliverables provided by these consultants; however, based on requests for documentation and interviews, it remains unclear what specific actions have been taken related to these recommendations, and/or how determinations were made on whether to act upon recommendations. As such, we recommend DGS coordinate with DCPS, the Consolidated Maintenance Contractor at Roosevelt, DGS Legal Counsel, and other applicable stakeholders to develop an action plan. Goals may include the following:

- Assess whether legal action is warranted
- Review and amalgamate recommendations made by various consultants
- Determine what actions have been taken to address recommendations
- Determine which recommendations have not been implemented, and whether actions would currently be advantageous
- Based on the above, develop an action plan with estimated completion dates for addressing open recommendations and additional action items identified
- Provide regular reporting of progress on the action plan to DCPS and other District leadership

Establishment of a detailed action plan will provide transparency to stakeholders regarding the current status of remediation efforts and will also promote accountability through the development of specific actions items, completion dates, and progress reporting.

Moving Forward – Future Modernizations

Through discussions with DGS personnel, we understand that since the turnover of Roosevelt High School, DGS has begun developing processes specific to turnover and warranty. Documents reviewed indicate DGS' desired future state processes include the following:

- Inclusion of maintenance personnel in planning and design discussions
- Development of two-year post turnover maintenance and warranty plan, including related funding for each project
- Establishment of Salesforce Warranty Manager to identify whether service requests are covered under a warranty
- Quarterly touchpoint with maintenance to plan future projects and identify funding
- Establishing ProjectTeam as a central document repository of turnover and warranty documentation related to each project

CONCLUSIONS

Moving Forward – Future Modernizations (continued)

The documents also provide several flowcharts depicting the process for identification of issues covered under warranties, and communication between various stakeholder teams including DGS' Capital Construction Division ("CCD"), Facilities Intake Request Service Team ("FIRST"), Facilities Maintenance Division ("FMD"), and third-party Consolidated Maintenance Contractors ("CMC"). While the processes outlined in the documentation noted above provide the foundation for a more effective turnover process, DGS may consider expanding upon the existing flowcharts by developing standard operating procedures ("SOP").

Standard operating procedures would provide specific, actionable guidance for staff to reference in performance of duties and step-by-step instruction to help facilitate consistency in the completion of tasks and retention of documentation. Further, SOPs could be used to develop a checklist for management to validate that all procedures have been completed, and would also serve as a training aid to new employees.

In addition, DGS may also consider the following:

- Developing procedures for communicating potential warranty issues to DGS leadership and Legal Counsel prior to the end of the warranty period. Issues should be identified and reported in a timely manner to avoid service disruptions and incurring third-party repair costs after the warranty period.
- Engaging manufacturer representatives to assess HVAC installation and confirm equipment / systems were installed according to manufacturer requirements prior to turnover and substantial completion.
- Developing procedures to document consultant observations, recommendations, and action plans. If DGS does not plan to act upon consultant recommendations, reasons should be documented.
- Developing a process for documenting "lessons learned" for future modernization projects. Lessons learned provide evidence-based case studies which can be used for future decision-making, and may reduce the likelihood of future errors and foster continuous process improvement.

Objectives and Approach

The primary objective of the engagement was to gain an understanding of the maintenance and warranty issues that have occurred since the Roosevelt High School Modernization project. Through our work, RSM endeavored to obtain an understanding of the history of the Roosevelt High School Modernization project and the HVAC issues that have persisted since completion of the project. Due to the time elapsed between the completion of the Modernization and the performance of this audit, we were informed that certain documents could not be located, and some stakeholders involved in the Modernization were no longer available for interview.

As such, the information and conclusions presented within this report are limited to the resulting interviews and documentation made available to us. In addition, several potential sources of failure related to the HVAC system have been noted by various parties since project completion; however, evaluation of the technical aspects of these potential failures falls outside of our expertise and the scope of our engagement.

The internal audit was performed in accordance with the scope and approach set forth in our Consulting Services Agreement, dated March 10, 2022, and was limited to the procedures therein:

Approach:

- Obtained and reviewed the design-build agreement and mechanical (HVAC) subcontractor agreement to identify and assess contract articles related to warranties, as-builts, equipment manuals, and other relevant provisions
- Conducted interviews with relevant members of the District's facilities management team to gain an understanding of key events, the construction turnover process, and the testing / commissioning process
- Conducted interviews with the District's legal team to gain an understanding of potential legal action related to the Modernization
- Obtained and reviewed the final commissioning report and related documents
- Obtained and reviewed third-party HVAC assessments, site visit summaries, and product testing reports
- Obtained and reviewed case studies, internal investigations, and other process-level documentation created by the Department of General Services
- Obtained a population of work orders and performed data analytics

Deliverables:

<u>Roosevelt High School Modernization Follow Up Audit Report:</u>

- Listing of key warranty and turnover contract provisions
- Listing of key warranty and turnover subcontract provisions
- Analytics of CMMS data

APPENDIX A

APPENDIX A

CMMS Data Analytics: HVAC Work Orders

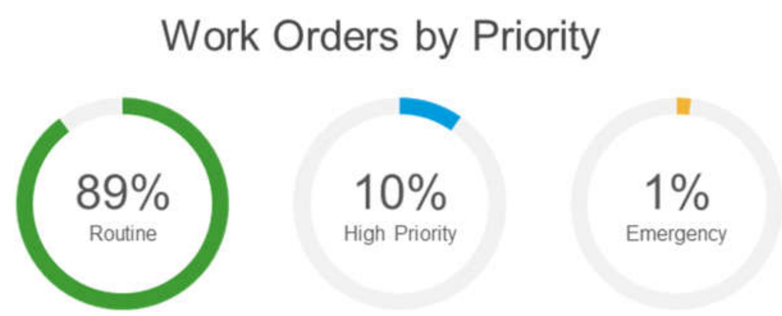
RSM obtained a population of all work orders requested to-date for Roosevelt High School, since the adoption of the District's current Computerized Maintenance Management System ("CMMS"). Data was provided by DGS' Facilities Intake Request Service Team ("FIRST").

The scope period for our analytics was August 2016 through June 2022. As part of our analysis, RSM performed data analytics and key word searches to compile a population of HVAC-related work orders. In total, two hundred eighty-eight (288) work orders were requested for HVAC-related issues during the period.

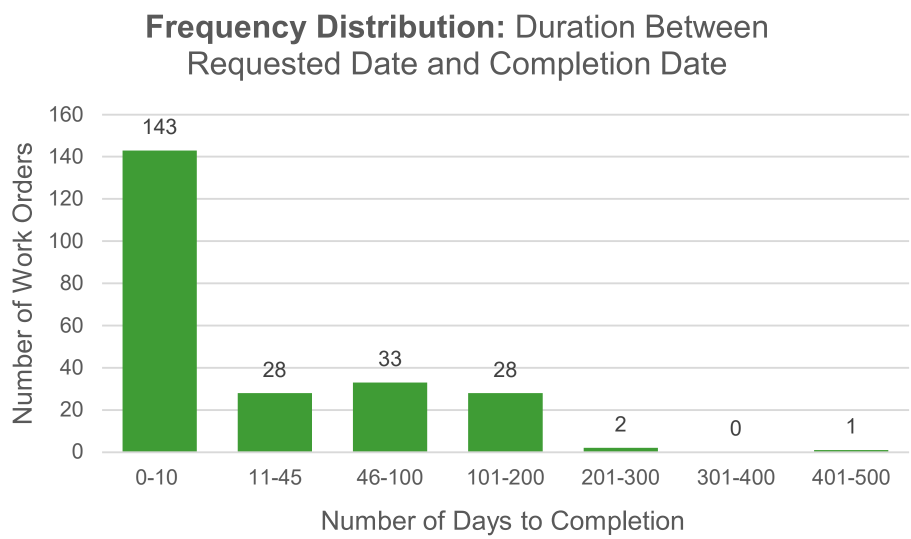
Since the development of the seven (7) main problem types for work orders in October 2018, "HVAC Services" accounted for approximately 17% of all work order requests, second-most behind "Interior Services" (39%).

The table below includes the total number of work orders requested and the status of those work orders as of June 30, 2022.

Work Orders by Status (as of June 30, 2022)		
Status	**# of Work Orders**	**% of Total**
Closed	231	80%
Cancelled	20	7%
Issued and in Process	19	7%
Rejected	7	2%
Approved	5	2%
Completed	4	1%
On Hold for Funding	2	1%
Total	**288**	



The graphic below was developed using data from **235** HVAC-related work orders that were completed and/or closed between August 2016 and June 2022. On average, **33 days** elapsed between the date requested and completion of the work order within the CMMS.



APPENDIX B

APPENDIX B

Key Warranty and Turnover Contract Provisions: Design-Builder

Agreement Name	Section	Section Name	Contract Language
Design-Build Agreement	2.11.1	Warranties and Representations	*All disclosures, representations, warranties, and certifications the Design-Builder makes in its proposal in response to the Request for Proposals for Design Build Services for Roosevelt High School ("RFP") shall remain binding and in effect throughout the term of the Contract. The Design-Builder reaffirms that all such disclosures, representations, warranties, and certifications are true and correct.*
Design-Build Agreement	2.11.2	Warranties and Representations	*If any disclosure, representation, warranty or certification the Design-Builder has made or makes pursuant to the RFP or the Contract, including, without limitation, representations concerning the Design-Builder's construction or design experience and qualifications, claims or litigation history or financial condition, is materially inaccurate, that shall constitute a material breach of the Contract, entitling the Department to all available remedies.*
Design-Build Agreement	2.11.3	Warranties and Representations	*The terms and conditions of Section 2.11 shall apply during the Preconstruction and the Construction Phases.*
Design-Build Agreement	2.14	Design-Builder Warranty of Construction Work	*The Design-Builder warrants to the Department that materials and equipment furnished under the Contract Documents will be of good quality and new unless otherwise required or permitted by the Contract Documents, that for the one (1) year period following the Substantial Completion Date the construction work will be free from defects not inherent in the quality required or permitted, and that the Work will conform to the requirements of the Contract Documents.* *The Design Builder's warranty excludes remedy for damage or defect caused by abuse, modifications not executed by the Design-Builder, improper or insufficient maintenance, improper operation, or normal wear and tear and normal usage. The Design-Builder and a representative of the Department shall walk the Project together eleven (11) months after the Substantial Completion Date to identify any necessary warranty work.*
Design-Build Agreement	4.13.2	Close-out & FF&E	*The Design-Builder shall be required to prepare and submit at close-out a complete set of product manuals, warranties, etc. The Design-Builder shall also provide the Department with a complete set of its Project files, including, but not limited to, shop drawings, etc., at close out so as to assist the Department and/or DCPS in operating the building. In addition, at the beginning of the first heating and cooling season following turnover of the Project, the Design-Builder shall be available to assist with, and train the building engineers and staff in the start-up of the building systems for the new weather cycle.*

APPENDIX B

Key Warranty and Turnover Contract Provisions: Design-Builder

Agreement Name	Section	Section Name	Contract Language
Design-Build Agreement	13.28	Survival	*All agreements warranties, and representations of the Design-Builder contained in the Contract or in any certificate or document furnished pursuant to the Contract shall survive termination or expiration of the contract.*
Design-Build Agreement	16.22	Substantial Completion	*Section 16.22 Substantial Completion. Substantial Completion shall mean that all of the following have occurred: (1) the construction and installation work have been completed with only minor punch list items remaining to be completed; (2) a permanent certificate of occupancy and all other required permits or approvals have been obtained; (3) all operating and maintenance manuals, training videotapes and warranties required by the Contract have been delivered to the Department; (4) any supplemental training session required by the Contract for operating or maintenance personnel have been completed; (5) all clean-up required by the Contract has been completed; and (6) the Project is ready for the Department to use it for its intended purpose. "Minor punch list items" are defined for this purpose as items that, in the aggregate, can be completed within ninety (90) days without interfering with the Department's normal use of the Project.*

APPENDIX B

Key Warranty and Turnover Contract Provisions: HVAC Subcontractor Agreement (HVAC Provisions)

Agreement Name	Section	Section Name	Contract Language
HVAC Subcontractor Agreement	24.2.2	Correction of Work	***Defects Discovered within One Year.*** *If, within one year after the Date of Final Completion of the Work or as may be prescribed by law or by the terms of any applicable special warranty required by the Contract Documents, any of the Work performed by Subcontractor is found to be defective or not in accordance with the Contract Documents, Subcontractor shall correct it promptly after receipt of a written notice from Contractor or Owner to do so, unless Owner has previously given Contractor or Subcontractor a specific written acceptance of such condition.*
HVAC Subcontractor Agreement	25	Warranties	*Warranties. Subcontractor warrants its Work hereunder to Contractor on the same terms, and for the same period, as Contractor warrants work to Owner under the Prime Contract; and, with respect to Subcontractor's Work, Subcontractor shall perform all warranty obligations and responsibilities assumed by Contractor under the Prime Contract.*
HVAC Subcontractor Agreement	15	Schedule 1: Scope of Work (Section 15)	*All warrantees and guarantees will commence only upon substantial completion of the Project as documented by the Architect's issuance of a Certificate of Substantial Completion. Any/all costs to extend the full term of all warrantees/guarantees from any earlier date (i.e. delivery, in service dates, etc.) to the date of substantial completion of the Project are to be included within the cost of the work. In addition to performing any preventative maintenance required by the contract or correcting any deficiencies noted throughout the warrantee/guarantee period(s). The Subcontractor will participate in a Project walk through(s) immediately prior to the expiration of all warrantees and/or guarantees provided under the work of this contract. Any deficiencies noted will be corrected by this Subcontractor at no additional cost to the Smoot Gilbane/Owner.*
HVAC Subcontractor Agreement	41	Schedule 1: Scope of Work	*Provide frequent testing of the systems installed by this Subcontractor to allow the timely completion of work by other Subcontractors.*
HVAC Subcontractor Agreement	47	Schedule 1: Scope of Work	*All building Mechanical systems must be maintained and operated by this contractor until the Project Substantial Completion. Operation Manuals and As-builts must be submitted with two extra copies beyond specified amounts prior to Owner training.*

APPENDIX B

Key Warranty and Turnover Contract Provisions: HVAC Subcontractor Agreement (HVAC Provisions)

Agreement Name	Section	Section Name	Contract Language
HVAC Subcontractor Agreement	49	Schedule 1: Scope of Work	*Smoot Gilbane will need the base building HVAC systems available for temporary heating during the winter of 2014-15, and for temporary cooling during the spring/summer of 2015. Include all costs to put the systems into temporary service, including temporary controls, extended warranties, service and maintenance of the equipment, filter replacement, and refurbishment of the equipment as required before final Owner acceptance. Should the permanent systems not be available for heating, it is the responsibility of this Subcontractor to provide and maintain other temporary means of heating from the gas services available on site.*
HVAC Subcontractor Agreement	61	Schedule 1: Scope of Work	*This Subcontractor shall provide a complete operational system prior to commissioning. Should any deficiencies be found in the original contract scope this Subcontractor shall make the necessary corrections immediately and notify Smoot/Gilbane in writing upon completion. Should the deficiencies be found a second time, this Subcontractor shall bear all costs associated with the inefficiencies of others due to lack of performance.*
HVAC Subcontractor Agreement	66	Schedule 1: Scope of Work	*Service and maintain the HVAC equipment for temporary conditioned air requirements until accepted and turned over to the Owner. All warranties shall start from the time of substantial completion as indicated in the Contract Documents, not at the time of use for conditioned air requirements.*
HVAC Subcontractor Agreement	67	Schedule 1: Scope of Work	*Provide, install, and maintain all temporary protection and filter media on all equipment requiring filters during startup, commissioning, and temporary use. Perform all required cleaning and air flushes of the HVAC system. Furnish and install final filters immediately prior to occupancy.*
HVAC Subcontractor Agreement	72	Schedule 1: Scope of Work	*This Subcontractor is responsible for completing all pre-functional checks associated with the work of this Contract.*
HVAC Subcontractor Agreement	93	Schedule 1: Scope of Work	*Any systems that are figured to be cleaned and turned over are in a fully functional "like-new" condition.*

APPENDIX B

Key Warranty and Turnover Contract Provisions: HVAC Subcontractor Agreement (HVAC Provisions)

Agreement Name	Section	Section Name	Contract Language
HVAC Subcontractor Agreement	96	Schedule 1: Scope of Work	*All existing ductwork is to be cleaned, and protected, and all new ductwork is to be protected and maintained throughout. If new ductwork is adequately protected, and clean at turnover, then it need not be cleaned again "after installation". Ductwork is required to be cleaned "in place" as part of this scope if this Subcontractor does not adequately protect and maintain such ductwork. As a specific example, ductwork with excessive dust or other particulates from construction activities would need to be cleaned under this scope, as protection should be adequate to resist these expected conditions.*

Appendix C

Case Study: Roosevelt SHS

2016 – 2021 VRF Related Heating Issues

Background: In FY 2016 Summer, Roosevelt Senior High School was turned over to DGS after a $125M Modernization Project in time for DCPS' SY16-17 Instructional year. The school was equipped with new Mechanical, Electrical and Plumbing Systems. This included all new finishes and portions of the roof were replaced. A new Garage, "B" Wing and 3rd floor were added to the gross square footage. The Mechanical System installed is known as a "VRF" or Variable Refrigerant Flow Heating and Cooling System. A Gray Water plumbing system was added for use in non-potable scenario's such as irrigation and toilet flushing. Hot water is partially provided by a Solar Heating system on the roof. The Atrium is garnished with a "Transition Glass" roof that adjusts its translucence automatically based on the day and the current weather conditions. This was done to support thermal comfort controls in one of the largest open atriums in the DCPS portfolio. Currently the Facility is being managed by DGS' CMC program that provides onsite operations and maintenance of all major systems 12 hours a day with a 24/7 on-call response capability.

Key Issues: The new primary heating and cooling are provided by the VRF System. The challenges with this system are:

1. The Manufacturer is LG. LG systems were deemed unreliable by DGS CCSD after this installation and written out of the Specs *permanently.*
2. The VRF Systems have large zones in this facility. 1 Zone going down could impact as many as 22 classrooms or 1 large big box space such as the atrium.
3. Since turnover in 2016, the VRF system has suffered catastrophic failure each year.
4. VRF system failures resulted in major component replacements and the need for costly contingency options like space heaters. (See timeline on the next slide)
5. The complexity of the systems and constant need for replacement parts make this a costly system to maintain and repair.

Steps taken to Resolve: Since 2016, year over year, DGS and key stakeholders have spent $2M+ to maintain and repair the VRF system at Roosevelt. More than half of the condensing units that control ~18 zones have been replaced since 2016. Dozens of compressors, inverter boards, valves and thermostats have been replaced. DGS' largest effort to date was to issue a latent defect notice to the installer to correct piping and component deficiencies that were identified by a 3rd party vendor after a 5-month investigation. This resulted in the removal and replacement of piping systems and major system components. The project took approximately 8 months to complete. (Appendix Slides provide a detailed timeline)

Current State: There are currently 8 Cooling work orders & 1 Heating work order at Roosevelt (10.20.21). The responsible CMC is managing current HVAC issues.

Appendix C

Case Study: Roosevelt SHS

2016 - 2021 Timeline of VRF Issues

August 2016: Turnover

LG was the manufacturer of the HVAC water-cooled VRF system. **Classes begin at the newly modernized Roosevelt High School.**

September 2016

VRV 1D-1 & ID-3 had leaks and compressor issues in June 2016. Both were fixed in September 2016.

November 2016 – January 2017

VRV 1C2 went down leaving several rooms without heat. It was determined that there was a bad compressor, a bad inverter board, and that the connecting wires had not been properly connected. Repair work began, but it was then discovered that the Heat Exchange had cracked letting water into the refrigerant system. This system remained down until January 26, 2017.

September 2017 – December 2017

VRV 2C2 experienced problems again and the warrantied compressor was removed and replaced again. This unit continued to exhibit issues at which time the Prime Contractor conferred with LG. VRV 1B experienced problems and was determined to have bad compressors replaced in September 2017. **Contractor warranty period for the VRV units ended on December 31, 2017.**

November 2018

VRV OA2 has gone down and has a leak. System is still down. Heaters were put in place until the boilers could be replaced. We are still waiting for the replacement to take place.

Winter 2018 – Summer 2019

Major HVAC Project: Commission each of the 11 VRV systems:

a. Remove refrigerant and compare to manufacturer required charge

b. Clean and test refrigerant piping per manufacturer's requirements

c. Test Vulcan Lokring mechanical fitting to confirm installation

Summer 2020

Major HVAC Outages Continued in Summer 2020: Multiple VRF systems were down, there were refrigerant leaks, and multiple component repairs.

Summer 2021 – October 2021

40 classrooms were offline during Summer 2021 readiness. Currently, the responsible CMC is managing current HVAC issues. As of 10/20/21, there are 8 Cooling & 1 Heating work orders. On 10/8/2021 DGS held an R

Leading Cause of HVAC Issues 2016 (Turnover) to 2018: Roosevelt High School experienced numerous and repetitive problems with the VRV units throughout the facility. Major mechanical system issues and failures include the VRF/VRV Systems, RTU's, AH's and Boilers. Those problems included but was not limited to replacement valves, replacement compressors, and leaks. There have been 161 HVAC work orders from FY16-FY21.

Appendix C

Case Study Appendix: Roosevelt SHS

2016 VRF Related Issues

VRF				
Item	System	First Observed	Perceived Issues	Resolution
1	VRV 1D-1 & 1D-3	6/13/2016	- Loud BS box and Hot in the spaces served by this system - Initially diagnosed with bad compressors - Analysis was completed verifying piping configuration and lengths on 6/23 - Leak was detected during piping analysis - Leak fixed by RSC and compressor replaced by Limbach Cx - An additional piping evaluation was done by Limbach Cx and crossed refrigerant piping was found prior to the loud BS box	Fixed piping and replaced a 2nd BS box. Desk fans and donuts provided to staff for the warm temps.
2	VRV OA2.1 & 2.2	8/16/2016	- Rooms being served were hot (band and choral rooms) - FCU serving choral room had (2) bad motors - Band room needed a new thermostat	2 fan motors were replaced in the choral room FCU. Stat replaced by critical in band room.
3	VRV 1C-1 & VRF 1E	9/12/2016	- Error Code CH151 - CS came to site.. 4 way Valves making noise while switching modes 9/14 - CS tech recommended we ask LG if AC renew would work in lieu of replacing 4 way valves 9/16 - LG confirmed AC Renew was not an option and valves were ordered	4-way Valves replaced in both systems
4	VRV 2C-2	10/26/2016	- Error code CH121 - Rooms being served were hot - Compressor wouldn't ramp up	Compressor replaced
5	VRV 3C-1	10/26/2016	- Error code CH151 - Rooms being served were hot - 4 way valve making noise while switching modes	4-way Valve replaced
6	VRV 3D-1 & 2	10/26/2016	- Error code CH151 - Rooms being served were hot - 4 way valve making noise while switching modes	4-way Valves replaced in both systems
7	VRV 1C-2	11/23/2016	- Received complaints regarding "No heat in the school" - Limbach Cx determined it was a bad compressor, inverter board and the connecting wires between both 11/23. Previous work from Critical was left incomplete (wires not fully connected)... See Notes - Board and Wires arrived 11/25 via UPS overnight and we were prepared for a weekend install. Compressor was behind and tracking with FedEx had us set up for a Wednesday arrival. Multiple attempts made with FedEx for earlier delivery but due to holiday we were unsuccessful. - 11/30 Critical Systems went to RHS to begin repair work and found the HX in the CU to be cracked. Water found in the refrigerant system. Began draining water and trying to dry the moisture out of the system with Nitrogen that day and thru the evening - 12/1 System still watered down after 4 more bottles of Nitrogen. Last unit on the system checked and is contaminated with water. Drying out process still currently being attempted. - Visit from LG and Critical Systems on 12/6: found a hole in the strainer on the condenser (water side)	Began draining water and trying to dry the moisture out of the system with Nitrogen.. Process still ongoing. Checked each unit on the system for water contamination. Piping remidiation process still ongoing.
8	VRV 3C-2 and 3D-2	12/9/2016	- No call, but building engineer reported rooms were cold when we were on site - No error code - Set point at 72, raised to 76.... Space temp still reading 63 degrees - Fan running, cassettes don't appear to be blowing warm air	Checked condensing unit to confirm no error code (confirmed). System checked Saturday and it was noticed all windows were left open. Limbach directed CMC staff to check all windows then revisit the unit to see if this
9	VRV OD-2	12/16/2016	-Unit showing error code of 116 - O&M states either low oil or bad sensor	Critical Systems was on site and plugged in to the unit to diagnose
10	VRV OA-1	1/3/2016	- Error code 42: Low Pressure	Limbach tech investigated 1/3

Appendix C

Case Study Appendix: Roosevelt SHS

2016 AHU & HPU Related Issues

AHU's				
1	AHU-03	11/21/2016	- Outside Air Sensor reading temps in the 70s when it is 55 degrees out - Unit being reset numerous times on low pressure alarms - Compressor will kick on then shut off before completely ramping up	Adjustments were made by Trane making the unit functional. New sensors were ordered.
2	AHU-04	11/21/2016	- Complaints from staff and CMC about Atrium being freezing cold - Unit put itself into unoccupied mode at 9am that day (reason unknown) - At 12am, the BAS schedule told the unit to go into occupied mode - When Limbach arrived, the atrium was warm and the unit blowing 89 degree air. A compressor alarm for high pressure was present	Unit reset and power cycled for compressor alarm. No further issues with this unit.
3	AHU-05	11/21/2016	- Outside Air Sensor reading temps in the 70s when it is 55 degrees out	Pritchett believes problem will be solved when new RTU-2 controller is provided
4	AHU-08	11/21/2016	- Number of alarms... Including High Suction PSI, Abnormal Pressures, PSI Problem Wait, B3 Sensor Error - Outside Air Sensor reading temps in the 70s when it is 55 degrees out	Compressor 1 contacts failed. Compressor checks out fine. Adjustments were made by trane to make unit functional. New sensors and contactors ordered.
4	AHU-10	11/21/2016	- Outside Air Sensor reading temps in the 70s when it is 55 degrees out	Pritchett believes problem will be solved when new RTU-2 controller is provided

