ERDC/CERL TR-17-26

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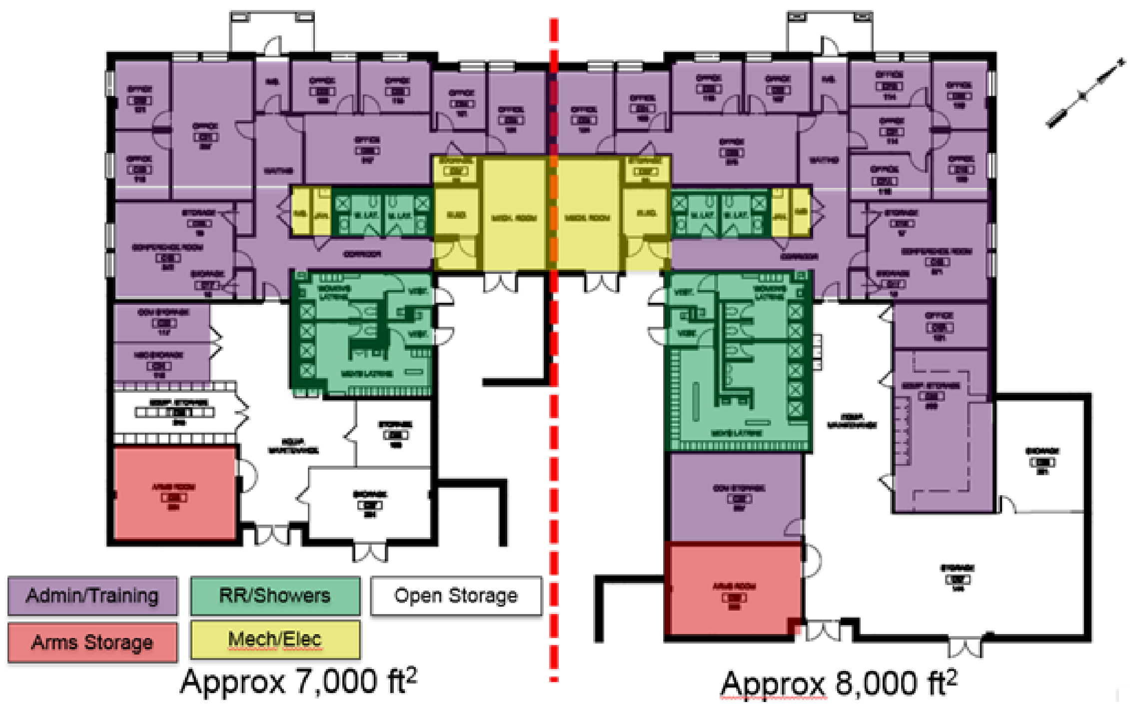
Environmental Security Technology Certification Program (ESTCP)

Systems Approach to Improved Facility Energy Performance

James P. Miller

February 2019



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Systems Approach to Improved Facility Energy Performance

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Final Report

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Abstract

The 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&B) 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 Supply (DOAS) system 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.

Executive Summary

The Department of Defense (DoD) is continually interested in improving their facilities in a variety of aspects, including enhancing energy performance and improving mold and mildew mitigation. This motivated a DoD funded research effort on a pair of single-story, brick clad administrative facilities (Bldgs 1540A&B) at Fort Detrick, MD. Bldg 1540A was the focus of facility improvements, and Bldg 1540B served as the control for comparison. These side-by-side buildings were approximately 20 years old, of separate but nearly mirrored construction, and had the separating space between them enclosed to enable a continuous roof. However, the two buildings retained their separate conditioned envelopes. The selected building related concerns targeted in this research effort, and their corresponding performance objectives, are:

- **Concern:** Mold and mildew problems resulting from uncontrolled relative humidity (RH).
- **Objective:** Reduce mold and mildew potential by achieving an average RH below 60%.
- **Concern:** Occupant comfort.
- **Objective:** Satisfy American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 55, *Thermal Environmental Conditions for Human Occupancy*.
- **Concern:** Reducing energy consumption.
- **Objectives:** Achieve a building air leakage rate less than 0.15 cfm/ft^2 at 75 Pa.; Achieve a 20% reduction in heating, cooling, and ventilation system energy.
- **Concern:** Economic improvement.
- **Objective:** Cost-effective investment with a simple payback less than 5 years; Easily maintainable by existing staff.

Each building contained its own heating, ventilating, and air-conditioning (HVAC) and boiler systems. However, Bldg 1540A was retrofitted with three complementary and innovative technologies that collectively addressed the aforementioned concerns. These technologies were:

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

These technologies were considered successful despite the fact that they did not entirely meet some of their aggressive objectives. The analysis and results from Bldg 1540A were as follows: Blower door testing was used to assess building envelope air leakage, and enabled sealing efforts that decreased infiltration from 0.82 to 0.39 cfm/ft^2 at 75 Pa. While infiltration was greater than the 0.15 cfm/ft^2 at 75 Pa. objective, it was a 52% reduction in building air leakage. The DOAS system dehumidified the outdoor air used to both ventilate the space and to supply makeup air for air that was mechanically exhausted. 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 ASHRAE Standard 55 (2010). The 95th percentile of Bldg 1540A space temperatures and RH values during occupied hours (6:00 a.m. to 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. Economically, an absence of maintenance concerns demonstrated the system's Operations and Maintenance (O&M) success; however, the system's 26.7 year simple payback exceeded the 5 year objective. Table ES-1-1 lists the quantitative and qualitative performance objectives of this work.

Renovation activities in Bldg 1540A began in Nov 2014 and were completed in Apr 2015. Mechanical system deficiencies in Bldg 1540B were repaired and both sides of the building were commissioned/recommissioned to operate according to their respective design intent. Bldg 1540A was reoccupied in Jun 2015 and a 12-month period of measuring and recording energy performance of both sides of the building commenced in September 2015.

Table ES-1. Performance objectives.

Performance Objective	Success Criteria	Results
Quantitative Performance Objectives		
Reduced building envelope air leakage	< 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	20% reduction in heating, cooling and ventilation system energy	46% reduction in overall energy usage (electric + gas) Objective met
Cost effectiveness	Simple Payback: < 5 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 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 a.m. and 6 p.m. Objective met.
Reduced relative mold/mildew potential	Measurement of interior surfaces at or below 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 O&M burden	Objective met

This project resulted in a number of 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 system 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 when compared with conventional all-air HVAC systems.
5. Radiant systems are easily maintainable and require no special skills for HVAC technicians.
6. 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 favorable with traditional all-air HVAC systems.

Contents

Tables and Figures

Tables

Figures

Preface

Funding for this demonstration was provided by the Environmental Security Technology Certification Program (ESTCP) under Military Interdepartmental Purchase Requests (MIPRs) No. W74RDV23461416, W74RDV20749510, W74RDV20749509, W74RDV53553148, and W74RDV70303974 under FY14 Energy and Water Project EW-201150. The ESTCP technical monitor was Scott Clark.

The work was managed by the Energy Branch (CFE) of the Facilities Division (CF) of ERDC-CERL. At the time of publication, Mr. Andrew Nelson was Chief, CEERD-CF-E; L. Michelle Hansen was Acting Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CV-T was the Technical Director. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel.

Thanks are owed to ESTCP, particularly Dr. James Galvin, for his unwavering support of this project. Mr. Brian Dean and Mr. Scott Clark, of HydroGeoLogic, Inc.(HGL), are acknowledged for their technical advice throughout the critical planning and renovation stages of this project. Mr. Timothy Tetreault and Ms. Sarah Medepalli provided continued support as the project transitioned to the data collection and reporting phase. Mr. Larry Potter, Fort Detrick's Director of Public Works, for his support of this project throughout it many stages. Mr. Larry Wright, Directorate of Public Works (DPW) Operations and Maintenance (O&M) Supervisor and Mr. Mark Zangara, Fort Detrick's Energy Manager both provided invaluable support. Fort Detrick's 21st Signal Brigade and 514th Signal Battalion are recognized for their support, patience, and cooperation, especially during the months when they were displaced from their building while the demonstration system was being installed and tested. Mr. Paul Smeck, O&M Supervisor of the 21st Signal Brigade, provided invaluable service coordinating activities between the Contractors and the building occupants. Thanks are proffered to the U.S. Army Corps of Engineers (USACE) Baltimore District, including Mr. Glenn Murphey, Ms. Katie Brown, and Mr. Patrick Welker for their excellent support in overseeing day-to-day construction activities, system commissioning, and coordination of Contractor access to the installation.

COL Bryan S. Green was Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

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.

In recent years, mold and mildew became a public relations concern for the Army and the other services as well. Major news stories documented the poor state of Army barracks facilities. For example, USA TODAY (2008) reported that "At Fort Campbell, soldiers struggle in the hot Kentucky summers to keep mold from taking over their showers." As a result of a 2008 worldwide review of conditions in barracks facilities, the Army committed to spend $248 million to address mold, plumbing, and temperature-control problems at eight major installations in the Continental United States (CONUS) and Hawaii (USA Today 2008).

Concerns about mold and mildew in Army facilities are not a recent occurrence. For many years, the Army has attempted to address these problems through routine maintenance, minor remediation efforts, and major renovation of Army facilities. In many cases, building interiors were completely demolished and replaced and new HVAC systems installed. Unfortunately, in spite of the millions of dollars invested, the Army's efforts to get a handle on this issue persistently failed to achieve long-term fixes. Both newly constructed and recently renovated facilities in hot and humid locations commonly experienced mold and mildew problems within a few years of completion.

Project Background and Potential Contribution to DoD. This project was initiated to demonstrate integration of three innovative technologies that would address 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 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 system 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 system 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). The radiant panel system is expected to perform better than a conventional HVAC system. According to the Dec 2013 ASHRAE Journal article "Cooling Load Calculations For Radiant Systems" (Bauman, Feng, and Schiavon 2013), an experimental study revealed "The radiant system has a higher cooling rate than the air system, meaning that it is faster to remove heat gains while maintaining equivalent comfort conditions. For the tested cases, 75% to 82% of the total heat gain was removed by the radiant system … while for the air system, 61% to 63% was removed." With good control of humidity conditions in the building, there should be little risk of moisture condensing on the cold surfaces of radiant panels when operating in the cooling mode.

