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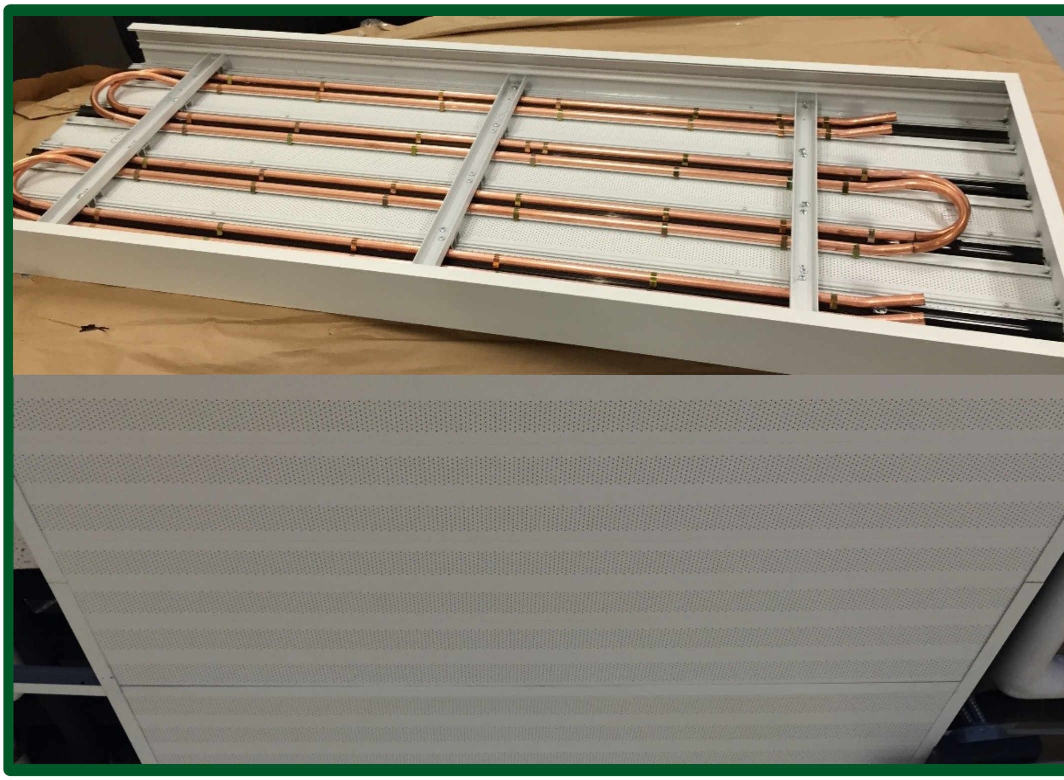

Systems Approach to Improved Facility Energy Performance

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14. ABSTRACT
The U.S. Department of Defense (DoD) is interested in improving its facilities to enhance energy performance and improve mold and mildew mitigation. This research effort used a pair of administrative facilities (Bldgs 1540A and 1540B) at Fort Detrick, MD, to investigate the use of radiant heating and cooling systems to cost effectively improve such facilities using technologies that are easily maintainable by existing staff. This project found that: (1) it is feasible to significantly improve the air tightness of an existing building envelope without implementing major changes or disruptions to the interior or exterior surfaces of the building envelope; (2) radiant heating and cooling systems can adequately maintain comfort conditions in administrative buildings in locations with significant heating and cooling loads; (3) radiant cooling systems, when combined with a Dedicated Outdoor Air System (DOAS) to properly dehumidify outdoor air and maintain proper space humidity conditions, can prevent condensation forming on the surface of the radiant cooling panels; (4) radiant heating and cooling systems are capable of improved energy efficiency when compared with conventional all-air Heating, Ventilating, and Air-Conditioning (HVAC) systems; (5) radiant systems are cost competitive with conventional all-air HVAC systems; and (6) radiant systems are easily maintainable and require no special skills for HVAC technicians.

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ACRONYMS AND ABBREVIATIONS

AHU	air handling unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
Bldg	Building
BTU	British Thermal Unit
CDD	Cooling Degree Day
cfm	cubic foot/feet per minute
DBT	dry bulb temperature
DOAS	dedicated outdoor air system
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DP	differential pressure
DPT	dew point temperature
DPW	Directorate of Public Works
ECB	Engineering and Construction Bulletin
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory (U.S. Army)
ESTCP	Environmental Security Technology Certification Program
EUI	Energy Use Intensity (kWh/ft^2)
FEMP	Federal Energy Management Program
ft	foot/feet
ft^2	square foot/feet
FY	fiscal year
HDD	Heating Degree Day
HVAC	heating, ventilating, and air-conditioning
KW	Kilowatt
kWh	kilowatt hour(s)
LCC	life-cycle cost
MOU	Memorandum of Understanding
NIST	National Institute of Standards and Technology

O&M	operations and maintenance
OMB	Office of Management and Budget
Pa	pascal(s)
PV	Photovoltaic
RH	relative humidity
SERDP	Strategic Environmental Research and Development Program
SIR	Savings-to-Investment Ratio
UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers
VAV	variable air volume
yrs	years

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EXECUTIVE SUMMARY

The U.S. Department of Defense (DoD) is interested in improving their facilities in a variety of aspects, including enhancing energy performance and reducing potential for mold and mildew formation. To this end, the DoD funded a research effort focused on a pair of single-story, brick-clad administrative facilities (Buildings [Bldgs] 1540A and 1540B) at Fort Detrick, MD. Bldg 1540A was the focus of facility improvements, and Bldg 1540B served as the control for comparison.

OBJECTIVES OF THE DEMONSTRATION

Military facilities experience many problems with mold and mildew formation, especially in hot, humid locations. DoD installations are also mandated to reduce energy consumption. This project aimed to simultaneously reduce energy consumption, maintain occupant comfort, and reduce the potential for mold and mildew formation with a heating, ventilating, and air-conditioning (HVAC) system that was easily operated and maintained and life-cycle cost (LCC)-effective.

Quantitative and qualitative performance objectives for this project are shown in Table ES 1-1:

Table ES 1-1. Quantitative and Qualitative Performance Objectives.

Performance Objective	Success Criteria	Results
Quantitative Performance Objectives		
Reduced building envelope air leakage	<0.15 cubic feet per minute (cfm)/square foot (ft^2) of air leakage at 75 pascals (Pa)	0.39 cfm/ft^2 of air leakage at 75 Pa Estimated 0.27 cfm/ft^2 of air leakage at 75 Pa with improved fenestration **Objective not met.**
Reduced energy consumption	20% reduction in heating, cooling, and ventilation system energy	46% reduction in overall energy usage (electric + gas) **Objective met.**
Cost effectiveness	Simple Payback: <5 years (yrs) Savings-to-Investment Ratio (SIR): >1.2	Simple Payback of 26.7 yrs SIR of 1.0 **Objective not met.**
Qualitative Performance Objectives		
Improved comfort	Temperatures and relative humidity (RH) within comfort criteria defined by ASHRAE Standard 55-2010, Section 5.2.1.1 "Graphic Zone Comfort Method"	The building satisfied ASHRAE Standard 55-2010 by maintaining an average of 70 °F and 43% RH between 6:00 a.m.–6:00 p.m. **Objective met.**
Reduced relative mold/mildew potential	Measurement of interior surfaces ≤80% surface RH	The building's 43% RH average was well below ASHRAE's 60% RH recommendation for the prevention of mold growth. **Objective met.**
Easily operable and maintainable	Maintainable by existing staff, no special skills required, less operations and maintenance (O&M) burden	**Objective met.**

TECHNOLOGY DESCRIPTION

This demonstration was conducted in two closely connected buildings, which were approximately 20 years old, of separate but nearly mirrored construction, and had the separating space between them enclosed to enable a continuous roof, though the two buildings retained their separate conditioned envelopes. Each building contained its own HVAC and boiler systems. During this demonstration, Bldg 1540A was retrofitted with three complementary and innovative technologies that collectively addressed the aforementioned concerns. These technologies were:

1. Improved building envelope air tightness to minimize unconditioned outdoor air infiltration.
2. A dedicated outdoor air system (DOAS) to properly condition makeup air.
3. A ceiling-mounted radiant heating and cooling system.

These technologies are complementary in a number of ways. Improved air tightness of building envelopes reduces unconditioned air infiltration and the amount of makeup air required to maintain a slight positive air pressure in the building interior. A dedicated outdoor air system ensures delivery of proper volumes of conditioned outdoor air to meet the building's ventilation/makeup air requirements. The tightened building envelope combined with the dedicated outdoor air system makes it possible to maintain proper humidity levels within the building. Maintaining proper interior humidity levels facilitates use of radiant heating and cooling systems without the concern of developing condensation on cool radiant surfaces. Hydronic radiant heating/cooling systems should be able to deliver heating and cooling energy more efficiently than all-air systems.

The team installed these technologies in Bldg 1540A and repaired/recommissioned Bldg 1540B to bring it into conformance with its original design. The energy performance of both buildings were measured, recorded, analyzed, and compared.

DEMONSTRATION RESULTS

These demonstrated technologies were considered successful even though they did not entirely meet some of their aggressive objectives. Building envelope sealing efforts decreased air infiltration from 0.82 to 0.39 cfm/ft^2 at 75 Pa. While this did not meet the envelope air tightness objective, it was a 52% reduction in building air leakage. The DOAS satisfactorily dehumidified the outdoor air used to both ventilate the space and to supply building makeup air. The temperature of the conditioned space was managed by the radiant heat transfer of water flowing through the ceiling panels—absorbing heat and cooling the space during cold water flow and emitting heat and warming the space during hot water flow. The combined DOAS and ceiling-mounted radiant panel systems demonstrated their long-term ability to satisfy American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 55 (2010). The 95th percentile of Bldg 1540A space temperatures and RH values during occupied hours (6:00 a.m.–6:00 p.m.) were between 62 and 78 °F, and 28 and 58% RH, respectively. These RH values also satisfied the aim of reducing mold and mildew potential. Energy reduction goals were also achieved. Overall, Bldg 1540A consumed 46% less energy compared with the prior fiscal year, and 20% less energy than Bldg 1540B during this fiscal year. An absence of maintenance concerns demonstrated the system's O&M success; however, the system's 26.7-year simple payback exceeded the 5-year objective.

This project resulted in several significant findings:

1. It is feasible to significantly improve the air tightness of an existing building envelope without implementing major changes or disruptions to the interior or exterior surfaces of the building envelope.
2. Radiant heating and cooling systems can adequately maintain comfort conditions in administrative buildings in locations with significant heating and cooling loads.
3. Radiant cooling systems, when combined with a DOAS to properly dehumidify outdoor air and maintain proper space humidity conditions, can operate without condensation forming on the surface of the radiant cooling panels.
4. Radiant heating and cooling systems are capable of improved energy efficiency compared to conventional all-air HVAC systems.
5. Radiant systems are easily maintainable and require no special skills for HVAC technicians.

IMPLEMENTATION ISSUES

The radiant system installed in this project did not prove to be cost competitive with respect to a conventional all-air HVAC system. Considering first cost, energy savings, and reduced maintenance costs, the demonstrated system was calculated to have a long simple payback of 26.7 years. Nevertheless, it may be possible that using different approaches and technologies could cause a radiant system to compete favorably with traditional all-air HVAC systems.

Installing ceiling-mounted radiant panels in an existing ceiling grid proved to be very challenging. In retrospect, completely replacing the existing ceiling grid would have been a less-challenging approach. The team also found it difficult to coordinate installation of these radiant panels with the location of existing ceiling-mounted light fixtures and sprinkler heads. If this had been a new construction project, it might have been possible to better coordinate the location of the radiant ceiling panels with ceiling light fixtures and sprinkler heads.