HPU's				
1	HPU-0143	8/24/2016	- HPU-0143 wasn't cooling - Diagnosed with a bad fan motor 8/24	Motor replaced by Limbach Cx
2	Tag Unkown.. Kitchen Unit	10/19/2016	- Report that Kitchen HPU wasn't communicating properly - Limbach Cx diagnosed the unit with a bad discharge air sensor	Sensor Replaced by Limbach Cx
3	HPU-0234A	10/21/2016	- HPU-0234A compressor not ramping up - Compressor ordered 10/21	Compressor replaced by Limbach Cx

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Case Study Appendix: Roosevelt SHS

2016 RTU & Boiler Related Issues

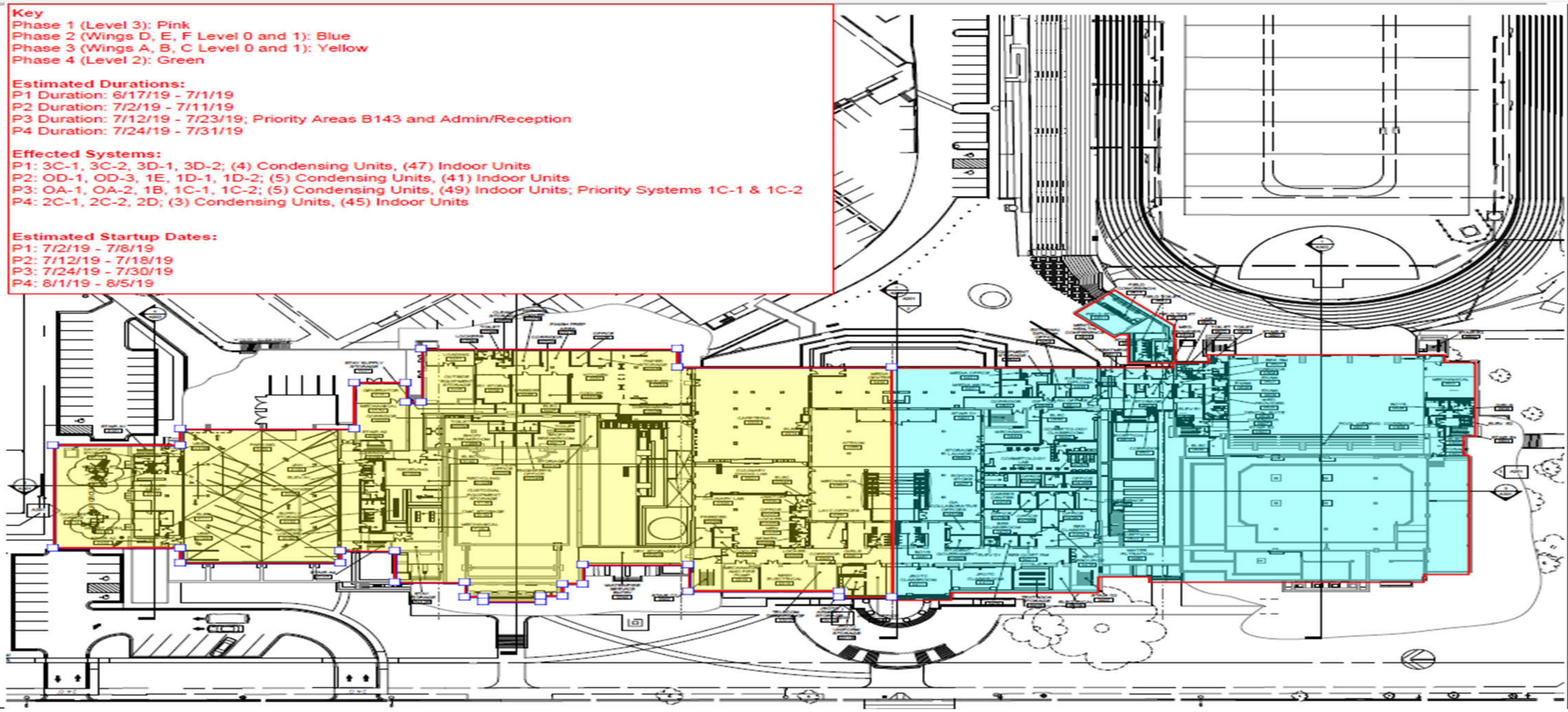
RTU's				
1	RTU-1	11/14/2016	- Unit communication dropping in and out of the system	Q and X updated in PC1000 controller
2	RTU-2	11/14/2016	- Initially reported Comm Issues - When Pritchett disconnected the unit from the BACnet, comm issues were resolved - According to Trane, the PC1000 ocassionally reboots, resetting the address. An address of 0 even for a brief second causes the head end to bog down. After cycling power, the unit stayed in reboot mode for over 30 minutes. Valent recorded findings remotely and is programming a new controller for the unit	Controller replaced

Boiler				
1	B-1	11/14/2016	- Boiler goes into lockout for "Gas Pressure Switch Open" - Reset Numerous Times Daily (according to CMC) - Recommended PM was completed and boiler still having issues - On 12/14 the unit was looked at briefly and appeard to be operating fine with no recent resets. We will still continue our investigation to ensure issue is resolved entirely.	Possible gas valve or regulator issue.. Investigation ongoing

Appendix C

Case Study: Roosevelt SHS

2019 Phasing Plans



Leading Cause of HVAC Issues 2016 (Turnover) to 2018: Roosevelt High School experienced numerous and repetitive problems with the VRV units throughout the facility. Major mechanical system issues and failures include the VRF/VRV Systems, RTU's, AH's and Boilers. Those problems included but was not limited to replacement valves, replacement compressors, and leaks. There have been 161 HVAC work orders from FY16-FY21.

The issues identified in this report would be indicative of Limbaugh who maintained the HVAC equipment until December 2017.

From: Paul Deluliis [mailto:pauld@thejoyceagency.com]
Sent: Friday, January 12, 2018 1:10 PM
To: Don Vanderhoof <DonV@donohoe.com>; Dave Skaja <DaveS@donohoe.com>
Cc: Ryan Anderson <randerson@thejoyceagency.com>; Donald Troupe <donald.troupe@lge.com>
Subject: [EXTERNAL] Roosevelt HS - LG VRF failed condenser

Don / Dave,

As requested, The Joyce Agency along with an LG National Service Technician visited Roosevelt High School and reviewed the failed condenser. Although we were unable to clearly identify what caused the failure or exactly why the heat exchanger would have frozen and or ruptured, we believe key application and maintenance items may require exploration. In fact, it may be advantageous to initiate discovery on all VRF systems at this site to confirm operating conditions and reduce additional failures.

The system that operates to produce heating, cooling and dehumidification of the returned air in the school is a "water-cooled vrf system" manufactured by LG. There are several independent systems located throughout the site each with its own condensing unit and a network of refrigerant piping designed to transfer heat from space to space and back to the condensing unit where energy is then transfer from the refrigerant system to a shared condenser water loop that serves the entire building. Each condenser contains a "brazed plate" heat exchanger that connects without contamination the water and refrigerant loops. This heat exchanger has documented design limitations for operating temperatures, operating pressure and should continuously be protected from particulate that can be introduced from the condenser water that passes through it. When applying a system like this, devices and associated setup is required to manage the flows and pressures to within prescribed operating limits. Automatic temperature control systems for condenser water pumps, mixing valves, geothermal loop control and associated boilers must be maintained and calibrated to moniter and manage flow and loop temperature.

Each vrf condenser at Roosevelt has a dedicated and externally installed circuit setter to help manage condenser water flow volume, a condenser water flow switch to validate that flow exists, a condenser water control valve to accommodate flow demand and a condenser water strainer installed upstream and before the heat exchanger to filter particulate that can be accumulated and possibly damage the heat exchanger if the screen does not exist.

The most critical items collected in our visit the other day include the following:

1. No strainer "screen" existed on the failed unit when the strainer assembly was opened. This confirms the heat exchanger operated without any protection from particulate traveling at possibly very high pressures and speeds. The general consensus based on the difficulty in opening the strainer and the fact that it had no markings on it was that the strainer has not been serviced since its initial installation.
2. The control valve did not appear to be "stroking" properly when it was manually reset in effort to close the valve for service. It is not confirmed, but its possible the valve is not capable of fully closing and water could be circulating through the heat exchanger while the unit is off without a call to satisfy demand.
3. We were made aware that a condenser water boiler had failed recently for some period of time. Depending on the boiler application, it may be instrumental in keeping the condenser water loop above the prescribed operating temperatures at all times. It should be noted that

our area endured ambient conditions as low as 3 deg F the prior week but we do not know exactly when the boiler failure occured.

4. We were made aware that the water contamination of the vrf system's refrigerant piping network was extreme and to the point water was migrating throughout the conditioned zones and leaking out of vrf "heat recovery boxes" and even some of the indoor units. This is very concerning and may have permanently contaminated all of the vrf devices connected to that system to the point of no return. Also, if the refrigerant piping were to be reused, a stringent process should be followed in effort to clean and dry the refrigerant piping prior to its reuse.
5. We were informed refrigerant leaks have been discovered at some of the mechanical fittings used throughout the building. Each refrigeration system must be free of leaks to ensure refrigerant is not lost and systems are sealed. If the piping network loses charge, poor distribution of refrigerant and associated oil may occur producing failures such as seized compressors or even frozen coils or heat exchangers.

To help in confirming system operation for this and other systems currently operational at the school, we have included the following information or suggestions for your review:

- To verify refrigerant piping was installed per manufacturers guidelines. P. 49-72 of attachment #1
- To verify the strainer is intact and the correct size (size 50 mesh) p. 80 of attachment #1. We recommend an immediate review of all strainers be initiated to validate screens exist, are clean and intact and they are the appropriate type.
- To verify all hydronic side components were installed properly i.e. flow switch is installed in the proper location and setup per manufactures recommendations P. 77-83 of attachment #1
- Confirm operating water temperatures are maintained above prescribed temperatures
- Confirm Variable flow kits or circuit setters are installed, balanced and operating properly
- Confirm overall water quality requirements are adhered to
- Confirmed flow switches are sound and not damaged from high velocities or unfiltered particulate.
- To confirm function settings are set properly. P. 92 of attachment #1
- To review that recommended general maintenance was sufficient. p. 112 of attachment #1
- To review a summary of freeze protection from LG. Attachment #2

Feel free to call if you have any questions.

Thanks

The
JOYCEAGENCY
HVAC PRODUCTS GROUP

THEODORE ROOSEVELT HIGH SCHOOL HVAC ASSESSMENT

Location

THEODORE ROOSEVELT HIGH SCHOOL
4301 13TH STREET NW,
WASHINGTON D.C. 20011

For

D.C. DEPARTMENT OF GENERAL SERVICES
12/19/2018
Final Report

NorthArrow DESIGN • BUILD • MANAGE

820 FIRST STREET NE, SUITE LL170, WASHINGTON, DC 20002 202-975-0986 WWW.NORTHARROWINC.COM

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EXECUTIVE SUMMARY

Theodore Roosevelt High School completed a major modernization in 2016 placing over 300,000 SF under roof. The HVAC system is a state of the art, energy efficient design, utilizing numerous energy reduction methods including geothermal water source heat pumps, rainwater harvesting and employing strategies from LEED for Schools. North Arrow assessed ongoing issues associated with the HVAC system.

It was evident a majority of the HVAC issues were related to compressor failures and refrigerant leaks in the water source heat pump subsystems. Leaks appear to be related to a wide variety of issues during construction, startup, and operation of the system that appear to be culminating into a cascading series of failures leaving numerous educational spaces without HVAC.

North Arrow reviewed the original design to include system design architecture and controls strategy, the commissioning plan, construction checklists, functional performance tests, operations and maintenance manuals, maintenance records, water treatment reports, current and past HVAC problems, previous corrective actions and proposed corrective actions. We conducted interviews with DGS design and construction staff, facilities personnel, operators, and the LG manufacturer's representative.

We recommend a variety of actions, immediate, short term and longer term to re-commission the overall water source heat pump system to operate as intended. These recommendations focus on the geothermal distribution loop (which represents over 40 miles of piping) and the mechanical equipment connected to this loop (emphasizing the DOAS and VRV equipment).

Due to operational constraints we are recommending an approach that focuses on keeping the system running to complete the remainder of the school year with functional HVAC equipment that focuses on repairing equipment as it breaks with a slightly more robust diagnostic procedure when failures occur. During the course of the school year, work to re-commission the geothermal distribution loop, followed by a complete evaluation of the LG VRV units serving the classrooms.

INTRODUCTION

North Arrow was placed under contract on Friday, December 14, 2018 to review the as-built design and commissioning reports for the Roosevelt High School HVAC system to understand how the system was intended to work, and how it did work when it went into service. The end game of our effort is to offer confirmation of our short-term plan to provide heating through the winter season, and a strategy for the long-term fix.

Beginning that evening, North Arrow was provided with a link to access information in order to become acquainted with the design and issues before visiting the school. After taking the time available Saturday to review the records provided, North Arrow made a visit to the school Sunday to gain firsthand knowledge of the issues identified, the repairs already made, and the overall installation.

After a tour of the facility to review the HVAC installation and some of the issues with it, we arranged for a follow up visit Monday to randomly verify installation of screens inside strainers at each piece of HVAC equipment using condenser water from the geothermal distribution loop.

Due to time constraints, data gathering, synthesis of the data, and analysis was planned to occur simultaneously. Ultimately this phase concluded with assembly of data gathered, summarization of findings, and the range of possible causes and solutions identified.

North Arrow facilitated a small group discussion surrounding the analysis in order to understand what can and cannot be done operationally, financially and contractually and help identify the preferred course of action.

FACILITY SUMMARY

Theodore Roosevelt High School, located at 4301 13th Street, NW, Washington DC 20011, underwent a complete modernization in 2014-2015. The resulting facility is approximately 331,900 SF (square feet). Operational for nearly two years, the school opened to students for the 2016-2017 school year. The design incorporated requirements from the Leadership in Energy and Environmental Design (LEED) for Schools 2009. Additionally, it was commissioned by a third-party commissioning agent.

The school has a large and complex heating, ventilating, and air conditioning system (HVAC) with many subsystems. The central plant that provides much of the heating and cooling is a large geothermal field underneath the athletic fields. The geothermal system is the water source for a variety of heat pump systems within the building that provide climate control to the classrooms, auditorium, gymnasium, library, cafeteria, and administrative and other support spaces. The HVAC system is monitored and controlled by a building automation system (BAS).

The primary HVAC system serving the classrooms is a variable refrigerant volume (VRV) system with a dedicated outdoor air system (DOAS) for ventilation. The building has been plagued by continuous problems with its HVAC system and in particular with failed compressors and refrigerant leaks associated with the VRV units and their distribution piping.

RECOMMENDATIONS

Our recommendations for action are based on a review of our findings along with limitations related to air conditioning outages during school, and availability of contractors to work off hours or over holidays.

We have based our recommendations on keeping the HVAC system running until such a time that the HVAC system can be taken offline. We anticipate the earliest this can occur is summer of 2019.

Immediate Actions

1. Address open work tickets for known HVAC issues
2. Adjust water quality of condenser water loop to be within LG's water quality requirements including pH (see attached)
3. Trend condenser water loop temperature; this appears to require modification to the building automation system
4. Modify existing process related to failed heat pumps when a compressor needs to be replaced or a refrigerant leak is detected as follows:
    a. Remove refrigerant and compare to manufacturer required charge
    b. Clean and test refrigerant piping per manufacturer's requirements
    c. Repair leak
    d. Recharge refrigerant
5. Modify existing process for future refrigerant leaks to include documenting location within the system and how leak was detected, for example:
    a. Location: refrigerant piping leak, downstream of LG VRV condensing unit
    b. Detected: oil stain visible on ceiling tile
6. Set leaving air temperature to 95 degrees for any DOAS unit serving areas where LG VRV units are out of service. Leave DOAS in Occupied Mode. Reset DOAS when LG VRV is operational.

Remainder of the school year

1. Re-commission the condenser water loop (geothermal distribution) system to include:
    i. Re-balance entire condenser water loop
    ii. Reset control set points
2. LG VRV condensers
    a. Test pressure drop on LG VRV units and compare to manufacturer data – evaluate unit for replacment that exceed manufacturer's specifications
    b. Install thermometers and pressure gauges on piping at LG VRV units
3. Evaluate the condenser water distribution system's ability to handle the following additional equipment:
    a. Industrial sand filter
    b. Glycol

Summer 2019

1. Flush the entire condenser water loop similarly to attached specification.
2. Validate commissioning of condenser water loop, to include re-verification of control valves, balancing valves, control set points.
3. Commission each of the 11 VRV systems.
    a. Remove refrigerant and compare to manufacturer required charge

   b. Clean and test refrigerant piping per manufacturer's requirements
   c. Test Vulcan Lokring mechanical fitting to confirm installation
4. Continue with independent verification and validation (IV&V) of HVAC system commissioning to include optimizing condenser water loop temperatures with installed equipment

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FINDINGS

North Arrow was provided a substantial amount of data on the original design, commissioning, as-builts, and operations data. We also received documentation related to the ongoing heating, ventilating, and air conditioning (HVAC) issues as well as the attempts to address them. Anecdotal information suggested an unusually high rate of problems with refrigerant piping or the water source variable refrigerant volume units provided by LG (herein referred to as LG VRV units).

After reviewing all the information provided it was evident the majority of the issues (8 of 9 on the "*Current HVAC Problems 12_14_18*" list), historical, and anecdotal were related to a failure of a compressor or a refrigerant leak. The other issues identified related to one off occurrences that we considered in the range of normal for a system this large. These issues might be an electronic controller or circuit board failure.

We reviewed the commissioning report to confirm start up and operational tests occurred and that they were done in accordance with manufacturer's recommendation and the design requirements. The commissioning documents contained a record of equipment construction checklists, functional test procedures and opposite season test procedures. These documents identified issues we consider normal and these issues, in general, appear to have been resolved in a manner to the satisfaction of the commissioning authority. The checklists contain the following statement:

"This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report."

We would anticipate some form of documentation confirmation the installer followed the startup requirements. This would be done either through a manufacturer sign off box on the equipment construction checklist or the installer documenting their compliance via the operation and maintenance (O&M) manual process.

We reviewed the mechanical O&M manuals. The O&M did include the various manufacturer's "checkout and startup procedures," however these documents were not completed. We were unable to locate completed versions of these documents.

We reviewed an email from The Joyce Agency dated January 12, 2018. In this email they noted a missing strainer screen on a failed LG VRV unit. The part of the system where a majority of the HVAC issues have appeared. These units are reported to have failed because the heat exchanges froze. A variety of factors can cause the heat exchanger in the LG VRV units to freeze. It can be caused by partial blockages of the water side passages, low condenser water supply temperature, or low flow (or some combination). Anecdotally we learned from The Joyce Agency email and two other facility staff members that multiple strainer screens had been missing. A review of the maintenance logs did not locate any documentation supporting the missing screens. We spot checked several strainers for the existence of screens and can confirm screens were installed. We recommend the LG VRV maintenance requirements for annual and 5-year actions be incorporated into the facilities staff's standard operating procedure.

We attempted to locate documentation on the initial flushing and testing of the condenser water loop and could not locate any. Debris could be left in the piping if this process was not accomplished or effectively executed. This debris will cause damage and likely premature failure of heat exchangers connected to the condenser water loop.

It was also reported anecdotally the existence of a strainer screen with a hole in it and circuit setter valves not set properly. High pressure could be the cause of both the hole in the strainer screen and problems with the LG VRV units. M504 detail 9 “water cooled condensing unit” on the design drawings calls for pressure plugs to enable pressure readings. The manufacturer’s requirements show pressure gauges in both the supply and return. We recommend pressure gauges, instead of pressure and temperature ports, be added following the manufacturer’s requirements. Pressures in the condenser water loop were approximately 65 psi and in line with our expectations.

We observed a refrigerant piping leak downstream of an LG VRV unit. The leak was over a small office and was visible due to an oil spot on the acoustical ceiling tile. The cause of this leak was not determined at the time. We reviewed the documentation provided in an attempt to learn if the manufacturer’s requirements for testing and cleaning refrigerant piping occurred. During this review, we noted a proposed substitution by the contractor to use mechanical couplings in lieu of brazed joints as the method for joining refrigerant piping associated with the LG VRV units. The records indicate it was flagged by the designer, but ultimately approved with a cautionary note about being careful with dissimilar metals. The Vulkin Lokring Solderless Connection System was provided by Critical Systems. Their submittal indicates owner training and pressure testing are not included.

Regardless of the joining method, we would expect to find documentation witnessing the refrigerant piping held the appropriate vacuum pressure required by the manufacturer (note 11 on page 97 of LG installation manual; Tab 23-8146.1 of the contractor’s O&M). We were unable to confirm the LG pre-commissioning process was followed or witnessed.

The condenser water loop, also referred to as the geothermal distribution, is a closed loop system. In essence this means it is not open to the atmosphere. The closed loop does require water treatment. The installation manual for the LG VRV units details the water quality requirements (attached). It does not appear this information has been provided to the water treatment specialist currently providing this function. We were not able to verify through existing documentation the condition of the water at the time of startup. The pH this year (2018) appears to have been maintained between 10.0 - 10.5 and the manufacturer’s requirements is a range from 7.0 - 8.0. We recommended adjusting the water quality to meet the manufacturer’s recommendations to avoid the possibility of early failure of the LG VRV units.

Temporary HVAC

Options for interim HVAC to maintain space temperatures inside the school were evaluated. Unfortunately, there is very little in the way of redundant systems in the Roosevelt High School. Most equipment is connected into the condenser water loop, so if that loop is not operating, there is no heating or cooling.

The space load in the classrooms are conditioned by ceiling cassettes connected to the LG VRV units. Outside air is provided by dedicated outdoor air system (DOAS) in mechanical rooms. This air is delivered through a ducted system. The leaving air temperature for these units is adjustable by the building automation system.

Drawing M301 from the construction documents set shows the heating set point for the DOAS units ranges from 95 degrees F to 100 degrees F. It is possible to use these units to provide small fraction of the space heating load when an LG VRV unit is not operational. We recommend setting the DOAS unit area in occupied during the winter with the leaving air temperature set to maximum setting per M301 until the LG VRV unit is repaired.

Outside each classroom is a junction box with three 208V (volts) circuits. It is possible to connect 5kW (kilowatts) of electric heat to this circuit. This amount of heat is only a portion of the classroom heating requirement. If we were to implement this course of action, there would not be any power left to the classroom for receptacles, i.e. students would not have power to plug in laptops or other electronic devices.

APPENDIX A

SECTION 232500 - FLUSHING FOR CLOSED HYDRONIC SYSTEMS

PART 1 – METALLIC PIPING SYSTEMS

1.1 After the mechanical contractor has prepared the building and the piping to be flushed after it has been tested. Provide a complete water flushing and cleaning of the closed loop chilled and hot water systems as specified herein. Systems must be commissioned as clean and meet the water treatment specifications.

1.2 All chilled, and hot water piping and related equipment shall be thoroughly flushed out with pre-cleaning chemicals designed to remove deposits such as pipe dope, oils, loose rust, mill scale and other extraneous materials. Recommended dosages of pre-cleaner chemical products shall be furnished by water treatment supplier, added and circulated throughout the water systems. The water systems shall then be drained, refilled and flushed thoroughly until no foreign matter is observed and total alkalinity of the rinse water is equal to or better than that of the make-up water.

1.3 All temporary connections required for cleaning, purging, and circulating shall be included. Provide suitable pipe bypasses at each coil and heat exchanger during this cleaning operation.

1.4 Flushing & Cleaning – a third party flushing company should be used. Permanent facility pumps should not be used for circulating the cleaning water. However, if its impractical to use temporary pumps, the permanent facility pump may be used provided that the pump is unconditionally warranted for two years, parts and labor, after the date of substantial completion by the mechanical contractor. A documented flush plan may be required at the discretion of the engineer. All operators should be aware of and abide by the Safety and PPE regulations of the project site. Operation should be manned continuously during the flushing process.

1.5 Self-Contained Flush Unit Requirements – Should contain a pump or pumps connected that will meet or exceed the volume required to flush and purge the system at the required velocity rate through the largest pipe. A pump curve will be submitted along with other important documentation for the related equipment on the unit. This will include, at minimum, filtration, flow meter(s), pressure gauges, and unit description or picture.

1.6 Pre Flush - Bypass loops should be installed at all equipment components. Strainers can be removed when a self-contained purge unit is used in conjunction with on board filtration. Flush ports should be identified along with the type of high pressure hose or piping that will be used to connect to the system. The water source should be identified and must be adequate to fill and make up water in a timely manner to the system during the flush process.

1.7 Clear Water Flush – Fill the piping system with clean potable water. The first flush is a clear-water flush intended to circulate water through the system and force loose debris to low point drains and the flush cart filtration system. This flush should be at minimum velocity throughout the system of 5 to 7 ft/sec. Filtration should be 25 micron.

1.8 Cleaning & Passivation - The second flush cycle is a combined flushing cycle where cleaning and passivation chemicals are introduced into the system to clean the oils and treat the inside wall of the piping system. This process will be monitored by the chemical treatment company

to meet the chemical specifications of the water. The cleaning velocity should be between 3 to 5 ft/sec and the circulation time will be based on the chemical testing but will typically be up to 48 hours.

1.9 Treatment – After cleaning and before adding chemical initial charge, system must be flushed to meet these minimum requirements:

- **A. Conductivity no higher than 20 mmho above domestic water level**
- **B. No foam**
- **C. Copper level less than 0.5 ppm**
- **D. Iron level less than 1.0 ppm**
- **E. pH 9.4 or less**
- **F. Less than 1 ppm phosphates (ortho-phosphate PO4)**

1.10 Final Clear Water Flush – The system will be continuously flushed while discharging chemicals into the sanitary system as approved locally. As the existing treated water is being discharged a fresh water make-up source will be utilized to ensure air is not introduced into the system. Continue to drain the system while adding domestic water to dilute the treated water. The chemical treatment company will monitor the outgoing water composition and compare the composition with the incoming water. Flush with fresh water until the conductivity is reduced to that of the make-up water and iron level is 1.0 ppm or less The final system water should be approved by the chemical treatment company. Filtration should be 5 micron.

1.11 Final Chemical Fill – Once the chemical treatment company has determined the system has been brought back to the correct composition, the chemical treatment company will inject the final chemicals into the system. Once the system is filled with the final chemicals it is important that the water is not to be left stagnant. Chemical treatment shall be comparable to existing treatment program.