Project Intent: The intent of this project was to demonstrate the feasibility and benefits resulting from the integration of building envelope improvements with a DOAS system and a radiant heating/cooling system. The significance of this effort included:

- **Tightened Building Envelope:** Significant tightening of the Bldg 1540A envelope was an important accomplishment because it demonstrated the potential for DoD to greatly improve the building envelopes of many thousands of existing military facilities. In many cases, the Contractor used minimally invasive sealant methods such as sealing with closed-cell spray polyurethane foam (ccSPF) and/or caulking with backer material where necessary. In several locations, large unfinished openings in the building's air barrier were sealed with gypsum board and drywall compound.
- **Proper Building Ventilation and Humidity Control:** We successfully demonstrated that a DOAS system can maintain building humidity conditions at levels that will not cause condensation on radiant cooling surfaces and maintain building conditions that are relatively less favorable to the formation of mold and mildew than buildings without a DOAS system.
- **Radiant Heating/Cooling System:** By successfully installing and demonstrating a radiant heating/cooling system we showed that it is possible to condition a building in a humid climate without experiencing condensation on cool radiant surfaces. We also demonstrated that radiant heating/cooling systems are able to efficiently and cost effectively heat and cool admin/training facilities and satisfy occupant comfort requirements while being easily operable and maintainable.

Project Timeline. ESTCP approved this project for funding in Fiscal Year 2011 (FY11). An extended project delay occurred resulting from a decision by the original demonstration site to withdraw from the project. Our original proposal to ESTCP was to perform this demonstration on a VOLAR Barracks facility at Fort Polk, LA. As Fort Polk was in the midst of an ongoing program to renovate 31 of these existing barracks facilities, we proposed to revise the plans and specifications for one of these facilities and have the renovation Contractor execute the revised plans and specifications on that facility. Following Fort Polk's withdrawal from the demonstration, we conducted a DoD-wide search to find a suitable replacement demonstration site. Fort Detrick's Bldg 1540 was identified as the new demonstration site. Because Bldg 1540 was quite different from the VOLAR Barracks at Fort Polk, our entire approach to the project had to be revised. A revised proposal was submitted to ESTCP in the second quarter of FY12. Subsequently, ERDC Contract No. W9132T-14-C-0001 was awarded to the PERTAN Group on 30 Oct 2013. This project was scheduled to be executed over a 30-month period. Table 1-1 lists major project milestones and descriptions of these milestones.

Table 1-1. Project milestones.

Milestone	Start	Finish
Contract Award	30 Oct 2013	30 Oct 2013
Onsite Kickoff Meeting	20 Nov 2013	20 Nov 2013
"Before" Air Tightness Testing of Demonstration Building Envelope (1540A)	7 May 2014	8 May 2014
Prepare Concept Retrofit Design	12 May 2014	20 Jun 2014
Finalize Retrofit Design	21 Jun 2014	6 Aug 2014
Retrofit System Installation (1540A)	17 Nov 2014	24 Apr 2015
System Commissioning of Demonstration Bldg (1540A)	7 May 2015	8 May 2015
"After" Air Tightness Testing of Demonstration Building Envelope (1540A)*	10 Aug 2015	14 Aug 2015
Identification, repair of Mechanical System Deficiencies in Baseline Bldg 1540B	6 Mar 2014	7 Aug 2015
Recommissioning of Baseline Bldg 1540B	10 Aug 2015	14 Aug 2015
Energy Monitoring	1 Sep 2015	30 Sep 2016
Data Analysis and Draft Final Report	1 Sep 2015	30 Sep 2016
Final Report and Cost and Performance (C&P) Report	1 Jan 2017	31 Mar 2017
*Due to weather conditions, air barrier testing of Bldg 1540A in Mar 2014 was repeated 7-8 May 2014.		

1. "Before" Air Tightness Testing of Demonstration Building Envelope. At the start of the project, the demonstration side of the facility (1540A) underwent air barrier testing to establish the existing air leakage rate (measured as cfm/ft^2 of leakage through the building envelope @75 Pa) for the demonstration facility (refer to Section 6.1 "Baseline Performance").
2. Prepare Concept Retrofit Design. Based on the results of "Before" air tightness testing, as-built drawings, and a survey of existing conditions, PERTAN prepared a concept design for building system improvements (im-

proved building envelope, DOAS system and radiant heating/cooling system) (refer to Chapter 2, "Technology Description"). They also developed a concept instrumentation plan and data acquisition system design, which were submitted for Government review/comments.

3. Finalize Retrofit Design. After receiving Government review comments, PERTAN prepared a final demonstration design for building system improvements and a design for the instrumentation and data acquisition system.
4. Retrofit System Installation. PERTAN subcontracted with a general Contractor (Musser Mechanical, Mercersburg, PA) to install the retrofit design. This included system commissioning of the demonstration facility and repairing and recommissioning of the baseline facility to ensure that it was operating according to its original design intent. Other subcontractors installed instrumentation and a data acquisition system for measuring and recording operational data.
5. "After" Air Tightness Testing of Demonstration Building Envelope. "After" testing was performed to establish the air leakage rate for the improved demonstration facility (refer to Section 6.1, "Baseline Performance").
6. Identification, Repair of Mechanical System Deficiencies in Baseline Bldg 1540B. Numerous deficiencies were identified in the baseline Bldg 1540B system, which were certain to impact the energy performance of Bldg 1540B. After trying unsuccessfully to get these deficiencies repaired by the Directorate of Public Works (DPW), we executed a contract modification to have the demonstration Contractor make the necessary repairs.
7. Recommissioning of Baseline Bldg 1540B: Following completion of repair work in Bldg 1540B, the building was recommissioned to ensure that it was performing per its original design specifications.
8. Energy Monitoring: On completion of renovation, commissioning and installation of performance data collection systems in Bldgs 1540A&B, PERTAN collected and analyzed performance data for a period of 12 months (refer to Section 5.5, "Sampling Protocol"). Because repair and recommissioning of Bldg 1540B was completed in Sep 2015, the Energy Monitoring period was extended through Sep 2016.
9. Data Analysis and Draft Final Report: On completion of the Energy Monitoring period, the Contractor completed the data analysis and prepared a draft final report.
10. Final Reports: After submittal and review of the draft Final Report, CERL incorporated ESTCP's comments into a Final Report and a C&P Report (refer to Chapter 7, "Cost Assessment").

1.1 Objective

The 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. The findings from this project will not influence or change ASHRAE or other national standards by itself, but can add momentum to larger, collective research efforts concerning radiant cooling systems (e.g., the Center for the Built Environment's ongoing Radiant Systems Research, http://www.cbe.berkeley.edu/research/radiant-systems.htm) (UC Regents 2014)).

This project will help DoD to improve building energy performance by demonstrating the value and feasibility of achieving very airtight building envelopes for both new and existing facilities. Combined with DOASs to accurately control delivery of properly conditioned outdoor air, building interior humidity conditions can be controlled at levels that make radiant heating and cooling feasible. Improved building envelopes reduce the amount of outdoor air required to pressurize buildings while DOAS systems deliver properly conditioned outdoor air to meet occupant ventilation requirements. Radiant heating/cooling provides occupant comfort with less energy than conventional "all-air" systems. 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." Therefore, by maintaining less than 60% RH inside the facility and reducing infiltration of unconditioned outdoor air, there should be a relatively negligible probability of mold and mildew problems in the building.

Validate: This project installed the subject technologies in one half of the study facility (Bldg 1540A) and the other half of the facility (Bldg 1540B) remained unrenovated to serve as a baseline. The energy performance of the renovated and baseline portions of the facility was recorded, analyzed, and compared. The relative economics of the two halves of the facility were also compared, including the first cost of demonstrated technologies vs. first cost of a conventional design, as well as the relative maintenance and energy costs. In addition, the relative comfort of the two facilities were compared.

Findings and Guidelines. The insights gained from the demonstration illustrate the possibility of significantly improving the air tightness of existing building envelopes. By successfully controlling humidity in the building, we have demonstrated that it is possible to radiantly heat and cool a facility without increasing the risk of condensation on cool surfaces within the building.

With a calculated simple payback of 26.7 years, this project did not successfully demonstrate the cost effectiveness of radiant heating/cooling systems with respect to conventional all-air HVAC systems. Nevertheless, it may be that radiant systems could be found to be cost competitive with all-air HVAC systems as designers and installers gain experience with these systems and as the suppliers of radiant system components achieve increased sales volume. It is also possible that the energy performance of the demonstrated system could be further optimized to realize greater energy savings. Due to network security restrictions, it was very difficult for the Contractor to adjust system parameters to attempt to optimize performance.

In older facilities that may not have adequate interstitial space above the ceiling to facilitate installation of HVAC ductwork, radiant systems could prove to be a viable method of providing heating and cooling in these spaces.

Technology Transfer. This project demonstrated a novel approach to controlling environmental conditions in an active military facility in a hot and humid portion of the country. This technology will be transferred by articles on the Whole Building Design Guide (WBDG) website and by updating Unified Facilities Criteria (UFC) 3-410-01, Heating, Ventilating, and Air-Conditioning Systems (HQUSACE, NAVFAC, and AFCESA 2011). It will also be documented in an ERDC Technical Report and articles in publications such as the Army's Public Works Digest, The Military Engineer, and the ASHRAE Journal. We will also submit an article to Dr. Stanley Mumma's DOAS-Penn State University website (http://doas.psu.edu/).* Dr. Mumma is a highly published expert on radiant heating and cooling and DOAS systems.

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* Dr. Stanley Mumma, of Penn State University, State College, PA, is a source of a wealth of information on dedicated outdoor air systems and radiant heating/cooling systems. See, for example:
http://doas.psu.edu/
http://www.cbe.berkeley.edu/research/radiant_cooling.htm
http://www.healthyheating.com/Page%2055/Page_55_i_cooling_eq.htm

Acceptance. This project showed that this technology, particularly radiant cooling, can be successfully used in the hot and humid southeastern United States. If it can work well in that portion of the country, and if it can ultimately be shown to be economically competitive (on a first cost basis) while reducing maintenance costs and satisfying occupant comfort requirements, it will overcome the reluctance of other DoD locations to try a technology that appears to be novel and unproven.

Additional Benefits. This project will benefit the radiant heating and cooling industry. Radiant heating enjoys a small niche in the industry, but would probably realize a significant increase if it could be shown that radiant heating and radiant cooling are both technically feasible and economically viable. Currently, there is little incentive to install a radiant heating system in a space if it is also necessary to install an all-air cooling system, which would require investment in two different systems.