This project was deliberately sited in a location characterized by hot and humid conditions, which required significant dehumidification and cooling capacity. In more mild climates, the economics of the demonstrated systems might be more favorable. As with any system, before deciding to design/install a radiant system, one should perform a thorough economic analysis to determine the most cost-effective alternative.

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1.0 INTRODUCTION

1.1 BACKGROUND

This project was originally conceived as a result of the Army's efforts to address chronic and persistent mold and mildew problems in Army facilities. Mold and mildew infestations of Army facilities pose indoor air quality concerns and risk the health, wellness, and quality of life of soldiers. Remediating mold and mildew in facilities costs the Army millions of dollars annually.

This project was initiated to demonstrate integration of three innovative and complementary technologies that would address the U.S. Department of Defense's (DoD's) need to simultaneously address mold and mildew problems, maintain indoor air quality, provide occupant comfort, and reduce energy consumption in military facilities. Building envelope improvements reduce infiltration of moist outdoor air in and through wall structures where it can contribute to ideal conditions for development of mold and mildew, cause damage to building structural elements and architectural finishes, and negatively affect health and comfort within facilities. Reduced infiltration of unconditioned outdoor air also lowers a building's overall heating and cooling loads, eliminates drafts, and improves occupant comfort.

A tightened building envelope increases the importance of assuring adequate ventilation. Many military facilities employ variable air volume (VAV) systems, which are notorious for their inability to deliver adequate ventilation air at part load conditions. This problem is addressed by the integration of a dedicated outdoor air system (DOAS), which provides the required volume of conditioned ventilation air under all load conditions. In addition, a DOAS is better able to dehumidify air entering a building because it modulates its dehumidification capacity based on the actual moisture content of the ventilation air stream.

Combining an improved, tightened building envelope with a DOAS enables excellent control of humidity conditions inside a building. With humidity conditions under control, a radiant heating and cooling system becomes a feasible choice for managing the sensible comfort conditions inside of the building. Radiant systems heat and cool spaces by circulating hot (or chilled) water through radiant ceiling panels so that heat transfer between objects and occupants in the space and the radiant heating/cooling process occurs primarily via radiant heat transfer (rather than by convective heat transfer).

1.2 OBJECTIVES OF THE DEMONSTRATION

The overall objective of this project was to demonstrate the energy performance, occupant comfort, and sustainability benefits of integrating three complementary technologies (improved building envelopes to minimize uncontrolled infiltration of unconditioned outdoor air, DOAS to accurately deliver properly conditioned outdoor air, and radiant heating/cooling systems) in a military facility. Specific performance objectives and results against these objectives are shown in Table 1-1.

Table 1-1. Quantitative and Qualitative Performance Objectives.

Performance Objective	Success Criteria	Results
Quantitative Performance Objectives		
Reduced building envelope air leakage	<0.15 cubic feet per minute (cfm)/square foot (ft^2) of air leakage at 75 pascals (Pa)	0.39 cfm/ft^2 of air leakage at 75 Pa Estimated 0.27 cfm/ft^2 of air leakage at 75 Pa with improved fenestration **Objective not met.**
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Reduced relative mold/mildew potential	Measurement of interior surfaces ≤80% surface RH	The building's 43% RH average was well below ASHRAE's 60% RH recommendation for the prevention of mold growth. **Objective met.**
Easily operable and maintainable	Maintainable by existing staff, no special skills required, less operations and maintenance (O&M) burden	**Objective met.**

As shown in Table 1-1, the demonstrated systems resulted in significant energy savings and demonstrated improved comfort in all but one room, realized reduced mold growth potential, and were found to be easily operable and maintainable. The project did not attain its aggressive goal of reduced building envelope air leakage and did not meet cost-effectiveness objectives.

1.3 REGULATORY DRIVERS

This project responded to a number of regulatory drivers, including:

- **Executive Order 13693 –** Agencies shall promote building energy conservation, efficiency, and management by reducing agency building energy intensity measured in British thermal units per gross square foot by 2.5% annually through the end of fiscal year 2025 (FY25), relative to the baseline of the agency's building energy use in FY15 and taking into account agency progress to date.
- **Energy Policy Act of 2005 (EPACT) –** New Federal buildings shall be designed to require 30% less energy than buildings designed in accordance with American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2004 (ASHRAE 2004a) or the International Energy Code.

- **Energy Independence and Security Act of 2007 (EISA) –** New and renovated Federal buildings must reduce fossil fuel use by 55% (from 2003 levels) by 2010, and 80% by 2020. All new Federal buildings must be carbon-neutral by 2030.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

This project made use of a hydronic radiant heating/cooling system consisting of metallic panels that were incorporated in a 2x4-foot (ft) grid ceiling system and metallic "cloud" panels suspended from the unfinished ceiling of a conference room and a training room. Hot and/or chilled water was piped through a serpentine copper tubing network that was thermally bonded to the upper surface of the metallic panel system. Insulation was applied above the panels in accordance with the manufacturer's recommendations. Radiant heat transfer with the room occurred primarily due to the 4th power of the temperature difference between objects in the room and the surface of the radiant ceiling panels.

Figure 2-1 shows an upper surface view of a two-circuit radiant panel for installation in a ceiling grid. Figure 2-2 shows the finished surface side of a grid-mounted panel illustrating that the finished surface can be designed to match the surrounding suspended-ceiling system, in this case, to resemble an acoustic ceiling tile.

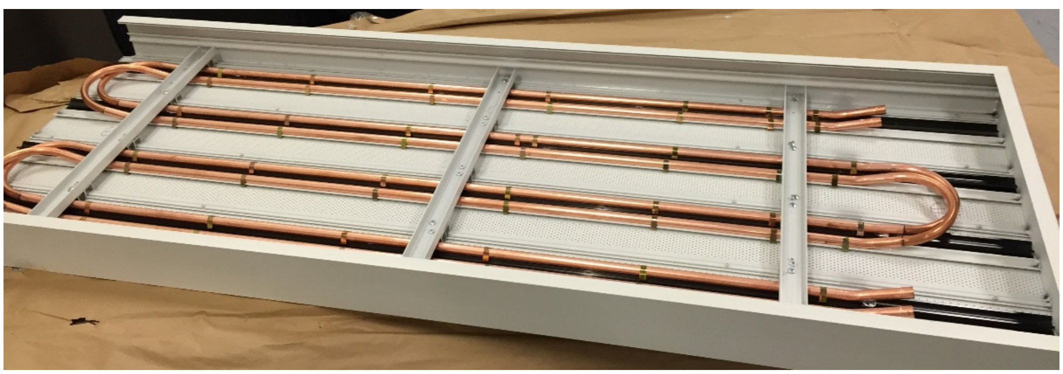

Figure 2-1. Upper Surface View of a Two-circuit Radiant Heating/Cooling Panel for Suspended-ceiling Application.

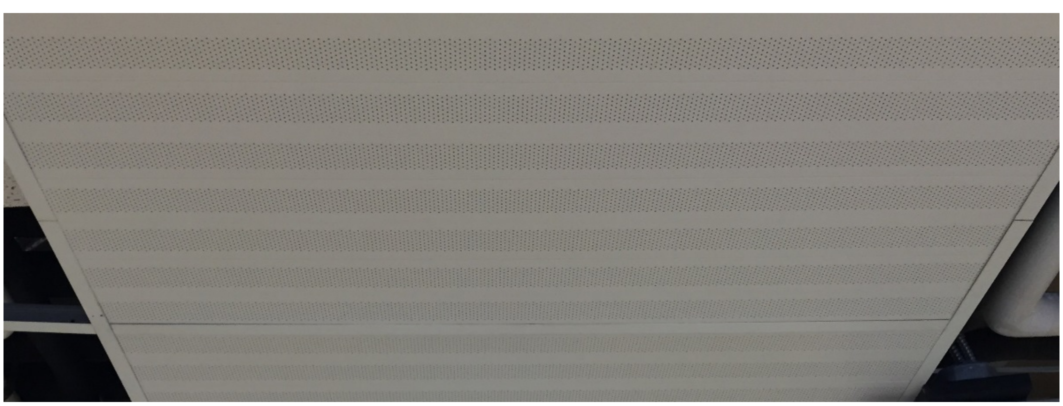

Figure 2-2. Finished Surface View of a Suspended-ceiling Radiant Panel.

Two configurations of radiant panels were used on this project. In conditioned spaces with existing grid ceilings, 2x4-ft grid-mounted radiant panels were used. In conditioned spaces without an existing grid ceiling, “cloud” panels were suspended from the hard overhead ceiling. Depending on zone load requirements, some panels were two-circuit units that incorporated separate heating and cooling tubing. In some spaces, additional “cooling-only” panels were installed to satisfy cooling requirements beyond the capacity of the two-circuit panels.

Figure 2-3 provides the floor plan schematic for the demonstration area. On the Building (Bldg) 1540A side of Figure 2-3, spaces indicated with purple (Administrative, Training, Conference Rooms) were retrofitted with radiant heating/cooling panels. Yellow-colored spaces were unconditioned, spaces indicated with green were exhausted and heated with existing cabinet unit heaters, white spaces were heated with existing hydronic unit heaters, and spaces indicated with red (Arms Storage) were not included in this project. On the Bldg 1540B side, the spaces were conditioned in the same manner except that the purple-indicated spaces (Administrative, Conference Rooms) were conditioned with a direct expansion (DX) VAV air handling unit (AHU) with hot water reheat coils at the VAV boxes.

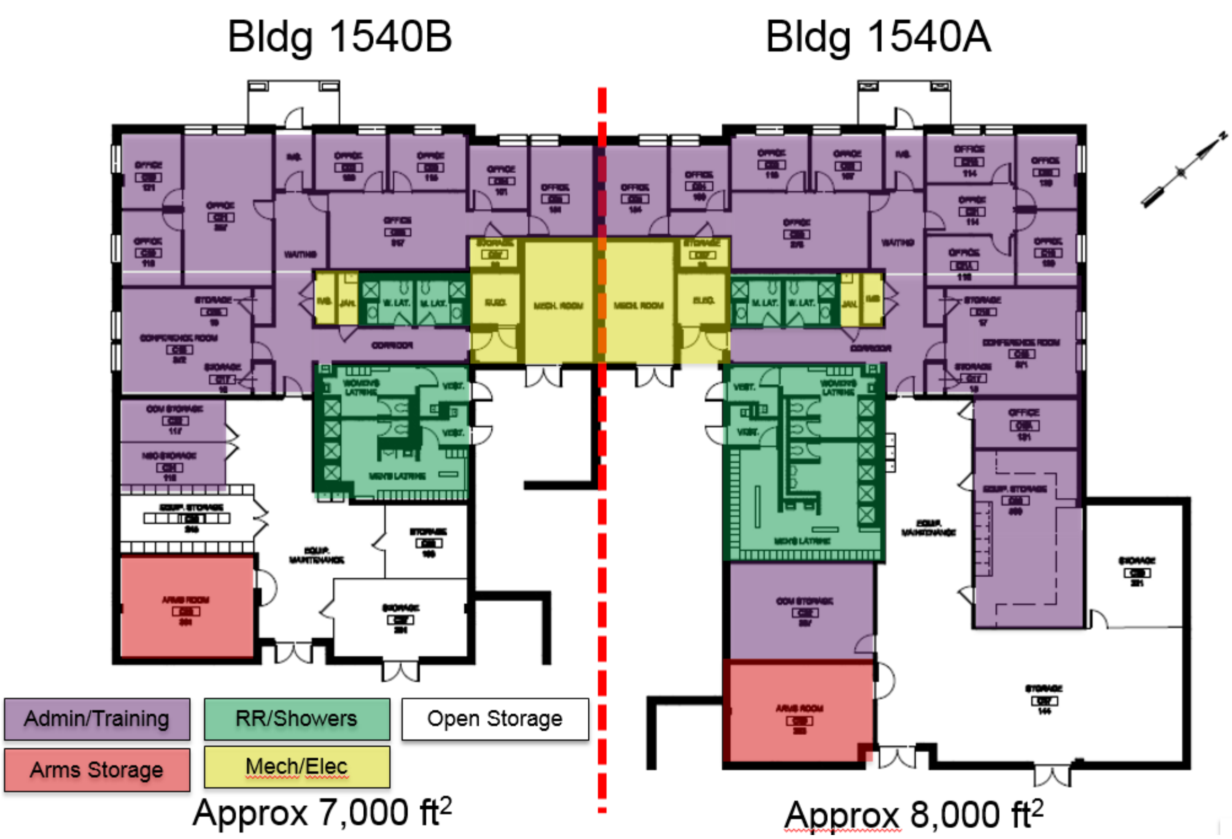

Figure 2-3. Bldg 1540 Floor Plan Schematic.