1.12 Verify satisfactory completion of clean pipe and a final flushing and chemical treatment report should be signed by field personnel and submitted.

APPENDIX B

PRE-COMMISSIONING

Prepare the Refrigerant Piping System

Pressure (Leak) Test

Verify a pressure (leak) test has been performed and passed. If not, perform one now. Use medical grade dry nitrogen and pressure test the refrigerant piping system to a minimum of 550 psi for a period of 24 hours.

Evacuate the Refrigerant Piping System

Note:

The water source unit may be put in "vacuum mode." Generally, using the vacuum mode feature does assist with the vacuum process and is not necessary if a vacuum pump is connected to all charging ports at the water source unit simultaneously as suggested herein. See the Technical Service Manual for this product for more information.

Note:

DO NOT apply power to any Multi V system device prior to performing a system evacuation. There is a possibility that EEV valves may close and isolate sections of the pipe system, Contact your LG Applied Rep champion or service technician for the procedure to reopen the EEV valves before evacuation.

1. Release the Pressure Test dry nitrogen charge from all refrigerant pipes.
2. Verify ALL field installed isolation ball valves are OPEN (including those that are capped for future use).
3. Remove and discard the Schrader valve cores at the water source unit charging ports. This ipreventive step ensures that valves used after charging the system have not been subjected to the high pressure used during the Pressure Test.
4. Attach a 5/16" core removal tool equipped with ball valve and a fresh core to each charging port on the water source unit.
5. Check the vacuum pump(s) you intend to use and verify the oil in the sump is fresh and not contaminated.
6. Attach the vacuum pump(s) to each charging port simultaneously using high quality refrigerant vacuum hoses.
7. Perform a triple evacuation.
8. Achieve a micron gauge reading of less than 500 microns.
9. At 500 microns, valve off the charging port by closing the core removal tool ball valves.
10. Remove the vacuum hoses and pumps.
11. Leave the refrigerant piping system in a vacuum until the commissioning agent arrives and is satisfied with the micron gauge reading.

Note:

- *There is no danger in leaving the refrigerant piping system in a vacuum as all piping and equipment are dry and have never had oil in them.*
- *The system must be left in a vacuum until the Commissioning Agent arrives and verifies the quality of the evacuation process. If the evacuation procedure was not conducted properly, the system will likely malfunction and operate erratically. Significant costs may be incurred including but not limited to refrigerant reclaim, recycle, and replacement.*
- *Do not open the water source unit service valves and release the factory refrigerant charge until the commissioning agent authorizes to do so.*

WATER CIRCUIT INSTALLATION

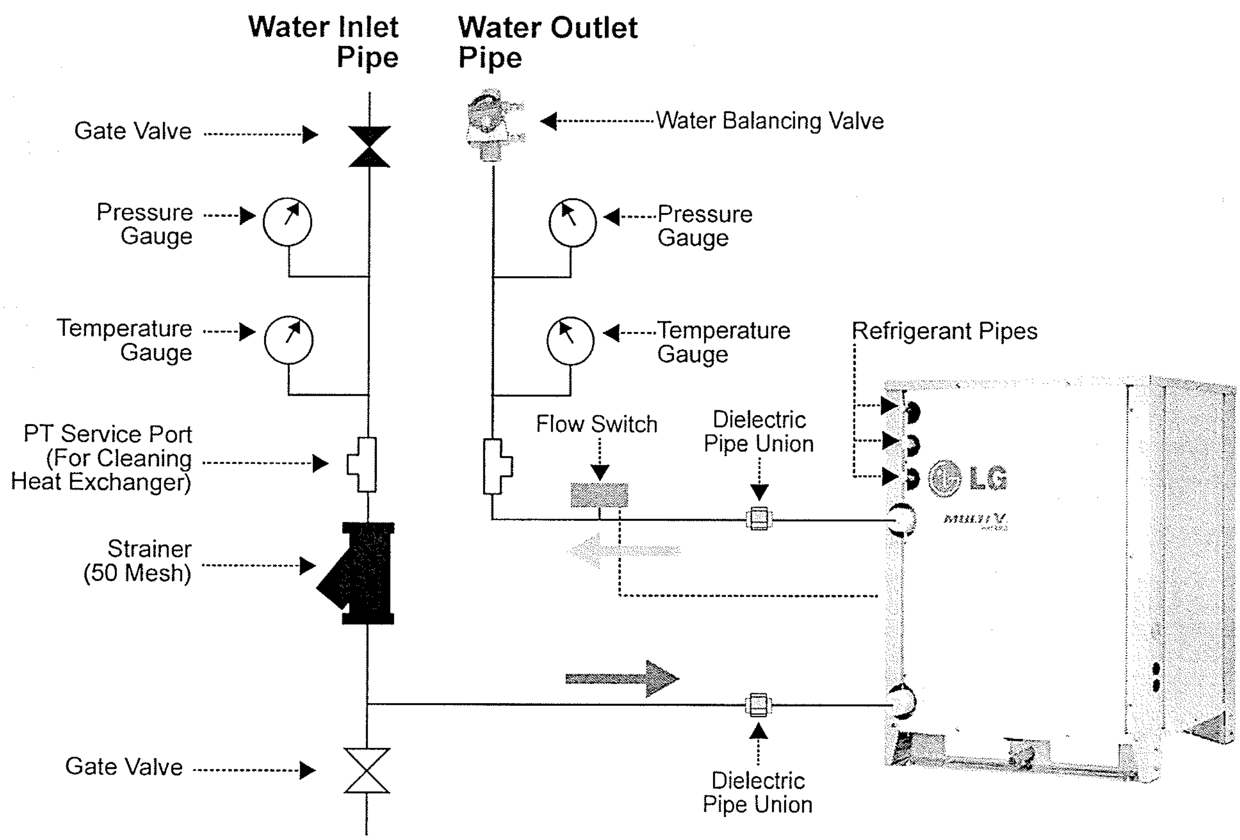
Field-Supplied Components for WSU Installation

Piping System

As shown in Figure 53, the following field supplied components should be installed at each Multi V IV Water Source Unit:

- Best practice is to install field-provided dielectric pipe unions to prevent the possibility of galvanic corrosion.
- Use a field-provided strainer with minimum 50 mesh screen at inlet. The mesh screen should be cleaned twenty-four (24) hours after startup, and then cleaned regularly to prevent water flow blockage.
- Pressure gauges at inlet and outlet.
- Thermometers at inlet and outlet.
- Flexible connectors at inlet and outlet (optional).
- Flow switch should be installed at outlet in the horizontal pipe. Flow switch should be wired to communication terminals and should be set to shut off the WSU if flow falls below 50% of WSU design flow. The flow switch must be the normally-closed type. The flow switch must be installed within at least five (5) pipe diameters downstream and at least three (3) pipe diameters upstream of elbows, valves, or reducers which can cause turbulence and lead to flow switch flutter.
- Shutoff valves at the inlet and outlet to permit service of the WSU.
- Condensate drain trap shall be designed per local code.
- Service port with hose connections at inlet and outlet. These are used to flush the WSU heat exchanger when isolated from the water loop system.
- A circuit setter, flow control valve, or balancing valve is suggested to regulate proper water flow to each WSU.
- Inhibitors should be used in the water loop, especially if water temperature operates above 104°F.
- Maintain water quality requirements.

Figure 53: Typical Field-Supplied Components and Connections for Multi V IV WSU.



Appendix E

Water Quality Requirements

Impurities in the water can influence the performance and life expectancy of the water cooled unit. Use a local water treatment professional to test and treat the water. Maintain the following levels:

Table 61:Minimum Water Quality Requirements.

Basic Item	Closed Type System		Effect	
	Circulating Water	Supplemented Water	Corrosion[1]	Scale[1]
pH (77°F)	7.0 ~ 8.0	7.0 ~ 8.0	•	•
Conductivity (77°F) mS/m	Below 30	Below 30	•	•
Chlorine ions (mg Cl^-/ℓ)	Below 50	Below 50	•	
Sulfate ions (mg SO_4^{2-}/ℓ)	Below 50	Below 50	•	•
Acid consumption (pH4.8) (mg$CaCO_3/\ell$)	Below 50	Below 50		•
Total Hardness (mg $CaCO_3/\ell$)	Below 70	Below 70		•
Calcium Hardness (mg $CaCO_3/\ell$)	Below 50	Below 50		•
Ionic-static silica (mg SiO_2/ℓ)	Below 30	Below 30		•
Reference Item				
Iron (mg Fe/ℓ)	Below 1.0	Below 0.3	•	•
Copper (mg Cu/ℓ)	Below 1.0	Below 0.1	•	
Sulfate ion (mg SO42/ℓ)	Must not be detected	Must not be detected	•	
Ammonium ion (mg NH4+)ℓ	Below 0.3	Below 0.1	•	
Residual chlorine (mg Cl/ℓ)	Below 0.25	Below 0.3	•	
Free carbon dioxide (mg CO_2/ℓ)	Below 0.4	Below 4.0	•	
Stability index			•	•

[1]The "•" mark for corrosion and scale means that there is a possibility of occurrence.

Note:
- *Use inhibitors in the water loop, especially if water temperature operates above 104°F.*
- *Purge air from the system.*

Pipe Insulation

Water pipe insulation is suggested in the following conditions:

- If water pipe is subject to freezing.
- If water can condense on surface of pipe from ambient room temperatures higher than temperature of water in the pipe.
- On boiler water pipes to save energy losses from heat source.
- On condensate drain lines.
- Where required by local code.

If water temperature is maintained at 68°F in winter and 86°F in summer, insulation is not required (unless required by local code).

APPENDIX C

Periodic commissioning meetings will be held. Through installation, pre-commissioning checking and startup, those meetings will be held in conjunction with CxA site visits. During testing the meetings will be weekly or as deemed appropriate. Meetings will always occur for pre-startup coordination of equipment subject to commissioning.

These meetings will be the primary venue for discussing issues relating to commissioning. It is important that the appropriate individuals attend.

B. COMMUNICATION

Between meetings, it is appropriate to communicate via mail, e-mail, phone, or face-to face. All non-written communications will be documented with a memo. The Commissioning Authority will direct all of their communications through the Architect with copies to the owner and appropriate contractors and designers.

C. SUBMITTAL REVIEW

The Commissioning Authority will review all mechanical, plumbing and electrical submittals that pertain to the systems to be commissioned as outlined in Section IV. This review will allow the CxA to gather information pertinent to the production of the Functional Performance Tests, as well as satisfy EAc3 requirements. This review will be conducted in conjunction with the design team review and does NOT supplant their review. CxA comments will be forwarded to the design team, who will incorporate into one list of review comments. This will then be forwarded to the Contract Team.

Prompt provision of record copy submittals to the CxA is critical to effectively move forward with the commissioning process. Commissioning documents, including the Construction Checklists and Functional Performance Test Procedures, are designed and/or edited based on the actual equipment provided for this project.

D. CONSTRUCTION CHECKLISTS

The CxA will produce Construction Checklists (CCs) for all systems listed in Part IV. As these are project specific and written around actual installed equipment, they cannot be produced until submittals are approved. The installing contractors are responsible for the completion and sign off a Construction Checklist for each piece of equipment installed for the systems listed in Part IV. A **sample** showing the rigor and format can be found in Appendix C.

E. FUNCTIONAL TEST PROCEDURES

The CxA will produce Functional Test Procedures (FTP) for all systems listed in Part IV. As these are project specific and written around actual installed equipment, they cannot be produced until submittals are approved. A **sample** showing rigor and format can be found in Appendix D.

F. SITE OBSERVATIONS

The inspection of the quality of construction is the Design Team's responsibility. The Design Team shall provide for the routine inspection of the construction site to ensure that the installation meets the standards of the design specifications, plans and good construction practices.

The CxA shall make periodic observations of the job during the construction phase. The CxA's observations shall concentrate on those systems to be commissioned with emphasis on equipment accessibility, ability to be balanced and ability to be commissioned. The CxA's site inspection will also review how well the construction lends itself to the operation and maintenance by the O&M personnel. Any problems identified during these visits shall be brought to the attention of the Commissioning Team. The Team will review the problem and a solution will be developed. The Contractor is responsible for correction of contract deficiencies identified during site investigations. The Design Team is responsible for correction of design deficiencies found during site investigations.

G. SYSTEM START-UP

As described above under Team Member Responsibilities and in the specifications, it is each subcontractor's responsibility to start-up the equipment in their portion of the specifications. Prior to equipment start-up, the appropriate subcontractor(s) will fill out their respective Construction Checklists and submit them to the CxA. The CxA's visual verification at site should occur prior to equipment startup. Each individual piece of equipment requires a start-up checklist and readiness report to be provided before startup procedures; it is not acceptable to submit one checklist for each equipment type.

H. POINT-TO-POINT

It is suggested that the Controls Contractor perform point-to-point testing of all control components, regardless of whether they are functionally tested. Point-to-point test procedures and associated forms are to be provided to the CxA for review. The procedures and methods for this testing will be submitted for approval. The checkout will be witnessed by the Owner, at their option. For the equipment to be tested by the CxA, all sensor calibration and all dampers and valve actuation (full open and full closed) will be verified. The executed point-to-point checklists will be submitted to the CxA prior to functional testing.

I. TEST AND BALANCING

As the contractors complete installation of systems, the TAB Contractor will start balancing those systems. All systems do not have to be complete before the balancer starts. It is very useful, and therefore desirable for the Commissioning Authority to have the balance data while performing the functional testing. Copies of balancing data taken each day will be provided to the Commissioning Authority, on the day that they are completed.

J. FUNCTIONAL PERFORMANCE TESTING

Effective functional testing cannot begin until the contractors have completed all portions of their work and the systems are fully operational. This includes testing, start up, controls, and test and balance. To ensure these requirements are met, the contractor must submit the construction checklist for each piece of equipment prior to each functional test. See Appendix C.

The actual Functional Test Procedure will be performed in compliance with the project specifications by the appropriate contractor(s) under the direction of the CxA.

For any equipment type with a quantity greater than 30, Liberty will test a sample of the equipment at a minimum of 30 or at a rate of 25%, whichever is greater. This sampling rate will change if a high percentage of equipment tested is found to not function properly.

The flow chart on page 19 diagrams the implementation procedure for functional testing.

K. COMMISSIONING REPORTING AND DEFICIENCY TRACKING

Throughout the process, items requiring attention will be reported on a Commissioning Issues Log and tracked thereon. An example of a Commissioning Issues Log can be found in the Appendix A. These items will be treated like any other punchlist, with room on the report for resolution description. The Issues Logs will become part of the final Cx Manual.

The Commissioning Issues Log is NOT the project Punchlist. All Contractor(s)/Trades work and open items are to be tracked separately by the appropriate contractor(s).

L. TRAINING

As described in the specifications, each contractor is responsible for training of equipment and systems in their respective sections. Each contractor will submit a training plan to the CxA for review for LEED™ compliance. This plan will include the design intent of the equipment or system, use of the O&M manuals, review of controls, interaction with other systems, adjustments and optimizing methods for energy conservation, relevant health and safety issues, special maintenance and replacement sources, and tenant interaction issues. The General Contractor is responsible for scheduling the training. The GC will submit a schedule to the CxA for review.

M. O&M DOCUMENTATION

As described in the specifications, each contractor is responsible for submitting operation and maintenance information for each piece of equipment and/or system in their respective sections. The O&M's are to be project specific with installed equipment clearly marked and irrelevant sections crossed out. The O&M data shall include: instructions for installation, start-up, operation, maintenance, replacement, special maintenance and replacement sources, parts list, a list of special tools, performance data and warranty information.

NorthArrow DESIGN • BUILD • MANAGE

APPENDIX D

Liberty 20150520
✓ Except as noted

CC-012 VRV Condensing Unit Construction Checklist

Project:	DGS Roosevelt High School Cx

Date:	05/06/2015
Equipment Tag:	VRV-0A-1
Building:	Theodore Roosevelt Senior High School
Location:	Ground Floor Zone A

Submittal / Approvals

Submittal. The above equipment and systems integral to them are complete and ready for functional testing. The checklist items are complete and have been checked off only by parties having direct knowledge of the event, as marked below, respective to each responsible contractor. This construction checklist is submitted for approval, subject to an attached list of outstanding items yet to be completed. A Statement of Correction will be submitted upon completion of any outstanding areas. None of the outstanding items preclude safe and reliable functional tests being performed. ___ **List attached.**

[signature] Mechanical Contractor	5/19/15 Date	[signature] Controls Contractor	4/5/16 Date
[signature] Electrical Contractor	5-19-15 Date	Sheet Metal Contractor	Date
TAB Contractor	Date	[signature] General Contractor	5-19-15 Date

Construction checklist items are to be completed as part of startup and initial checkout, preparatory to functional testing.

- This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report.
- If this form is not used for documenting, one of similar rigor shall be used.
- Contractors assigned responsibility for sections of the checklist shall be responsible to see that checklist items by their subcontractors are completed and checked off.

Approvals. This filled-out checklist has been reviewed. Its completion is approved with the exceptions noted below.

[signature] Commissioning Authority	05 APR 2016 Date	[signature] Owner's Representative	05 APR 2016 Date

Appendix E

Condensing Unit Information							
Make	LG			**Model Number**	ARWB192DAS4		
Serial Number	406KAYR00002			**Capacity**	157/191.5 Cool/Heat	**GPM**	50.7
Volts/Phase	460/3	**Fan Qty**	N/A	**Service Area**	0137 MECHANICAL ROOM		
Motor Hp (ea)	N/A	**Motor Eff (ea)**	N/A	**RPM (ea)**	N/A		

Comments: Water cooled condensing units do not have condenser fans. The relevant electrical information is as follows:

Compressor Info		Unit Electrical Information		
Compressor Qty	Comp RLA	MCA	MOCP	RFA
1	22.4	28	50	35

Associated Checklists					
Ceiling Cassette Unit	☑	**Fan Coil Unit**	☑		☐

Comments:

Requested documentation submitted	**Rec'd**	**Comments**
Manufacturer's cut sheets	☑	
Performance data (pump curves, coil data, etc.)	☑	
Installation and startup manual and plan	☑	
O&M manuals	☑	
Factory test results	☑	
Sequences and control strategies	☑	
Warranty Certificate	☑	

Comments:

Installation Checks

Check if Acceptable; Provide comment if unacceptable		**NA**	***Comment***
General			
General appearance good, no apparent damage.	☑	☐	Cover not installed
Foundation is installed per structural drawings.	☐	☑	
Manufacturer's required maintenance clearance provided.	☑	☐	
Permanent labels affixed.	☑	☐	Permanent label & pipe labels not affixed
Vibration isolation installed if applicable.	☐	☑	
Valves, Piping and Coils			
Pipe fittings complete and pipes properly supported.	☑	☐	
Pipes properly labeled.	☑	☐	
Pipes properly insulated.	☑	☐	[illegible] Strainer, fittings, valves not insulated
No leaking apparent around fittings.	☑	☐	
All coils are clean and fins are in good condition.	☑	☐	

Piping installation checked against the drawings and all devices gages and appurtenances are in place.	☑	☐	
Piping supported independently of the unit.	☑	☐	
Piping type and flow direction labeled on piping.	☑	☐	
Valves and piping specialties installed.	☑	☐	
Valves properly labeled.	☐	☑	
Valves installed in proper direction.	☐	☑	
Fan N/A No fan			
Fan drive properly aligned.	☐	☐	
Fan turns freely, fan wheel is balanced.	☐	☐	
Fan and Motor rotation checked.	☐	☐	
Fan guard or shield is properly installed.	☐	☐	
Vibration isolation devices installed and functional.	☐	☐	
Vibration sensor is installed and wired if applicable.	☐	☐	
Electrical and Controls			
Power disconnects located within site of the unit.	☑	☐	
Safeties installed and operational.	☑	☐	
Starter overload breakers installed and correct size.	☑	☐	
All control devices and wiring complete.	☑	☐	
Control system interlocks connected and functional.	☑	☐	
Sensors and Gages			
Temperature, pressure and flow gages and sensors installed.	☐	☐	
Piping gages, BAS and associated panel temperature and pressure readouts match.	☐	☐	

Operational Checks			
Check if Acceptable; Provide comment if unacceptable		**NA**	**Comment**
Specified point-to-point checks have been completed and documentation record submitted for this system.	☐	☐	
Startup report completed with this checklist attached (includes full listing of all internal settings with notes as to which settings are BAS controlled or monitored and which are integral.	☐	☐	
Startup report includes written certification from cooling tower manufacturer that all specified features, controls and safeties have been installed and are functioning properly and that the installation and application comply with the manufacturer's recommendations.	☐	☐	

Start up complete.	☐	☐	

Comments:

APPENDIX E

√ Liberty
20150624
Except As Noted

CC-002 Air Handling Unit (AHU) Construction Checklist

Project:	DGS Roosevelt High School Cx

Date:	6/17/15
Equipment Tag:	AHU - 9
Building:	Zone D
Location:	Second Floor Mechanical Room 2440

Submittal / Approvals

Submittal. The above equipment and systems integral to them are complete and ready for functional testing. The checklist items are complete and have been checked off only by parties having direct knowledge of the event, as marked below, respective to each responsible contractor. This construction checklist is submitted for approval, subject to an attached list of outstanding items yet to be completed. A Statement of Correction will be submitted upon completion of any outstanding areas. None of the outstanding items preclude safe and reliable functional tests being performed. ___ **List attached.**

[signature]	6/17/15	Kermit E. Nowacyk [signature]	6/19/15
Mechanical Contractor	Date	Controls Contractor	Date
[signature]	6-19-15	[signature]	6.19.15
Electrical Contractor	Date	Sheet Metal Contractor	Date
[signature]	3/21/14	[signature]	6-19-15
TAB Contractor	Date	General Contractor	Date

Construction checklist items are to be completed as part of startup and initial checkout, preparatory to functional testing.

- This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report.
- If this form is not used for documenting, one of similar rigor shall be used.
- Contractors assigned responsibility for sections of the checklist shall be responsible to see that checklist items by their subcontractors are completed and checked off.

Approvals. This filled-out checklist has been reviewed. Its completion is approved with the exceptions noted below.

[signature]	05 APR 2016	[signature]	4/5/16
Commissioning Authority	Date	Owner's Representative	Date

AHU Information						
Make	Imovent		Model Number	ERU-OU-WH-4200-FF-HP-HG-460		
Serial Number	2097441.0420		Capacity	191 (MBH)	CFM	4200
Volts/Phase	460 / 3Ø	Function		Service Area	DOAS D2	
Comments:						

Components Included					
Supply Fan	☑	Economizer	☑	Cooling/Heating Coil	☑
Exhaust / Relief Fan	☑	VFD(s)	☑	Re-Heat Coil	☐
Humidifier	☐	Filter(s)	☑	Humidifier	☐
Heat Recovery Wheel	☑		☐		☐

Associated Checklists					
Exhaust Fan	☐	VAV	☐		☐
Comments:					

Requested documentation submitted	Rec'd	Comments
Manufacturer's cut sheets	☑	
Performance data (fan curves, coil data, etc.)	☑	
Installation and startup manual and plan	☑	
O&M manuals	☑	
Factory test results	☑	
Sequences and control strategies	☑	
Warranty Certificate	☑	
Comments:		

Installation Checks			
Check if acceptable, provide comment if unacceptable		NA	Comment
General			
Unit is level and plumb	☑	☐	
Cabinet and general installation	☑	☐	
Permanent labels affixed, including for fans	☑	☐	

Installation Checks			
Check if acceptable, provide comment if unacceptable		**N A**	**Comment**
Casing condition good: no dents, leaks, door gaskets installed	☑	☐	
Access doors close tightly - no leaks	☐	☐	
Connection between duct and unit tight and in good condition	☑	☐	
Vibration isolation equipment installed & released from shipping locks	☑	☐	
Seismic restraints in place	☐	☑	
Maintenance access acceptable for unit and components	☑	☐	
Sound attenuation installed	☐	☑	
Thermal insulation properly installed and according to specification	☑	☐	
Instrumentation installed according to specification (thermometers, pressure gages, flow meters, etc.)	☑	☐	
Clean up of equipment completed per contract documents	☑	☐	
Filters installed and replacement type and efficiency permanently affixed to housing	☑	☐	
Construction filters removed	☑	☐	
Valves, Piping and Coils			
Pipe fittings complete and pipes properly supported	☑	☐	
Pipes properly labeled	☐	☐	
Pipes properly insulated	☑	☐	
Piping system properly flushed	☑	☐	
Strainers in place and clean, blowdown installed	☑	☐	
No leaking apparent around fittings	☑	☐	
All coils are clean and fins are in good condition	☑	☐	
All condensate drain pans clean and slope to drain, per spec	☑	☐	
Valves properly labeled	☑	☐	
Valves installed in proper direction	☑	☐	
OSAT, MAT, SAT, RAT, chilled water supply sensors properly located and secure (related OSAT sensor shielded)	☑	☐	
Test plugs (P/T) and isolation valves installed per drawings	☑	☐	
Unions installed to allow for easy removal of control valves	☑	☐	
Fans and Dampers			
Supply fan and motor alignment correct	☑	☐	
Supply fan belt tension and condition good	☐	☑	Direct Drive
Supply fan protective shrouds for belts in place and secure	☐	☑	
Supply fan area clean	☑	☐	

Installation Checks			
Check if acceptable, provide comment if unacceptable		**NA**	**Comment**
Supply fan and motor properly lubricated	✓		
Return/exhaust fan and motor aligned	✓		
Return/exhaust fan belt tension & condition good		✓	Direct Drive
Return/exhaust fan protective shrouds for belts in place and secure		✓	
Return/exhaust fan area clean	✓		
Return/exhaust fan and motor lube lines installed and lubed	✓		
Filters clean and tight fitting	✓		
Filter pressure differential measuring device installed and functional (magnahelic, inclined manometer, etc.)	✓		
Smoke and fire dampers installed properly per contract docs (proper location, access doors, appropriate ratings verified)	✓		
All dampers close tightly	✓		
All damper actuators installed	✓		
Ducts			
Sound attenuators installed	✓		
Duct joint sealant properly installed	✓		
No apparent severe duct restrictions	✓		
Turning vanes in square elbows as per drawings	✓		
OSA intakes located away from pollutant sources & exhaust outlets	✓		
Pressure leakage tests completed		✓	
Branch duct control dampers operable	✓		
Ducts cleaned as per specifications	✓		
Balancing dampers installed as per drawings and TAB's site visit	✓		
Electrical and Controls			
Power disconnects located within site of the unit it controls and labeled	✓		
All electric connections tight	✓		
Grounding installed for components and unit	✓		
Safeties installed and operational	✓		
Starter overload protection installed and correct size	✓		
All control devices and wiring complete	✓		
Control system interlocks connected and functional			
Smoke detectors in place	✓		

Installation Checks			
Check if acceptable, provide comment if unacceptable		**NA**	**Comment**
VFD			
Installation per manufacturer's requirements and start up instructions completed	☑	☐	
Drive location not subject to excessive moisture or dirt	☑	☐	
Drive location not subject to excessive temperatures	☑	☐	
Appropriate Volts vs. Hz curve is being used	☑	☐	
Drive size matches motor size	☑	☐	
Drive mounted on house keeping pad (if applicable)	☐	☑	
Cooling air flow path clean and unobstructed	☑	☐	
Permanent label affixed and UL stamp approved	☑	☐	
VFD interlocked to control system	☑	☐	
Unit is programmed with full written programming record on site	☑	☐	
Accel time set to 30 sec and Decel time set to 60 sec	☑	☐	
Operation checked in HAND, OFF, and AUTO. As applicable operation also checked in BYPASS	☑	☐	
Where applicable, ensure safeties are active in all modes	☑	☐	
Coordinated with BAS for all interface ranges and signal isolation	☑	☐	
Restart on Power Failure parameter set to auto	☑	☐	
VFD powered (wired to controlled equipment)	☑	☐	
Grounding installed for components and unit	☑	☐	
Drive min and max speed set to 20 Hz min and 60 Hz max	☑	☐	
Security settings set per Owner direction and Password documented for Owner	☑	☐	
Drive response to loss of signal set to min	☑	☐	
Output pulse resolution set to swirg pwm MHz. (This is coordinated with the application to minimize audible noise and coordinated with driven bearing allowances.)	☑	☐	
Checked the input voltage with drive disconnected	☑	☐	
Input of motor FLA represents 100% to 105% of motor FLA rating	☑	☐	
Upper frequency limit set at 100%, unless explained otherwise	☑	☐	
Sensors and Gages			
Temperature, pressure and flow gages and sensors installed	☑	☐	

Installation Checks			
Check if acceptable, provide comment if unacceptable		**NA**	**Comment**
Piping gages, BAS and associated panel temperature and pressure readouts match	☑	☐	
TAB			
Installation of system and balancing devices allowed balancing to be completed following specified NEBB or AABC procedures and contract documents	☑	☐	

Operational Checks			
Check if acceptable, provide comment if unacceptable		**NA**	**Comments**
Supply fan rotation correct (If VFD, check rotation in bypass and VFD Inverter mode)	☑	☐	
Return/relief/exhaust fan rotation correct	☑	☐	
Return/relief/exhaust fan acceptable noise & vibration	☑	☐	
Supply fan has no unusual noise or vibration	☑	☐	
Inlet vanes aligned in housing, actuator spanned, modulate smoothly and proportional to input signal and EMS readout	☑	☐	
All dampers (OSA, RA, EA, etc.) stroke fully without binding and spans calibrated and BAS reading site verified	☑	☐	
Valves stroke fully and easily and spanning is calibrated	☑	☐	
Valves verified to not be leaking through coils when closed at normal operating pressure	☑	☐	
Specified point-to-point checks have been completed and documentation record submitted for this system	☑	☐	
Supply fan rotation correct (If VFD, check rotation in bypass and VFD Inverter mode)	☑	☐	

Sensor and Actuator Calibration
All field-installed sensors and gages, and all actuators (dampers and valves) on this piece of equipment shall be calibrated in accordance with Specification Section 01810. All test instruments shall have had a certified calibration within the last 12 months: **Y/N**______. Sensors installed *in* the unit at the factory with calibration certification provided need not be field calibrated.