Deliverables. Deliverables include an ERDC/CERL technical report, an article submitted to The Military Engineer (Society of American Military Engineers) and to the ASHRAE Journal. We will also submit articles to the Army's Public Works Digest and to Air Force and Navy equivalents.

1.2 Background

Current State of Technology in DoD. USACE issued Engineering and Construction Bulletin (ECB) 2009-29, *Building Air Tightness Requirements*, on 30 Oct 2009 (HQUSACE 2009). For all new Army construction projects and all major Army renovation construction projects after FY10, ECB 2009-29 required that building envelope air barrier material(s) must have an air permeance not to exceed 0.004 cfm/ft^2 at 0.3 inches of water gauge (iwg) [0.02 L/s-m^2 @75 Pa] when tested in accordance with American Society for Testing and Materials (ASTM) E 2178 (ASTM 2013). It also required testing of the completed building to demonstrate building envelope air leakage of less than 0.25 cfm/ft^2 (1.25 L/s-m^2) at a pressure differential of 0.3 iwg (75 Pa) in accordance with ASTM E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* (ASTM 2003a) or ASTM E 1827, *Standard Test Methods for Determining Air tightness of Buildings Using an Orifice Blower Door* (ASTM 2011)

DoD recognizes the importance of achieving airtight building envelopes as a means of reducing building energy consumption and minimizing the infiltration of moist air into the building interior. Subsequent to the Army's adoption of ECB 2009-29, the DoD issued UFC 3-101-01 (HQUSACE, NAVFAC, and AFCESA 2011). Per this Tri-Service document, the Army and Navy adopted the ECB 2009-29 requirements. For Air Force projects, the building air leakage rate shall not exceed 0.4 cfm/ft^2 (2.00 L/s-m^2) when test results measured at a pressure differential of 0.2 iwg (50 Pa) are extrapolated to 0.3 iwg (75 Pa).

USACE's experience with new construction has shown that meeting the requirement for envelope leakage not to exceed 0.25 cfm/ft^2 at a pressure differential of 0.3 iwg (75 Pa) is quite achievable for new construction. A number of new construction projects have been documented with air leakage rates as low as 0.1 cfm/ft^2 at a pressure differential of 0.3 iwg (75 Pa). It is, however, much more difficult to achieve air leakage rates this low on renovation projects, depending on the extent of the renovation work. Regardless of the challenge, benefits can still be realized. For example, research has demonstrated that improvements in window sealing can decrease building leakage 5 to 30%. (U.S. Department of Energy 2016).

VAV systems often fail to deliver required quantities of ventilation air to occupied spaces as a building's cooling load is reduced. Central air handling units (AHUs) and fan coil units (FCUs) often lack the latent cooling capacity to adequately control building moisture levels, especially at reduced sensible cooling levels. As a result, DOASs are increasingly being used on new construction and renovation projects as they are recognized as being more capable of controlling the quantity and quality of ventilation air than other HVAC systems.

DOAS systems and improved building envelopes are complementary technologies. As building envelopes are tightened, it becomes more critical to ensure adequate quantities of ventilation air because uncontrolled infiltration of outdoor air cannot compensate for inadequate delivery of ventilation air by the HVAC system. DOAS systems are able to reliably provide required quantities of ventilation air under a variety of building operating conditions. In general with any HVAC system, a tighter building envelope minimizes air leakage, thereby allowing the DOAS system to be downsized to deliver sufficient outdoor air to maintain a slight positive pressure within the facility.

Radiant heating systems are widely used in the DoD in shops, high bay maintenance facilities, hangars and other applications. They have been shown to heat such facilities more effectively than traditional forced air systems. By radiantly warming objects in a space rather than directly heating the air in the space, occupants perceive comfort in relation to the radiant temperature of their surroundings. Radiant heating systems are quieter and cleaner than forced convection systems in that they do not mechanically circulate air. Hydronic radiant heating systems can provide comfort at lower hot water temperatures than forced air heating systems, which improves the efficiency of the hot water generation system. In addition, it is more energy efficient to deliver a given quantity of heating energy hydronically (via a pump) than through forced air (via a fan).

Radiant cooling systems are not widely used in the U.S. construction industry although they have enjoyed increasing use in Europe and Australia. Like hydronic radiant heating systems, radiant cooling systems (which are inherently hydronic) are quieter and cleaner than forced air systems. They also require less energy to deliver a given amount of cooling capacity and can effectively provide occupant comfort while using chilled water that is warmer than the air of conventional forced air cooling systems.

Hydronic radiant heating/cooling systems have not penetrated the U.S. construction industry for at least a couple of reasons. First, the American construction industry is relatively unfamiliar with radiant heating/cooling systems. As a result, most designers are reluctant to use technologies that appear to be novel or unproven. Secondly, there is a well-founded concern that cool surfaces of radiant cooling systems could be subject to condensation. This project demonstrated that this possible problem can be avoided by combining a tight building envelope (to prevent uncontrolled infiltration of unconditioned outdoor air) with a DOAS system to control the moisture levels of outdoor air introduced to the building, hence the dewpoint of the air within the conditioned spaces can be maintained at levels that will not result in condensation on cooling surfaces.

Technology Opportunity. If adopted, the combination of these technologies could have a significant impact on DoD's mission accomplishment, energy costs, energy security and attainment of energy goals. DoD annually spends millions of dollars to renovate buildings that have been contaminated with mold and mildew. This project sought to demonstrate a way to reduce the potential for mold and mildew formation in existing buildings while efficiently and cost effectively heating and cooling these facilities and satisfying occupant comfort requirements. This project enables DoD to greatly reduce the high costs of remediating mold and mildew in military facilities while saving energy, thereby helping the DoD to meet energy performance mandates.

1.3 Regulatory drivers

- **Executive Orders**:
  - Executive Order (EO) 13423 – NOTE: Revoked by EO 13693 on 19 Mar 2015.
  - Agencies shall:
  - Reduce energy intensity by 3% annually through the end of FY2015, or
  - Reduce energy intensity by 30% by the end of FY2015, relative to an FY2003 baseline.
  - Ensure that:
    - New construction and major renovation of agency buildings complies with the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings.
    - 15% of the existing Federal capital asset building inventory of the agency as of the end of FY2015 incorporates the sustainable practices in the Guiding Principles.
    - EO 13514 – NOTE: Revoked by EO 13693 on 19 Mar 2015.
  - Implement high performance sustainable Federal building design, construction, operation and management, maintenance, and deconstruction by:
    - Ensuring all new Federal buildings entering the design phase in 2020 or later are designed to achieve zero net energy by 2030.
    - Ensuring all new construction, major renovations, or repair or alteration of Federal buildings comply with the Guiding Principles for *Federal Leadership in High Performance and Sustainable Buildings* (USEPA 2006).
    - Ensuring at least 15% of existing agency buildings and leases (above 5,000 gross square feet) meet the Guiding Principles by FY2015 and that the agency makes annual progress towards 100% compliance across its building inventory.

    - * Pursuing cost-effective, innovative strategies to minimize consumption of energy, water, and materials.
    - * Managing existing building systems to reduce the consumption of energy, water, and materials, and identifying alternatives to renovation that reduce existing asset deferred maintenance costs.
  - EO 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.
- **Legislative Mandates**:
  - Energy Policy Act of 2005 (EPACT) – New Federal buildings shall be designed to require 30% less energy than buildings designed in accordance with ASHRAE Standard 90.1-2004 (ASHRAE 2004) 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.
- **Federal Policy:** Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (MOU) (USEPA 2006).
- **Energy Efficiency:** For new construction, reduce the energy cost budget by 30% compared with the baseline building performance rating per ASHRAE Standard 90.1-2004 (ASHRAE 2004) . For major renovations, reduce the energy cost budget by 20% below the pre-renovation 2003 baseline.
- **Ventilation and Thermal Comfort:** Meet the requirements of ASHRAE Standard 55-2010, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 2010), including continuous humidity control within established ranges per climate zone, and ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2004).
- **Moisture Control:** Establish and implement a moisture control strategy for controlling moisture flows and condensation to prevent building damage and mold contamination.

- **DoD Policy:** "2016 Strategic Sustainability Performance Plan," Energy Security MOU with the U.S. Department of Energy (USDOE) (OMB 2016).
- **Service Policy:** Army, Navy, Air Force.
- **Regulations:** Air Force Instructions.
- **Guides:** Whole Building Design Guide (WBDG, http://www.wbdg.org/).
- **Specifications:** ASHRAE, Leadership in Energy and Environmental Design (LEED).

2 Technology Description

2.1 Technology overview

Bldg 1540A used two complementary technologies to manage occupant comfort, the DOAS and radiant ceiling panel systems. The DOAS system dehumidifies the outdoor air used to both ventilate the space and supply makeup air to replace air that was mechanically exhausted. The temperature of the conditioned space was managed by the radiant heat transfer from the heating/cooling water flowing through the radiant ceiling panels. Pumps supplied either heated or chilled water through the radiant ceiling panels depending on the system's demand for heating or cooling. Therefore, the panels either absorbed heat and cooled the space during chilled water flow, or emitted heat and warmed the space during hot water flow.

2.2 Description

Radiant heating systems have been around for centuries in the form of fireplaces, cast iron radiators, and other devices. Radiant heating systems have been incorporated into heated floors and gas-fired radiant heaters, which see widespread usage in shops and high bay facilities.

This project made use of a hydronic radiant heating/cooling system. The system consisted of metallic panels that were incorporated in a 2x4 ft. grid ceiling system and metallic "cloud" panels suspended from the unfinished ceiling of a conference room and a training room. Hot 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 4^{th} power of the temperature difference between objects in the room and the surface of the radiant ceiling panels. Figure 2-1 shows a schematic of a typical hydronic radiant panel.

Figure 2-2 shows an upper surface view of a two-circuit radiant panel for installation in a ceiling grid. Figure 2-3 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. Radiant heating/cooling panel for ceiling mount application.