The radiant panel system was supplied with hot water from an existing boiler and chilled water from a new air-cooled chiller. Figure 2-4 shows the layout of the hot water system and Figure 2-5 shows a schematic of the chilled water system.

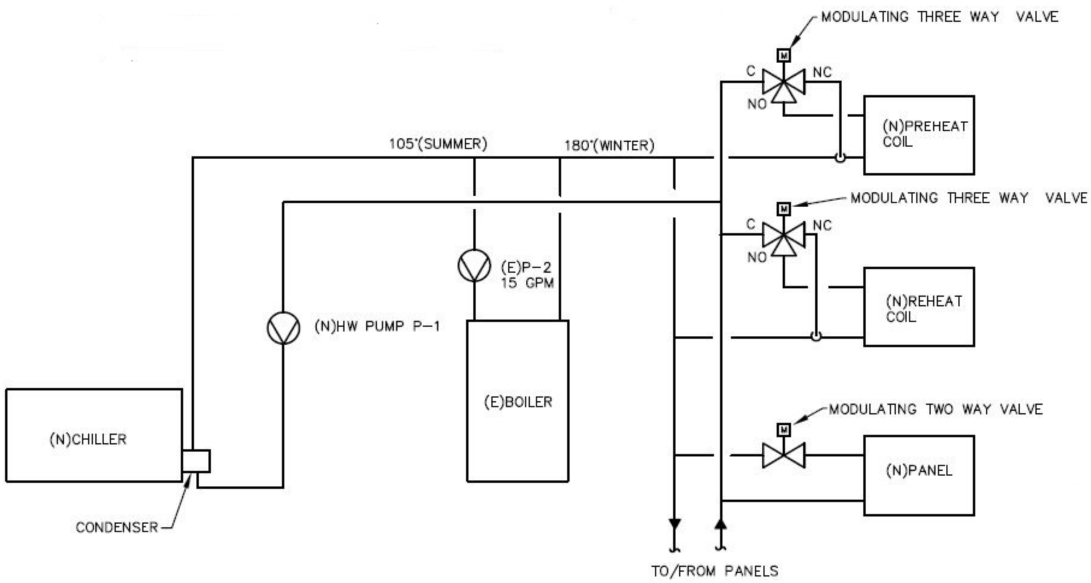

Figure 2-4. Hot Water System Schematic.

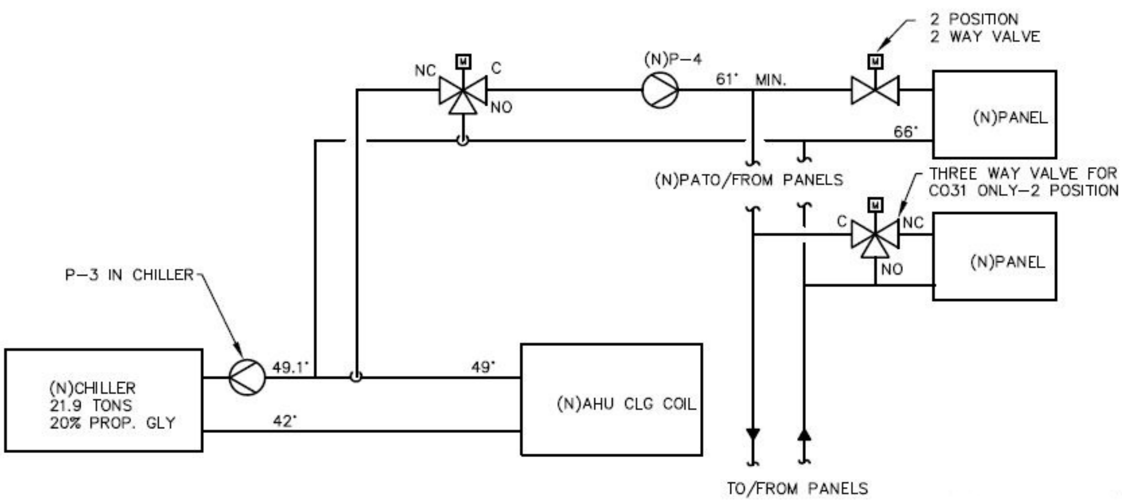

Figure 2-5. Chilled Water System Schematic.

Figure 2-6 shows the DOAS AHU. This is a constant volume device that filters and preheats (if needed) outside air. The air then passes through an enthalpy wheel where it exchanges energy (sensible and latent) with building exhaust from the latrines. The ventilation air then passes through a deep cooling coil that cools and dehumidifies the air before it enters the reheat coil where it is warmed to a neutral temperature before delivery to the occupied zones.

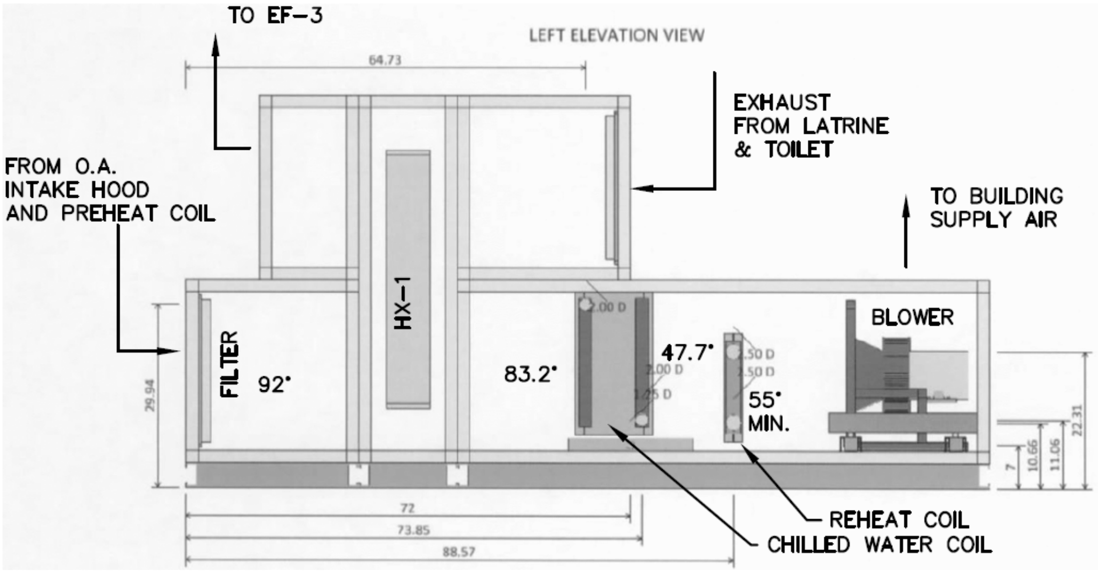

Figure 2-6. DOAS AHU.

Modern hydronic radiant technology has been used in various configurations for many years as an alternative to all-air heating, ventilating, and air-conditioning (HVAC) systems to condition occupied spaces. Several authors over past decades attest to the research and deployment of radiant technology, predominantly in Europe, and the successfully operation of this technology and its systems. There are several International Standard Organization (ISO) and ASHRAE standards that have been developed to guide the design and installation of hydronic radiant ceiling systems. According to Mumma (2001), Europeans have deployed ceiling radiant cooling panels, in connection with DOAS, since the mid-1980s with little adoption in the United States although there are relatively few barriers prohibiting their adoption.

The type of linear radiant panel used on this project is a mature technology that has been used in Europe for many decades. These panels have most predominantly been deployed within Europe and Canada. In recent decades, this configuration has been adopted in the United States as an alternative to all-air systems. The designer and manufacturer of these panels, Frenger Systemen BV, was founded in 1950 in the Netherlands. At the same time, the company installed their first heated ceiling application. In 1960, the first chilled ceiling was installed. Twa Panel Systems, Inc, the Frenger Panel manufacturer and distributor, was first established in 1986 to support the installation of this system in North America.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The demonstrated combination of technologies reduces overall energy consumption by delivering heating and cooling energy to occupied spaces more efficiently than all-air systems. Fan energy is a significant portion of HVAC energy. Hydronic delivery of thermal energy is more efficient because hydronic pumping costs are significantly less than fan energy costs. Due to the way humans perceive comfort, building occupants may experience comfort at slightly cooler air temperatures during the heating season and slightly warmer air temperatures during the cooling season with a radiant system.

Radiant heating/cooling systems with DOAS can reduce energy consumption and could be very helpful in moving the DoD a step closer to net zero energy facilities. Radiant heating/cooling systems require less above-ceiling space than all-air systems (which require ducts) and could prove to be quite useful in retrofitting existing buildings where space above the ceiling is very limited. Applications of radiant heating/cooling could be widespread to many types of facilities.

The radiant heating/cooling technology has applicability to buildings that have tight envelopes and that have the capability of controlling indoor humidity. The technology would not be applicable to buildings in humid climates with leaky building envelopes, or to buildings that are frequently operated with doors or windows open to the outdoor environment because such openings would allow unconditioned humid outdoor air to enter the building where it would condense on cool radiant panel surfaces. The technology may also be unsuitable for comfort cooling in zones with a very high cooling load as the radiant panels may not have sufficient cooling capacity to satisfy the load requirements.

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3.0 PERFORMANCE OBJECTIVES

Table 3-1 details the performance objectives, metrics, data requirements, success criteria, and results for this demonstration.

Table 3-1. Performance Objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative performance objectives				
Reduced building envelope air leakage	cfm/ft^2 of air leakage at 75 Pa	Blower door test results (cfm and corresponding differential pressure [DP] readings)	<0.15 cfm/ft^2 of air leakage at 75 Pa	0.39 cfm/ft^2 of air leakage at 75 Pa Estimated 0.27 cfm/ft^2 of air leakage at 75 Pa with improved fenestration **Objective not met.**
Reduced energy consumption	Site energy use (kilowatt hours [kWh])	Thermal energy delivered and mechanical systems electrical usage	20% reduction in heating, cooling, and ventilation system energy	46% reduction in overall energy usage (electric + gas) **Objective met.**
Cost effectiveness	Simple payback, SIR	First costs, O&M costs, energy costs, and useful life	Simple Payback: <5 yrs SIR: >1.2	Simple Payback of 26.7 yrs SIR of 1.0 **Objective not met.**
Qualitative performance objectives				
Improved comfort	Occupant satisfaction	Space dry bulb temperature (DBT), mean radiant temperature, air speed, RH, activity level, and clothing	Temperatures and RH within comfort criteria defined by ASHRAE Standard 55-2010, Section 5.2.1.1 "Graphic Zone Comfort Method"	The building satisfied ASHRAE Standard 55-2010 by maintaining an average of 70 °F and 43% RH. **Objective met.**
Reduced relative mold/mildew potential	Mold and mildew potential	Interior humidity levels and temperatures of "cold" surfaces	Measurement of interior surfaces ≤80% surface RH	The building's 43% RH average was within ASHRAE's recommended range for the prevention of mold growth. **Objective met.**
Easily operable and maintainable	Operability and maintainability	Maintenance records and discussions with O&M personnel	Maintainable by existing staff, no special skills required, less O&M burden	**Objective met.**

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4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

This demonstration was conducted at Bldg 1540 at Fort Detrick, which is located in Frederick, MD, approximately 49 miles northwest of Washington, D.C., and about 45 miles west of Baltimore. Fort Detrick supports a number of research organizations including the National Institutes of Health, the U.S. Department of Agriculture, a biodefense campus, and others. There are no training ranges at Fort Detrick. Installation operations primarily consist of administrative or research activities.