Sensor or Actuator Tag & Location	Location OK	1st Gage or BAS Value	Instrument Measured Value	*Final* Gage or BAS Value	Pass Y / N

Sensor or Actuator Tag & Location	Location OK	1st Gage or BAS Value	Instrument Measured Value	*Final* Gage or BAS Value	Pass Y / N

Comments:

TP-002d Air Handler DOAS Unit (AHU-5 thru 11) Test Procedure

Project:	DGS Roosevelt High School Cx

Tag:	AHU-5, AHU-6, AHU-7, AHU-8, AHU-9, AHU-10, AHU-11	*circle one*
System:	VAV, DX DOAS with Energy Recovery	
Building:	4301 13th Street NW, Washington DC 20011	
Location:		

First Test Date	Re-Test Date	Reason for Re-Test	Seasonal Test Required
9/1/2015		Previous issues testing see issues log, new program full retest	
9/23/2015			

05 OCT 2015 ← 11 MAY 2016 retest interlocks with VRF

Conditions of Testing

Ambient Conditions					
DB	52-69°F	**WB**	49°F	**RH**	68%

Signatures / Approvals

This filled-out test procedure has been reviewed. Its completion is approved with the exceptions noted below.

[signature] Mechanical Contractor	10/5/15 Date	[signature] Controls Contractor	10/5/15 Date
		[signature] General Contractor	10/5/15 Date
[signature] Commissioning Authority	17 OCT 2016 Date	[signature] Owner's Representative	10/17/16 Date

Occupancy Schedule			
School	7AM – 6PM M-F	**Administration**	6AM – 7PM M-F

Setpoints	Design	Actual
Supply Air Temperature Setpoint	**70°F**	
Heating Lockout OA Temperature Setpoint	**>70°F + 2°F hysteresis**	
Cooling Lockout OA Temperature Setpoint	**<55°F - 2°F hysteresis**	
Economizer Lockout OA Temperature Setpoint	**<25°F - 2°F hysteresis**	
Emergency Heating Supply Air Temperature Setpoint	**85°F**	
Emergency Heating Enable OA temperature setpoint	**<10°F + 2°F hysteresis**	
Supply Dew Point Setpoint	**55°F**	
Defrost Setpoint	**20°F**	
Filter Differential Pressure Setpoint	**0.75 in WG**	
Supply Duct Static Pressure Setpoint	**+1.75 in WG**	
Space Static Pressure Setpoint	**+0.04 in WG**	

Describe Overrides / Status and Operating Condition of Equipment:

Appendix E

Test Participants

Manufacturers:	
Contractors:	
Building Owner / Representatives:	
Commissioning Specialists:	

Test Instruments

Instrumentation				
Manufacturer/Model	**Serial Number**	**Range**	**Accuracy/Resolution**	**Last Calibration Date**
Fluke 568	27570114 / 28050163	-40°F to 1472°F	2.0°F or 1.0%	20 June 2014 / 06 August 2014

System Description

Master Setpoint Schedule (ASI-002 Sheet M600 dated 13 August 2014):

Except where noted differently, use these values for initial DGS acceptable space setpoints.

Temperature (globally heating mode when OAT <60 °F and reset to cooling mode when OAT >70 °F, and reset back to heating when back below heating setpoint, adjustable, but local switchover to occur at setpoints as noted below):

- Heating Range Occupied: 68 to 75.5 °F with 71 °F as setpoint with ability to adjust locally ±2 °F
- Heating Unoccupied: 55 °F setpoint with deadband of +4 °F
- Cooling Range Occupied: 73 to 79.5 °F with 75 °F as setpoint with ability to adjust locally ±2 °F
- Cooling Unoccupied: 85 °F setpoint with deadband of -4 °F
- Pool Continuous: 84 °F setpoint (assuming pool temperature of 83 °F) with deadband of ±3 °F
- DOAS supply air (SA) setpoint to be 70 °F (adj)
  - Except when outside air is less than 10 °F, then sa setpoint is set for 80 °F until outside air rises above 14 °F
  - Except when outside air is more than 98 °F, then sa setpoint is set for 60 °F until outside air drops below 94 °F

Relative Humidity : Dehumidification: 60%

Ventilation: ≤ 1000 ppm co2 with deadband of -50 ppm co2

Occupancy: Confirm anticipated schedule with client for initial school year (starting fall 2015)

- School: 7 am to 6 pm m-f with holidays excepted
- Administration: 6 am to 7 pm m-f with holidays excepted
- Gymnasium: school schedule plus as scheduled after-hours activities
- Pool: school schedule plus as scheduled after-hours activities
- Track: school schedule plus as scheduled after-hours activities

Filter: After unit air balance, measure filter air pressure drop (apd) and set initial air filter change setpoint alarm to 0.75" w.g. higher than the measured apd. Incorporate client policy regarding time duration setpoint alarm.

Dedicated Outside Air Systems (DOAS) – AHU-05 through AHU-11 Sequence of Operations (ASI-010 Sheet M609 dated 17 November 2014; edits in strikethroughs and underlines per GES/Trane markup to RTU-1 29 June 2015 FTP):

System description. Dedicated outside air units, variable volume, constant temperature, with energy recovery. Unit is equipped with standalone DDC controller with BACnet MSTP BMS interface. Unit DDC shall have an input allowing the unit to be started/stopped by others. A global outside air temperature shall be communicated by the BMS.

Unit Start

- Actuators for the outside air damper are powered.
- DDC controller checks damper actuator end switch status.
- Exhaust fan starts (gravity dampers).
- Supply fan starts 5 sec (adjustable) after the exhaust fan.
- Heating, cooling, and bypass operation per below.

Unit Stop

- Fans are de-energized

- All damper actuators are de-energized and spring return to their fail position after a 120sec on delay.

Occupied/Unoccupied Modes

- Occupied/unoccupied mode shall be controlled through the BMS interface.
- Occupied Mode: Supply fan on. Exhaust fan on. Heating, cooling, and economizer as shown here.
- Unoccupied Mode: Unit shall remain off, unless ~~seq. on to meet unocc space setpoints or~~ sequenced by the BMS for after-hours occ.

Heat Wheel

- Operation is continuous (with wheel rotation) during occupancy, except as noted below for economizer operation

Cooling

- Cooling lockout: the clg will be locked out when the OA is < 55°f -2°f hysteresis, adj. (i.e. once in clg mode, clg will remain on till OA is < 53°f, and then reset to clg at 55°f or higher)
- Outside air and exhaust air heat wheel bypass dampers shall be open in economizer mode.
- Economizer (energy recovery reduction type)
- The economizer will be locked out when the outside air is < 25°f - 2°f hysteresis, adjustable.
- Heat reclaim wheel rotation shall be stopped in economizer mode.
- Heat pump cooling: the water regulating valve shall be opened upon a command for cooling. The valve shall be modulated to maintain maximum and minimum head pressure as needed (to be determined on the field). Compressors shall be energized and staged for cooling.
- Cooling temperature control: the economizer and cooling are controlled to maintain the cooling coil temperature set point. Economizer, if available, will be used as the first stage of cooling.

Heating

- Lockout: the heating will be locked out when the outside air is > 70°f + 2°f hysteresis, adjustable.
- Heat pump heating: the water regulating valve shall be opened upon a command for heating. The valve shall be modulated to maintain maximum and minimum head pressure as needed. Reversing valve shall be energized. Compressors shall be energized and staged for heating. The heating is controlled to maintain the supply temperature set point.
- Emergency heating mode: the unit discharge air setpoint will be reset to 85°f when the OA is < 10°f + 2°f hysteresis, adjustable.

Hot Gas Reheat

- Hot Gas Reheat: hot gas reheat shall be activated in cooling mode. The reheat is controlled to maintain the unit supply temperature set point.

Supply Temperature Set Point

- The DDC controller will maintain a constant supply discharge temperature per master setpoint schedule.

Cooling Coil Set Point

- The DDC controller will set the cooling coil leaving air temperature set point to the dew point set point.
- Supply dew point set pt: 55.0°f, adjustable

Supply Fan Control

- Duct static pressure: the SF VFD shall modulate based on the supply duct static pressure set point (set point= 1.75" WC adjustable)
- Supply air flow monitoring will be collected for data aggregation per LEED credit.

Exhaust Fan Control

- Space pressure: the EF VFD shall modulate in order to maintain space positive pressure (set pt=+0.040" wc, adjustable) as compared to a reference static pressure. The location of the space pressure sensor and reference pressure sensor shall be per the drawings.

Defrost

- The heat wheel VFD modulates wheel speed in order to maintain the EA temperature above the defrost set point (set point=20°f).

Compressor head pressure shall be protected by condenser water regulating valve.

Smoke Detector(s). Upon sensing the products of combustion, the smoke detector shall signal the DDC to de-energize the unit.

Dirty Filter Switches. If the filter diff pressure rises above the adj SP of the switch, the diff pressure switch shall signal the DDC to alarm.

Alarm Indication. DDC shall have one digital output for remote indication of an alarm condition.

Interlock with associated VRV system upon occupancy

Dehumidification

A. The controller shall enable the dehumidification control sequence when both of the following conditions are met.
   - Outdoor air temperature is greater than the supply temperature.
   - Outdoor dewpoint is greater than the indoor air dewpoint.

B. The controller shall perform the following functions in the dehumidification mode
   - If the ambient temperature is greater than the space temperature, enable the energy recovery wheel at full speed.
   - ~~Modulate capacity to the supply air temperature set point~~
   - modulate cooling capacity to maintain the coil leaving air temperature setpoint
   - Modulate hot gas reheat valve to maintain the supply air temperature setpoint

Sensor Calibration Verification

AHU-9

Check the sensors listed below for calibration and adequate location. All field-installed sensors and gages, and all actuators (dampers and valves) on this piece of equipment shall be calibrated in accordance with Specification Section 01810. All test instruments shall have had a certified calibration within the last 12 months: **Y/N**______. Sensors installed *in* the unit at the factory with calibration certification provided need not be field calibrated.

Sensor	Location OK	1st Gage or BAS Value	Instrument Measured Value	*Final* Gage or BAS Value	Pass Y / N
Supply Duct Static Pressure Sensor					
Space Static Pressure Sensor					

Device Calibration Verification

All field-installed sensors and gages, and all actuators (dampers and valves) on this piece of equipment shall be calibrated in accordance with Specification Section 01810. All test instruments shall have had a certified calibration within the last 12 months: **Y/N**______. Sensors installed *in* the unit at the factory with calibration certification provided need not be field calibrated.

Device or Actuator	Procedure / State	1st BAS Value	Site Observation	*Final* BAS Value	Pass Y / N
Outside Air Damper					
Condensing Water Valve					
Reversing Valve					

Load Verification Testing

Load Parameter	Design	Actual	Comments
Supply Airflow	3860	3874	
Discharge Static Pressure	N/A	2.65	
Fan RPM	3235	3097	

Static Inspections

Static Inspection	P	F	Comments
Verify sufficient clearance around equipment for servicing.			
Model and tag checked against plans & equipment list. Unit identification tag affixed.			
Electrical power disconnect within line of sight.			

Functional Testing

Test Procedure	Expected Response	P	F	Comments
Start with unit in Off position; Adjust time of day schedule from the BAS such that the unit is in Unoccupied Mode.. (Verify interlocked VRV system Off.)	CW and reversing valves Close; OA damper Closes; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off. 15.5%	✓		VRV ______ Status: Off valves stuck
Occupied Mode Adjust time of day schedule from the BAS such that the unit is in Occupied Mode. Simulate a DAT SP equal to the DAT. SF 52.8% EF 38.8% EW 100%	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off. 58.7%	✓		VRV ______ Status: On

0741

(X) 0829 turning off to check compressor alarm

Appendix E

Attn 9 — VALVE ISSUE

Test Procedure	Expected Response	P	F	Comments
0817 **Occupied Cooling Economizer (Disable Energy Recovery Wheel)** Simulate a Occupied Cooling setpoint 5°F below DAT and a Return enthalpy 5°F above OA enthalpy. SF 52.4% EF 38.4% EW 42.3%	CW and reversing valves remain Closed; OA damper Opens; SF, EF, and energy wheel Enable; compressors remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors status as Off.	17.6% O		OA temp: 64.0°F DAT: 71.9°F RA temp: 76.8°F Occ. Clg. SP: 65.0°F RA humidity: 50.6% OA humidity: 63.7% Hot Gas Reheat Status: 0 VRV _____ Status: On
0845 (X) **Economizer Lockout** Simulate the Economizer Lockout OA temperature setpoint 5°F above OA temperature and DAT setpoint 5°F below DAT. SF 52.7% EF 38.7% EW 100% VAV	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors status as Off. — 0	89%	valve open ✓	OA temp: Econ LO OA temp: 20°F Space temp: 71.0°F Occ. Clg SP: 65.0°F Hot Gas Reheat Status: 0% VRV _____ Status: On
0905 Simulate the Economizer Lockout OA temperature setpoint 5°F below OA temperature and DAT setpoint 5°F below DAT. SF 52.8% EF 38.3% EW 48.9% 0914 changed SAT SP = 63°F	CW and reversing valves remain Closed; OA damper Opens; SF, EF, and energy wheel Enable; compressors remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors status as Off. — 0	89.0%		OA temp: Econ LO OA temp: 55°F Space temp: 71.6°F Occ. Clg SP: 65.0°F Hot Gas Reheat Status: 0% VRV _____ Status: On
0932 **Occupied Cooling** EW 0% Simulate a Occupied Cooling setpoint 5°F below DAT and a Return enthalpy 5°F below OA enthalpy. SF 52.6% EF 38.6% EW 29.7% lowered SAT SP from 60 to 50 to ensure call for cooling	CW valve Opens; reversing valve remains Closed; OA damper Opens; SF, EF, and energy wheel remain Enabled; compressors Enable. BAS shows CW valve Open; reversing valve Closed; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel, and compressors statuses as On. — 0%	57.1% 0940 25.2%		OA temp: 70°F DAT: 60°F RA temp: 72.6 Occ. Clg. SP: 50.0°F No. compressors On: 1 of 1 RA humidity: 51.0% OA humidity: 72.7% Hot Gas Reheat Status: 0% VRV _____ Status: On
0959 **Cooling Lockout** Simulate Cooling lockout OA temperature setpoint 5°F above OA temperature and DAT setpoint 5°F below DAT. SF 52.8% EF 38.8 EW 100	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses On; compressor status as Off. — 0	5.2% 100% went to 89%		OA temp: Clg LO OA temp: 70°F Space temp: 68.3°F Occ. Clg SP: 73.6°F Hot Gas Reheat Status: 0 VRV _____ Status: On
Simulate Cooling lockout OA temperature setpoint 5°F below OA temperature and DAT setpoint 5°F below DAT. override OAT to 47.5°F SF 52.8 EF 38.8 EW 100%	CW valve Opens; reversing valve remains Closed; OA damper Opens; SF, EF, and energy wheel remain Enabled; compressors Enable. BAS shows CW valve Open; reversing valve Closed; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel, and compressors statuses as On. — 0%	Closed for lockout 89.1		OA temp: Clg LO OA temp: 47.5 Space temp: 68.3 Occ. Clg SP: 66.0°F Hot Gas Reheat Status: 0% VRV _____ Status: On

Test Procedure	Expected Response	P	F	Comments
1213 **Occupied Dehumidification** Override the adjustable delay at the unit display to 1 minute. Simulate an OA temperature 5°F above the DAT and a return relative humidity 5% above relative humidity setpoint. SF 53.4 EF 39.9 EW 0%	CW valve Opens; reversing valve remains Closed; OA damper Opens; SF, EF, compressors, and energy wheel remain Enabled. BAS shows CW valve Open; reversing valve Closed; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel, and compressors statuses as On. 7.3%	59.8 ✓		OA temp: 65 F DAT: 65.1 °F ~~OA DP~~: 65.5 % ~~Indoor DP~~: 51.3 % Hot Gas Reheat Status: 6.7 % ~~VRV ______ Status: On~~ SAT SP 67.5
12:51 Simulate an OA temperature 5°F below the Cooling Enable OA temperature setpoint. Simulate DAT SP equal to the DAT. SF 52.8% EF 38.0% EW 100%	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off. – 0%	89.1% ✓ –0%		VRV ______ Status: On
1058 **Occupied Heating** Simulate an OA temperature 5°F below the Heating Enable OA temperature setpoint. Simulate DAT SP 5°F above the DAT. SF 53.0% EF 39.0% EW 100% attempted to satisfy before re-over[ride]	CW and reversing valves Open; OA damper Opens; SF, EF, compressors, and energy wheel Enable; hot gas reheat remains Disabled. BAS shows valves Open; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel and compressor statuses as On; hot gas reheat status as Off. 42.6%	34.5% ✓		OA temp: DAT: 71.6 F RA temp: 76.2 F Occ. Htg. SP: 81.2 °F ~~VRV ______ Status: On~~
1130 **Heating Lockout** Simulate Heating lockout OA above temperature setpoint 5°F ~~below~~ OA temperature and DAT setpoint 5°F below DAT. raise to 72F which locks out htg SF 53.8 EF 39.9 EW 100%	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off. – 0%	89.5% ✓		OA temp: Htg LO OA temp: 75% Space temp: 73.2 SPT Occ. Htg SP: 81.2% ~~VRV ______ Status: On~~
1147 Simulate Heating lockout OA below temperature setpoint 5°F ~~above~~ OA temperature and DAT setpoint 5°F below DAT. SF 54% EF 40 EW 100	CW and reversing valves Open; OA damper Opens; SF, EF, compressors, and energy wheel Enable; hot gas reheat remains Disabled. BAS shows valves Open; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel and compressor statuses as On; hot gas reheat status as Off. – 17.4%	69.2% ✓ – 0%		OA temp: Htg LO OA temp: 65 Space temp: 73.0 F Occ. Htg SP: 81.2 °F VRV ______ Status: On RAT 76.4 °F
~~**Emergency Heating** Simulate Emergency Heating enable setpoint 5°F above OA temperature.~~	~~DAT Setpoint resets to Emergency Heating DAT setpoint. Unit remains Enabled in Heating Mode to satisfy setpoint.~~			~~OA temp: Emer. Htg. Enable SP: DAT: DAT SP: VRV ______ Status: On~~

Attv. 9

UNIT DOES NOT HAVE

Test Procedure	Expected Response	P	F	Comments
Simulate Emergency Heating enable setpoint 5°F below OA temperature.	DAT Setpoint resets to DAT setpoint. Unit remains Enabled in Heating Mode to satisfy setpoint.			OA temp: Emer. Htg. Enable SP: DAT: DAT SP: VRV ______ Status: On
Simulate DAT SP equal to the DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.			VRV ______ Status: On
11 MAY 2016 0942 **Interlock** Adjust time of day schedule from the BAS such that the AHU and interlocked VRV system are in Unoccupied Mode. Simulate Unoccupied Cooling setpoint minus the Unoccupied Cooling diff 5°F above the return air temperature (Unoccupied Heating setpoint plus the Unoccupied Heating diff 5°F below return air temperature).	CW and reversing valves Close; OA damper Closes; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off.	✓		VRV ______ Status: Off
11 MAY 2016 0949 Adjust time of day schedule from the BAS such that the interlocked VRV is in Occupied Mode.	CW and reversing valves remain Closed; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.	✓		VRV ______ Status: On
Supply Fan Speed Control Simulate a duct static pressure setpoint above duct static pressure.	Supply fan ramps up. BAS displays SF speed accurately.			Duct Pressure: Duct Pressure SP: SF speed:
Simulate a duct static pressure setpoint below duct static pressure.	Supply fan ramps down. BAS displays SF speed accurately.			Duct Pressure: Duct Pressure SP: SF speed:
Exhaust Fan Speed Control Simulate space static pressure setpoint below space static pressure.	Exhaust fan ramps up. BAS displays EF speed accurately.			Space Pressure: Space Pressure SP: EF speed:
Simulate space static pressure setpoint above space static pressure.	Exhaust fan ramps down. BAS displays EF speed accurately.			Space Pressure: Space Pressure SP: EF speed:
Energy Wheel Speed Control Simulate Defrost setpoint 5°F above exhaust air temperature.	Energy wheel ramps up. BAS displays energy wheel speed correctly.			EA temp: Defrost SP: Wheel speed:
Simulate Defrost setpoint 5°F below exhaust air temperature.	Energy wheel ramps down. BAS displays energy wheel speed correctly.			EA temp: Defrost SP: Wheel speed:

Test Procedure	Expected Response	P	F	Comments
Dirty Filter Alarm Simulate a filter differential pressure above the filter differential pressure setpoint.	BAS displays dirty filter alarm.			Filter Pres.: Filter Pres. SP:
Smoke Detection Simulate smoke at the smoke detector in the supply duct.	Unit Disables. OA damper and gas valve Close; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off. Alarm is generated at BAS indicating smoke shutdown.			See Fire Marshall test reports for smoke detector safety operation verification. VRV ______ Status: Off
Simulate smoke at the smoke detector in the return duct.	Unit Disables. OA damper and gas valve Close; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off. Alarm is generated at BAS indicating smoke shutdown.			See Fire Marshall test reports for smoke detector safety operation verification. VRV ______ Status: Off

Required Monitoring

All points listed below shall be trended by the BAS for the period indicated.

Point	Trend Interval (min.)	Minimum Time Period of Trend	Hard Copy? (Y/N)	ASCII File? (Y/N)
Supply Fan Status	2	26 hours		
Exhaust Fan Status	2	26 hours		
Compressors Status	2	26 hours		
Energy Recovery Wheel Status	2	26 hours		
Hot Gas Reheat Status	2	26 hours		
OA damper position	2	26 hours		
Supply Air Temperature	2	26 hours		
Return Air Temperature	2	26 hours		
Return Air Humidity	2	26 hours		
Outside Air Temperature	2	26 hours		
Outside Air Humidity	2	26 hours		
Wheel Leaving Air Temperature	2	26 hours		
Heat Pump Discharge Temperature	2	26 hours		
Exhaust Air Temperature	2	26 hours		
Space Temperature	2	26 hours		

Remarks:

Acceptance Criteria (referenced by function or mode ID)

For the conditions, sequences and modes tested, the fans, integral components and related equipment respond to changing conditions and parameters appropriately as expected, as specified and according to acceptable operating practice.