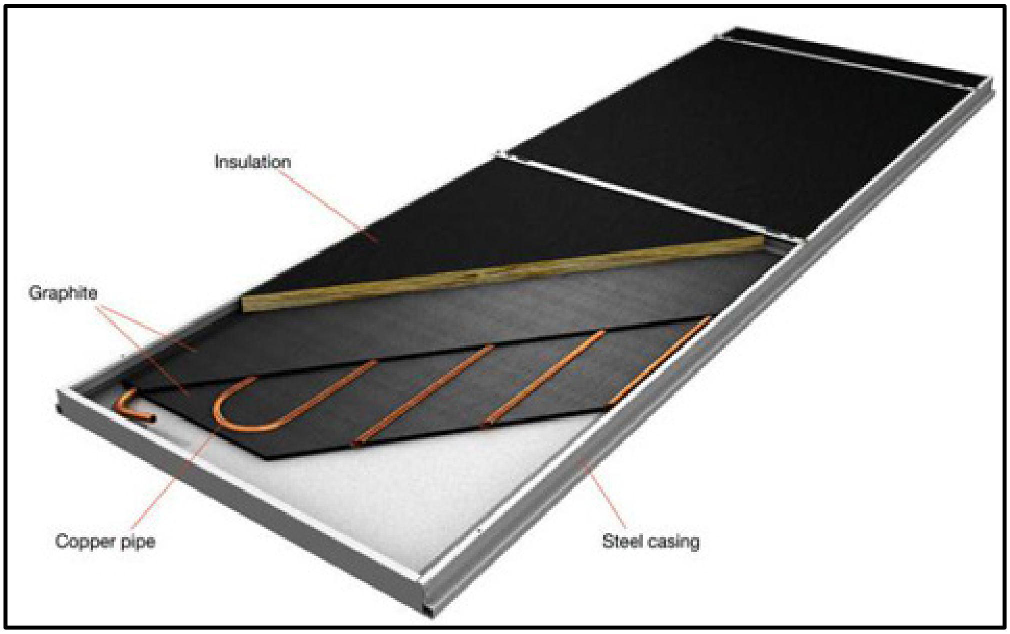


Figure 2-2. Upper surface view of a two-circuit radiant heating/cooling panel for suspended-ceiling application.

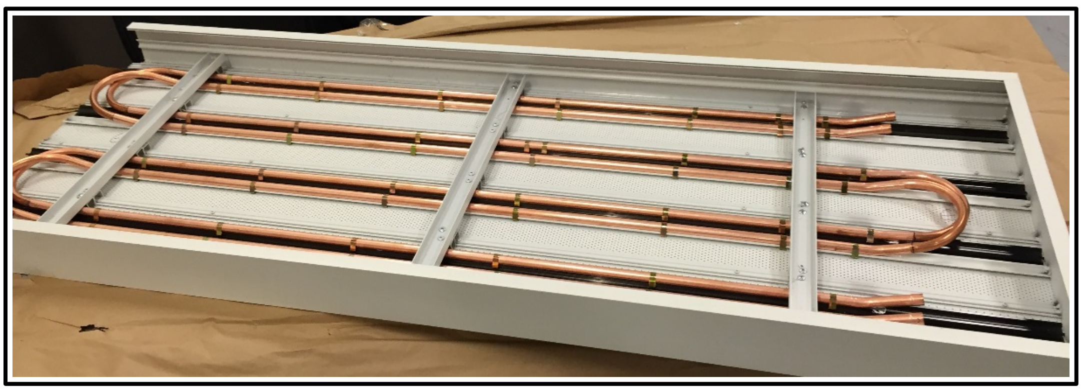
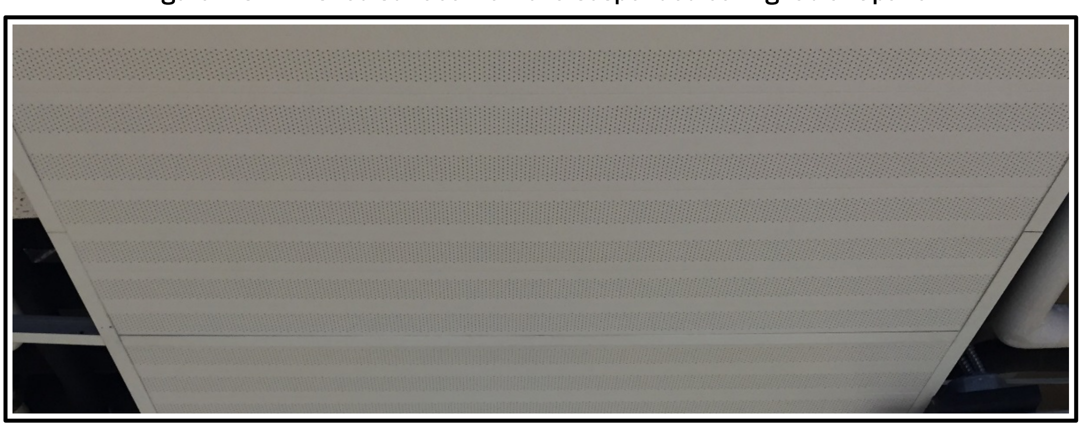


Figure 2-3. Finished surface view of a suspended-ceiling radiant panel.



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 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. Figures 2-4 and 2-5 show partial plan views of radiant panel installation in Bldg 1540A.

Note that a number of rooms in Bldg 1540A were not retrofitted with radiant panels. In the Bldg 1540A side of Figure 2-6, the spaces were conditioned as follows:

- Purple spaces (admin, conference room, training) – radiant heating/cooling
- Yellow spaces (mechanical/electrical) – unconditioned
- Green spaces (locker room/restroom) – exhausted only
- Red spaces (arms storage) – existing unit heater, split DX Alternating Current (AC) system
- White spaces (general storage/work area) – existing hydronic unit heaters.

In the Bldg 1540B side shown in Figure 2-6, the spaces were conditioned in the same manner except that the Purple spaces (admin, conference room) were conditioned with a DX VAV air handling unit with hot water reheat coils at the VAV boxes.

We deliberately elected not to install radiant heating/cooling in spaces in Bldg 1540A that were not previously conditioned by its existing VAV air handling unit. First, it seemed to be unnecessary to attempt to condition spaces beyond what was already provided. Second, if we had installed heating and/or cooling in spaces that were not previously so provided, any attempts to compare the energy performance of the demonstrated system with that of the original system or with that of the baseline system in Bldg 1540B would have become irrelevant. Finally, for budget purposes, we prioritized designing and installing a system that effectively conditioned spaces that were previously conditioned rather than attempting to condition the entire facility.

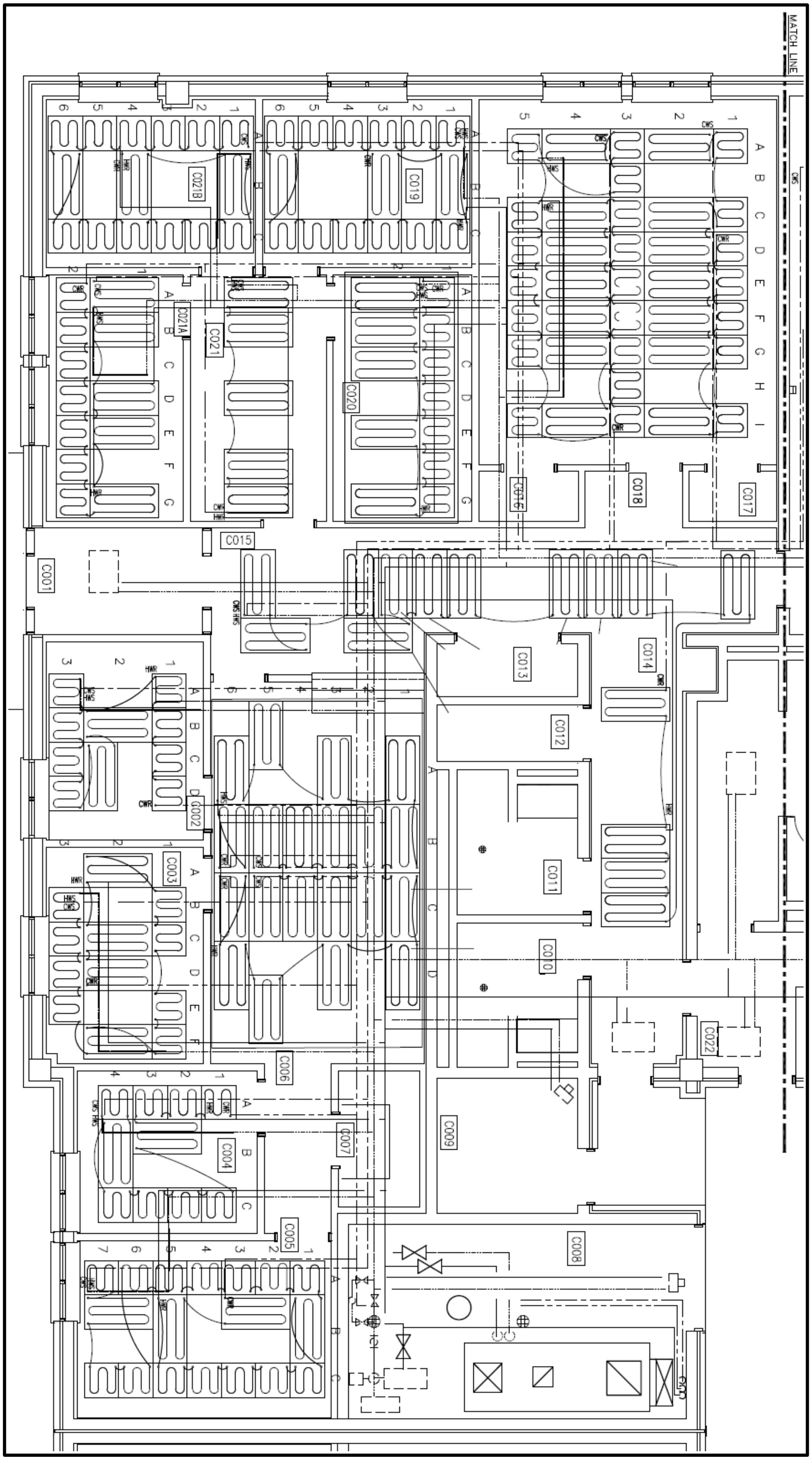


Figure 2-4. Partial plan view (northeast half) of Bldg 1540A showing radiant panels.