The 21st Signal Brigade is one of the major tenants of the installation. Bldg 1540 is occupied by elements of the 21st Signal Brigade and serves as an administrative and training building for the 514th Signal Battalion. The building houses administrative staff, chaplain offices, conference rooms, an Information Assurance training classroom, arms storage rooms, large shower/locker rooms, and unfinished open storage/work areas. Bldg 1540's HVAC systems had not been functioning satisfactorily and the installation had been unable to correct the situation. The building occupants were not satisfied with comfort conditions in the building. The building had been very hot in the summer and humidity in the building had not been well controlled. This was evidenced by the fact that the occupants had installed dedicated dehumidifiers to prevent rusting of the weapons being stored in the Arms Storage Room.

4.2 FACILITY/SITE CONDITIONS

The following criteria were used to select the demonstration site.

- **Geographic Criteria:** The team sought a demonstration site that had both a significant heating season and a significant cooling season. In addition, a location was sought that was considered "wet" or "humid" as a means of addressing concerns that radiant cooling systems will experience condensation problems in humid areas.

- **Facility Criteria:** The team sought a facility that was a reasonable size—big enough to be meaningful, but small enough to feasibly conduct a demonstration. The team also wanted a facility that was in fairly good condition to avoid the massive costs of a major renovation project. A facility that was used for a residential (barracks) or administrative occupancy was also desirable to demonstrate an ability to satisfy typical occupant comfort requirements.

- **Ability to retrofit the selected building and have a similar building available to use as a baseline for comparison purposes:** Fortunately, the team found a single building that fit this requirement well. Fort Detrick's Bldg 1540 (Figure 4-1) is divided into two sub-facilities, Bldg 1540A and Bldg 1540B, which are separated by a very short "common wall" as seen in Figure 2-3. This short plane of separation served as the building envelope demarcation line between Bldgs 1540A and 1540B. Bldgs 1540A and 1540B are very similar in size, layout, and occupancy. Each half of the existing building has completely independent boilers, AHUs, and cooling units so that it was possible to retrofit one side (1540A) without disrupting the mechanical systems of the other half of the building.

- **Facility Representativeness:** The selected building is typical of hundreds of other DoD buildings in a variety of respects. Bldg 1540 is a Base Realignment and Closure (BRAC) facility that is approximately 20 years old. It is a single-story administrative/training facility similar to many DoD buildings of similar age, size, and usage. The building uses slab-on-grade construction with concrete masonry unit (CMU) walls with brick cladding and a standing seam pitched metal roof. Both sides of the building use VAV air handlers to condition the occupied spaces. Finished rooms have gypsum walls with 2x4 lay-in grid ceilings.

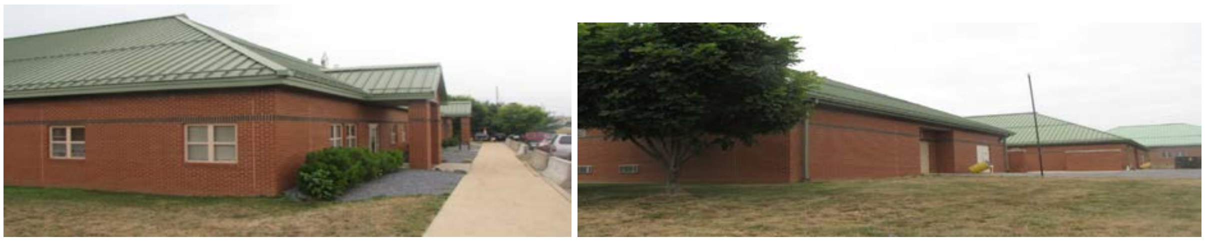

Figure 4-1. Northeast Corner of Bldg 1540 (left) and Southwest Corner of Bldg 1540 (right).

5.0 TEST DESIGN

The team attempted to demonstrate the feasibility and efficacy of integrating building envelope improvements with a DOAS and a radiant heating/cooling system to effectively condition a military facility while reducing energy consumption and costs, avoiding condensation on cold surfaces within the facility, and reducing relative mold and mildew potential. The goal was to provide a cost-effective alternative to the all-air approach to conditioning military buildings.

On identifying the demonstration building, the Contractor collected energy performance baseline data and prepared a demonstration design for Bldg 1540A. The demonstration design was installed and both Bldgs 1540A and 1540B were commissioned and instrumented for energy performance data collection. Numerous mechanical system deficiencies identified in the baseline for Bldg 1540B were repaired to bring this half of the building up to its design energy performance.

5.1 CONCEPTUAL TEST DESIGN

The data necessary to perform this demonstration included:

- Envelope leakage data: Before and after making building envelope repairs, blower door testing was performed to determine building envelope air tightness.
- Thermal comfort data: During the post-retrofit phase, the Bldg 1540A interior DBT and RH were measured at various locations.
- Electrical and thermal energy data: The team measured the total electrical energy and HVAC electrical energy of both Bldg 1540A and 1540B. The team also measured the natural gas usage of both buildings and thermal energy supplied to the DOAS and the radiant panels.
- Cost data: Costs of labor, material, and equipment for the demonstrated systems were tracked.
- Maintainability data: The team requested information from the installation maintenance organization on maintenance issues associated with the demonstration system.
- Local weather data: The team accessed local weather data from the Frederick Municipal Airport.

5.2 BASELINE CHARACTERIZATION

Baseline information required for this project included:

- Bldg 1540A baseline envelope air tightness data
- Bldg 1540A and 1540B environmental conditions: temperatures and RH at various locations
- Bldg 1540A and 1540B gas and electric energy consumption
- Estimated labor and material costs to install a conventional system
- Labor and materials costs to operate and maintain the baseline system
- Relative occupancy of Bldgs 1540A and 1540B

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

Two configurations of radiant panels were used on this project. In conditioned spaces with existing grid ceilings, 2x4-ft grid-mounted radiant panels were used. In conditioned spaces without an existing grid ceiling, “cloud” panels were suspended from the hard overhead ceiling. Depending on zone load requirements, some panels were two-circuit panels that incorporated separate heating and cooling tubing. In some spaces, additional “cooling-only” panels were installed to satisfy cooling requirements beyond the capacity of the two-circuit panels.

The radiant panel system was supplied with hot water from an existing boiler and chilled water from a new air-cooled chiller. Figure 2-4 shows the layout of the hot water system and Figure 2-5 shows a schematic of the chilled water system. Chilled water was delivered to the DOAS AHU cooling coil at 42 °F and left at 49 °F. It was then delivered to the three-way mixing valve where it was blended with return water from the radiant cooling panels. The chilled water was then delivered to the radiant cooling panels where it was supplied at 61 °F and left at 66 °F. Cascading chilled water from the DOAS AHU cooling coil improved system efficiency by providing a larger delta temperature (ΔT) to the chiller. Also, delivering warmer chilled water to the ceiling-mounted radiant cooling panels minimized the risk of condensation on the cool surfaces of the panels by keeping the panel surfaces above the dew point temperature (DPT) of the air in the conditioned spaces.

Figure 2-6 shows the DOAS AHU. This was a constant volume device that filtered and preheated (if needed) outside air. The air then passed through an enthalpy wheel where it exchanged energy with building exhaust from the latrines. The ventilation air then passed through a deep cooling coil that cooled and dehumidified it before it entered the reheat coil where it was warmed to a neutral temperature before delivery to the occupied zones.

5.4 OPERATIONAL TESTING

The Contractor performed “before” testing of the building envelope to determine the relative tightness of the existing building. Based on this information, the Contractor designed an approach to improve the building envelope. Post-retrofit testing of the building envelope of the demonstration facility was performed to determine the effectiveness of envelope sealing activities.

The Contractor was unable to measure/record energy consumption of the baseline facility and demonstration facility during the retrofit design phase to obtain baseline energy usage due to an inability to get timely approval for their proposed energy monitoring system. Baseline (pre-retrofit) energy consumption data was dependent on the installation’s monthly utility records. On completion of installation of the retrofit systems, energy performance monitoring of the demonstration facility and of the baseline facility was initiated and continued for 12 months through September 2016 under typical outdoor ambient conditions and normal building occupancy. No modeling or simulations were conducted.

5.5 SAMPLING PROTOCOL

Table 5-1 details the elements of the data sampling, recording, and storage protocol for this demonstration. Performance data from Contractor-provided and installed sensors was acquired via a Contractor-provided energy monitoring system and transmitted to the Contractor’s location via a cellular phone connection. No Army data was collected, and this project did not access the installation’s enterprise networks.

Table 5-1. Data Sampling, Recording, and Storage Protocol.

Parameter	Data Collector	Data Recording	Data Storage and Backup	Data Collection Diagram	Non-Standard Data
Building air tightness testing	Building envelope air tightness testing Contractor	Automatic data recording by test apparatus	Data stored in test instrument	N/A	N/A
Temperature	Demonstration Contractor	Temperature loggers	Remote data access	N/A	N/A
RH	Demonstration Contractor	RH loggers	Remote data access	N/A	N/A
Gas consumption	DPW personnel	Manual recording	Paper and/electronic records	N/A	N/A
Electric consumption	DPW personnel	Manual recording	Paper and/electronic records	N/A	N/A
First costs	Demonstration Contractor	Invoices	Paper and/electronic records	N/A	N/A
O&M costs	DPW personnel	Work orders	Paper and/electronic records	N/A	N/A
Occupant satisfaction	Demonstration Contractor	Temperature loggers, Humidity loggers	Data stored in test instrument	N/A	N/A

DPW – Directorate of Public Works; NA – Not Applicable

- Energy Consumption – Electrical (kWh) and Thermal (British Thermal Units [BTU], converted to kWh).
  - Electrical data points were monitored via current transformer (CT) clamps and voltage measurements inside the main and branch circuit panels in each electrical room.
  - Thermal data points were monitored via BTU pulse meters (flow + temperatures) using supply and return water temperature sensors and a flow meter in the thermal distribution piping. This did not include domestic hot water supply.
- Outside Temperature and Humidity (°F and % RH).
  - Points were monitored via temperature and humidity sensors.
- Interior Room Temperature and RH of three selected rooms (°F and % RH).
  - Points were monitored via temperature and humidity sensors.
- Differential Pressure at two locations.
  - These instruments measured the pressure difference (Pa) between the exterior ambient air pressure and the air pressure within the building. These data indicated whether the building pressurization was ‘positive’ or ‘negative.’

Throughout the data-monitoring period, a monthly energy performance report used the kWh and BTU (converted to kWh) data to establish the total energy use of the two buildings. These data were in turn used as metrics to compare the differences in energy use of the two HVAC systems.

5.6 SAMPLING RESULTS

Sampling results are addressed in Section 6, Performance Assessment. Obtaining adequate energy performance data posed many challenges. For example, obtaining complete baseline energy performance data was not possible (Section 6.2.1) and it was difficult to make use of energy performance data from the first 12-month monitoring period (Section 6.2.2) because of significant occupancy differences between Bldg 1540a and Bldg 1540B.