Comments with Acceptance Criteria:

TP-002d Air Handler DOAS (AHU-5 thru 11) Opposite Season Test Procedure

Project:	DGS Roosevelt High School Cx

Tag:	~~AHU-5, AHU-6, AHU-7, AHU-8,~~ AHU-9, ~~AHU-10, AHU-11~~	*circle one*
System:	VAV, DX DOAS with Energy Recovery	
Building:	4301 13th Street NW, Washington DC 20011	
Location:		

First Test Date	Re-Test Date	Reason for Re-Test	Seasonal Test Required
			2/8/2016

Conditions of Testing

Ambient Conditions					
DB	34°F - 46°F	WB	36°F	RH	64

Signatures / Approvals

This filled-out test procedure has been reviewed. Its completion is approved with the exceptions noted below.

[signature] Mechanical Contractor	2/8/16 Date	Alexander J Hilton Controls Contractor	2/8/16 Date
		[signature] General Contractor	10/17/16 Date
[signature] Commissioning Authority	05 Apr 2016 Date	[signature] Owner's Representative	Date

Occupancy Schedule			
School	7AM – 6PM M-F	**Administration**	6AM – 7PM M-F

Setpoints	Design	Actual
Supply Air Temperature Setpoint	**70°F**	
Heating Lockout OA Temperature Setpoint	**>70°F + 2°F hysteresis**	
Cooling Lockout OA Temperature Setpoint	**<55°F - 2°F hysteresis**	
Economizer Lockout OA Temperature Setpoint	**<25°F - 2°F hysteresis**	
Emergency Heating Supply Air Temperature Setpoint	**85°F**	
Emergency Heating Enable OA temperature setpoint	**<10°F + 2°F hysteresis**	
Supply Dew Point Setpoint	**55°F**	
Defrost Setpoint	**20°F**	
Filter Differential Pressure Setpoint	**0.75 in WG**	
Supply Duct Static Pressure Setpoint	**+1.75 in WG**	
Space Static Pressure Setpoint	**+0.04 in WG**	

Describe Overrides / Status and Operating Condition of Equipment:

Test Participants

Manufacturers:	
Contractors:	Alex Hilton (Pritchett)
Building Owner / Representatives:	
Commissioning Specialists:	Caroline Dougherty, John Ramel, Miranda Myers

Test Instruments

Instrumentation				
Manufacturer/Model	**Serial Number**	**Range**	**Accuracy/Resolution**	**Last Calibration Date**
Fluke 568	27570114 / 28050163	-40°F to 1472°F	2.0°F or 1.0%	20 June 2014 / 06 August 2014

System Description

Master Setpoint Schedule (ASI-002 Sheet M600 dated 13 August 2014):
Except where noted differently, use these values for initial DGS acceptable space setpoints.
Temperature (globally heating mode when OAT <60 °F and reset to cooling mode when OAT >70 °F, and reset back to heating when back below heating setpoint, adjustable, but local switchover to occur at setpoints as noted below):

- Heating Range Occupied: 68 to 75.5 °F with 71 °F as setpoint with ability to adjust locally ±2 °F
- Heating Unoccupied: 55 °F setpoint with deadband of +4 °F
- Cooling Range Occupied: 73 to 79.5 °F with 75 °F as setpoint with ability to adjust locally ±2 °F
- Cooling Unoccupied: 85 °F setpoint with deadband of -4 °F
- Pool Continuous: 84 °F setpoint (assuming pool temperature of 83 °F) with deadband of ±3 °F
- DOAS supply air (SA) setpoint to be 70 °F (adj)
  - Except when outside air is less than 10 °F, then sa setpoint is set for 80 °F until outside air rises above 14 °F
  - Except when outside air is more than 98 °F, then sa setpoint is set for 60 °F until outside air drops below 94 °F

Relative Humidity : Dehumidification: 60%
Ventilation: ≤ 1000 ppm co2 with deadband of -50 ppm co2
Occupancy: Confirm anticipated schedule with client for initial school year (starting fall 2015)

- School: 7 am to 6 pm m-f with holidays excepted
- Administration: 6 am to 7 pm m-f with holidays excepted
- Gymnasium: school schedule plus as scheduled after-hours activities
- Pool: school schedule plus as scheduled after-hours activities
- Track: school schedule plus as scheduled after-hours activities

Filter: After unit air balance, measure filter air pressure drop (apd) and set initial air filter change setpoint alarm to 0.75" w.g. higher than the measured apd. Incorporate client policy regarding time duration setpoint alarm.
Dedicated Outside Air Systems (DOAS) – AHU-05 through AHU-11 Sequence of Operations (ASI-010 Sheet M609 dated 17 November 2014; edits in strikethroughs and underlines per GES/Trane markup to RTU-1 29 June 2015 FTP):
System description. Dedicated outside air units, variable volume, constant temperature, with energy recovery. Unit is equipped with standalone DDC controller with BACnet MSTP BMS interface. Unit DDC shall have an input allowing the unit to be started/stopped by others. A global outside air temperature shall be communicated by the BMS.
Unit Start

- Actuators for the outside air damper are powered.
- DDC controller checks damper actuator end switch status.
- Exhaust fan starts (gravity dampers).
- Supply fan starts 5 sec (adjustable) after the exhaust fan.
- Heating, cooling, and bypass operation per below.

Unit Stop

- Fans are de-energized

- All damper actuators are de-energized and spring return to their fail position after a 120sec on delay.

Occupied/Unoccupied Modes

- Occupied/unoccupied mode shall be controlled through the BMS interface.
- Occupied Mode: Supply fan on. Exhaust fan on. Heating, cooling, and economizer as shown here.
- Unoccupied Mode: Unit shall remain off, unless ~~seq. on to meet unocc space setpoints or~~ sequenced by the BMS for after-hours occ.

Heat Wheel

- Operation is continuous (with wheel rotation) during occupancy, except as noted below for economizer operation

Cooling

- Cooling lockout: the clg will be locked out when the OA is < 55°f -2°f hysteresis, adj. (i.e. once in clg mode, clg will remain on till OA is < 53°f, and then reset to clg at 55°f or higher)
- Outside air and exhaust air heat wheel bypass dampers shall be open in economizer mode.
- Economizer (energy recovery reduction type)
- The economizer will be locked out when the outside air is < 25°f - 2°f hysteresis, adjustable.
- Heat reclaim wheel rotation shall be stopped in economizer mode.
- Heat pump cooling: the water regulating valve shall be opened upon a command for cooling. The valve shall be modulated to maintain maximum and minimum head pressure as needed (to be determined on the field). Compressors shall be energized and staged for cooling.
- Cooling temperature control: the economizer and cooling are controlled to maintain the cooling coil temperature set point. Economizer, if available, will be used as the first stage of cooling.

Heating

- Lockout: the heating will be locked out when the outside air is > 70°f + 2°f hysteresis, adjustable.
- Heat pump heating: the water regulating valve shall be opened upon a command for heating. The valve shall be modulated to maintain maximum and minimum head pressure as needed. Reversing valve shall be energized. Compressors shall be energized and staged for heating. The heating is controlled to maintain the supply temperature set point.
- Emergency heating mode: the unit discharge air setpoint will be reset to 85°f when the OA is < 10°f + 2°f hysteresis, adjustable.

Hot Gas Reheat

- Hot Gas Reheat: hot gas reheat shall be activated in cooling mode. The reheat is controlled to maintain the unit supply temperature set point.

Supply Temperature Set Point

- The DDC controller will maintain a constant supply discharge temperature per master setpoint schedule.

Cooling Coil Set Point

- The DDC controller will set the cooling coil leaving air temperature set point to the dew point set point.
- Supply dew point set pt: 55.0°f, adjustable

Supply Fan Control

- Duct static pressure: the SF VFD shall modulate based on the supply duct static pressure set point (set point= 1.75" WC adjustable)
- Supply air flow monitoring will be collected for data aggregation per LEED credit.

Exhaust Fan Control

- Space pressure: the EF VFD shall modulate in order to maintain space positive pressure (set pt=+0.040" wc, adjustable) as compared to a reference static pressure. The location of the space pressure sensor and reference pressure sensor shall be per the drawings.

Defrost

- The heat wheel VFD modulates wheel speed in order to maintain the EA temperature above the defrost set point (set point=20°f).

Compressor head pressure shall be protected by condenser water regulating valve.
Smoke Detector(s). Upon sensing the products of combustion, the smoke detector shall signal the DDC to de-energize the unit.
Dirty Filter Switches. If the filter diff pressure rises above the adj SP of the switch, the diff pressure switch shall signal the DDC to alarm.
Alarm Indication. DDC shall have one digital output for remote indication of an alarm condition.
Interlock with associated VRV system upon occupancy
Dehumidification

A. The controller shall enable the dehumidification control sequence when both of the following conditions are met.
    - Outdoor air temperature is greater than the supply temperature.
    - Outdoor dewpoint is greater than the indoor air dewpoint.

B. The controller shall perform the following functions in the dehumidification mode
    - If the ambient temperature is greater than the space temperature, enable the energy recovery wheel at full speed.
    - ~~Modulate capacity to the supply air temperature set point~~
    - modulate cooling capacity to maintain the coil leaving air temperature setpoint
    - Modulate hot gas reheat valve to maintain the supply air temperature setpoint

Sensor Calibration Verification

Check the sensors listed below for calibration and adequate location. All field-installed sensors and gages, and all actuators (dampers and valves) on this piece of equipment shall be calibrated in accordance with Specification Section 01810. All test instruments shall have had a certified calibration within the last 12 months: **Y/N**______. Sensors installed *in* the unit at the factory with calibration certification provided need not be field calibrated.

Sensor	Location OK	1st Gage or BAS Value	Instrument Measured Value	*Final* Gage or BAS Value	Pass Y / N
Supply Duct Static Pressure Sensor					
Space Static Pressure Sensor					

Device Calibration Verification

All field-installed sensors and gages, and all actuators (dampers and valves) on this piece of equipment shall be calibrated in accordance with Specification Section 01810. All test instruments shall have had a certified calibration within the last 12 months: **Y/N**______. Sensors installed *in* the unit at the factory with calibration certification provided need not be field calibrated.

Device or Actuator	Procedure / State	1st BAS Value	Site Observation	*Final* BAS Value	Pass Y / N
Outside Air Damper					
Condensing Water Valve					
Reversing Valve					

Load Verification Testing

Load Parameter	Design	Actual	Comments
Supply Airflow			
Discharge Static Pressure			
Fan RPM			

Static Inspections

Static Inspection	P	F	Comments
Verify sufficient clearance around equipment for servicing.	✓		
Model and tag checked against plans & equipment list. Unit identification tag affixed.	✓		
Electrical power disconnect within line of sight.	✓		

Functional Testing

Test Procedure	Expected Response	P	F	Comments
Start with unit in Off position; Adjust time of day schedule from the BAS such that the unit is in Unoccupied Mode.. (Verify interlocked VRV system Off.)	CW and reversing valves Close; OA damper Closes; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off.	✓		VRV ______ Status: Off
<u>**Occupied Mode**</u> Adjust time of day schedule from the BAS such that the unit is in Occupied Mode. Simulate a DAT SP equal to the DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.	✓		VRV ______ Status: On DAT 69.9°F DAT SP 66°F OA 48.5°F

Test Procedure	Expected Response	P	F	Comments
<u>Occupied Cooling Economizer (Disable Energy Recovery Wheel)</u> Simulate a Occupied Cooling setpoint 5°F below DAT and a Return enthalpy 5°F above OA enthalpy.	CW and reversing valves remain Closed; OA damper Opens; SF, EF, and energy wheel Enable; compressors remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors status as Off.	[redacted]		
<u>Economizer Lockout</u> Simulate the Economizer Lockout OA temperature setpoint 5°F above OA temperature and DAT setpoint 5°F below DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors status as Off.			
Simulate the Economizer Lockout OA temperature setpoint 5°F below OA temperature and DAT setpoint 5°F below DAT.	CW and reversing valves remain Closed; OA damper Opens; SF, EF, and energy wheel Enable; compressors remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors status as Off.			
<u>Occupied Cooling</u> Simulate a Occupied Cooling setpoint 5°F below DAT and a Return enthalpy 5°F below OA enthalpy.	CW valve Opens; reversing valve remains Closed; OA damper Opens; SF, EF, and energy wheel remain Enabled; compressors Enable. BAS shows CW valve Open; reversing valve Closed; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel, and compressors statuses as On.			
<u>Cooling Lockout</u> Simulate Cooling lockout OA temperature setpoint 5°F above OA temperature and DAT setpoint 5°F below DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses On; compressor status as Off.			
Simulate Cooling lockout OA temperature setpoint 5°F below OA temperature and DAT setpoint 5°F below DAT.	CW valve Opens; reversing valve remains Closed; OA damper Opens; SF, EF, and energy wheel remain Enabled; compressors Enable. BAS shows CW valve Open; reversing valve Closed; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel, and compressors statuses as On.			

Test Procedure	Expected Response	P	F	Comments
Occupied Dehumidification Override the adjustable delay at the unit display to 1 minute. Simulate an OA temperature 5°F above the DAT and a return relative humidity 5% above relative humidity setpoint.	CW valve Opens; reversing valve remains Closed; OA damper Opens; SF, EF, compressors, and energy wheel remain Enabled. BAS shows CW valve Open; reversing valve Closed; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel, and compressors statuses as On.	[redacted]		
Simulate an OA temperature 5°F below the Cooling Enable OA temperature setpoint. Simulate DAT SP equal to the DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.			
Occupied Heating Simulate an OA temperature 5°F below the Heating Enable OA temperature setpoint. Simulate DAT SP 5°F above the DAT.	CW and reversing valves Open; OA damper Opens; SF, EF, compressors, and energy wheel Enable; hot gas reheat remains Disabled. BAS shows valves Open; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel and compressor statuses as On; hot gas reheat status as Off.	✓		OA temp: 48.5°F DAT: 67.?°F → 77.1 RA temp: 76.4°F Occ. Htg. SP: 74°F VRV ______ Status: On
Heating Lockout Simulate Heating lockout OA temperature setpoint 5°F below OA temperature and DAT setpoint 5°F below DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.	✓		OA temp: 48.5 Htg LO OA temp: Space temp: 74.3 Occ. Htg SP: 95 VRV ______ Status: On
Simulate Heating lockout OA temperature setpoint 5°F above OA temperature and DAT setpoint 5°F below DAT.	CW and reversing valves Open; OA damper Opens; SF, EF, compressors, and energy wheel Enable; hot gas reheat remains Disabled. BAS shows valves Open; OA damper Open to percent visually verified at equipment; SF, EF, energy wheel and compressor statuses as On; hot gas reheat status as Off.	✓		OA temp: 48.5 Htg LO OA temp: Space temp: 91.5 Occ. Htg SP: 95 VRV ______ Status: On
Emergency Heating Simulate Emergency Heating enable setpoint 5°F above OA temperature.	DAT Setpoint resets to Emergency Heating DAT setpoint. Unit remains Enabled in Heating Mode to satisfy setpoint.	✓		OA temp: Emer. Htg. Enable SP: DAT: DAT SP: VRV ______ Status: On

Appendix E

Test Procedure	Expected Response	P	F	Comments
Simulate Emergency Heating enable setpoint 5°F below OA temperature.	DAT Setpoint resets to DAT setpoint. Unit remains Enabled in Heating Mode to satisfy setpoint.	✓		OA temp: Emer. Htg. Enable SP: DAT: DAT SP: VRV ______ Status: On
Simulate DAT SP equal to the DAT.	CW and reversing valves Close; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat Disable. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.	[redacted]		
<u>Interlock</u> Adjust time of day schedule from the BAS such that the AHU and interlocked VRV system are in Unoccupied Mode. Simulate Unoccupied Cooling setpoint minus the Unoccupied Cooling diff 5°F above the return air temperature (Unoccupied Heating setpoint plus the Unoccupied Heating diff 5°F below return air temperature).	CW and reversing valves Close; OA damper Closes; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off.			
Adjust time of day schedule from the BAS such that the interlocked VRV is in Occupied Mode.	CW and reversing valves remain Closed; OA damper Opens; SF, EF, and energy wheel Enable; compressors and hot gas reheat remain Disabled. BAS shows valves Closed; OA damper Open to percent visually verified at equipment; SF, EF, and energy wheel statuses as On; compressors and hot gas reheat statuses as Off.			
<u>Supply Fan Speed Control</u> Simulate a duct static pressure setpoint above duct static pressure.	Supply fan ramps up. BAS displays SF speed accurately.			
Simulate a duct static pressure setpoint below duct static pressure.	Supply fan ramps down. BAS displays SF speed accurately.			
<u>Exhaust Fan Speed Control</u> Simulate space static pressure setpoint below space static pressure.	Exhaust fan ramps up. BAS displays EF speed accurately.			
Simulate space static pressure setpoint above space static pressure.	Exhaust fan ramps down. BAS displays EF speed accurately.			
<u>Energy Wheel Speed Control</u> Simulate Defrost setpoint 5°F above exhaust air temperature.	Energy wheel ramps up. BAS displays energy wheel speed correctly.			
Simulate Defrost setpoint 5°F below exhaust air temperature.	Energy wheel ramps down. BAS displays energy wheel speed correctly.			

Test Procedure	Expected Response	P	F	Comments
Dirty Filter Alarm Simulate a filter differential pressure above the filter differential pressure setpoint.	BAS displays dirty filter alarm.	[redacted]		
Smoke Detection Simulate smoke at the smoke detector in the supply duct.	Unit Disables. OA damper and gas valve Close; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off. Alarm is generated at BAS indicating smoke shutdown.			
Simulate smoke at the smoke detector in the return duct.	Unit Disables. OA damper and gas valve Close; SF, EF, compressors, energy wheel, and hot gas reheat Disable. BAS shows valves Closed; OA damper Closed; SF, EF, compressors, energy wheel, and hot gas reheat statuses as Off. Alarm is generated at BAS indicating smoke shutdown.			

Required Monitoring
All points listed below shall be trended by the BAS for the period indicated.

Point	Trend Interval (min.)	Minimum Time Period of Trend	Hard Copy? (Y/N)	ASCII File? (Y/N)
Supply Fan Status	2	26 hours		
Exhaust Fan Status	2	26 hours		
Compressors Status	2	26 hours		
Energy Recovery Wheel Status	2	26 hours		
Hot Gas Reheat Status	2	26 hours		
OA damper position	2	26 hours		
Supply Air Temperature	2	26 hours		
Return Air Temperature	2	26 hours		
Return Air Humidity	2	26 hours		
Outside Air Temperature	2	26 hours		
Outside Air Humidity	2	26 hours		
Wheel Leaving Air Temperature	2	26 hours		
Heat Pump Discharge Temperature	2	26 hours		
Exhaust Air Temperature	2	26 hours		
Space Temperature	2	26 hours		

Remarks:

Acceptance Criteria (referenced by function or mode ID)
For the conditions, sequences and modes tested, the fans, integral components and related equipment respond to changing conditions and parameters appropriately as expected, as specified and according to acceptable operating practice.

Comments with Acceptance Criteria:

American VULKAN Corporation
2525 Dundee Road, Winter Haven, FL 33884
Tel: (863) 324-2424 – Fax: (863) 324-4008
www.vulkan.com

LOKRING FAILURE ANALYSIS

REPORT 00020

Conducted for: Gilbane Company
John Baker
Project: Roosevelt High School, Washington, DC

Prepared By:

Curtis Richards

Curtis Richards
Mechanical Engineer
March 14, 2019

TABLE OF CONTENTS

Table 1: List of Parts Received

Name	Quantity
LOKRING 12,7 NK Ms 50	5
LOKRING 16 MTK Ms 50	1
LOKRING 28,6 NK Ms 50	1

ANALYSIS

All samples were tested for leaking except the 5/8 connector due to testing equipment constraints. The testing used a hydrogen/nitrogen gas mixture pressurizing the tubes to 300 psi and used our LOKTRACE hydrogen leak detector. Video was taken of each test and are provided with the report. The samples that failed the leak test were then cut apart and visually inspected for LOKPREP distribution and proper installation. The LOKPREP distribution was inspected by placing the samples under a black light to illuminate the fluorescent LOKPREP and inspected if the application of LOKPREP was enough and if leak paths were present.

Fig.1: 1 1/8 Connector Sample Received from Gilbane Company

Fig.2: B141 Sample Received from Gilbane Company

Fig.3: B149 Sample Received from Gilbane Company

Fig.4: B150A Sample Received from Gilbane Company

Fig.5: B150B Sample Received from Gilbane Company

Fig.6: B152 Sample Received from Gilbane Company

Fig.7: B203 Sample Received from Gilbane Company

CONCLUSION

When the products were received a visual inspection was done and it was found that B141, B149, B150A & B150B all had external rings not seated properly on the external stop of the coupling body. Which could lead to an uneven distribution of LOKPREP within the coupling and damaging of the coupling body due to pressure not being evening distributed across the flange face. The straight connectors that failed the leak test were cut apart and inspected for proper installation of LOKPREP. The connectors B141 (Fig. 8), B149 (Fig.9), B150A (Fig.10), and B150B (Fig. 11) all showed low levels of LOKPREP on varies sides of each connection and are highlighted in each figure respectively.

Based on the results from the visual inspection performed it can be concluded that any potential leaking in the samples may have been a result of insufficient amounts of LOKPREP and improper installation. (Fig. 6) shows an example of a 16-size straight connector with appropriate levels of LOKPREP and has been tested using our LOKTRACE hydrogen leak detector that showed not to leak.

Fig.8: B141 Connection

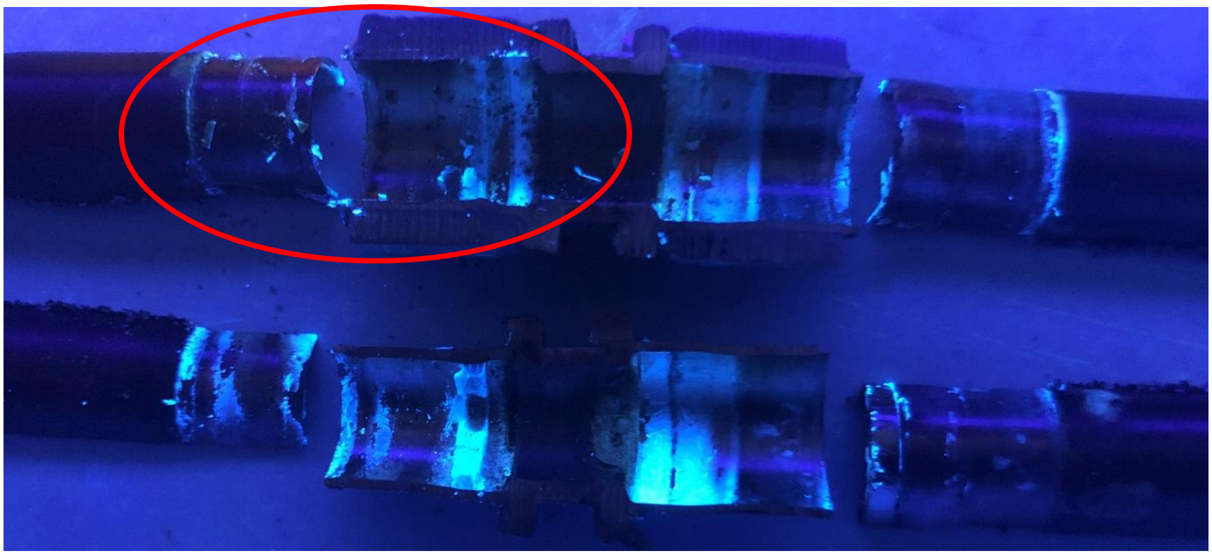


Fig.9: B149 Connection

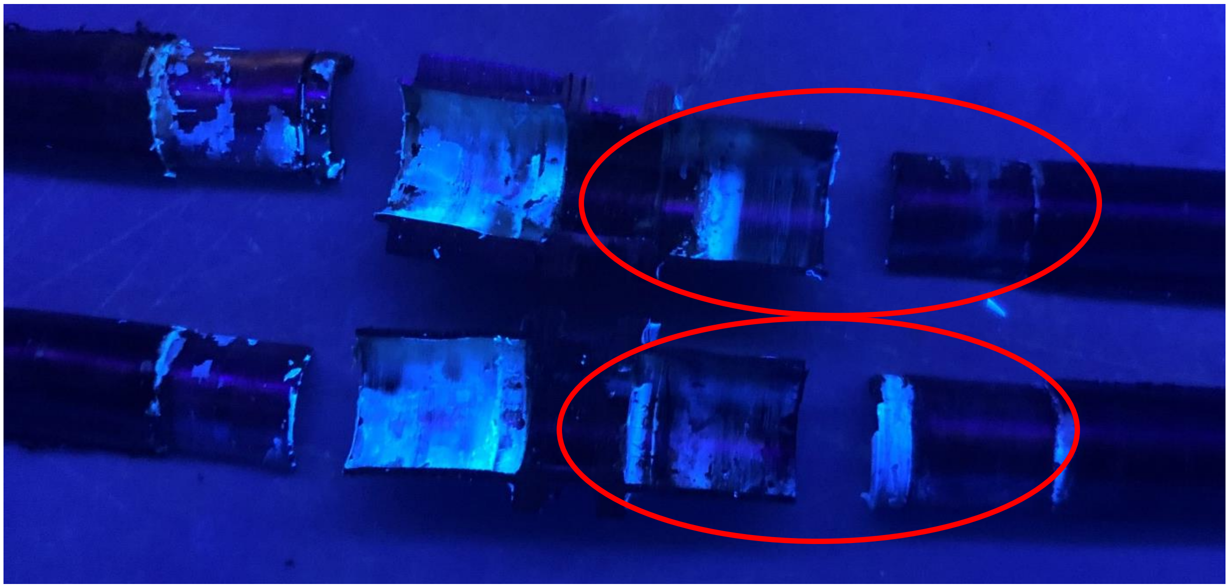


Fig.10: B150A

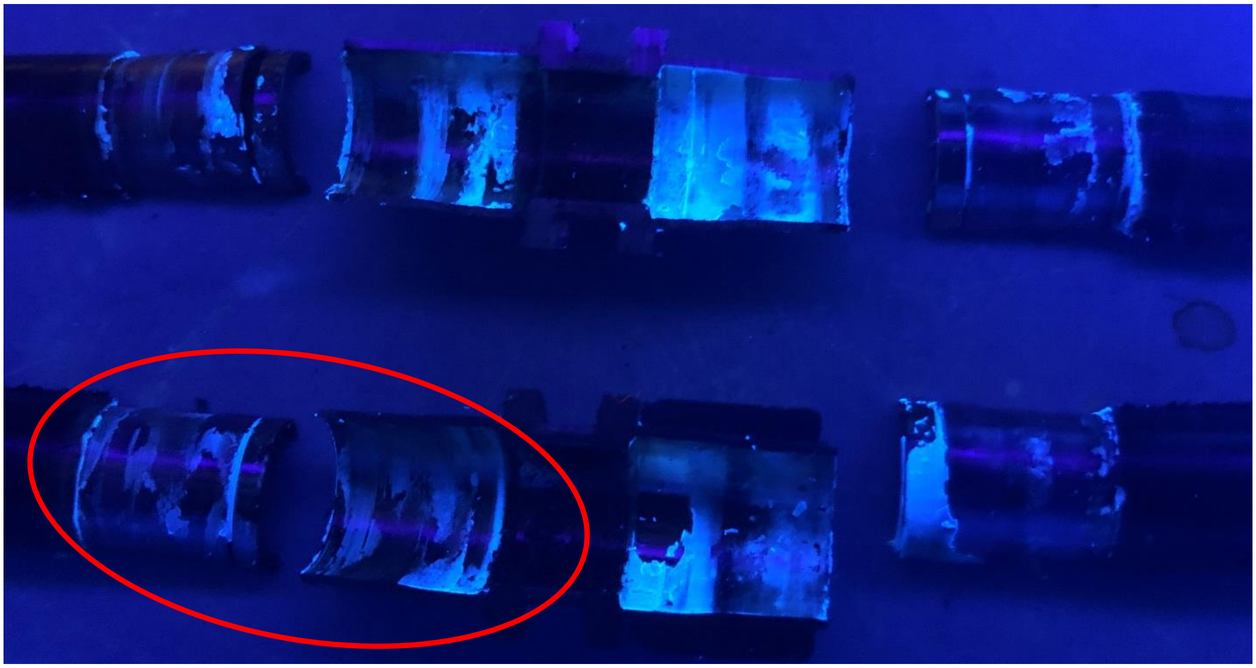


Fig.11: B150B Connection

Fig.12: Sample LOKRING 16 NK Ms 50

GOVERNMENT OF THE DISTRICT OF COLUMBIA
DEPARTMENT OF GENERAL SERVICES

THEODORE ROOSEVELT HIGH SCHOOL HVAC ISSUES INVESTIGATION SUMMARY REPORT

Location

THEODORE ROOSEVELT HIGH SCHOOL 4301 13TH STREET NW,
WASHINGTON D.C. 20011

D.C. DEPARTMENT OF GENERAL SERVICES
May 3, 2019

GOVERNMENT OF THE DISTRICT OF COLUMBIA
DEPARTMENT OF GENERAL SERVICES

HVAC Issues Investigation Summary Report
Roosevelt High School Modernization
May 3, 2019

Contents

Brief summary of refrigerant piping / fittings issue:

There are 11 total VRV systems or trees throughout the building with a total of 21 VRV condensers supporting the system. Long time exposure or repeated leaks on any given VRV system leads to compressor failures. When a compressor fails there is a longer lead time to bring the system back online. The downtime leads to school and staff complaints due to the uncomfortable temperature conditions. In addition, space heaters have been implemented during the heating season whenever downtime does occur leading to higher utility costs.