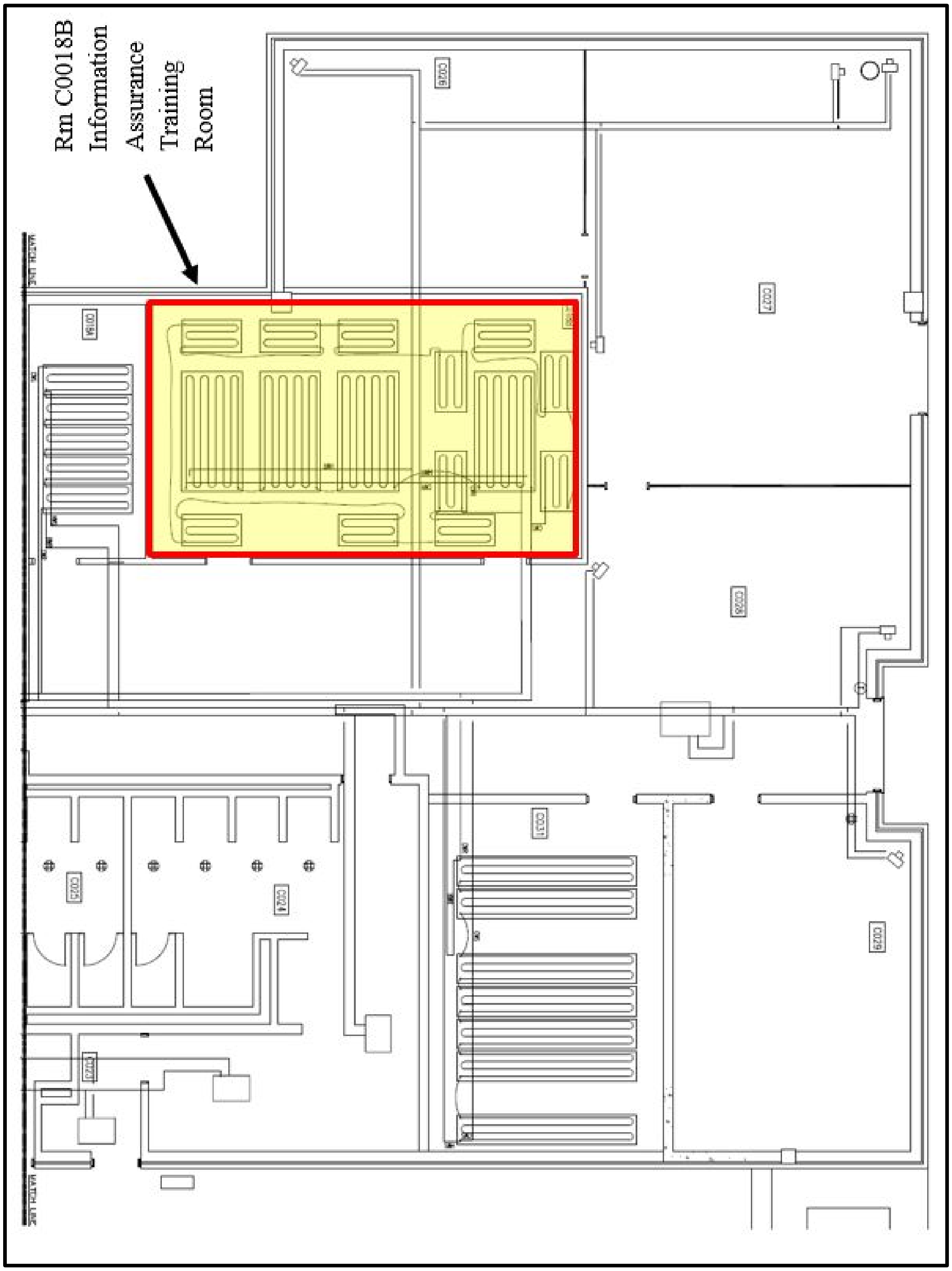


Figure 2-5. Partial plan view (southwest half) of Bldg 1540A showing radiant panels. The 11 smaller panels shown in Room C018B (highlighted) added to address a cooling capacity issue.

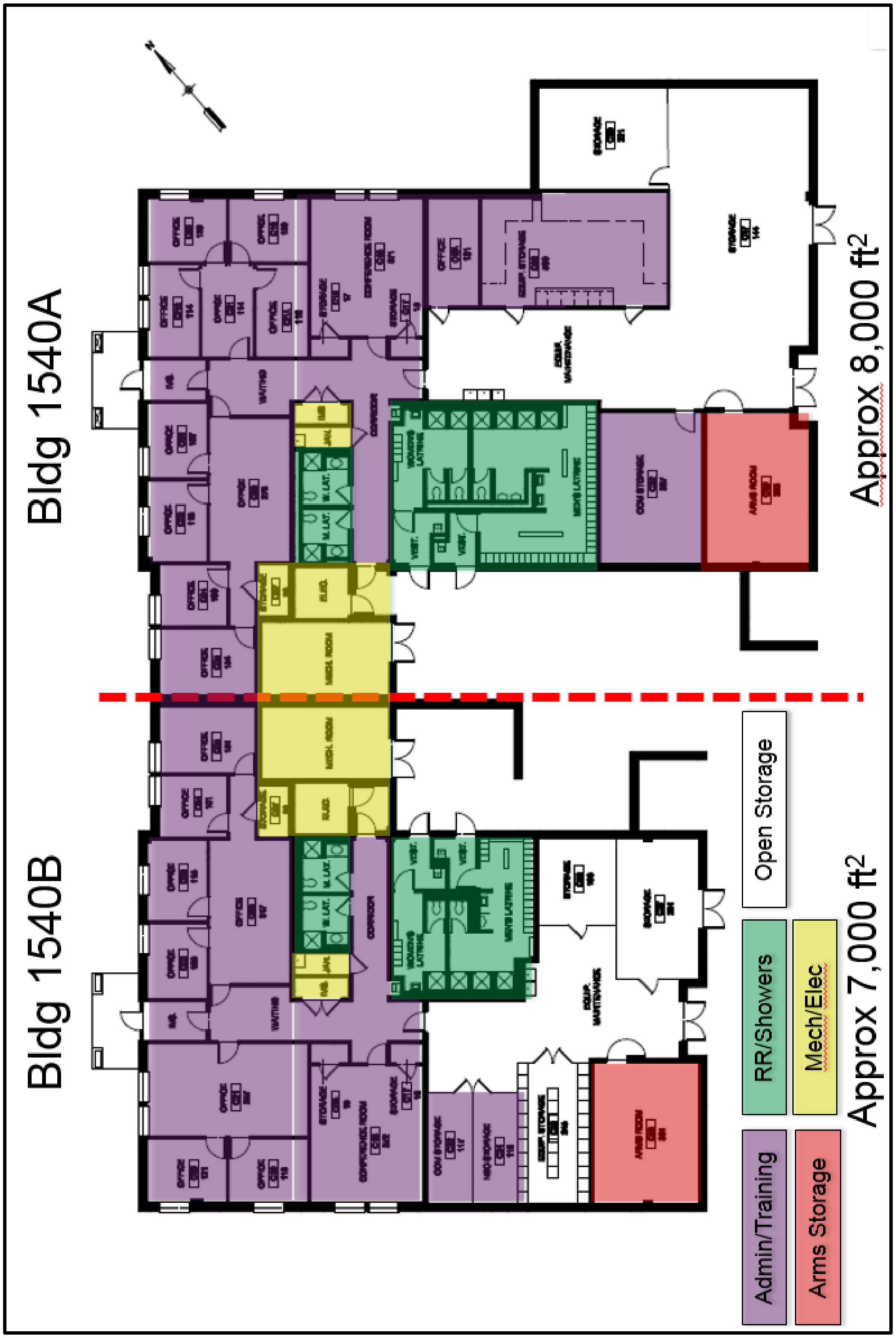


Figure 2-6. Bldg 1540 floor plan schematic.

Certainly, electing not to cool the general storage/work area reduced the building's cooling load. On hot days, the warm temperatures in the general storage/work area would have induced additional cooling load on the adjacent fully conditioned spaces (conference room, Information Assurance training room, admin spaces), but it would be highly speculative to attempt to quantify the effect.

The radiant panel system is supplied with hot water from an existing boiler and chilled water from a new air-cooled chiller. Figure 2-7 shows the layout of the hot water system and Figure 2-8 shows a schematic of the chilled water system. Note that chilled water is delivered to the DOAS AHU's cooling coil at 42 °F and leaves at 49 °F. Chilled water is then delivered to the three-way mixing valve where it is blended with return water from the radiant cooling panels. The chilled water is then delivered to the radiant cooling panels where it is supplied at 61 °F and leaves at 66 °F. Cascading chilled water from the DOAS AHU's cooling coil improves system efficiency by providing a larger ΔT to the chiller. Also, delivering warmer chilled water to the ceiling-mounted radiant cooling panels minimizes the risk of condensation on the cool surfaces of the panels by keeping the panel surfaces above the dewpoint temperature of the air within the conditioned spaces.

Figure 2-9 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 it before it enters the reheat coil where it is warmed to a neutral temperature before delivery to the occupied zones.

Figure 2-7. Hot water system schematic.