The second 12-month energy performance monitoring period (Section 6.2.3) provided results that were more readily explainable. During this period, both sides of the facility were fully occupied and Bldg 1540B had been repaired and recommissioned to its original design intent.

Assessing "cost effectiveness" (Section 6.3) was challenging in that getting actual material and labor costs (versus contracted costs) from construction contractors is difficult and was not the focus of their activities. Also, cost effectiveness was largely based on a comparison with the estimated costs of installing a conventional VAV HVAC system versus the demonstrated system, which introduces a high degree of uncertainty.

Improved comfort (Section 6.4) was assessed based on temperature and RH data logged in a number of locations and anecdotal discussions with people familiar with the building. The team attempted to conduct an occupant survey to gauge satisfaction and obtain comfort-level feedback, but no responses were returned.

Sampling temperature and RH data provided a good indication of reduced mold and mildew potential (Section 6.5).

Due to limited maintenance activities, assessing maintainability of the demonstrated system (Section 6.6) was largely dependent on anecdotal evidence from maintenance personnel.

6.0 PERFORMANCE ASSESSMENT

6.1 REDUCED BUILDING ENVELOPE AIR LEAKAGE

The first quantitative Performance Objective was to reduce building envelope air leakage. Baseline building envelope air leakage testing was performed in accordance with the *U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes* (HQUSACE 2012b), which was based on American Society for Testing and Materials (ASTM) E779 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* (ASTM 2003a). Subsequently, work was performed to seal envelope leaks, followed by a repeat of building envelope leakage testing. Results are shown in Table 6-1.

Table 6-1. Building Envelope Air Leakage.

Building	Baseline Envelope Air Leakage	Post-Repair Envelope Air Leakage	Change
1540A	0.82 cfm_{75}/ft^2	0.39 cfm_{75}/ft^2	-52.5%
1540B	1.12 cfm_{75}/ft^2	Not Measured	N/A

While the goal of reducing envelope air leakage to <0.15 cfm_{75}/ft^2 was not achieved, significant improvement was demonstrated.

6.2 ENERGY PERFORMANCE

6.2.1 Baseline Energy Performance

Table 6-2. FY2013 Utilities Data for Bldg 1540 from the Fort Detrick Directorate of Public Works (DPW).

	Bldg 1540A			Bldg 1540B		
Date	Elec (kWh)	Gas (Therm)	Gas (kWh)	Elec (kWh)	Gas (Therm)	Gas (kWh)
Oct-12	6790.1	655.9	19,223	9316.7	530.4	15,544
Nov-12	4460.4	727.9	21,333	6174	679	19,900
Dec-12	3719.7	871.1	25,529	5205	784.6	22,994
Jan-13	4463.6	828.6	24,284	5980	779.2	22,836
Feb-13	4948	796.8	23,352	6956	536.6	15,726
Mar-13	3744	757.4	22,197	5090	332.9	9,756
Apr-13	6742	684.8	20,070	8532	460.2	13,487
May-13	8704	457	13,393	9201	430.4	12,614
Jun-13	15269	287.6	8,429	13313	235.1	6,890
Jul-13	7203		0	7313		0
Aug-13	0	231.3	6,779	0	22.9	671
Sep-13	0		0	0		0
TOTALS	66,044	6,298	184,588	77,081	4,791	140,419
TOTALS	250,632 kWh			217,500 kWh		
EUI	32.9 kWh/ft^2 (based on 7,618 ft^2)			38.9 kWh/ft^2 (based on 5,590 ft^2)		

The second quantitative Performance Objective was to demonstrate reduced energy consumption. The team was unable to measure pre-retrofit energy performance data due to the inability to obtain timely approval of the energy monitoring system from the installation's Network Enterprise Command (NEC). As a result, the team had to rely on access to Fort Detrick DPW utility records for FY2013 for baseline (pre-retrofit) energy performance data.

Based on total building areas of 7,618 ft^2 (Bldg 1540A) and 5,590 ft^2 (Bldg 1540B), the baseline Energy Use Intensity (EUI) was 32.9 kWh/ft^2 for Bldg 1540A and 38.9 kWh/ft^2 for Bldg 1540B. The team was unsure how to address data gaps for the months of July through September 2013.

6.2.2 Energy Performance – First 12-Month Monitoring Period (September 2014–August 2015)

After approval of the energy monitoring system, the team collected 12 consecutive months of energy use data for both Bldg 1540A and 1540B and compared the first 12 months of Bldg 1540A energy performance data to the first 12 months of Bldg 1540B energy performance data (Table 6-3).

Table 6-3. First 12-Month Energy Performance Monitoring Period (September 2014–Aug 2015).

	Bldg 1540A			Bldg 1540B		
Month	**Electric (kWh)**	**Gas (Therms)**	**Gas (kWh)**	**Electric (kWh)**	**Gas (Therms)**	**Gas (kWh)**
Sep 2014	7,893	248	7,268	4,332	432	12,661
Oct 2014	4,980	403	11,811	6,317	373	10,932
Nov 2014	4,980	816	23,915	6,071	710	20,808
Dec 2014	8,506	957	28,047	6,366	754	22,098
Jan 2015	10,010	894	26,201	6,679	792	23,211
Feb 2015	9,177	881	25,820	6,152	957	28,047
Mar 2015	20,165	447	13,100	677	606	17,760
Apr 2015	358	104	3,048	45	495	14,507
May 2015	1,263	82	2,403	5,779	423	12,397
Jun 2015	12,010	115	3,370	2,234	259	7,591
Jul 2015	10,083	83	2,432	3,374	133	3,898
Aug 2015	7,785	91	2,667	3,796	133	3,898
TOTAL	**97,210**	5,121	**150,082**	**51,822**	6,068	**177,806**
TOTALS	**247,292 kWh**			**229,628 kWh**		
EUI	32.5 kWh/ft^2 (based on 7,618 ft^2)			41.8 kWh/ft^2 (based on 5,590 ft^2)		
COLOR KEY	Pre-Retrofit Period (Unoccupied)		Retrofit Period (Unoccupied)		Post-Retrofit Period (Reoccupied)	

During the first 12 months of data collection, Bldg 1540A underwent a variety of phases related to the renovation process. These phases were: (1) an unoccupied, pre-retrofit period (September–October 2014), (2) an unoccupied retrofit period (November 2014–May 2015), and (3) a reoccupied post-retrofit period (June–August 2015).

Note that Bldg 1540B was continuously occupied throughout the duration of this project. Also, these first 12 months of data were collected prior to completing mechanical system repairs and recommissioning of Bldg 1540B.

6.2.3 Energy Performance – Second 12-Month Monitoring Period (September 2015–August 2016)

The team collected 12 additional months of energy use data for both Bldg 1540A and 1540B. These data were used to compare the first 12 months of Bldg 1540A energy performance data to the second 12 months of Bldg 1540A energy performance data. Also, the first 12 months of Bldg 1540B energy performance data was compared to the second 12 months of Bldg 1540B energy performance data. Finally, the second 12 months of Bldg 1540A energy performance data was compared to the second 12 months of Bldg 1540B energy performance data.

Table 6-4. Significance of First and Second 12-Month Monitoring Periods.

Building	First 12 Month Period (September 2014–August 2015)	Second 12 Month Period (September 2015–August 2016)
1540A Demonstration	Pre-retrofit, unoccupied – 2 months Retrofit in progress, unoccupied – 7 months Retrofit completed, occupied – 3 months	Post-retrofit, fully occupied
1540B Baseline	Pre-repair and recommissioning, fully occupied	Post-repair and recommissioning, fully occupied

Table 6-5. Second 12-Month Energy Performance Monitoring Period (Post-retrofit, Occupied, September 2015–August 2016).

	Bldg 1540A			Bldg 1540 B		
Month	**Electric (kWh)**	**Gas (Therms)**	**Gas (kWh)**	**Electric (kWh)**	**Gas (Therms)**	**Gas (kWh)**
Sep 2015	8,087	49	1,436	5,359	139	4,074
Oct 2015	6,203	166	4,865	4,449	323	9,466
Nov 2015	5,711	231	6,770	4,096	411	12,045
Dec 2015	5,370	251	7,356	4,540	485	14,214
Jan 2016	5,163	529	15,503	4,853	771	22,596
Feb 2016	4,665	425	12,456	4,621	697	20,427
Mar 2016	4,664	228	6,682	4,929	445	13,042
Apr 2016	5,233	158	4,631	4,665	281	8,235
May 2016	6,326	100	2,931	4,296	225	6,594
Jun 2016	8,086	32	938	4,830	43	1,260
Jul 2016	8,719	29	850	5,990	10	293
Aug 2016	9,809	31	909	6,235	12	352
TOTALS	**78,036**	2,228	**65,326**	**58,864**	3,842	**112,598**
TOTALS	**143,362 kWh**			**171,462 kWh**		
EUI	18.8 kWh/ft^2 (based on 7,618 ft^2)			30.67 kWh/ft^2 (based on 5,590 ft^2)		

6.2.4 Energy Performance Discussion

This project demonstrated apparent energy savings for Bldg 1540A's radiant system over the original all-air system and over the baseline Bldg 1540B system. Overall energy consumption (electric + gas) in Bldg 1540A for the period September 2015–August 2016 decreased 42% compared with the prior 12 months (September 2014–August 2015) (Table 6-3 and Table 6-5). This decrease was due to an apparent 20% decrease in electricity usage, and a 56% decrease in gas usage. Unfortunately, the apparent energy improvements in Bldg 1540A are difficult to explain. Increased energy use would have been expected in the second 12-month period since construction was complete and the building was fully occupied.

To try to understand this, the team compared Heating Degree Days (HDDs) and Cooling Degree Days (CDDs) from one year to the next. Daily average DBT data were obtained from the nearby Frederick Municipal Airport and used to generate HDD and CDD using a balance point of 60 °F. Table 6-6 shows that there were 14% more HDDs and 4% more CDDs in the period of September 2014–August 2015 than for the period September 2015–August 2016, not significant enough to account for the considerably more electrical and gas energy consumed in the period of September 2014–August 2015. Table 6-7 provides the summary of energy performance.

Table 6-6. Monthly Electric and Gas Usage with Corresponding HDD and CDD for Bldg 1540A for September 2014–August 2015 and September 2015–August 2016.

	September 2014–August 2015				September 2015–August 2016				
Month	**HDD_{60}**	**CDD_{60}**	**Electric (kWh)**	**Gas (Therms)**	**Month**	**HDD_{60}**	**CDD_{60}**	**Electric (kWh)**	**Gas (Therms)**
Sep 2014	5.4	282.5	7,893	248	Sep 2015	0	266.4	8,087	49
Oct 2014	56.6	77.8	4,980	403	Oct 2015	201.3	13.8	6,203	166
Nov 2014	442.9	3.1	4,980	816	Nov 2015	319.1	18.3	5,711	231
Dec 2014	614.4	0	8,506	957	Dec 2015	422.6	5.6	5,370	251
Jan 2015	886.5	0	10,010	894	Jan 2016	911.7	0	5,163	529
Feb 2015	943.7	0	9,177	881	Feb 2016	713.1	0	4,665	425
Mar 2015	624.1	0	20,165	447	Mar 2016	363.3	15.3	4,664	228
Apr 2015	167.3	29.3	358	104	Apr 2016	264.4	22.7	5,233	158
May 2015	11.7	282	1,263	82	May 2016	87.4	119.8	6,326	100
Jun 2015	2.9	371.1	12,010	115	Jun 2016	0	359.9	8,086	32
Jul 2015	0	496.9	10,083	83	Jul 2016	0	544.6	8,719	29
Aug 2015	0	438.1	7,785	91	Aug 2016	0	542.7	9,809	31
Total	3755.5	1980.8	97,210 kWh	5,121 Therms	Total	3282.9	1909.1	78,036 kWh	2,229 Therms
TOTAL			**247,292 kWh**		**TOTAL**			**143,362 kWh**	

Table 6-7. Summary of Energy Performance.