The mechanical fittings have been failing in isolated locations leading to heating and cooling downtime throughout the school. When the mechanical fittings fail, refrigerant leaks occur at the fitting requiring complete replacement of the effected fittings. The replacement effort involves removing the mechanical fitting and replacing with copper brazed connections. When low refrigerant is detected within the systems, the building automation system signals an alarm error code indicating low pressure in the refrigerant line. Based on conversations with the maintenance contractor (Spectrum), when a refrigerant leak is discovered the affected system is disabled until the leak has been repaired through a service call by a mechanical contractor. Finding and repairing leaks also requires the refrigerant piping insulation to be replaced in order to restore the integrity of the insulation systems.

After a leak has been repaired in any given VRV system and the system is brought back online, new leaks occur at other mechanical fittings within the same VRV system in isolated locations which indicates these failures will continue to occur over time leading to more system downtime. The HVAC equipment is all less than five years of age and these types of failures are not expected within a system so new. There are an estimated of 5,000 mechanical fittings throughout the building requiring replacement with brazed fittings to ensure the leaks are not constantly an ongoing issue throughout the system.

Building Management Practices when HVAC issues occur (process performed by Spectrum):

HVAC issues are identified by the Building Automation System (BAS) through alarms which generate error codes associated with the respective HVAC equipment. Spectrum's Building Manager reviews the BAS at the start of each morning to review the status of all HVAC equipment. The status of each maintained piece of equipment is recorded daily. Some alarms are handled directly by the building management staff. However, when a service call is required – the issue is reported directly upstream to the Facilities Management Division (FMD). The typical turnaround time before issues are addressed by an outside contractor is 2-3 days. All HVAC status reports are initially handwritten and are filed daily. The handwritten reports are converted into excel spreadsheets. The excel files are emailed to FMD monthly for record keeping purposes. A copy of a typical daily excel file was requested but not received.

For refrigerant leaks associated with the VRF system the process is as follows: The error code indicating low pressure refrigerant or system pressure is alarmed through the BAS. The building manager reports the alarm to FMD requesting an outside contractor to repair the leak. When the leak is identified – the associated VRF system is not run and is turned off unless absolutely necessary based on weather conditions or events. According to Spectrum, the majority of the alarms received are generated by refrigerant leaks. During a DGS meeting with Spectrum occurring on April 9, 2019 – there was a refrigerant leak reported on unit E1 (code 421).

GOVERNMENT OF THE DISTRICT OF COLUMBIA
DEPARTMENT OF GENERAL SERVICES

Spectrum Letter of VRV Issues to Facilities (Feb 2018 – updated Dec 2018)

Upon taking over the HVAC maintenance responsibilities Spectrum notified DGS Facilities of the multiple issues occurring throughout Roosevelt High School which is captured in the following letter:

TO: Jerome Jimason
Area I Manager, Facilities

FROM: Lakisia Hull
Project Operations Manager

CC: Rob Roper
John Neville

DATE: February 7, 2018
UPDATED: December 10, 2018

RE: Roosevelt VRV Issues

Roosevelt High School has experienced numerous and repetitive problems with the VRV units throughout the facility. Those problems included but was not limited to, replacement valves, replacement compressors, and leaks. During this time period, Limbach was solely responsible for all PM and repair work as part of the extended warranty between them and SMOOT Gilbane. Neither the CMC (Spectrum) or DGS were responsible for any of the mechanical equipment. Limbach's warranty period for the VRV units officially ended on December 31, 2017.

Below please find the issues chronicled beginning in June of 2016 through February 2018.

June 2016

VRV 1D-1 & ID-3 – Leak was found and compressor issues. Both were fixed in September 2016.

August 2016

VRV OA2.1 & 2.2 – Fan coil unit had 2 bad motors and there was a bad thermostat in the room. Motors & Thermostat were replaced in September 2016.

September 2016

VRV 1C-1 & VRF IE – Valves were making noise while switching modes. 4-way valves were replaced 10/1/16.

October 2016

VRV 2C-2 – Error codes determined the unit had a bad compressor. The compressor was replaced in November 2016.

VRV 3C-1 – Valves were making noise when unit switched modes. 4-way valves were replaced in November 2016.
VRV 3D-1 & 2 – Valves were making noise when unit switched modes. 4-way valves were replaced in November 2016.

November 23, 2016

VRV 1C2 went down leaving several rooms without heat. It was determined that there was a bad compressor, a bad inverter board, and that the connecting wires had not been properly connected. Repair work began, but it was then discovered that the Heat Exchange had cracked letting water into the refrigerant system. This system remained down until January 26, 2017.

December 2016

VRV 3C2 & 3D2 went down on December 9, 2016 and a specific issue was never quite determined. The strainers were cleaned but that didn't solve the issue so refrigerant was added to the system but unit remained down. It was later determined that the solenoid valves were bad and needed to be replaced. This unit remained down until January 27, 2017.

Note: Limbach arranged for a representative from LG to meet with them onsite at Roosevelt, however, we were excluded from this meeting. We were notified that LG had theories as to why the condenser cracked and that a report would be forthcoming. We (CMC) never saw the report.

January 2017

VRV-OA1 experienced issues which was later determined to be due to a leak in the condensing unit. While the repair was taking place, a second leak was found and both were repaired mid-January.

April 2017

VRV 2C2 wasn't cooling and it issue was determined to be a bad compressor. Compressor was replaced within the same month.

May 2017

VRV OD2 wasn't functioning properly and had an error code that was corrected. However, unit exhibited problems again later in the month and was shown to be low on charge.
VRV IE1 wasn't functioning properly and had an error code that was corrected.
VRV 1D1 showed low on charge. Limbach notified us that further investigation was required. System was believed to have a leak.

June 2017

VRV 1D1 continued to have problems and a leak search was started. We never received a written report as to the findings, however, Limbach verbally acknowledged the leak but stated their contract with Smoot didn't include leak repairs.

August 2017

VRV 2C2 experienced problems again and the warrantied compressor was removed and replaced again. This unit continued to exhibit issues (slave and master wouldn't run together) at which time Limbach conferred with LG. We were notified that the problem had been solved.
VRV 1B experienced problems and it was determined to be a bad compressor and bad valves which were replaced in September 2017.

September 2017

VRV 2C2 & 2C1 began to experience problems again. 2C2 was tripping off but not showing any error codes. 2C1 was monitored and found to be low on refrigerant. Refrigerant was added and the units were deemed to be operational.
VRV OD2 went down and a call was placed to Limbach. They came and indicated that they would come back but never did. We continued to call.

November 2017

VRV 1C2 went down and required parts. The unit was repaired the following week.

December 2017

VRV 3D2 went down on 12/21 and was found to have leaks in the line. Repairs were completed by an outside vendor as Limbach's warranty was up.
VRV 2C2 went down on 12/31 and was found to have a bad Schrader Valve. The repair was made.

January 2018

VRV OD2 went down the morning of January 5th. Our vendor called upon LG to send a representative out to asses the problem. The Joyce Agency, representative for LG, met with our vendor and engineer on January 9th. It was determined that the whole unit needed to be replaced as there was not "screen" in the place when the strainer assembly was opened. In addition to a host of other issues (report attached for reference).
VRV 1E & OA1 both went down on January 26th. We observed error codes that indicated a compressor failure. Both units needed new compressors and new converter boards.

February 2018

VRV 1D1 & 1D1.2 experienced issues today. Upon inspection by our vendor, it was determined that both units have bad converter boards that need to be replaced. VRV 3C-1 went down on February 2 and it was determined that the system had a leak. VRV 1B wend down on February 14 and it was determined that the system had a leak as well.

March 2018

Boiler began to have problems again. We needed to clean the flame rods.

April 2018

VRV 3C-2 went down. Vendor determined that there was a leak in the system.

June 2018

We experienced problems with VRV 1D-1, VRV 1C-1, VRV 2D-2, and RTU-3. VRV 1D-1 and VRV 2D-2 both needed new compressors and inverter boards. VRV 1C-1 had a leak and RTU-3 also had a leak.

July 2018

AHU-3 exhibited issues again. We had Boland come to investigate and it was determined that new controllers are needed on the Innovent unit and the Trane unit. These repairs remain incomplete. We also found that the solenoid needs to be replaced on the cooling tower. Replacement still needs to be done.

August 2018

VRV 3D-1 experienced issues causing a lack of A/C to 3 classrooms and 7 offices. There is a leak that needs to be found and repaired. VRV 2D-1 has the same issue (10 classrooms and 4 offices) as well as 1D-1 (5 classrooms and 9 offices). All three systems remain down.

September 2018

Reported that the boiler has completely failed. Proposals were received and sent on 9/25 for approval.

October 2018

VRV B1 went down and it was determined that there is a leak. Unit remains down. In addition, a new compressor is needed for WSHP 1226 (awaiting approval).

November 2018

VRV OA2 has gone down and also has a leak. System is still down. Heaters were put in place until the boilers could be replaced. We are still waiting for the replacement to take place.

Spectrum Preventative Maintenance Records observations

The preventative maintenance records received for review included a small sampling (received 150 work orders out of 2,000 plus for 2018). The following observations were observed:

1) VRV units are inspected and preventative maintenance is performed monthly. Based on observation of the PM work orders, it appears the following actions are included **(although it is not fully clearly if all of these actions are being performed each time due to the documentation nature)**:
    a. Checking equipment general performance
    b. Checking electrical connections and noise vibration
    c. Inspecting for water or refrigerant leaks
    d. Check for corrosion and clean out water line strainer
2) Air handling units are PM'd quarterly. This includes the following actions:
    a. Make necessary repairs or adjustments to maintain efficient and dependable operation
    b. Change filters as required
    c. Check operation of dampers
    d. Check all temperature controls

In addition to the above, there is evidence of the VRV strainers being checked and cleaned throughout isolated work orders. As mentioned previously above, DGS only had a small, representative sample of PM records to review.

Regarding the bolded statement above – the VRV work order PM sheets do not clearly indicate which actions are performed. For instance, when viewing work orders 2439 and 2429 (pages 7 and 8 of 66) – the comments are "Running OK" or "Running OK Drain Lines". These comments do not clearly specify which PM actions were performed. Jumping ahead to work order 3257 (page 57 of 66) – we see a much more detailed and in depth comment being provided which includes the following: "Performed preventative maintenance on VRV-2C.1 Checked equipment general performance, electrical connections, water and refrigerant leaks, checked for corrosion and cleaned out water line strainer all checked out good".

A suggestion and recommendation would be to standardize these forms and to ensure the appropriate PM checks are being performed each and every time. It should be absolutely clear which actions are performed including any comments pertaining to issues observed.

Phone: Fax:

Work Order 2429

Service	VAV Monthly, 2/28/2018				
Property	Roosevelt High School	Issued	2/1/2018	Std Hrs	1
Shop		Due	2/28/2018	Priority	2
Supervisor		Status	Open	Type	Preventive
Account	<none>	Substatus		Taken By	
Description					

Asset **VRV 2D.1**
Description B238 Mechanical
Location
Building
Parent
Department
Requested 1/29/2018 11:25:33 AM
Requester
Phone

☐ Shutdown ☐ Lockout/Tagout ☐ Safety ☐ Warranty ☑ Inspection

Labor	Activity	Category	Hours: Est.	Reg.	O.T.	Dbl.	Other

Parts	Description	Location	Aisle/Shelf/Bin	Qty Est.	Qty Used

Other Costs	Description	Est. Cost

Primary Failure: Secondary Failure:
Downtime: Lost Time:
Comments: Running On Drain Lines
Date Completed: 2-26-18 Charge to:

C.M / J.D 30 mins

Phone: Fax:

Work Order 2439

Service: VAV Monthly, 2/28/2018
Property: Roosevelt High School
Shop:
Supervisor:
Account: <none>
Description:

Issued: 2/1/2018
Due: 2/28/2018
Status: Open
Substatus:

Std Hrs: 1
Priority: 2
Type: Preventive
Taken By:

Asset: **Variable Refrigerent VRV-OA-2-B**
Description: Mechanical Room AG-13
Location:
Building:
Parent:
☐ Shutdown ☐ Lockout/Tagout ☐ Safety ☐ Warranty ☐ Inspection

Department:
Requested: 1/29/2018 11:25:33 AM
Requester:
Phone:

Labor	Activity	Category	Hours: Est.	Reg.	O.T.	Dbl.	Other

Parts	Description	Location	Aisle/Shelf/Bin	Qty Est.	Qty Used

Other Costs	Description	Est. Cost

Primary Failure: Secondary Failure:
Downtime: Lost Time:
Comments: Running O.K
Date Completed: 2-21-18 Charge to:

30 min C.M~94

Phone: Fax:

Work Order 3257

Service: VAV Monthly, 6/28/2018
Property: Roosevelt High School
Shop:
Supervisor:
Account: <none>
Description:

Issued: 6/5/2018
Due: 6/28/2018
Status: Open
Substatus:

Std Hrs: 1
Priority: 2
Type: Preventive
Taken By:

Asset: **VRV-2C.1** ✓
Description: B222 Mechanical
Location:
Building:
Parent:
☐ Shutdown ☐ Lockout/Tagout ☐ Safety ☐ Warranty ☐ Inspection

Department:
Requested: 6/4/2018 8:45:44 AM
Requester:
Phone:

Labor	Activity	Category	Hours: Est.	Reg.	O.T.	Dbl.	Other
Kenan / Charles							

Parts	Description	Location	Aisle/Shelf/Bin	Qty Est.	Qty Used

Other Costs	Description	Est. Cost

Primary Failure: Secondary Failure:
Downtime: Lost Time:
Comments:
Date Completed: 6/14/18 Charge to:

Performed Preventative Maintenance On VRV-2C.1
Checked equipment general Performance, electrical connections
water and refrigerant leaks, checked for corrotion and
cleaned out water Line strainer all checked out good

1 hr.

Limbaugh PM Records

Limbaugh maintained the HVAC system at Roosevelt High School during the warranty period. A very small sampling of Limbaugh PM records was reviewed (29 total). Isolated records show troubleshooting required at various VRV units.
Typical issues include:

- Bad compressors
- Faulty boards
- Refrigerant leaks

In addition, the following major issue was observed which indicates a hole was observed in a VRV strainer:

VRF				
Item	System	First Observed	Perceived Issues	Resolution
7	VRV 1C-2	11/23/2016	- Received complaints regarding "No heat in the school" - Limbach Cx determined it was a bad compressor, inverter board and the connecting wires between both 11/23. Previous work from Critical was left incomplete (wires not fully connected)... See Notes - Board and Wires arrived 11/25 via UPS overnight and we were prepared for a weekend install. Compressor was behind and tracking with FedEx had us set up for a Wednesday arrival. Multiple attempts made with FedEx for earlier delivery but due to holiday we were unsuccessful. - 11/30 Critical Systems went to RHS to begin repair work and found the HX in the CU to be cracked. Water found in the refrigerant system. Began draining water and trying to dry the moisture out of the system with Nitrogen that day and thru the evening - 12/1 System still watered down after 4 more bottles of Nitrogen. Last unit on the system checked and is contaminated with water. Drying out process still currently being attempted. - Visit from LG and Critical Systems on 12/6: found a hole in the strainer on the condenser (water side)	Began draining water and trying to dry the moisture out of the system with Nitrogen.. Process still ongoing. Checked each unit on the system for water contamination. Piping remidiation process still ongoing.

The resolution for the above outlined issue was to replace the associated condenser and clean and remove water from refrigerant lines. However, with a hole being developed in the strainer – this points to possible issues with the condenser water conditions.

Smoot-Gilbane pre-start up documents

These documents are not available for review within the closeout documents. This documentation would be helpful in determining if the condenser water line was flushed as required.

Open Heating and Cooling Related Work Orders 12-14-2018

The open HVAC work orders at Roosevelt indicate lots of refrigerant leaks leading to heating and cooling downtime. The entire list shown below was addressed by R&R through repairs performed during winter break (2018/2019). Additional leaks were subsequently identified at the school by R&R as repairs were being performed.

Roosevelt SHS
Current HVAC System Issues
12/14/18

1. AHU#3 – The Innovent Unit and the Trane Unit need new controllers. If the controllers are replaced, then the issue in the Culinary Arts classroom will be solved. (Sales Force Ticket #580278)
2. VRF 1D-1 – This system has a leak. If this unit is repaired it will solve the heating issue in 15 rooms on the Stay side on the 1st Floor. (Sales Force Ticket #594419)
3. VRF 2D-1 – This system has a leak. If this unit is repaired it will solve the issue in 14 rooms on half of the 2nd floor on the Roosevelt side. (Sales Force Ticket #567416)
4. VRV 3D-1 – This unit needs a compressor and an inverter board. If repaired, it will alleviate the heating issue in 14 rooms for half of the 3rd floor on the Roosevelt side. (Sales Force Ticket #567420)
5. VRV 1B – This unit has been charged but it didn't alleviate the issue. A second visit determined that the unit has a leak. This unit controls the Principal's office (Stay side) in addition to 9 rooms. (Sales Force Ticket #580284)
6. Water Source Heat Pump #1226C – Controls the auditorium equipment room and needs a new compressor. This is vital so as not to damage the sensitive equipment for the auditorium. (Sales Force Ticket #580288)
7. VRV OA-2 – This system has a leak. If repaired, would solve the issue in the Day Care, Instrument rooms (x2), multi-purpose room, science shop, and open gallery area. (Sales Force Ticket #580289)
8. VRV 2C2 – This unit began showing problems on 12/12/18. Our vendor determined today that the unit needs a new compressor and inverter board. If repaired, this would solve the issue in 14 rooms and offices on half of the 2nd floor.
9. AHU #11 – A leak has been located. If repaired, this would alleviate problems on the 3rd floor in the hallways.

Mechanical couplings, leak repairs, and lab testing

There are an estimated 5,000 mechanical couplings located throughout Roosevelt. When a leak is identified at a coupling – the leaky coupling is removed and all replacement work is done by brazing. The mechanical contractor (R&R) performing leak repairs estimates a total of approximately 10-20 couplings have been replaced in this manner. The refrigerant leaks have led to compressor failures and downtime for heating and cooling systems.

i. Smoot-Gilbane sent off the leaky couplings to be lab tested in February 2019 to the manufacturer to check integrity of the faulty couplings.
j. Based on conversations with Aaron Trout – the results have been received by Smoot-Gilbane and they felt they were not conclusive evidence. They are looking to have further testing done. **The results of the manufacturer's lab tests will be forwarded to DGS.**

Refrigerant piping specification regarding fittings

Refrigerant piping specifications indicate REFLOK fittings with Daikin systems only. The VRV systems throughout are manufactured by LG and not Daikin.

There was a change from Daikin to LG which is observable in the piping submittals. The actual VRV equipment submittals were unable to be located in the closeout documents.

Email correspondence between DGS / Limbach regarding VRF leaks

In email correspondence between DGS / Limbach regarding the ongoing refrigerant leaks, Limbach indicated RSC would be conducting inspections of the VRF system every 3 weeks. It is stating the RSC technicians will hook up their computers to the condensing units and confirm that pressures inside each of the systems are maintaining the desired pressure based upon the conditions. This action by RSC needs to be confirmed.
In addition, Limbach indicated they stand behind the integrity of the piping installation and will continue to work with DGS and S/G to ensure satisfaction.

From: Petrarca, Rich [mailto:rich.petrarca@limbachinc.com]
Sent: Thursday, February 25, 2016 2:39 PM
To: Michael Fuller
Cc: Paul Mueller; Speicher, Bradley; Matt Corrigan <matt.corrigan@limbachinc.com> (matt.corrigan@limbachinc.com); Tony Barton - Gilbane; Fritz, Eric
Subject: Re: FW: Roosevelt- VRF Refrigerant Line Leaks

Mr. Whitley's email states that "the VRF system is having major issues." While we sympathize with the delays associated with the repairs to 3 of the 18 systems, Limbach has committed substantial resources to the repair of the leaks in the refrigerant lines installed by RSC.

- One of these three systems, 3C is now online and functional as of yesterday.
- It was identified on Tuesday that system 1C has a bad compressor. The compressor was ordered and expected to be onsite by the end of this week, however we learned this afternoon that it is due to arrive from the manufacturer on Monday and will be installed on Tuesday.
- System 0A2 which serves the first floor of A and the daycare area has passed it's evacuation and the manufacturer is scheduled for startup tomorrow.

It's worth noting that the majority of the VRF system was ready to be commissioned in November. The CxA decided not to commence testing since systems 1C and 3C were not online (see notes above).

RSC is a certified LG VRF installation and maintenance contractor. Limbach will furnish the installer certifications by COB tomorrow. RSC recognizes the owners concerns and has committed to conduct inspections of the VRF system every 3 weeks. RSC technicians will hook up their computers to the condensing units and confirm that pressures inside each of the 18 systems are maintaining the desired pressure based upon the conditions (please note that the system pressure varies between heating and cooling load).

Attached is the approved piping submittal for the refrigerant system which includes the Lok Ring system. Please note this selection was made during the design development phase in conjunction with the EOR.

Limbach stands behind the integrity of its installation and will continue to work with DGS and S/G to ensure satisfaction.

DGS DEPARTMENT OF GENERAL SERVICES BUILD MAINTAIN SUSTAIN

WE ARE WASHINGTON DC

LG acceptance letter of Vulcan LOKRING fittings:

Limbach submittal dated October 6, 2014 includes a letter from LG indicating acceptance of Vulcan LOKRING fittings for refrigerant pipe connections.

LG Electronics

MANUFACTURER RESPONSE TO ORIGINAL SUBMITTAL COMMENTS

LG Electronics U.S.A., Inc.
1000 Sylvan Avenue
Englewood Cliffs, NJ 07632

September 19, 2014

To whom it may concern,

Re: Lokring mechanical fittings for LG Multi V VRF Systems (Roosevelt High School)

This letter is to address a question regarding LGEUS and Vulkan Lokring.
The use of Vulcan Lokring mechanical fittings for piping in LG Electronics Multi V VRF systems is perfectly acceptable. LG recognizes and supports Vulkan Lokring as a manufacturer of mechanical fittings and the appropriateness of the use of such fittings with LG Electronics Multi V VRF systems.

LG and Vulkan Lokring have a long history of working together in the USA and have partnered on many projects. As dual authorities in our mutual areas of expertise it must be noted that we mutually believe that considerations should be taken to the following:

- Additional Pressure drop for joints. Pressure drops for mechanical fittings used must be per industry accepted standards.
- In all cases, materials must be suitable for application and any applicable codes, including but not limited to diameter and wall thickness continuity per ACR standards.
- The quality of the work performed by the installing contractor and that proper leak checks are performed regardless of joint connection type.

There is no possible reason to possibly preclude LG and Lokring on a project using VRF technology.

If there are questions they can be directed to:

Brian Bogdan - LG Engineering at 678. 328.6408
Bill Osborn - Vulkan Lokring at 863-207-5336
or you can contact me directly as well at 678.620.7149.

We look forward to working with you on this project.

Sincerely,

Kevin C. McNamara
Vice President & General Manager
LG Electronics U.S.A., Inc. Commercial Air Conditioning

SMOOT Gilbane CONSTRUCTION

Roosevelt High School	Project #DC-13-002	
☑ Reviewed	☐ Reviewed with Comments	
Submittal No.:	23 2300-0001-1	
Spec. Sec/Rev:	23 2300	
Description:	Revised Refrigerant Piping Product Data	
Reviewed By:	Eric Fritz	
Date:	10/6/2014	
LEED Review:	☐ Required	☑ Not Required

This review does not constitute, nor does it assume, design responsibility. It does not relieve the trade contractor/supplier from complying with the contract requirements, coordinating their work with other trade contractors and verifying field dimensions, etc.