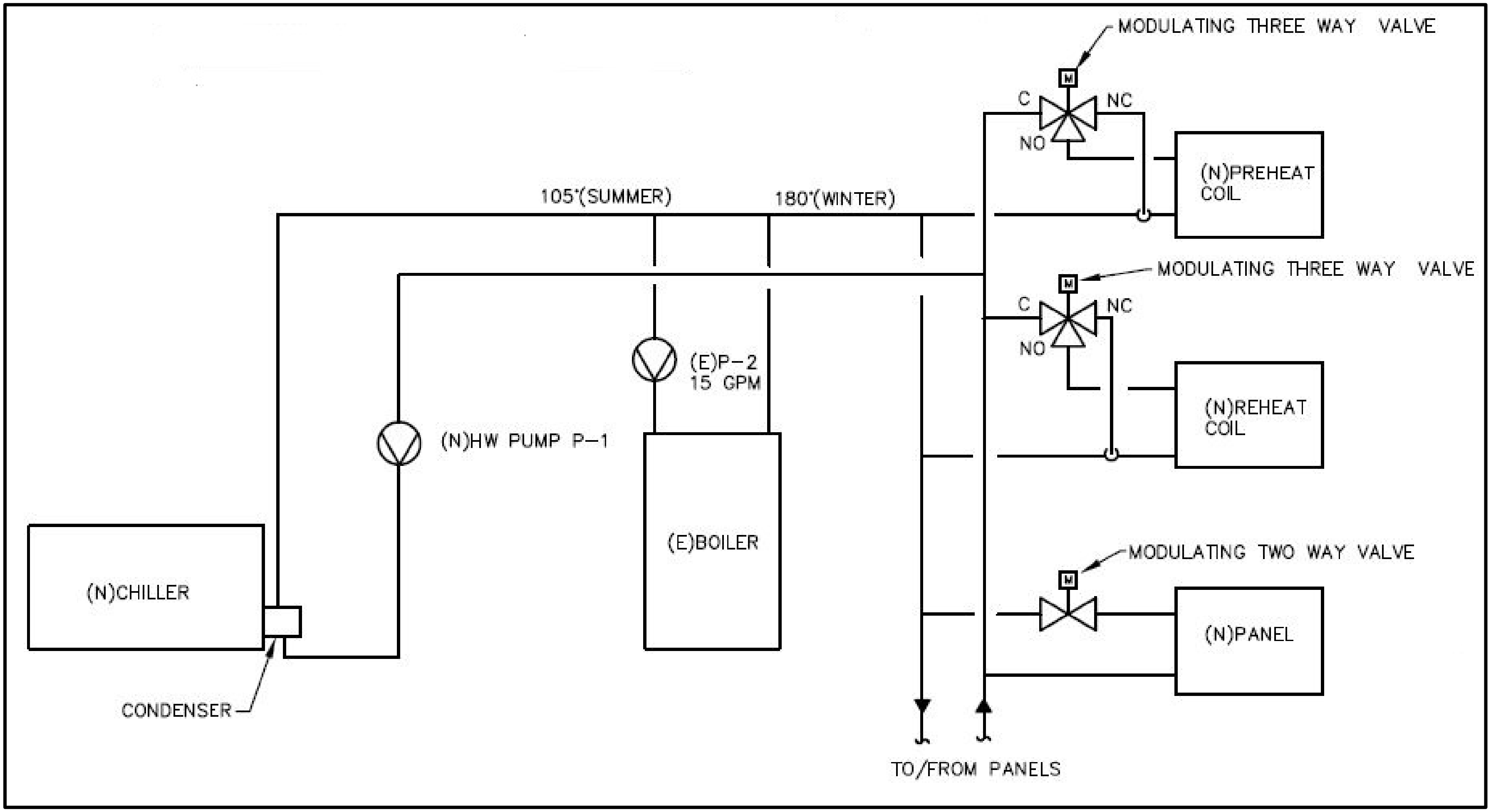
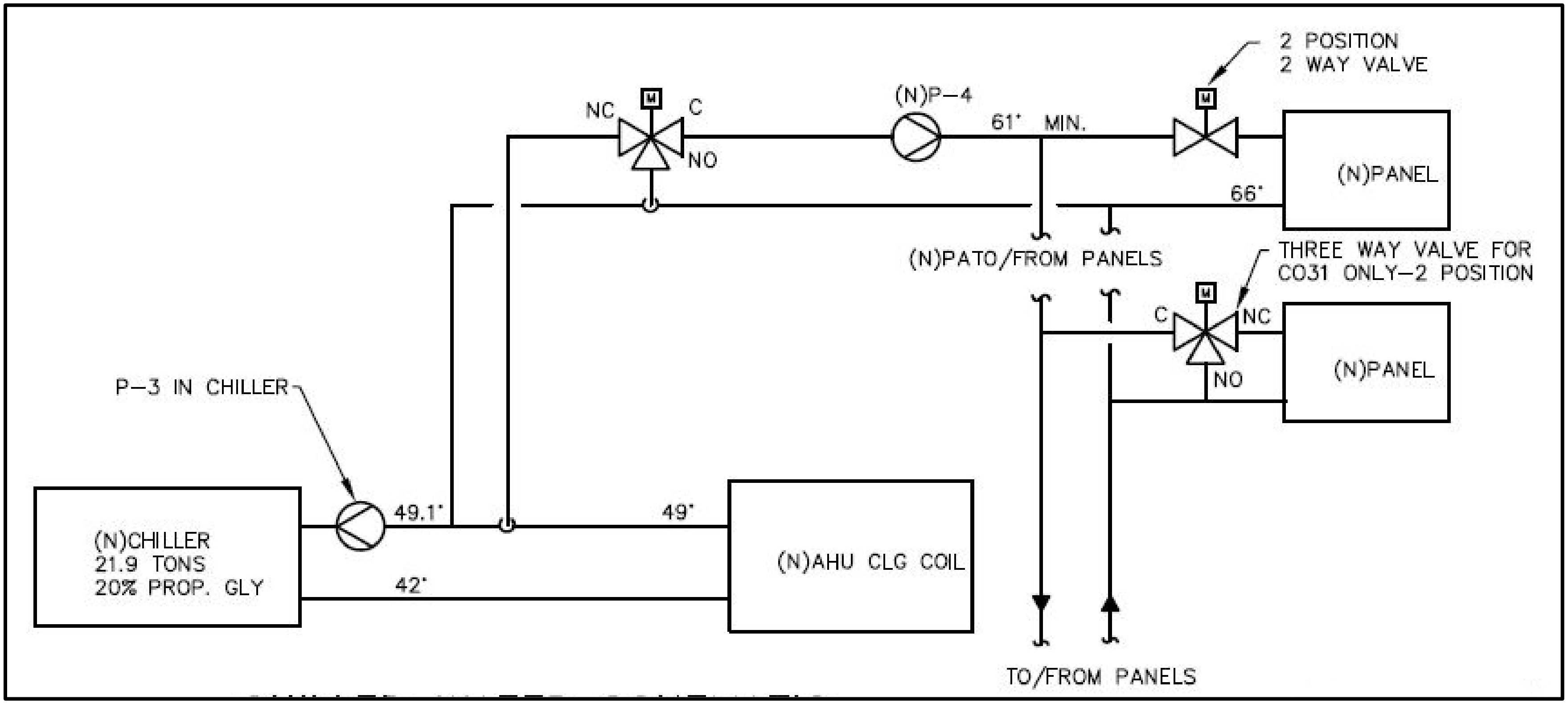


Figure 2-8. Chilled water system schematic.



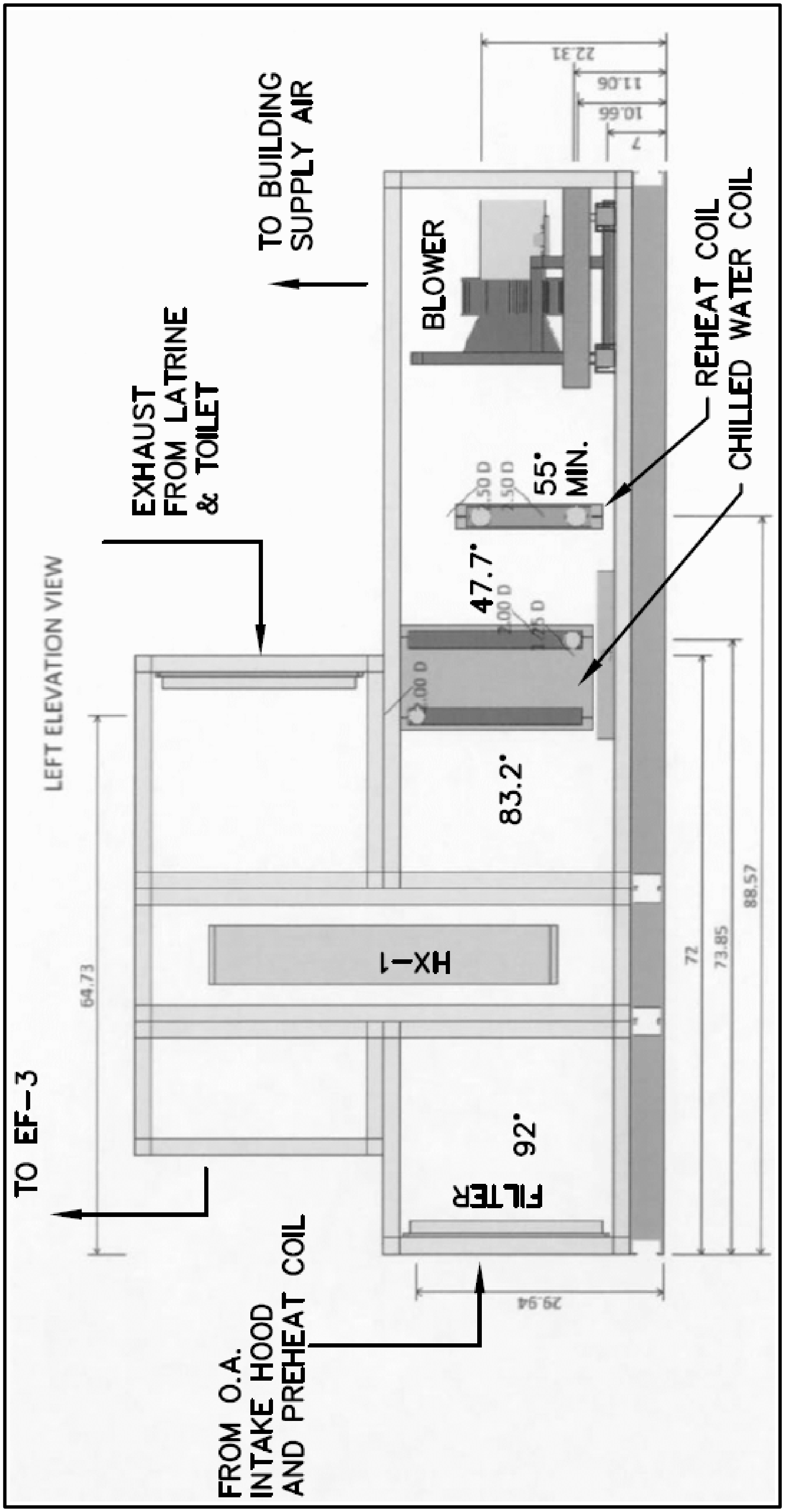


Figure 2-9. DOAS air handling unit.

This technology has applicability to buildings that have tight envelopes and that have capability of controlling indoor humidity. It would not be applicable to buildings in humid climates with leaky building envelopes, or to buildings that were 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. At average panel surface temperatures of 63.5 °F (61 °F entering water temperature and 66 °F leaving water temperature), the panels have a cooling capacity of 82 British Thermal Units (BTU) per ft^2 (24.03 Watt-hr per ft^2). Of course, one could increase the cooling capacity by lowering the average panel surface temperature as long as the dewpoint temperature of the air within the conditioned spaces remains below the average panel surface temperature.