	Bldg 1540A				Bldg 1540B			
	Elec (kWh)	Gas (kWh)	Total (kWh)	EUI	Elec (kWh)	Gas (kWh)	Total (kWh)	EUI
FY2013 DPW Data	66,044	184,588	250,632	32.9	77,081	140,419	217,500	38.9
Demonstration Data Sep 2014-Aug 2015	97,210	150,082	247,292	32.5	51,822	177,806	229,628	41.1
Demonstration Data Sep 2015-Aug 2016	78,036	65,326	143,362	18.8	58,864	112,598	171,462	30.7

The team also noted that although Bldg 1540A was unoccupied from September 2014 to May 2015 (as the building was being renovated and commissioned), it still had comparable or greater electrical usage during several months in this period than during the same months in the following year; also, recorded gas usage during most months was greater than gas usage in the same months of the following (fully occupied) year. The Contractor went to great efforts to account for these anomalies, including checking the calibration of meters and instrumentation, reviewing sequences of operation and operational schedules, and verifying conversion factors on gas meters.

Construction contractor activities could have consumed an inordinate amount of electricity during the unoccupied period, but this is considered to be unlikely. The demonstration Contractor detected and corrected a boiler controls problem that allowed the boiler to stay fired during unoccupied periods even though no spaces had fallen below the night thermostat setting. The Contractor also detected that various room temperature setpoints had been adjusted downward on a number of occasions. This was especially intriguing since the Contractor themselves had no means to make such adjustments without hiring the installation’s controls contractor to make these changes. This anomaly remained unresolved.

6.3 COST EFFECTIVENESS

A third quantitative Performance Objective was to demonstrate cost effectiveness when compared to a conventional all-air HVAC system. The team tracked the costs to install the demonstrated systems and the cost to operate and maintain them, to include the cost of energy. These costs were compared with the costs to install, operate and maintain a conventional system in the same building. Costs associated with demolition of the previously existing all-air HVAC system were excluded from this analysis so that the included costs were similar to what might be experienced in a new construction project. The team also made sure that the costs attributed to the demonstrated systems did not include the costs of ancillary systems such as sensors and data collection systems that would not be included in a normal construction project. The team also attempted to reasonably adjust the purchase and installation costs of the demonstrated systems to account for the fact that the first costs for these systems would be expected to fall if they were to become more widely used.

The success criteria for this Performance Objective was to demonstrate a simple payback for the retrofit system of <5 years and an SIR >1.2. This objective was not met as the results were a simple payback of 26.7 years and an SIR of 1.0.

6.4 IMPROVED COMFORT

The first qualitative Performance Objective was to maintain occupant comfort. The comfort criteria referenced ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy, Section 5.2.1.1 "Graphic Zone Comfort Method" (ASHRAE 2010) (see Figure 6-1). No modeling or simulation was performed. The team did not perform a sensitivity analysis to determine how occupant comfort might be impacted by unusual outdoor temperature or humidity conditions. An attempt was made to survey occupants of Bldgs 1540A and 1540B on their comfort level, but no responses were received.

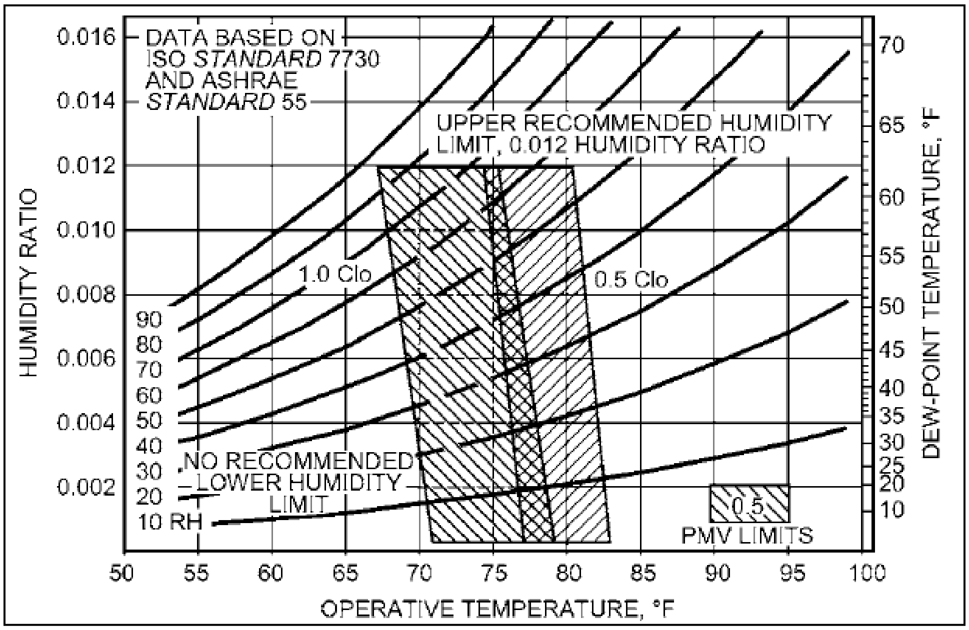

Figure 6-1. A Graphical Zone Method Chart Derived from ASHRAE Standard 55.

ASHRAE's Graphical Zone Method defines a plotted area of temperature and humidity combinations where 80% of occupants in mechanically cooled spaces will be comfortable while performing low exertion activities (typing, filing, etc.). The upper and lower temperature bounds in this standard are 82 °F in the summer and 67 °F in the winter. For Bldg 1540A, 95% of the daily temperatures (6:00 a.m.–6:00 p.m.) ranged between 62 °F and 78 °F, averaging 70 °F. Similarly, 95% of the daily relative humidities (6:00 a.m.–6:00 p.m.) ranged between 28–58% RH, averaging 43% (see Figure 6-2). These parameters for Bldg 1540A were predominantly within the standard's plotted area of acceptability, demonstrating Bldg 1540A's compliance with ASHRAE Standard 55-2010 (ASHRAE 2010). Interior temperatures during unoccupied periods were cooler than the Standard's 67 °F lower boundary due to the 55 °F night temperature setpoint. Although interior temperatures never fell to the 55 °F night setback temperature, temperatures were often below 67 °F at the start of the "occupied" period (6:00 a.m.–6:00 p.m.) in the winter months, accounting for many of the data points below the ASHRAE Standard 55 minimum temperature as seen in Figure 6-3.

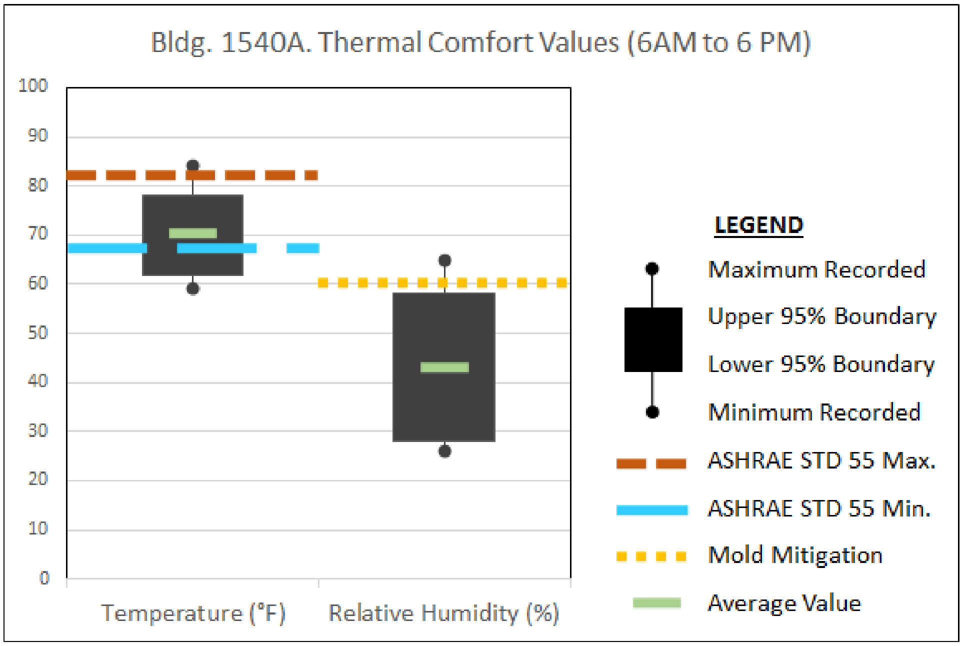

Figure 6-2. Thermal Comfort Values for Bldg 1540 during Occupied Hours (6:00 a.m.–6:00 p.m.).

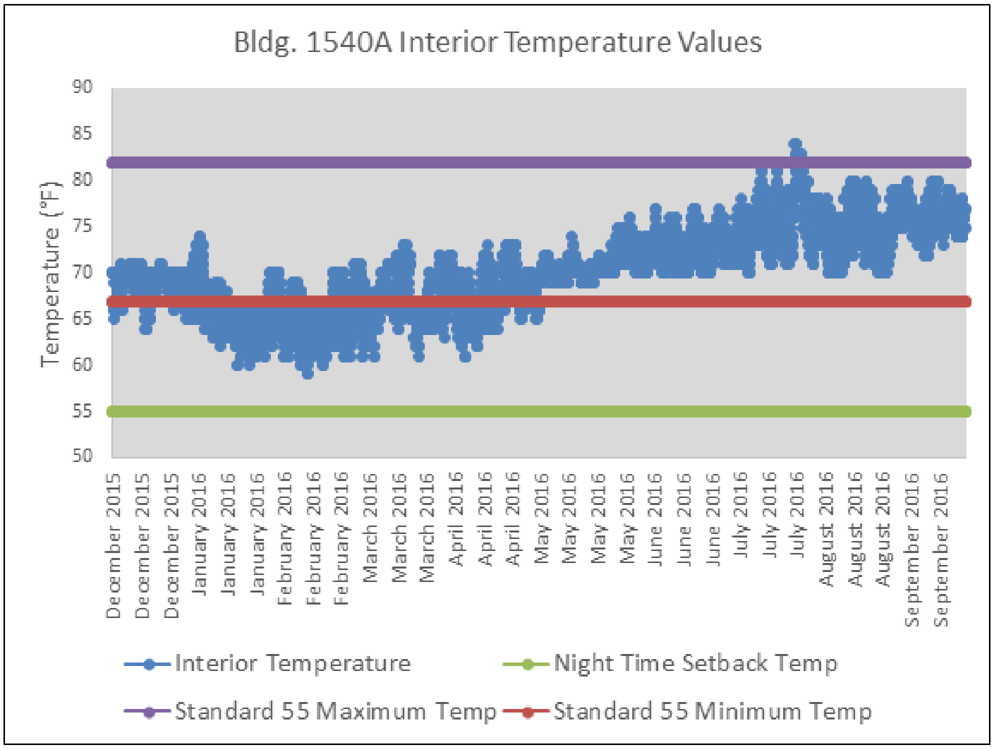

Figure 6-3. Interior Temperatures Recorded within Bldg 1540A.

In general, the team heard a number of very favorable anecdotal comments regarding comfort within Bldg 1540A, including remarks about comfortable temperatures and the quiet environment in most of the rooms. However, there were complaints of uncomfortably warm conditions in Bldg 1540A's Room C018B (the Information Assurance training classroom). Upon investigation, the team found that there were about twice as many occupants and computers occupying this room than had been initially planned for. In response to this complaint, the Contractor installed additional cooling panels in the ceiling of this room in an attempt to alleviate the lack of adequate cooling capacity. Subsequently, the team learned that the temperatures in the classroom were still too hot and that the occupants had brought in a portable cooling unit to blow cool air into the classroom.