PH Level / Water Tests for closed condenser water loop:

The condenser water equipment consists of a Lochinvar Boiler, a Bell & Gosset Heat Exchanger, Trane Heat Pumps, Innovent Air Handling Units, and the LG VRF Equipment. The Trane Heat Pumps and LG VRF equipment have specified pH requirements in their respective O&M manuals in the maintenance sections. The O&M Manuals for the other pieces of equipment do not call for a specific pH level. These manuals can be found in Books XV and Books XVI of the Roosevelt Submittal documentation. All pieces of condenser water equipment are shown on the Hydronic Line Diagram (Page 79 of 106 in mechanical drawings PDF). The water pH level was being maintained at a pH of 10.2 (from recent water quality report below) – uncertainty of why the pH level is kept this high? DGS requested the pH level to be brought down to 8.0 which would meet the Trane Heat Pump and LG VRF pH requirements (on 3/28/19).

MAINTENANCE

MULTI V WATER IV

General Maintenance Schedule

1. Water Quality Control
   - The heat exchanger is not designed to be disassembled or cleaned, and does not contain any replaceable parts. If the heat exchanger is not usable, the entire exchanger must be replaced.
   - To prevent corrosion or scaling, water quality must be controlled. Refer to the recommendations in Table 67 for minimum water quality requirements.
   - Use only anti-corrosion agents or corrosion inhibitor additives that do not contain chemicals which damage or attack 316 stainless steel and ACR copper.
   - Drain and replace the water / glycol mixture on a regular basis as needed. Frequency will depend upon the quality of the water treatment program used.

Table 67: Minimum Water Quality Requirements.

Basic Item	Closed Type System		Effect	
	Circulating Water	Supplemented Water	Corrosion[1]	Scale[1]
pH (77°F)	7.0 ~ 8.0	7.0 ~ 8.0	•	•
Conductivity (77°F) mS/m	Below 30	Below 30	•	•
Chlorine ions (mg Cl⁻/ℓ)	Below 50	Below 50	•	
Sulfate ions (mg SO_4^{2-}/ℓ)	Below 50	Below 50	•	•
Acid consumption (pH4.8) (mg$CaCO_3$/ℓ)	Below 50	Below 50		•
Total Hardness (mg $CaCO_3$/ℓ)	Below 70	Below 70		•
Calcium Hardness (mg $CaCO_3$/ℓ)	Below 50	Below 50		•
Ionic-static silica (mg SiO_2/ℓ)	Below 30	Below 30		•
Reference Item	**Closed Type System**		**Effect**	
	Circulating Water	Supplemented Water	Corrosion[1]	Scale[1]
Iron (mg Fe/ℓ)	Below 1.0	Below 0.3	•	•
Copper (mg Cu/ℓ)	Below 1.0	Below 0.1	•	
Sulfate ion (mg SO42/ℓ)	Must not be detected	Must not be detected	•	
Ammonium ion (mg NH4+)ℓ	Below 0.3	Below 0.1	•	
Residual chlorine (mg Cl/ℓ)	Below 0.25	Below 0.3	•	
Free carbon dioxide (mg CO2/ℓ)	Below 0.4	Below 4.0	•	
Stability index			•	•

[1]The "•" mark for corrosion and scale means that there is a possibility of occurrence.

2. Flow Rate Control
   - The heat exchanger may freeze if water flow rate is insufficient.
   - Check for a restricted strainer or if air is in the water piping system. Also measure the temperature and pressure difference between the inlet and outlet to verify the flow rate is per specifications.
   - If the temperature and pressure difference is above the specified range, the flow rate is insufficient. Immediately cease system operation, locate the source of the problem and repair as needed. After any water circuit maintenance is preformed, always bleed air from the water system at all installed air vents.
3. Antifreeze Concentration Management
   - Use the manufacturer's recommended type and amount of antifreeze. Do not use solutions with calcium chloride; these can corrode the heat exchanger.
   - Maintain antifreeze levels. If there is a drop in the amount of antifreeze, the heat exchanger may freeze. Ensure that the antifreeze is not exposed to the atmosphere, and periodically measure antifreeze levels, adding as necessary.

Maintenance

⚠WARNING

Hazardous Service Procedures!

The maintenance and trouble shooting procedures recommended in this section of the manual could result in exposure to electrical, mechanical or other potential safety hazards. Always refer to the safety warnings provided throughout this manual concerning these procedures. When possible, disconnect all electrical power including remote disconnects before servicing. Follow proper lockout/tagout procedures to ensure the power can not be inadvertently energized. When necessary to work with live electrical components, have a qualified licensed electrician or other individual who has been trained in handling live electrical components per these tasks. Failure to follow all of the recommended safety warnings provided, could result in death or serious injury.

Preventive Maintenance

Maintenance on the unit is simplified with the following preventive suggestions:
Filter maintenance must be performed to assure proper operation of the equipment. Filters should be inspected at least every three months, and replaced when it is evident they are dirty. Filter sizing is shown in Table 57, p. 101:

Table 57. Filter sizing

Size (60 Hz)	Size (50 Hz)	Filter Size (Actual) inches (mm)
GEH		
006-015	006-012	14 5/8 x 20 ¼ (371 x 514)
018-030	015-024	17 7/8 x 23 7/8 (454 x 607)
036-042	030-036	18 5/8 x 25 3/8 (473 x 645)
048-060	042-060	20 5/8 x 29¾ (524 x 755)
072-120	072-090	20 x 25 (3) (508 x 508)
150-180	120-150	25 x 25 (3) (635 x 635)
GEH/GEV		
018-030	015-024	17 3/8 x 23 5/8 (441 x 600)
GEV		
006-015	006-012	15 7/8 x 19 7/8 (403 x 504)
018-032, 040	015-024	17 7/8 x 24 7/8 (454 x 632)
036-042	030-036	19 7/8 x 24 7/8 (504 x 632)
048-060	042-060	27 7/8 x 29 7/8 (708 x 759)
GEV 072-120	090	20 x 20 (4) (508 x 508)
150-300	120-240	19 5/8 x 24 5/8 (6) (498 x 625)
EXH		
018-024	—	17 7/8 X 23 7/8 (454 X 607)
030-036	—	18 5/8 x 25 3/8 (473 x 645)
042-070	—	20 5/8 x 29 3/4 (524 x 755)
EXV		
018-024	—	17 7/8 x 24 7/8 (454 x 632)
030-036	—	19 7/8 x 24 7/8 (504 x 632)
042-070	—	27 7/8 x 29 7/8 (708 x 759)

Check the contactors and relays within the control panel at least once a year. It is good practice to check the tightness of the various wiring connections within the control panel.

A strainer (60 mesh or greater) must be used on an open loop system to keep debris from entering the unit heat exchanger and to ensure a clean system.

For units on well water, it is important to check the cleanliness of the water-to-refrigerant heat exchanger. Should it become contaminated with dirt and scaling as a result of bad water, the heat exchanger will have to be back flushed and cleaned with a chemical that will remove the scale. This service should be performed by an experienced service person.

⚠WARNING

Hazardous Chemicals!

Cleaning agents can be either acidic or highly alkaline. Handle chemical carefully. Proper handling should include goggles or face shield, chemical resistant gloves, boots, apron or suit as required. For personal safety, refer to the cleaning agent manufacturers Materials Safety Data Sheet and follow all recommended safe handling practices. Failure to follow all safety instructions could result in death or serious injury.

It should be noted that the water quality should be checked periodically. See Table 58, p. 101.

Table 58. Water quality

Scaling	Amount
Calcium and magnesium (total hardness)	Less than 350 ppm
Corrosion	
pH	7-9.5
Hydrogen Sulfide	Less than 1 ppm
Sulfates	Less than 25 ppm
Chlorides	Less than 125 ppm
Carbon Dioxide	Less than 75 ppm
Total dissolved solids (TDS)	Less than 1000 ppm
Biological Growth	
Iron Bacteria	Low
Erosion	
Suspended Solids	Low

Condensate Trap

For units incorporating a negative trap design, ensure that the condensate system is primed with water at all times. Allowing a negative, pressure condensate system to run dry could cause a break in the condensate seal allowing the fan to draw water from the condensate line to spray moisture into the mechanical system. By maintaining a primed condensate trap, a seal will be created and will help prevent these complications.

BOND WATER TECHNOLOGIES

Service Report

Spectrum Management LLC
Theodore Roosevelt High School
4301 13th St NW
Washington District of Columbia 20011
(202) 671-6349

Wednesday, March 20, 2019 11:44 AM EDT

Report Number: 243006
Recorded By: Ryan Conner
(301) 801-6006
rconner@bondwater.com

4301 13th St NW - HVAC

Test	GeoThermal System			
Conductivity (as mmhos)	2340 (3500 max)			
pH	10.2 (8 - 10.5)			
Sodium Nitrite (ppm as $NaNO_3$)	680 (500 - 1000)			

GeoThermal System Online

Test results are within desired ranges at this time indicating corrosion protection.

Commissioning Report and Meeting Minutes:

Liberty's final commissioning report does not explicitly state refrigerant leaks were occurring. However, the refrigerant leak concerns were brought up during commissioning meetings and were captured in the meeting minutes (such as minutes shown below) which indicates refrigerant leaks were occurring during the early stages of the modernization.

PROJECT: DGS Roosevelt HS Cx DATE: 27 January 2016
PROJECT NUMBER: 20.14005.00 PREPARED BY: M.Myers
BUILDING/AREA: Cx Meeting PAGE #: 2 of 3

LIBERTY ENGINEERING

- Emmille H. asked what the team's confidence is with these leak repairs since we went through the same process of vacuum and charge, it seemed to be operational for a few days. Emmillee H. also asked if there is anything that can be adjusted in this process to increase confidence of no new leaks.
  - Johnathan B. noted that the flow in the system is dynamic and the activity has jarred loose connections to result in leaks. Johnathan B. will be out this week and will be out over the next two weeks to supervise and confirm that the recharging process results in no leakage.
- Emmillee H. gave an update on the temperatures around the building. Next Monday the unoccupied override will be released and then all temperatures will be verified.
- Emmillee H. noted that branch selector BS-1D-1.3 making a large amount of noise has been a chronic issue spanning a few months. Emmillee H. asked if there has been any discussion regarding replacement of the branch selector.
  - Rich P. noted there was a communication issue so when the unit was being called for heating the valves were closed down.
    - Tentative target for completion 29 JAN/01 FEB. Pritchett to complete Tuesday, 02 FEB. Testing Wednesday, 03 FEB.

Joyce Agency Report January 2018:

The issues identified in this report would be indicative of Limbaugh who maintained the HVAC equipment until December 2017.

From: Paul Deluliis [mailto:pauld@thejoyceagency.com]
Sent: Friday, January 12, 2018 1:10 PM
To: Don Vanderhoof <DonV@donohoe.com>; Dave Skaja <DaveS@donohoe.com>
Cc: Ryan Anderson <randerson@thejoyceagency.com>; Donald Troupe <donald.troupe@lge.com>
Subject: [EXTERNAL] Roosevelt HS - LG VRF failed condenser

Don / Dave,

As requested, The Joyce Agency along with an LG National Service Technician visited Roosevelt High School and reviewed the failed condenser. Although we were unable to clearly identify what caused the failure or exactly why the heat exchanger would have frozen and or ruptured, we believe key application and maintenance items may require exploration. In fact, it may be advantageous to initiate discovery on all VRF systems at this site to confirm operating conditions and reduce additional failures.

The system that operates to produce heating, cooling and dehumidification of the returned air in the school is a "water-cooled vrf system" manufactured by LG. There are several independent systems located throughout the site each with its own condensing unit and a network of refrigerant piping designed to transfer heat from space to space and back to the condensing unit where energy is then transfer from the refrigerant system to a shared condenser water loop that serves the entire building. Each condenser contains a "brazed plate" heat exchanger that connects without contamination the water and refrigerant loops. This heat exchanger has documented design limitations for operating temperatures, operating pressure and should continuously be protected from particulate that can be introduced from the condenser water that passes through it. When applying a system like this, devices and associated setup is required to manage the flows and pressures to within prescribed operating limits. Automatic temperature control systems for condenser water pumps, mixing valves, geothermal loop control and associated boilers must be maintained and calibrated to moniter and manage flow and loop temperature.

Each vrf condenser at Roosevelt has a dedicated and externally installed circuit setter to help manage condenser water flow volume, a condenser water flow switch to validate that flow exists, a condenser water control valve to accommodate flow demand and a condenser water strainer installed upstream and before the heat exchanger to filter particulate that can be accumulated and possibly damage the heat exchanger if the screen does not exist.

The most critical items collected in our visit the other day include the following:

1. No strainer "screen" existed on the failed unit when the strainer assembly was opened. This confirms the heat exchanger operated without any protection from particulate traveling at possibly very high pressures and speeds. The general consensus based on the difficulty in opening the strainer and the fact that it had no markings on it was that the strainer has not been serviced since its initial installation.
2. The control valve did not appear to be "stroking" properly when it was manually reset in effort to close the valve for service. It is not confirmed, but its possible the valve is not capable of fully closing and water could be circulating through the heat exchanger while the unit is off without a call to satisfy demand.
3. We were made aware that a condenser water boiler had failed recently for some period of time. Depending on the boiler application, it may be instrumental in keeping the condenser water loop above the prescribed operating temperatures at all times. It should be noted that

our area endured ambient conditions as low as 3 deg F the prior week but we do not know exactly when the boiler failure occured.

4. We were made aware that the water contamination of the vrf system's refrigerant piping network was extreme and to the point water was migrating throughout the conditioned zones and leaking out of vrf "heat recovery boxes" and even some of the indoor units. This is very concerning and may have permanently contaminated all of the vrf devices connected to that system to the point of no return. Also, if the refrigerant piping were to be reused, a stringent process should be followed in effort to clean and dry the refrigerant piping prior to its reuse.
5. We were informed refrigerant leaks have been discovered at some of the mechanical fittings used throughout the building. Each refrigeration system must be free of leaks to ensure refrigerant is not lost and systems are sealed. If the piping network loses charge, poor distribution of refrigerant and associated oil may occur producing failures such as seized compressors or even frozen coils or heat exchangers.

To help in confirming system operation for this and other systems currently operational at the school, we have included the following information or suggestions for your review:

- To verify refrigerant piping was installed per manufacturers guidelines. P. 49-72 of attachment #1
- To verify the strainer is intact and the correct size (size 50 mesh) p. 80 of attachment #1. We recommend an immediate review of all strainers be initiated to validate screens exist, are clean and intact and they are the appropriate type.
- To verify all hydronic side components were installed properly i.e. flow switch is installed in the proper location and setup per manufactures recommendations P. 77-83 of attachment #1
- Confirm operating water temperatures are maintained above prescribed temperatures
- Confirm Variable flow kits or circuit setters are installed, balanced and operating properly
- Confirm overall water quality requirements are adhered to
- Confirmed flow switches are sound and not damaged from high velocities or unfiltered particulate.
- To confirm function settings are set properly. P. 92 of attachment #1
- To review that recommended general maintenance was sufficient. p. 112 of attachment #1
- To review a summary of freeze protection from LG. Attachment #2

Feel free to call if you have any questions.

Thanks

The JOYCEAGENCY
HVAC PRODUCTS GROUP

DGS DEPARTMENT OF GENERAL SERVICES BUILD MAINTAIN SUSTAIN

WE ARE WASHINGTON DC

North Arrow HVAC Assessment December 2018:
The North Arrow report included a comprehensive review of various construction documents including the commissioning report. A site visit was also performed to prepare the report. The findings and recommendations are provided below. More details can be reviewed in the actual report PDF.

NorthArrow
DESIGN • BUILD • MANAGE

FINDINGS

North Arrow was provided a substantial amount of data on the original design, commissioning, as-builts, and operations data. We also received documentation related to the ongoing heating, ventilating, and air conditioning (HVAC) issues as well as the attempts to address them. Anecdotal information suggested an unusually high rate of problems with refrigerant piping or the water source variable refrigerant volume units provided by LG (herein referred to as LG VRV units).

After reviewing all the information provided it was evident the majority of the issues (8 of 9 on the "*Current HVAC Problems 12_14_18*" list), historical, and anecdotal were related to a failure of a compressor or a refrigerant leak. The other issues identified related to one off occurrences that we considered in the range of normal for a system this large. These issues might be an electronic controller or circuit board failure.

We reviewed the commissioning report to confirm start up and operational tests occurred and that they were done in accordance with manufacturer's recommendation and the design requirements. The commissioning documents contained a record of equipment construction checklists, functional test procedures and opposite season test procedures. These documents identified issues we consider normal and these issues, in general, appear to have been resolved in a manner to the satisfaction of the commissioning authority. The checklists contain the following statement:

"This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report."

We would anticipate some form of documentation confirmation the installer followed the startup requirements. This would be done either through a manufacturer sign off box on the equipment construction checklist or the installer documenting their compliance via the operation and maintenance (O&M) manual process.

We reviewed the mechanical O&M manuals. The O&M did include the various manufacturer's "checkout and startup procedures," however these documents were not completed. We were unable to locate completed versions of these documents.

We reviewed an email from The Joyce Agency dated January 12, 2018. In this email they noted a missing strainer screen on a failed LG VRV unit. The part of the system where a majority of the HVAC issues have appeared. These units are reported to have failed because the heat exchanges froze. A variety of factors can cause the heat exchanger in the LG VRV units to freeze. It can be caused by partial blockages of the water side passages, low condenser water supply temperature, or low flow (or some combination). Anecdotally we learned from The Joyce Agency email and two other facility staff members that multiple strainer screens had been missing. A review of the maintenance logs did not locate any documentation supporting the missing screens. We spot checked several strainers for the existence of screens and can confirm screens were installed. We recommend the LG VRV maintenance requirements for annual and 5-year actions be incorporated into the facilities staff's standard operating procedure.

We attempted to locate documentation on the initial flushing and testing of the condenser water loop and could not locate any. Debris could be left in the piping if this process was not accomplished or effectively executed. This debris will cause damage and likely premature failure of heat exchangers connected to the condenser water loop.

It was also reported anecdotally the existence of a strainer screen with a hole in it and circuit setter valves not set properly. High pressure could be the cause of both the hole in the strainer screen and problems with the LG VRV units. M504 detail 9 "water cooled condensing unit" on the design drawings calls for pressure plugs to enable pressure readings. The manufacturer's requirements show pressure gauges in both the supply and return. We recommend pressure gauges, instead of pressure and temperature ports, be added following the manufacturer's requirements. Pressures in the condenser water loop were approximately 65 psi and in line with our expectations.

We observed a refrigerant piping leak downstream of an LG VRV unit. The leak was over a small office and was visible due to an oil spot on the acoustical ceiling tile. The cause of this leak was not determined at the time. We reviewed the documentation provided in an attempt to learn if the manufacturer's requirements for testing and cleaning refrigerant piping occurred. During this review, we noted a proposed substitution by the contractor to use mechanical couplings in lieu of brazed joints as the method for joining refrigerant piping associated with the LG VRV units. The records indicate it was flagged by the designer, but ultimately approved with a cautionary note about being careful with dissimilar metals. The Vulkin Lokring Solderless Connection System was provided by Critical Systems. Their submittal indicates owner training and pressure testing are not included.

Regardless of the joining method, we would expect to find documentation witnessing the refrigerant piping held the appropriate vacuum pressure required by the manufacturer (note 11 on page 97 of LG installation manual; Tab 23-8146.1 of the contractor's O&M). We were unable to confirm the LG pre-commissioning process was followed or witnessed.

The condenser water loop, also referred to as the geothermal distribution, is a closed loop system. In essence this means it is not open to the atmosphere. The closed loop does require water treatment. The installation manual for the LG VRV units details the water quality requirements (attached). It does not appear this information has been provided to the water treatment specialist currently providing this function. We were not able to verify through existing documentation the condition of the water at the time of startup. The pH this year (2018) appears to have been maintained between 10.0 - 10.5 and the manufacturer's requirements is a range from 7.0 - 8.0. We recommended adjusting the water quality to meet the manufacturer's recommendations to avoid the possibility of early failure of the LG VRV units.

Temporary HVAC

Options for interim HVAC to maintain space temperatures inside the school were evaluated. Unfortunately, there is very little in the way of redundant systems in the Roosevelt High School. Most equipment is connected into the condenser water loop, so if that loop is not operating, there is no heating or cooling.

The space load in the classrooms are conditioned by ceiling cassettes connected to the LG VRV units. Outside air is provided by dedicated outdoor air system (DOAS) in mechanical rooms. This air is delivered through a ducted system. The leaving air temperature for these units is adjustable by the building automation system.

Drawing M301 from the construction documents set shows the heating set point for the DOAS units ranges from 95 degrees F to 100 degrees F. It is possible to use these units to provide small fraction of the space heating load when an LG VRV unit is not operational. We recommend setting the DOAS unit area in occupied during the winter with the leaving air temperature set to maximum setting per M301 until the LG VRV unit is repaired.

Outside each classroom is a junction box with three 208V (volts) circuits. It is possible to connect 5kW (kilowatts) of electric heat to this circuit. This amount of heat is only a portion of the classroom heating requirement. If we were to implement this course of action, there would not be any power left to the classroom for receptacles, i.e. students would not have power to plug in laptops or other electronic devices.

RECOMMENDATIONS

Our recommendations for action are based on a review of our findings along with limitations related to air conditioning outages during school, and availability of contractors to work off hours or over holidays.

We have based our recommendations on keeping the HVAC system running until such a time that the HVAC system can be taken offline. We anticipate the earliest this can occur is summer of 2019.

Immediate Actions

1. Address open work tickets for known HVAC issues
2. Adjust water quality of condenser water loop to be within LG's water quality requirements including pH (see attached)
3. Trend condenser water loop temperature; this appears to require modification to the building automation system
4. Modify existing process related to failed heat pumps when a compressor needs to be replaced or a refrigerant leak is detected as follows:
    a. Remove refrigerant and compare to manufacturer required charge
    b. Clean and test refrigerant piping per manufacturer's requirements
    c. Repair leak
    d. Recharge refrigerant
5. Modify existing process for future refrigerant leaks to include documenting location within the system and how leak was detected, for example:
    a. Location: refrigerant piping leak, downstream of LG VRV condensing unit
    b. Detected: oil stain visible on ceiling tile
6. Set leaving air temperature to 95 degrees for any DOAS unit serving areas where LG VRV units are out of service. Leave DOAS in Occupied Mode. Reset DOAS when LG VRV is operational.

Remainder of the school year

1. Re-commission the condenser water loop (geothermal distribution) system to include:
    i. Re-balance entire condenser water loop
    ii. Reset control set points
2. LG VRV condensers
    a. Test pressure drop on LG VRV units and compare to manufacturer data – evaluate unit for replacment that exceed manufacturer's specifications
    b. Install thermometers and pressure gauges on piping at LG VRV units
3. Evaluate the condenser water distribution system's ability to handle the following additional equipment:
    a. Industrial sand filter
    b. Glycol

Summer 2019

1. Flush the entire condenser water loop similarly to attached specification.
2. Validate commissioning of condenser water loop, to include re-verification of control valves, balancing valves, control set points.
3. Commission each of the 11 VRV systems.
    a. Remove refrigerant and compare to manufacturer required charge

    b. Clean and test refrigerant piping per manufacturer's requirements
    c. Test Vulcan Lokring mechanical fitting to confirm installation
4. Continue with independent verification and validation (IV&V) of HVAC system commissioning to include optimizing condenser water loop temperatures with installed equipment

Additional Issue – Not Yet Disclosed by Smoot-Gilbane

There are strands of copper being found in some of the refrigerant piping by the mechanical contractor (R&R) while making repairs to the refrigerant lines. This could be a contributing factor to the failed compressors which has been occurring in conjunction with the leaking mechanical fittings. R&R is contracted through Gilbane to perform repairs so we will need to hear from Gilbane regarding this issue. This would point to a lack of flushing the refrigerant lines fully before charging the systems with refrigerant.

Actions Moving Forward

To ensure reliability of the heating and cooling system the following actions will need to occur:

- Replace all Vulcan LOKRING fittings with brazed copper fittings / connectors.
- Reduce condenser water line pH to 8.0.
- Ensure all required HVAC PMs are occurring through more detailed/consistent PM work orders.
- Determine if condenser water system will require flushing through monitoring a newly installed filter.
- Based on filter monitoring, flush the condenser water system in the summer (only if necessary).
- Commission all 11 VRV units, ensure required refrigerant charge is provided for each VRV system, clean and test refrigerant piping, AND perform a pressure drop test on each LG VRV condenser to determine if any units are compromised and install pressure gauges / thermometers at LG VRV units for monitoring purposes (North Arrow recommendations).

In addition to the above bulleted actions, we should see what type of data can be obtained from the main circuit boards of the LG VRV units. This is accomplished through connecting a computer running the LG monitoring view (LGMV) software to main printed circuit board (PCB) of the water source unit through an LG interface cable. There is an uncertainty at what type of data will be obtained AND if the data will even be time / date stamped. It is my understanding an LG technician would need to perform this action.

Site Visit Report Summary

Date: 10/28/22
Site Name: Roosevelt HS

Hobbs & Associates was contracted by DCPS to execute a full operational assessment of the LG VRF systems at Roosevelt High School. An assessment was performed and summarized in a report dated 5.13.22 and cataloged in **Appendix A.** This assessment identified a number of issues impacting performance of the VRF systems serving the building, including systems that were both inoperable due component failures. A comprehensive list of recommendations were compiled and a team consisting of North Arrow, Pro-Air, and Hobbs was contracted to perform the repairs and post-repair operational analysis.

A detailed log of work performed was created and tracked for all work performed. A summary of this work can be found in **Appendix. B**

Executive Summary:

A significant number of systems had active refrigerant leaks. In many cases these leaks had impacted system performance and resulted in numerous compressor failures. Leak checks were performed on these systems and in almost all cases leaks were found. The majority these leaks originated from isolation ball valves or condensing unit Schrader valves. Based on our experience leaks of this nature are a result of the valves being damaged during initial installation seals failing over time. Other systems that were suspected to be low on charge that did pass leak tests did were found to have improper amounts of refrigerant based on the latest as-built piping diagrams available.