2.2.1 Comparison to existing technology

Radiant heating/cooling differs from “conventional” HVAC systems in its primary mode of heat transfer. Conventional HVAC systems primarily transfer heat by forced convection. They directly heat (or cool) the air supplied to a space. The supply air mixes with the room air so that by controlling the quantity (and/or temperature) of heated (or cooled) air delivered to the space, the mixed air temperature in the space is maintained at a level that the occupants perceive as comfortable. Radiant heating/cooling primarily transfers heat radiantly. Radiant systems use large surface areas maintained at a slightly warmer (or cooler) temperature than the skin temperature of the occupants to transfer heat to (and from) the occupants.

Because radiant heat transfer is directly proportional to the 4^{th} power of the temperature difference between two objects, it is not necessary to have a large temperature difference between two objects to transfer significant heat. As a result, radiant systems can operate effectively with cooler heating water (and warmer cooling water) than conventional forced convection systems. By being able to use cooler heating water (and warmer cooling water), it is possible to generate heating water and cooling water more efficiently. Depending on availability, it is possible to cascade water leaving a heating coil (or leaving a cooling coil) to take advantage of the heating (cooling) capacity of the water before returning it to the boiler (or chiller). When this arrangement is used, the boiler (or chiller) sees a larger ΔT, resulting in improved capacity and increased efficiency.

The radiant panel system was expected to perform better than the conventional fan coil HVAC system. According to the Dec 2013 *ASHRAE Journal* article "Cooling Load Calculations For Radiant Systems" (Bauman, Feng, and Schiavon 2013), an experimental study revealed "The radiant system has a higher cooling rate than the air system, meaning that it is faster to remove heat gains while maintaining equivalent comfort conditions. For the tested cases, 75 to 82% of the total heat gain was removed by the radiant system … while for the air system, 61 to 63% was removed."

Radiant heating/cooling systems are made feasible by a tight building envelope and by use of a DOAS. This combination controls humidity levels within the building so that moisture and condensation problems do not occur on radiant cooling surfaces. Although all persons have experienced radiant heating/cooling (e.g., sitting in front of a fireplace or sitting near a large window on a sunny day or on a very cold evening), very few modern buildings in the United States attempt to actively control occupant comfort primarily through radiant heat transfer.

To enable the radiant system to operate effectively, the Contractor significantly improved the air tightness of the building envelope using minimally invasive sealant methods such as sealing with closed-cell spray polyurethane foam (ccSPF) and/or caulking with backer material where necessary. Our successful demonstration of this combination of envelope sealing technologies was quite challenging. Nevertheless, we believe it is an important capability to implement throughout DoD.

2.2.2 Chronological summary

This is a mature technology. It has been used extensively in Europe, but has not enjoyed much use in the United States. This is partly due to higher humidity and higher cooling needs in the United States compared with Europe; in the United States, there are concerns about condensation of moisture on cool surfaces, which can be a real issue if building humidity levels are not well controlled. Another concern has to do with the return on investment (ROI) of a radiant system vs. an all-air system. The perception has been that radiant systems are not as cost-effective as conventional all-air systems. This project addressed both humidity control issues and ROI concerns.

2.2.3 Future potential for DoD

Radiant heating/cooling systems with DOAS can reduce energy consumption and could be very helpful in moving 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 retrofit of existing buildings where space above the ceiling is very limited. Applications of radiant heating/cooling could be widespread to many types of facilities.

2.3 Technology development

Modern hydronic radiant technology has been used in various configurations for many years as an alternative to all-air HVAC systems to condition occupied spaces. Several authors over the 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

* BV = Besloten Vennootschap (Dutch or “Limited Company”)

Frenger Panel manufacturer and distributor, was first established in 1986 to support the installation of this system in North America.

The radiant panel system is expected to perform better than the conventional HVAC system. According to the Dec 2013 ASHRAE Journal article "Cooling Load Calculations For Radiant Systems" (Bauman, Feng, and Schiavon 2013), an experimental study revealed "The radiant system has a higher cooling rate than the air system, meaning that it is faster to remove heat gains while maintaining equivalent comfort conditions. For the tested cases, 75% to 82% of the total heat gain was removed by the radiant system … while for the air system, 61% to 63% was removed."

2.4 Advantages and limitations of the technology

2.4.1 Performance advantages

This combination of technologies may reduce 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 space air temperatures during the heating season and slightly warmer space air temperatures during the cooling season with a radiant system.

2.4.2 Cost advantages

With a calculated simple payback of 26 years, this project did not successfully demonstrate that this technology is cost competitive from a combined first cost, installation cost, and operational cost basis compared with traditional all-air HVAC systems. Nevertheless, Guruprakash and Rumsey (2014) claimed to demonstrate a radiant system that had an installed cost slightly lower (less than 1% cost savings) than its traditional cooling system counterpart. The radiant cooling system in that study also used 38% less energy than its traditional HVAC counterpart.

2.4.3 Performance limitations

A number of potential risks are associated with this technology:

- Risk: The DOAS could have proven to be difficult to operate and maintain, or it could fail to adequately control humidity levels in the building.

  Fortunately, we found the system to be easy to operate. DPW HVAC maintenance personnel were invited to witness the system commissioning process. They were pleased with the relative simplicity of the installed system. With over a year of operational experience, there have been few maintenance issues to date and the system has had no difficulty controlling humidity levels within the facility at suitable levels to maintain comfort and avoid condensation on cool surfaces.
- Risk: Building occupants might have left doors and windows open, deliberately or carelessly, allowing hot and humid air to enter the building and defeating the DOAS's ability to maintain humidity levels in the building.

  This did not prove to be a problem. Bldg 1540 is a secured building and posted signs within the building direct that all doors be kept closed. The occupants understand and respect the need to keep doors closed for both security reasons and to avoid allowing infiltration of unconditioned humid air. Had this not been the case, there could have been a risk that humidity and condensation problems might have been a problem.
- Risk: Radiant heating/cooling systems may fail to satisfy occupants' comfort requirements.

  For the most part, this was not a problem. However, there were problems of lack of cooling capacity in Information Assurance (IA) Training Room C018B. The Contractor originally counted the occupancy of this room to be 11 persons (10 trainees and one instructor along with their computers, lighting, a projector, etc.), and designed the radiant panel system accordingly. After the building was reoccupied, they discovered that the actual occupancy was about 21 persons (20 trainees and one instructor). The occupants of this room complained of being too hot. Eventually, the Contractor designed a solution to this problem, which consisted of adding additional radiant cooling panels as ceiling spaced allowed. This solution was installed in Jan 2016. Additional cooling capacity in this zone improved the situation. From Feb 2016 onward, the average occupied temperature was 71 °F, and only infrequently escalated above 80 °F.

Figure 2-10 shows the temperature recorded in Rm C018B for the 24-hr period ending at 4:55 pm on Tuesday, 23 Aug 2016. During this period, the temperature setpoint was 78 °F and the outdoor air temperature ranged from about 58 to about 84 °F. During the same period, the room temperature stayed at or below the setpoint, varying between about 73 and 78 °F. It is encouraging to see that the room temperature stayed at or below the setpoint. The facility, to include Rm C018B, was passively cooled by 8 hours of continuous exposure to outdoor conditions that were 18 °F cooler than the cooling setpoint.

Figure 2-10. Temperature display for IA Training Rm C018B for 24-hr period ending at 4:55 pm on 23 Aug 2016.

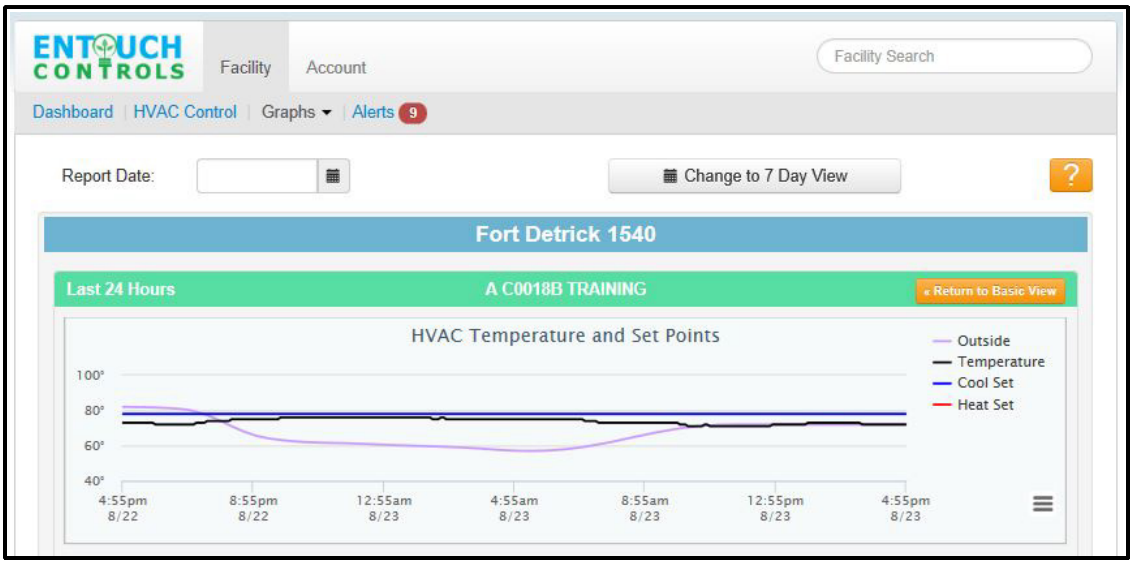
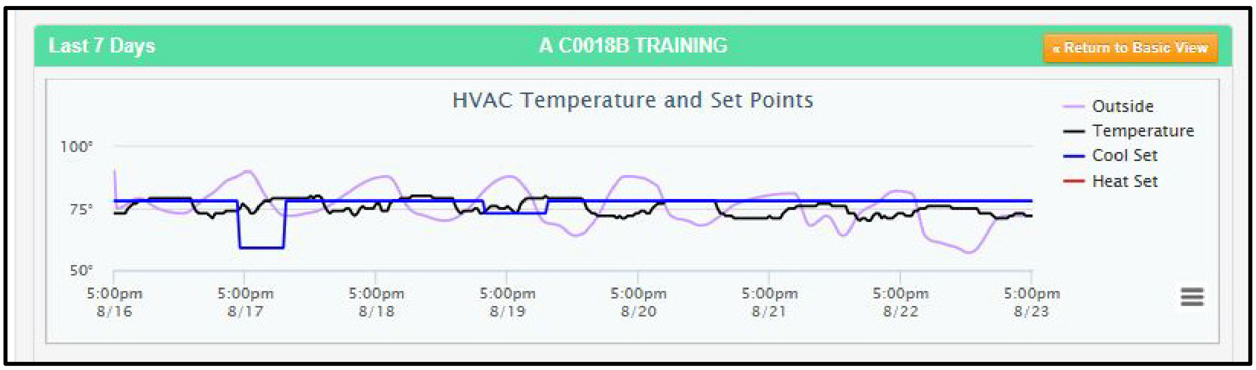