This problem does not necessarily indicate a failure of the radiant cooling technology per se. With the actual cooling load nearly double the design cooling load, the addition of a few radiant panels could not solve the problem. Without a major reworking of the entire system in Room C018B (piping, valves, rearrangement of originally installed radiant cooling panels, and additional panels), it was not possible to gain the additional cooling capacity to satisfy the room's added cooling load.

It is also possible that the occupants' use of this room may have exacerbated the cooling problem. It was noted that the occupants often operated the room with both of its doors open to an adjacent unconditioned high-ceilinged storage area. This would have allowed heat from this uncooled space to infiltrate the classroom space, adding to its cooling load.

Also noted was that it was impossible for the Contractor to remotely control the temperature of the chilled water delivered to the radiant panels. Because the Contractor was not allowed to remotely control chilled water temperatures and other system parameters, and because the Contractor was being very careful to maintain radiant panel temperatures above the space DPT (to avoid condensation on radiant cooling panel surfaces), it was not practical for the Contractor to "play" with chilled water temperatures to see if that would resolve the temperature issue in this space. For example, assuming a mean radiant temperature in the space of 78 °F and a mean cooling panel surface temperature of 63.5 °F, reducing the cooling panel's surface temperature by just 2 °F (to 61.5 °F) would increase the panel's cooling capacity by 12%.

An important takeaway is that any HVAC system is only as good as the heating/cooling load estimates upon which it is based. If actual loads are significantly different than the original design, adding additional capacity can be very challenging.

Other than this unresolved problem in Room C018B, the team had heard only positive comments concerning comfort in the remainder of Bldg 1540A. These comments were discussed with DPW personnel, who said they were unaware of any other issues related to comfort in the building.

6.5 REDUCED RELATIVE MOLD/MILDEW POTENTIAL

The second qualitative Performance Objective was to demonstrate reduced potential for mold and mildew formation. Of the necessary ingredients for the growth of mold and mildew (spores, food source, an acceptable temperature range, and adequate moisture in the food source), the only one that can realistically be controlled is the moisture content of the food source. Therefore, the analysis focused on the ability of the retrofitted facility to maintain humidity in the building at levels that would keep building elements and building contents dry enough to discourage mold and mildew formation and growth.

"Water activity" describes the amount of water adsorbed by a specified material when it is in equilibrium with air at a given RH. Two material samples of equal mass but dissimilar sorption characteristics would contain differing absolute masses of water at the same water activity level. In other words, a water activity of 0.75 would correspond to the moisture content of a material with a given sorption characteristic when exposed to and in equilibrium with air at a RH of 75%. Since most building materials and building contents are not susceptible to mold growth at water activity levels <0.75, the goal was to ensure that no building materials or building contents experienced a water activity >0.75.

According to the *2015 ASHRAE Handbook: HVAC Applications* (ASHRAE 2015), "… a conservative limit for no mold ever, on anything at any temperature, is below 60% RH." Furthermore, the *2012 ASHRAE Handbook on HVAC Systems and Equipment* (ASHRAE 2012c) details an optimum humidity range for human comfort and health between 30–60% RH. Bldg 1540A averaged 43% RH during the occupied period (6:00 a.m.–6:00 p.m.) demonstrating the HVAC system's success in mitigating microbial growth potential. These accomplishments validated the ability for a properly-designed radiant panel and DOAS combination to maintain temperature and humidity to minimize mold and mildew potential for indoor health and comfort.

6.6 EASILY OPERABLE AND MAINTAINABLE

The final qualitative Performance Objective was to show that the demonstrated system was easily operable and maintainable. Because this project replaced a conventional mechanical system, the hope was that the retrofitted system would be as easily operable and maintainable as the existing system. Operability and maintainability was to be determined through the analysis of frequency and extent of operational problems associated with the demonstrated systems and the degree of difficulty that maintenance personnel experience in addressing these problems in comparison to the operations and maintenance (O&M) of the conventional system within the baseline facility.

O&M data for this system are sufficiently sparse and therefore are statistically insignificant. The team engaged O&M staff during commissioning of the demonstrated systems. O&M personnel who participated in the commissioning of the systems expressed their satisfaction with the relative simplicity of the installed systems.

Subsequent to turnover of the system, the team attempted to discuss with the installation energy manager and O&M staff their experiences working with the demonstrated system. As this was an unfamiliar technology, the team hoped to identify any areas of misunderstanding or concepts that needed to be explained so that maintenance staff could more easily operate and maintain the systems. Maintenance issues were discussed with the DPW Chief of Operations after about two years of operational experience. He said that he was unaware of any significant issues or problems with the system. In the absence of information to the contrary, it is believed that the demonstrated system was as at least as operable and maintainable as the conventional VAV system that it replaced.

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7.0 COST ASSESSMENT

The life-cycle cost (LCC) analysis was conducted throughout the course of the project. First, costs (material and equipment purchases and installation labor) were compiled during the course of system installation, which occurred within approximately the first 8 months of the project. Operational costs, including energy costs and O&M costs, were gathered during the second 12-month energy performance data collection period. The LCC analysis was completed using “User Friendly” Building Life-Cycle Costing (Addison 1999), a U.S. Department of Energy (DOE)-funded program that is a derivative of efforts described in the National Institute of Standards and Technology (NIST) Handbook 135 (Fuller and Petersen 1995).

7.1 COST MODEL

Table 7-1. Cost Model for the Demonstrated System.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware capital costs	Estimates made based on component costs for demonstration. This includes, but is not limited to: boiler, chiller, control systems, hardware, piping, pumps, and radiant panels.	$220,632
Installation costs	Labor required to install equipment and materials.	$110,000
Consumables	Estimates based on rate of consumable use during the field demonstration.	$0
Facility operational costs	Reduction in energy required versus baseline data.	($2,746)
Maintenance	Based on frequency of required maintenance and labor and material per maintenance action.	$220
Hardware lifetime	Estimate based on component degradation during demonstration.	
Operator training	Estimate of training costs.	$2,500
	TOTAL	$330,606

7.2 COST DRIVERS

7.2.1 Heating, Cooling, and Dehumidification Loads

The most obvious cost driver for any HVAC system is the size of the heating, cooling, ventilation, and dehumidification loads it must satisfy. HVAC system requirements are based on external loads (e.g., building location, orientation, and enclosure details), internal loads (e.g., occupants, equipment, and appliances), infiltration, and unique system requirements and building quality. In a cool, dry location, very little cooling and dehumidification capacity would be required. Conversely, in a hot, moist location, the system would need a large cooling and dehumidification capacity. Local climate conditions can make a large difference in the cost of the installed system.

7.2.2 Local Utility Rates

Although it was noted that the demonstrated system realized lowered total energy use, the team saw that the retrofit system used less gas energy (a relatively inexpensive source) at the expense of increased electrical energy (a relatively expensive source). Depending on internal and external loads, local utility rates may favor or disfavor this technology.

7.2.3 Required Mechanical System Space

When equipped with a desiccant energy recovery wheel, DOAS AHUs tend to be much larger than conventional air handlers. As a result, to accommodate physically larger equipment, more mechanical room space may be required.

7.2.4 Condition of Building Envelope (Retrofit Projects)

An effective air barrier is essential for a radiant heating/cooling project, especially in humid locations. For a retrofit project, the condition of the facility's air barrier can have a large effect on project cost. This project selected a building with an existing interior air barrier that needed to be extensively repaired and completed for purposes of this project. Nevertheless, if the facility had no air barrier to begin with, installing a continuous air barrier would have added a large cost to this project.

7.3 COST ANALYSIS AND COMPARISON

An LCC analysis was performed comparing the project installation cost including materials and equipment costs, labor costs, energy costs, and O&M costs. The radiant panel system with DOAS was compared with a conventional chilled/hot water VAV system such as existed at Bldg 1540A before implementation of this demonstration project. The costs associated with a modern conventional chilled/hot water VAV system were estimated using RSMeans data.

Costs included:

- Base: (Conventional chilled/hot water VAV system)
  - Estimated first cost of system (using RSMeans): $259,250
  - Estimated yearly utility cost (derived from scaling Bldg 1540B consumption): $9,717
  - Yearly maintenance costs: $1,540
- Alternate: (Radiant panel system with DOAS)
  - Actual first cost of system: $332,632
  - Actual first year utility cost: $6,971
  - Yearly maintenance costs: $220

Assumptions were:

- DOE/Federal Energy Management Program (FEMP) Fiscal Year: 2015
- Real Discount Rate for Capital Costs: 3.0%
- Real Discount Rate for Operations Costs: 3.0%
- Study Period (years covered by the LCC analysis): 25
- Number of Years before Project Occupancy or Operation: 0
- DOE Fuel Price Escalation Region: 3
- Analysis Sector: 2.

The present value LCCs for 25 years were:

- Base: (Conventional chilled/hot water VAV system): $470,796
- Alternate: (radiant panel system with DOAS): $468,087

The study indicated a 23.9 year simple payback and a 26.7 year discounted payback for the radiant panel system with DOAS. ASHRAE research has documented radiant equipment in service for >20 years (ASHRAE 2017). Therefore, the 23.9 year simple payback and 26.7 year discounted payback timelines are plausible.

Efforts were made to improve the condition of both buildings (Table 7-2). The $3,500 spent in labor and materials to improve the air tightness of Bldg 1540A yielded $87.58 in annual energy savings (electric + gas). The simple payback on these sealing efforts is 40.0 years.

Table 7-2. Financial Overview of the Efforts Made to Improve the Condition of Bldgs 1540A and 1540B.

Building	Effort	Investment	Annual Savings	Payback (Years)
1540A	Improve air tightness of building envelope	$3,500	$87.58	40.0
1540B	Retro-commissioning	$48,996	$1,870	26.2

A total of $48,996 was invested in the retro-commissioning of Bldg 1540B. Comparison of the 2014/2015 and 2015/2016 fiscal years revealed that the retro-commissioning efforts yielded similar electrical energy usage to the prior year, but a 37% decrease in gas usage. This gas energy savings yields a $1,870 annual benefit, with a 26.2 year simple payback. Accounting for the annual finances associated with envelope leaks did not materially change the LCC analysis (Table 7-3).

Table 7-3. Annual Finances Associated with Envelope Leaks in Bldg 1540A.

Location	Annual Heating Cost Due to Leaks	Annual Cooling Cost Due to Leaks	Total Cost
Bldg 1540A (05/08/2014)	$312.00	$50.15	$362.15
Bldg 1540A (08/13/2015)	$224.42	$36.07	$260.49
	Heating Savings	**Cooling Savings**	**Total Savings**
Bldg 1540A (Resulting from Sealing Efforts)	$87.58	$14.08	$101.66
Bldg 1540A (If Window Leaks Eliminated)	$67.68	$10.88	$78.56

On a first cost basis, the radiant panel system with DOAS installed was $73,382 (28%) more expensive than the Conventional Chilled/Hot Water VAV System ($332,632 and $259,250, respectively). For rudimentary scaling purposes, this translates to $43.66/ft^2 for the radiant panel system with DOAS and $34.03/ft^2 for the Conventional Chilled/Hot Water VAV System (Table 7-4). Ultimately, the radiant panel system with DOAS produces a $2,709 present value life-cycle savings over a 25-year period compared with the Conventional Chilled/Hot Water VAV System (see Table 7-5 through Table 7-7). Therefore, the cost savings metric does not sufficiently distinguish radiant panel system with DOAS from the Conventional Chilled/Hot Water VAV System. However, the performance benefits of the radiant panel system with DOAS compared with the Conventional Chilled/Hot Water VAV System detailed in Section 6.0 Performance Assessment, provide motivation for adopting the radiant panel system.