There was significant evidence that routine maintenance had not been performed. This appeared to have a direct correlation to miscellaneous component failures such as indoor fan motors, condensate pumps, and boards.

A select number of indoor units were replaced due to electronic expansion valve (EEV) malfunctions.

There was evidence that a select number of condensing unit control boards had been improperly replaced or swapped with adjacent units causing communication and capacity errors.

Condensing unit door panels had also been swapped with adjacent units on neighboring systems making it difficult to identify system labels.

There was at least one instance where a refrigerant pipe was improperly installed from an heat recovery box to its non-respective indoor unit.

A team was dispatched to document indoor unit central control addresses to be used for future controls work.

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Conclusions and Recommendations:

1. Remaining items identified in initial assessment not already remedied should be addressed to prevent further performance issues and possible failures.
2. A thorough controls analysis and overhaul should be performed.
3. A preventive maintenance program should be implemented to regularly evaluate system operation and ensure routine maintenance is being performed. Hobbs & Associates Building Services would be happy to provide a customized Preventive Maintenance package designed to minimize unscheduled downtime and maximize performance and efficiency of these systems.

Appendix A:

****Initial Assessment Report****

Site Work Update

Date: 5.13.22
Site Name: Roosevelt HS
Site Address: 4301 13th Street NW Washington DC, 20011

Reported Issue & Reason for Visit:

Complete initial assessment of LG VRF Systems

Site Visit Summary & Work Performed:

An evaluation was performed on the operation of the LG VRF systems listed in Table 1 using LG Monitoring View (LGMV) Software:

VRV-OD-1: Inverter discharge temperature was higher than normal while operating in heat mode. There were two indoors that were group controlled that were going into a CH-53 (communication) error when the system was commanded from heat into cooling. Main EEV was pulsed higher than normal in heat mode. Cooling mode operation appeared to be normal.

VRV-OD-2: Ran system in both cooling and heating. Observed operation with LGMV and was normal

VRV-OD-3: Ran system in both cooling and heating mode. System performance in cooling was normal. In heating mode ID4/5/6 EEV's were pulsed above 300. Outdoor unit EEV was pulsed higher than normal (1216).

VRV-OA-1: IDU5 (Central address 32) kept going into heat. Could not rule out local control but appeared to be a control related issue. This room appears to be overheating. Took a while for system to meet target head pressure in heat mode. Inverter discharge temperature was high (208*F at 69 Hz). Temperature did appear to drop back to more normal temperatures after left running. Operation in cooling appeared to be normal.

VRV-OA-2: *Cooling Mode:* IDU1 & IDU5 (Central Addresses 1 & 30) were going into thermal off prematurely. Could not rule out local control by occupants but seemed to be a possible control issue. The IDU's that were in thermal off at 40 pulse seemed to still have liquid going to the coil.

Heating Mode: System went into a CH-21 1 at approx. 13:45 in the data set. IPM temp too was higher than normal. Allowed to reset. IDU4 went into a CH-3 (Communication error) at approx. 13:55. IPM temp 217+.

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backed down the compressors to prevent it going into CH-21 error again. compressors running higher than normal inverter discharge temperatures. Negative subcooling on ID10 (CC24). IDU10 went into a CH-10 at 14h 10m 42s. Possibly a loaded filter or airflow issue. System eventually leveled out once setpoint was commanded down but still seemed to be running abnormal in heating.

VRV-1-B: One of the HR boxes was not showing up in LGMV. System had to be re-commissioned and passed. Went into a CH-51 (connected capacity ratio) error. Suspect EEPROM chips may have been swapped with system VRV-1C-1.
VRV-1C-1: Operation appeared to be normal. Suspect EEPROM swapped with VRV-1-B.
VRV-1C-2: Operation normal.
VRV-1D-1: System was in a CH-21-2 Sub-unit compressor was grounded.
VRV-1D-2: System appears to be undercharged.
VRV-1E: Operation normal
VRV-2C-1: Operation normal
VRV-2C-2: System was in a CH-42 (low pressure) error. System was flat (no pressure)
VRV-2D: System was in a CH-26-1 (compressor failure to start) error.
VRV-3C-1: System appears to be undercharged.
VRV-3C-2: System appears to be undercharged.
VRV-3D-1: System operation normal.
VRV-3D-2: System appears to be operating normally, but going into a CH-200 (valve assignment error). Inverter fan had been removed. Re-installed fan.

System Tag	Model # (Main/Sub)	Serial (Main/Sub)
VRV-OD1	ARWB168DAS4	407KAXV00002
VRV-OD2	ARWB192DAS4	704KCAS14H92
VRV-OD3	ARWB168DAS4	406KACA00003
VRV-OA-1	ARUWB192DAS4	406KAYR00002
VRV-OA-2	ARWB192DAS4/ARWB192DAS4	407KABF0005/407KAVH0007
VRV-1B	ARWB168DAS4	407KAWQ0001
VRV-1C-1	ARWB192DAS4	406KAQJ0004
VRV-1C-2	ARWB192DAS4	611KAS05V88
VRV-1D-1	ARWB192DAS4/ARWB192DAS4	407KAYR00010/406KACA00003
VRV-1D-2	ARWB192DAS4	407KAYR00010
VRV-1E	ARWB168DAS4	410KCDG0A722
VRV-2C-1	ARWB192DAS4	408KATM00001
VRV-2C-2	ARWB144DAS4/RWB144DAS4	406KALC00008/406KAQJ00004
VRV-2D	ARWB192DAS4/ARWB192DAS4	407KAJP00004/407KARW00006
VRV-3C-1	ARWB192DAS4	410KCZP0QS33
VRV-3C-2	ARWB192DAS4	408KAMZ00003
VRV-3D-1	ARWB192DAS4	407KAHW00009
VRV-3D-2	ARWB192DAS4	407KAXV00002

Table 1. LG VRF Tag/Model/Serial List

Conclusions/Recommendations:

1. **VRV-OD-1:** Recommend verifying charge vs. latest as built
2. **VRV-OD-2:** Normal
3. **VRV-OD-3:** Identify what area ID 4, 5, and 6 serve and verity filters are not loaded and has proper airflow. Re-evaluate in heat mode.
4. **VRV-OA-1:**
    a. Verify area served by ID5 (Central address 32).
    b. Monitor system operation and if reduced performance is observed verify charge.
5. **VRV-OA-2:**
    a. Verify IDU1 & 5 local settings and installation conditions.
    b. Recommend calibrating system EEV's
    c. Confirm how the temperature sensing location sub-function is configured.
    d. Inverter board should be tested, and heat sink paste verified.
    e. ID4 wiring to it's thermostat should verified.
    f. ID10 airflow should be verified, and fan motor and board tested based on findings.
    g. Charge should be verified vs. latest as-builts.
6. **VRV-1-B:** EEPROM chip needs to be ordered, system re-commissioned, and system evaluated once CH-51 error is cleared.
7. **VRV-1-B:** Order proper EEPROM and re-commission system.
8. **VRV-1D-1:** Sub-unit compressor needs to be replaced.
9. **VRV-1D-2:** Leak check needs to be performed.
10. **VRV-2C-2:** Leak check needs to be performed.
11. **VRV-2D:** Main compressor needs to be replaced.
12. **VRV-3C-1:** Leak check needs to be performed.
13. **VRV-3D-2:** Attempt to resolve CH-200 error and if it cannot clear update software and possibly replace main PCB.

General Recommendations/Action Items:

1. Variable flow kits were not modulating flow valve on any of the systems monitored.
2. Hydronic side temperature and pressure gauges were not installed except on VRV-OD2. These are required per factory IOM.
3. Flow switches were paddle type and mounted in a vertical orientation. Factory IOM recommends mounting them in a horizonal orientation. Flow switch manufacturer states these can be mounted in a vertical orientation. Does not appear to be affecting system operation but should be monitored and corrected if nuisance errors are experienced. Flow switched should be tested for functionality as part of routine PM.
4. There are reports of various communication related issues with he AC Smart. Once all operational issues are resolved it is recommended that a full control evaluation be performed.
5. Hydronic balancing report needs to be provided to show that the proper flow rate has been recorded across the heat exchanger of each condensing unit.
6. Recommend implementing ICM450 phase monitor and surge protection devices.
7. Function codes at thermostats should be verified. Including but not limited to ESP settings, temp sensing locations, deadbands, etc.)
8. Please provide original air balancing report showing RPM settings on IDU fans were configured.
9. Please provide any historical service reports.

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10. All hydronic side components should be verified to be in accordance with factory IOM including proportional/linear flow valves and #50 mesh strainers (clean).

Thank you for choosing Hobbs & Associates as your trusted service provider. We welcome and encourage our customers feedback and input. Please let us know how your experience was by dropping us a line HERE.

Appendix B.

Summary of Work Performed:

System	Summary of Work Performed
OA-1	Leak checked
OA-2	Compressor replaced. Music room blower replaced. EEV's calibrated.
OD-1	Leaks identified and repaired on ball valves. Main PCB replaced. EEV's calibrated
OD-3	Dirty filters affecting performance. Notified facilities maintenance staff.
1B	Repaired main PCB on ODU due to EEPROM issue. Replaced main PCB on HR2
1C1	Repaired main PCB on ODU due to EEPROM issue.
1D-1	Compressor replaced. Leaks identified and repaired on ball valves.
1D-2	Leaks identified and repaired on ball valves. Air and waterside flowrate need to be verified.
2C-2	Leaks identified and repaired on ball valves. Compressors replaced.
2C-1	Leak check performed.
2D	IDU PCB replaced. FCU-24-20 bad EEV. Compressor replaced.
3C-1	IDU replaced due to defective EEV. System was low on refrigerant
3C-2	Leak identified on liquid line king valve schrader and repaired
3D-2	Unit damaged by fire. Still needs to be replaced.

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Agency Comments

On March 1, 2023, we sent a draft copy of this report to the Department of General Services (DGS) for review and written comment. DGS responded with comments on March 17, 2023. Agency comments are included here in their entirety.

GOVERNMENT OF THE DISTRICT OF COLUMBIA
DEPARTMENT OF GENERAL SERVICES

TO:	Kathleen Patterson, D.C. Auditor Office of the District of Columbia Auditor
FROM:	Keith A. Anderson, Director Department of General Services
DATE:	Friday, March 17, 2023
SUBJECT:	DGS Responses to the Office of the District of Columbia Auditor Internal Audit Report: Roosevelt HS Modernization Follow Up Audit

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Purpose:

The Office of the D.C. Auditors (ODCA), by RSM US LLP, requested an internal audit of the Roosevelt High School Modernization project. Specifically, the ODCA internal audit aims at understanding DGS' efforts to remediate issues related to Roosevelt's modernized HVAC system. The report identified three (3) conclusions and recommendations and two (2) moving forward recommendations for consideration by DGS. Below is a summary of DGS's Roosevelt High School commissioning efforts and management response to the audit conclusions and recommendations.

Roosevelt High School Recommissioning:

DGS is aware of the problems afflicting the mechanical system at Roosevelt spanning many years, and DGS appreciate the ODCA's deep dive into the issues. DGS approaches with a spirit of openness to learning from these events. DGS is committed to having an environment where students can learn comfortably and safely. DGS is striving to meet environmental goals as it modernize the schools, contract effectively, maintain systems, and hold contractors accountable for the quality of their work.

Between the summer of 2021 and the summer of 2022, DGS worked with the mechanical engineering firm North Arrow to perform a retro-commissioning of seven facilities, including Roosevelt HS. The primary intent of the retro-commissioning project was to identify energy conservation measures that could reduce carbon emissions and water consumption while increasing overall system health and energy efficiency.

DGS leveraged past evaluations of the HVAC system at Roosevelt High School to better inform the execution of testing and commissioning activities across the refrigerant side of the school's VRV system. This effort pressure tested, recharged, and restarted each of the site’s 18 refrigerant-based systems. During the process, DGS identified what it believes are system defects related to power fluctuations and electrical inconsistencies. This information, combined with other similar electrical occurrences at different locations, has resulted in DGS teams working to diagnose, isolate and protect VRF and VRV-based systems from power disruptions that impact these systems' sensitive electronics.

DGS is also in the process of replacing one of Roosevelt High School's VRV system's condensing units, which was heavily damaged by an electrical fire, plus the installation of water gauges on all condensing units, allowing for better tracking and trending of the system's water side performance.

Lastly, DGS is finalizing a scope of work that will upon completion enhance visibility into operational and maintenance data generated by the system's communication and control's platforms.

These ongoing efforts will collectively ensure the thermal comfort and reliability of the HVAC systems at Roosevelt High School and enhance how DGS monitors and maintains the various HVAC equipment and platforms across the facility.

DGS' Responses to Conclusions and Recommendations:

Contract Warranty Provisions	
Summary	DGS' Design-Build Agreement included industry-standard provisions for warranty and turnover, as well as flow-through provisions that applied to subcontracts. Although available, these provisions may not have been utilized to the fullest extent available.
Conclusion & Recommendation	Through review of contract documents, we noted that DGS' Design-Build Agreement includes industry-standard provisions for warranty and turnover. Specifically, the applicable provisions included language consistent with the American Institute of Architect's ("AIA") Standard Form of Agreement Between Owner and Design-Builder. The design-build agreement also included flow-down provisions, applicable to the subcontracts executed by the Design-Builder. Based on interviews with stakeholders and review of documentation, we noted that HVAC issues were identified and documented prior to turnover of the building to DGS. While remediation measures were taken during the one-year warranty period, the issues persisted and were still ongoing through the end of the warranty period. After the warranty period ended and the mechanical contractor stopped performing repairs, DGS solicited third-party vendors to avoid further failures and service disruptions, which resulted in additional costs to repair and maintain the VRF system. In discussions with DGS' General Counsel, we were informed that legal personnel present during the initial turnover, warranty period, and subsequent latent defect notice were no longer with

	DGS. However, Counsel noted that legal action had not been proposed by DGS since the initial latent defect notice in 2019.
Management Response	DGS agrees that carefully monitoring warranties is a critical component of contractor and agency accountability and that close communication among facilities, contracting and legal personnel is essential, as are having systems in place to institutionalize such communication and coordination. The Internal Services team in the Office of the City Administrator will be coordinating with DGS to follow up. That said, DGS did avail itself of the warranty provisions at Roosevelt. Roosevelt Senior High School was turned over in 2016 to DGS Facilities Management Division (FMD) with a one-year general builders warranty ending in 2017. DGS provided examples of timely application of both builder's and manufacturer warranties. For reference, please see Activity Matrix (page 109) warranty service call documentation. **Builders Warranty Example:** • All maintenance, service, and repairs performed between June 2016 and December 2017 were warranty calls placed by CMC Spectrum on behalf of DGS. **Manufacturer Warranty Example:** • DGS contacted the Joyce Agency, LG Manufacturer Representative, to review system operations and commission newly installed units. At no cost to the District, LG replaced one unit as a defect replacement in November 2016. DGS records are inconclusive as to whether legal action after the 2019 latent defect notice was considered or not by DGS in consultation with the Office of the Attorney General, which has the exclusive authority to litigate the matters referred to in the report. Such considerations, if they occurred, would have been confidential and may or may not have balanced the potential impacts of, among other things, potentially having to close the school property site down during a litigation discovery period that might have extended three (3) or more years, or keeping the site open, or partially open, and working cooperatively with contractors to resolve the problems given an industry standard one (1) year warranty period and a three (3) year statute of limitations. DGS is assessing how to most effectively take advantage of warranties where, as here, the government obtained that proved to be unreliable and unexpectedly expensive to maintain and repair.

<table>
<tr><th colspan="2">Timeliness of Action</th></tr>
<tr><td>Summary</td><td>Through interviews with stakeholders and review of documents, we identified instances in which months/years elapsed between the identification of issues and the actions performed to assess or remediate those issues.</td></tr>
<tr><td>Conclusion & Recommendation</td><td>During our analysis, we noted a general theme of untimely action by both third-party vendors and the Department of General Services. Through interviews with stakeholders and review of documents, we identified instances in which several months/years elapsed between the identification of issues and the actions performed to assess or remediate those issues. Examples include:

Repairs During Warranty Period: According to the timeline of issues included in Spectrum’s letter to DGS (Appendix G, page 102), the lead time on repairs and component replacements performed by Limbach often exceeded a month. Examples include:

In June 2016, two (2) VRF units experienced problems related to leaks and compressor issues. The units were not fixed until September 2016.
On November 23, 2016, a VRF unit went down which left several rooms without heat. The system remained down through January 26, 2017.
On December 9, 2016, a VRF unit went down and remained down until January 27, 2017.

Issuance of Latent Defect Notice: Although HVAC issues were still occurring through the end of the warranty period, DGS did not issue a latent defect notice to the Design-Builder until sixteen (16) months after the initial warranty period had ended.
The Joyce Agency Recommendations: The Joyce Agency assessment performed in January 2018 resulted in several recommendations, including the recommendation to initiate discovery on all VRF systems to confirm operating conditions and reduce additional failures. Based on the information provided, it does not appear that discovery was conducted until North Arrow’s HVAC Assessment in December 2018.
North Arrow Recommendations: The HVAC assessment performed by North Arrow in December 2018 resulted in thirteen (13) total recommendations. RSM inquired with DGS to determine what corrective actions took place as a result of North Arrow’s recommendations. Based on responses provided by DGS, we noted that four (4) of thirteen (13) recommended actions were completed; however, the remaining nine (9) recommendations had not
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	been addressed to date, are currently ongoing, or could not be confirmed by DGS. • **HVAC Work Order Data:** For two hundred thirty-five (235) HVAC-related work orders that were completed and/or closed between August 2016 and June 2022, the average duration between the work order request date and completion of the work order within the CMMS was thirty-three (33) days. Sixty (60) work orders were completed in fifty (50) days or more, and thirty-one (31) were completed in one hundred (100) days or more. Several factors may contribute to the overall duration of work orders, including the complexity of the work order, lead times for parts/components, third-party contracting/procurement requirements, etc.
Management Response	DGS agrees that repairs should be done promptly, particular for critical, non-redundant systems at schools during the school year. Although several factors contribute to the overall duration of a repair, including complexity, lead time, and third-party contracting and procurement requirements, DGS will continue to closely coordinate the activities of its Capital Construction, Facilities Management, and Contract & Procurement divisions to improve the timeliness of repairs undertaken by general contractors and their subcontractors. To further assist with the timely diagnosis and completion of calls for service after a school's renovation, all warranty-related work orders are sent to the general contractor and tracked in Salesforce.

Document Retention and Confirmation of Manufacturer Requirements	
Summary	Throughout our engagement, we noted that documentation was either not readily accessible or was not available.
Conclusion & Recommendation	Throughout our engagement, we noted that documentation was either not readily accessible or was not available. The following documents were requested, but were not provided: • Certificate of Substantial Completion (2016 Modernization) • Deliverables specific to HVAC, as issued by JDC Construction during the turnover process. • Contract or agreement with HVAC contractor Pro Air • Several monthly deliverable reports issued by the Consolidated Maintenance Contractor, Spectrum Management • Contract documentation related to the temporary heating and cooling solutions between 2016 and 2022 In addition to the missing documentation noted above, we also noted that the 2018 report issued by North Arrow included findings related to missing or incomplete documentation:

	• Anecdotally, staff shared that multiple strainer screens were missing; however, maintenance logs did not reference the missing screens
	• Operations and maintenance manuals included various manufacturer "checkout and startup procedures"; however, completed versions of those documents could not be located. The following were also specifically referenced:
	  o No documentation could be located as evidence of initial flushing and testing of the condenser water loop
	  o No documentation could be located as evidence of refrigerant line vacuum pressure testing
	  o No documentation could be located as evidence that water pH level at time of startup was within manufacturer's specified range

Management Response	DGS agrees that contract and maintenance record management is vital. DGS continues to improve methods for electronic document retention and management. DGS acknowledges that electronic access to documents will help minimize information displacement and provide quick access when needed. For example, DGS is actively working with OCTO to improve the accessibility to contracts through the DGS procurement webpage. Currently, DGS is migrating from a third-party platform to a District-owned platform. DGS anticipates this migration to be completed by the end of April 2023. Additionally, DGS will continue to promote and improve document retention through its ProjectTeams and Salesforce platforms.

Moving Forward – Roosevelt High School	
Recommendation	As described in the timeline section and throughout this report, several third parties have been contracted to conduct analyses, identify causes of the system failure, and/or assist with performance of repairs. Recommendations have been provided within the deliverables provided by these consultants; however, based on requests for documentation and interviews, it remains unclear what specific actions have been taken related to these recommendations, and/or how determinations were made on whether to act upon recommendations. As such, we recommend DGS coordinate with DCPS, the Consolidated Maintenance Contractor at Roosevelt, DGS Legal Counsel, and other applicable stakeholders to develop an action plan. Goals may include the following: • Assess whether legal action is warranted

	• Review and amalgamate recommendations made by various consultants • Determine what actions have been taken to address recommendations • Determine which recommendations have not been implemented, and whether actions would currently be advantageous • Based on the above, develop an action plan with estimated completion dates for addressing open recommendations and additional action items identified • Provide regular reporting of progress on the action plan to DCPS and other District leadership Establishment of a detailed action plan will provide transparency to stakeholders regarding the current status of remediation efforts and will also promote accountability through the development of specific actions items, completion dates, and progress reporting.
Management Response	DGS acknowledges the report's recommendation that DGS coordinate with DCPS, the Consolidated Maintenance Contractor at Roosevelt High School, DGS Legal Counsel, and other applicable stakeholders to develop additional action plans. DGS agrees and will also seek the guidance of the Office of the Attorney General, which has the exclusive authority to litigate further legal matters. Additionally, DGS will seek guidance from the Office of the Attorney General on whether legal action is warranted and possible beyond the lapsed three (3) year statute of limitations.

Moving Forward – Future Modernizations	
Recommendation	Through discussions with DGS personnel, we understand that since the turnover of Roosevelt High School, DGS has begun developing processes specific to turnover and warranty. Documents reviewed indicate DGS' desired future state processes include the following: • Inclusion of maintenance personnel in planning and design discussions • Development of two-year post turnover maintenance and warranty plan, including related funding for each project • Establishment of Salesforce Warranty Manager to identify whether service requests are covered under a warranty • Quarterly touchpoint with maintenance to plan future projects and identify funding • Establishing ProjectTeam as a central document repository of turnover and warranty documentation related to each project

	The documents also provide several flowcharts depicting the process for identification of issues covered under warranties, and communication between various stakeholder teams including DGS' Capital Construction Division ("CCD"), Facilities Intake Request Service Team ("FIRST"), Facilities Maintenance Division ("FMD"), and third-party Consolidated Maintenance Contractors ("CMC"). While the processes outlined in the documentation noted above provide the foundation for a more effective turnover process, DGS may consider expanding upon the existing flowcharts by developing standard operating procedures ("SOP"). Standard operating procedures would provide specific, actionable guidance for staff to reference in performance of duties and step-by-step instruction to help facilitate consistency in the completion of tasks and retention of documentation. Further, SOPs could be used to develop a checklist for management to validate that all procedures have been completed and would also serve as a training aid to new employees. In addition, DGS may also consider the following: • Developing procedures for communicating potential warranty issues to DGS leadership and Legal Counsel prior to the end of the warranty period. Issues should be identified and reported in a timely manner to avoid service disruptions and incurring third-party repair costs after the warranty period. • Engaging manufacturer representatives to assess HVAC installation and confirm equipment / systems were installed according to manufacturer requirements prior to turnover and substantial completion. • Developing procedures to document consultant observations, recommendations, and action plans. If DGS does not plan to act upon consultant recommendations, reasons should be documented. • Developing a process for documenting "lessons learned" for future modernization projects. Lessons learned provide evidence-based case studies which can be used for future decision-making and may reduce the likelihood of future errors and foster continuous process improvement.
Management Response	DGS agrees that processes for turnover and warranty were not ideal at Roosevelt, and it continues to improve these processes, as well as to build in "lessons learned" for future modernization projects. Since the turnover of Roosevelt High School, DGS has focused on developing SOPs from lessons learned to improve the

	turnover process. DGS' efforts are focused on ensuring future projects are managed effectively and efficiently. For example, DGS has enhanced Salesforce to manage warranties and warranty calls for service by adding general contractors' access to the platform. Work orders that are warranty-related are now sent directly to the general contractor, giving DGS a tool to report more accurately on and track the response of both DGS and the general contractor. Additionally, having the data in one location allows DGS to analyze trends of systems and components that have repeat work orders during a warranty period. DGS acknowledges the recommendation to develop procedures for communicating potential warranty issues to DGS leadership and Legal Counsel before the end of the warranty period. DGS agrees and will include the Office of the Attorney General in such procedures.

ODCA Response

ODCA appreciates DGS's responses to the draft report and that the agency agrees with the report's six recommendations for improvement.

We note DGS's commitment to expanding the use of its SalesForce CRM to manage better "all warranty-related" information. We further note that we referenced similar issues with DGS's use of the CRM system in our Multiple Failures of DGS Management of Work Orders report from November 2022 and indicated how effective use can help mitigate future issues.

DGS stated that records were "inconclusive" in whether the agency took legal action after issuing a latent defect notice. We are concerned that DGS did not avail themselves of every remedy to ensure District dollars are being spent effectively. We will be referring the report and the issues to the Office of the Attorney General and assume that DGS will also consult with OAG to ensure that the District rights are preserved and those who receive District tax dollars are held accountable for performance.

We again recommend that DGS develop better internal controls to improve oversight and consistently escalate issues to executive leadership when and as appropriate. We continue to believe that expanded use of DGS' CRM will provide improved asset management.

We appreciate DGS's stated awareness of the continuing problems impacting the students and staff at Roosevelt Senior High School and their commitment to resolving the issues. We look forward to returning to the audit's recommendations through our normal recommendation compliance process. We also extend our appreciate to the RSM US LLC team for their expertise and experience reflected in this report.

About ODCA

The mission of the Office of the District of Columbia Auditor (ODCA) is to support the Council of the District of Columbia by making sound recommendations that improve the effectiveness, efficiency, and accountability of the District government.

To fulfill our mission, we conduct performance audits, non-audit reviews, and revenue certifications. The residents of the District of Columbia are one of our primary customers and we strive to keep the residents of the District of Columbia informed on how their government is operating and how their tax money is being spent.

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