Table 7-4. A Comparison of Materials and Labor First Costs between Radiant Panel and Conventional HVAC Systems.

Parameter	Radiant Panel System	Conventional HVAC System
Materials	$222,632.00	$136,884.00
Labor	$110,000.00	$122,366.00
Total	$332,632.00	$259,250.00
Total per Square Foot	$43.66/ft^2	$34.03/ft^2

Table 7-5. LCC Analysis (Table 1 of 3).

		One-Time Costs		Total Utility		
		1st Year	LCC	1st Year	Undiscounted LCC	LCC
Case	Description	$	Photovoltaic (PV) $	$	PV $	PV $
Base	Conventional HVAC	$259,250	$259,250	$9,717	$269,000	$184,730
Alt 1	Radiant Panels	$332,632	$332,632	$6,971	$191,263	$131,624
Life-Cycle Savings						
Alt 1	Radiant Panels	($73,382)	($73,382)	$2,746	$77,737	$53,105

Table 7-6. LCC Analysis (Table 2 of 3).

		Maintenance		Total	Total	Net
		1st Year	LCC	Undiscounted LCC	LCC	Savings
Case	Description	$	PV $	PV $	PV $	NS
Base	Conventional HVAC	$1,540	$26,816	$566,750	$470,796	n/a
Alt 1	Radiant Panels	$220	$3,831	$529,395	$468,087	n/a
Life-Cycle Savings						
Alt 1	Radiant Panels	$1,320	$22,985	$37,355	$2,709	$2,709

Table 7-7. LCC Analysis (Table 3 of 3).

		Simple Payback	Discounted Payback	Investment Related	Operations Related	Saving-to-Invest. Ratio	Adjusted Internal Rate of Return
Case	Description	Years	Years	PV $	PV $	SIR	AIRR
Base	Conventional HVAC	N/A	N/A	$259,250	$211,546	N/A	N/A
Alt 1	Radiant Panels	N/A	N/A	$332,632	$135,455	N/A	N/A
Life-Cycle Savings							
Alt 1	Radiant Panels	26.7	23.9	$73,382	$76,091	1.0	3.1%

8.0 IMPLEMENTATION ISSUES

8.1 LESSONS LEARNED

8.1.1 Air Barrier Issues

When planning a retrofit project, it is important to pay attention to the condition of the facility's existing air barrier. This demonstration project used a typical existing DoD facility that incorporated an air barrier system built with drywall encompassing the entire interior of the building. The team discovered that the ceiling of the existing drywall air barrier system had been penetrated by numerous construction trades and never resealed to prevent air infiltration. Also found were other areas where large portions of the original air barrier were never installed. This is probably to be expected for many existing facilities and, hopefully, an avoidable problem on new construction projects.

8.1.2 Radiant Panel Installation

Above-ceiling access could be a future problem with grid-mounted radiant panel systems; however, this issue can be overcome with additional coordination of fire, electrical, and mechanical services located within the ceiling to consolidate the services as best as possible.

For retrofit applications, it may be best to plan to replace the entire existing ceiling grid system. Working around existing fire sprinklers and light fixture locations proved to be very difficult. In some cases, "cloud" radiant panels might be a good option (versus grid-mounted radiant panels) as they would give the designer and installers some flexibility in mounting the cloud radiant panels. This might also facilitate future above-ceiling access.

8.1.3 System Optimization

8.1.3.1 Adjust Ventilation Rate

Outside air flow should be adjusted to that required to satisfy the actual ventilation and pressurization requirements of the building. This project delivered a constant volume of ventilation air during occupied hours based on constant exhausting of large locker rooms. Considerable energy can be saved if the ventilation rate can be modulated to the actual ventilation/exhaust requirement.

8.1.3.2 Adjust DOAS Dehumidification Coil Leaving Air Temperature

Considerable energy could be saved if the leaving air temperature of the DOAS dehumidification coil could be adjusted to the building's actual dehumidification requirement.

8.2 TECHNOLOGY READINESS

All the equipment and design expertise required to implement these technologies is already in place from an industry perspective. Current design requirements are well acknowledged by HVAC designers. Commercial installation by HVAC installers is straightforward although not typically specified by HVAC designers.

No potential regulations or special permits are required to use these technologies. The required equipment is standard commercial off-the-shelf (COTS) and does not require customization or custom build procedures.

End-users have been reluctant to use radiant heating and cooling since it represents a paradigm shift in normal application of HVAC technology. A common concern is that this technology cannot adequately cool or dehumidify to satisfy occupant comfort. This project demonstrated that radiant systems are capable of satisfying occupants’ space heating and cooling requirements.

End-users have also been concerned that a radiant cooling system will experience condensation on the cool surface of the radiant panels. By properly dehumidifying ventilation air through the DOAS, by having a tight building envelope, and by maintaining the surface temperatures of the radiant panels above the DPT of the air within the space, the demonstration showed that it is possible to implement radiant cooling without risk of condensation problems within the facility.

9.0 REFERENCES AND WORKS CONSULTED

Addison, M.S., and Associates. 1999. “User Friendly” Life-Cycle Costing: The BLCC Procedure in an Easy-to-Use Spreadsheet. Albuquerque, NM: U.S. DOE Pollution Prevention Conference.

ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers). 1997. *ASHRAE Handbook: Fundamentals*. Atlanta, GA: ASHRAE.

ASHRAE. 2004a. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE Standard 90.1-2004. Atlanta, GA: ASHRAE.

ASHRAE. 2004b. *Ventilation for Acceptable Indoor Air Quality*. Standard 62.1. Atlanta, GA: ASHRAE.

ASHRAE. 2010. *Thermal Environmental Conditions for Human Occupancy*. ASHRAE Standard 55-2013. ASHRAE Standard 90.1-2004. Atlanta, GA: ASHRAE.

ASHRAE. 2012a. *ASHRAE Handbook*. Atlanta, GA: ASHRAE.

ASHRAE. 2012b. *Performance Measurement Protocols for Commercial Buildings: Best Practice Guide*. Atlanta, GA: ASHRAE.

ASHRAE. 2012c. *2012 ASHRAE Handbook—HVAC Systems and Equipment*. Atlanta, GA: ASHRAE.

ASHRAE. 2014. *Measurement of Energy, Demand, and Water Savings*. ASHRAE Guideline 14-2014. Atlanta, GA: ASHRAE.

ASHRAE. 2015. *2015 ASHRAE Handbook: HVAC Applications*. Atlanta, GA: ASHRAE.

ASHRAE. 2017. ASHRAE Owning and Operating Cost Database. “Miscellaneous - Service Life Data per Above Criteria.” Atlanta, GA: ASHRAE. Accessed January 23, 2017, http://xp20.ashrae.org/publicdatabase/system_service_life.asp?selected_system_type=8.

ASTM (American Society for Testing and Materials). 2003a *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. ASTM E779, West Conshohocken, PA: ASTM, http://www.ce.utexas.edu/prof/Novoselac/classes/CE397/Handouts/astm%20e779%20-%20air%20leakage%20by%20fan%20pressurization.pdf.

ASTM. 2003b *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*. ASTM E1186, West Conshohocken, PA: ASTM.

ASTM. 2011. *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door*. ASTM E 1827. West Conshohocken, PA: ASTM https://compass.astm.org/EDIT/html_annot.cgi?E1827+11.

ASTM. 2013. *Standard Test Method for Air Permeance of Building Materials*. ASTM E2178. West Conshohocken, PA: ASTM.

Bauman, Fred, Jingjuan Feng, and Stefano Schiavon. 2013. "Cooling Load Calculations for Radiant Systems: Are They the Same as Traditional Methods." *ASHRAE Journal* 55(12):20-27.

EISA (Energy Independence and Security Act of 2007). 2007. Pub.L. No. 110-140, 121 Stat. 1492, originally named the Clean Energy Act of 2007.

EnTouch. 2017. *ENTOUCH: Smart Building Solutions*. Web site, www.entouchgo.com.

EPACT (Energy Policy Act of 2005). 2005. Pub.L. 109–58, 119 Stat. 594.

Fuller, Sieglinde K., and Stephen R. Petersen. 1995. *Life-Cycle Costing Manual for the Federal Energy Management Program*. National Institute of Standards and Technology (NIST) Handbook 135. Washington, DC: U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, https://www.wbdg.org/FFC/NIST/hdbk_135.pdf.

HQUSACE (Headquarters, U.S. Army Corps of Engineers). 2009. *Building Air Tightness Requirements*, Engineering and Construction Bulletin (ECB) 2009-29. Washington, DC: HQUSACE, https://www.wbdg.org/FFC/ARMYCOE/COEECB/ARCHIVES/ecb_2009_29.pdf.

HQUSACE. 2012a. *Building Air Tightness and Air Barrier Continuity Requirements*. ECB 2012-16, Washington, DC: HQUSACE, https://www.wbdg.org/FFC/ARMYCOE/COEECB/ARCHIVES/ecb_2012_16.pdf.

HQUSACE. 2012b. *U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes*. Version 3. Washington, DC: HQUSACE, http://www.ibts.org/5-11-2012_usace_airleakagetestprotocol_V3_%20.pdf.

HQUSACE, Naval Facilities Engineering Command (NAVFAC), Air Force Civil Engineer Support Agency (AFCESA). 2003. *Heating, Ventilating, and Air-Conditioning Systems*. UFC 3-410-01 (CANCELLED). Washington, DC: HQUSACE, NAVFAC, AFCESA, http://www.wbdg.org/FFC/DOD/UFC/ufc_3_410_01_2013_c2.pdf.

HQUSACE, NAVFAC, AFCESA. 2010. *Design and O&M: Mass Notification Systems.* UFC 4-021-01. Washington, DC: HQUSACE, NAVFAC, and AFCESA, http://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-4-021-01.

HQUSACE, NAVFAC, AFCESA. 2011. *Architecture*. UFC 3-101-01. Washington, DC: HQUSACE, NAVFAC, and AFCESA, https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-101-01.

HQUSACE, NAVFAC, AFCESA. 2012. *DoD Minimum Antiterrorism Standards for Buildings*, Unified Facilities Criteria (UFC) 4-010-01. Washington, DC: HQUSACE, NAVFAC, AFCESA, https://www.wbdg.org/FFC/DOD/UFC/ufc_4_010_01_2012_c1.pdf.

Mumma, S. A. 2001. "Designing dedicated outdoor air systems." *ASHRAE Journal*. 43(5):28–31, http://doas-radiant.psu.edu/Journal1.pdf.

OMB (Office of Management and Budget). 2016. Memorandum of Understanding (MOU) with the U.S. Department of Energy (USDOE), Subject: "2016 Strategic Sustainability Performance Plan, Energy Security," https://energy.gov/sites/prod/files/2016/09/f33/DOE%202016%20SSPP%20Revision%2009022016.pdf.

Parsons, Robert (ed.). 1997. *1997 ASHRAE Handbook: Fundamentals*. Atlanta, GA: ASHRAE.

Sastry, Guruprakash, and Peter Rumsey. 2014. "VAV vs. Radiant: Side-by-Side Comparison." *ASHRAE Journal* 56(5):16-24.

UC Regents. 2014. "Radiant Systems Research." *CBE: Center for the Built Environment*. Web page. Accessed 19 October 2016, http://www.cbe.berkeley.edu/research/radiant-systems.htm.

USA TODAY. 2008. "Age, mold assail military barracks." *USA TODAY*. 9 May 2008.

USEPA (U.S. Environmental Protection Agency). 2006. MOU, subject: "Federal Leadership in High Performance and Sustainable Buildings," https://archive.epa.gov/greenbuilding/web/pdf/sustainable_mou.pdf
also see:
https://www.epa.gov/greeningepa/guiding-principles-federal-leadership-high-performance-and-sustainable-buildings.

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