Figure 2-11 shows a display of room temperatures, outside temperatures and setpoint for the same room for the period 16-23 Aug 2016. Also displayed are outside temperatures and the cooling setpoint. Interestingly, the room temperature often seems to move in a direction opposite to that of the outside temperature. This illustrated the transient nature of a mechanically cooled building's heat exchange with the outdoors, as noted in the *ASHRAE Handbook: Fundamentals* (ASHRAE 1997): "(1) time lag in conductive [outdoor] heat gain through opaque exterior surfaces and (2) time delay by thermal storage in converting [outdoor] radiant heat gain [in the structure] to [an interior] cooling load". At night when the temperatures are below the

HVAC setpoint the building is passively cooled from outside inward, and requires no HVAC operation. During the daytime, sunlight heats the previously cool thermal mass (the building), from outside inward. As the heat reaches the interior, the HVAC then actively and increasingly responds to the daytime heat gain and occupant activity.

Figure 2-11 also shows that the cooling setpoint was lowered to approximately 60 °F for a few hours on 17 Aug 2016 and was also lowered to about 70 °F for several hours on 19 Aug 2016. Considering that the Contractor had no capability to make remote system adjustments and that no Contractor personnel was on site on these dates, these setpoint changes indicated that occupant(s) had adjusted the thermostat.

Figure 2-11. Temperature display from Energy Monitoring System for IA Training Rm C018B for the 7-day period 16-23 Aug 2016.



- Risk: The demonstrated system might not prove to be cost effective.

  The first cost of the demonstration system was estimated to be $73,382, which was more expensive than the first cost of a conventional VAV HVAC system. However, the yearly O&M costs of the demonstration system were $220, which was $1,320 per year less than the O&M costs of the conventional VAV HVAC system alternative. The resulting simple payback was calculated at 26.7 years for the demonstration system vs. a traditional all-air HVAC system. Section 7.3, "Cost Analysis and Comparison," analyzed these differences in detail.

- Risk: The demonstrated system might not prove to be socially acceptable.

  Some occupants may not have felt that the demonstrated system maintained adequate comfort. We are aware of inadequate cooling problems in Information Assurance Training Room C018B. Otherwise, we have had very little feedback on comfort conditions in Bldg 1540A. We have heard a number of anecdotal remarks from several persons associated with this building:

"Conference Rm C0028 is very comfortable."
Major, 21st Signal Brigade
"The room has been too hot."
IA Instructor – IA Training Rm C018B
"The overall building is very comfortable and very quiet."
USACE Construction Representative
"Overall, the building has been satisfactory. There have been complaints from the Chaplains [Rms C019, C020, C021, C021A and C021B] that they have been too hot."
Brigade Maintenance Officer, 21st Signal Brigade

We are unaware of any complaints during the heating season of persons experiencing cold feet and legs while sitting at a desk because their feet and legs were not directly exposed to heat radiating from a ceiling-mounted radiant heating/cooling system.

Other than the anecdotal remarks above, we have heard no complaints that occupants are unable to adequately control the comfort conditions in their own space. Occupants can adjust the temperature setpoints within DoD permitted levels – heating 70 °F occupied, 55 °F unoccupied, and cooling 75 °F occupied, 80 °F unoccupied. A 0-60 minute override timer integrated in the thermostat for Administration Room 006 Zone-2 will override the time schedule and cause the systems to operate for up to 60 minutes on a timed override. Otherwise, the thermostats will default to the preprogrammed temperature schedule during occupied hours (6:00 a.m. to 6:00 p.m.) and unoccupied hours (6:00 p.m. to 6:00 a.m.).

Although occupants could experience a sense of discomfort due to insufficient air movement in their space during the cooling season, we have not heard any complaints related to this issue.

Implementation issues are identified in Chapter 8 "Implementation Issues."

3 Performance Objectives

Performance objectives are the primary criteria established by the investigator for evaluating this innovative technology. They provide the basis for evaluating the performance and costs of the technology. Meeting the following performance objectives is essential for successful demonstration and validation of the technology:

- **Energy and Water Security:** This technology will reduce energy intensity (kWh/ft^2). It will have no direct effect on building or installation water consumption.
- **Cost Avoidance:** The technology will lead to reduced energy consumption. The technology will also result in a facility that is more resistant to the formation of mold and mildew, which has a major impact on the cost of operating and maintaining military facilities.
- **Greenhouse Gas (GHG) Reduction:** GHG emissions will be directly related to energy reductions for this facility.

Table 3-1 details the performance objectives for this demonstration. System economics were analyzed in accordance with the Department of Energy Building Life-Cycle Cost program.

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 (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, Savings-to-Investment Ratio (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.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative performance objectives				
Improved comfort	Occupant satisfaction	Space dry bulb temperature, 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 at or below 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 w/ O&M personnel	Maintainable by existing staff, no special skills required, less O&M burden	Objective met

3.1 Quantitative objective: Reduced building envelope air leakage

- **Definition:** This objective refers to the amount of air that will infiltrate/exfiltrate through the building envelope when the building is pressurized/depressurized to a reference pressure differential of 75 Pa (0.3 iwg) with respect to the outdoor ambient environment.
- **Purpose:** Envelope air leakage is a very good indicator of the quality of construction of a building envelope and is directly related to the degree that the building will experience uncontrolled infiltration/exfiltration of unconditioned outdoor air. A tighter building envelope will require less energy to heat, cool, and dehumidify. It will also be easier to balance the HVAC system and will maintain better comfort conditions because it will be less affected by outdoor wind conditions. The Army's Engineer and Construction Bulletin (ECB) 2012-16, *Building Air Tightness and Air Barrier Continuity Requirements* (HQUSACE 2012a), addressed building air tightness requirements for new facilities and major retrofits of existing facilities. This project demonstrated that it is possible to effect significant air tightness improvements on existing facilities even without major deconstruction and replacement of building envelope components.
- **Metric:** The metric used was cfm of air leakage per unit area of the building envelope at a reference pressure of 0.3 iwg (75 Pa). For purposes of air barrier testing, the air barrier envelope area includes the area of all walls (including doors, windows and other "intentional openings"), the ceiling and the area of the floor. The leakage rate was expressed in units of "cfm/ft^2 at 75 Pa."

- **Data:** The data required to calculate or evaluate this metric included:
- Wall, ceiling and floor areas.
- Differential pressure (Pa) and corresponding air flow rate (cfm).
- **Analytical Methodology:** Testing was conducted in accordance with the requirements of ASTM E779 (ASTM 2003a). Per this standard, "intentional openings" in the building envelope (such as bathroom vents, outdoor air louvers, exhaust louvers, etc.) were sealed. Then the building was positively (or negatively) pressurized using a blower door apparatus as discussed in Section 5.2, "Baseline Characterization." Building pressure was gradually ramped upward in increments of 5 to 10 Pa over the range of at least 25 Pa to 50 Pa. At each increment, the differential pressure between the building's interior and the exterior ambient environment was recorded along with the flow rate (cfm) of air required to achieve that pressure differential (equivalent to the air leakage at that pressure difference). This procedure resulted in five to 10 differential pressure and flow rate data points in both the positive and negative pressurization modes. The resulting data were fitted to an exponential curve and extrapolated to the reference pressure of 75 Pa. The average of the results from the positive and negative pressurization modes was reported as the building envelope's leakage rate at 75 Pa.
- **Success Criteria:** The building envelope leakage rate performance objective was <= 0.15 cfm/ft^2 at 75 Pa. While the Army and Navy require building envelopes to leak no more than 0.25 cfm/ft^2 of building envelope at 75 Pa for new and major retrofit projects, the Army has shown that it is possible to achieve air tightness levels on new and major retrofit projects as low as 0.1 cfm/ft^2. Setting the goal for this demonstration at <=0.15 cfm/ft^2 at 75 Pa for an existing building was a very aggressive goal considering that we did not intend to execute major intrusive changes to the existing building envelope.
- **Results:** *Objective not met*. As stated, this was an extremely aggressive performance objective. Per UFC 3-101-01 (HQUSACE, NAVFAC, and AFCESA 2011), building envelopes on new construction projects and major renovation projects for the Army and Navy must leak no more than 0.25 cfm/ft^2 (1.25 L/s-m^2) when tested at a pressure differential of 0.3 iwg (75 Pa). For Air Force projects the building air leakage rate shall not exceed 0.4 cfm/ft^2 (2.00 L/s-m^2) when test results measured at a pressure differential of 0.2 iwg (50 Pa) are extrapolated to 0.3 iwg (75 Pa).

Note that these UFC criteria are for new construction or major renovation projects that offer ideal conditions for minimizing building envelope leakage. Even under these conditions, Contractors must carefully select and apply materials and pay close attention to construction details and workmanship to meet these criteria. Nevertheless, we have seen examples of new and major renovation projects in which building envelope leakage was reduced to $<=$ 0.10 cfm/ft^2 at a pressure differential of 0.3 iwg.

It is much more difficult to achieve such results with existing buildings, especially if the project does not involve major disruptive work on the building's exterior (such as complete removal of the exterior finish system and installation of a continuous air barrier). In this project, the exterior side of the building envelope was untouched.

Air barrier testing was performed by the Southern Independent Testing Agency, Inc. (SITA) of Lutz, FL. Initial building envelope pressurization testing was conducted on 21 Mar 2014 for both buildings, but it was determined that due to unfavorable weather conditions, Bldg 1540A would need to be retested at a later date. This was accomplished on 8 May 2014.

Initial ("Before") testing and all follow-up ("After") testing was performed in accordance with ASTM E779 (ASTM 2003a). Initial results for Bldg 1540A were 0.8157 cfm/ft^2 at 0.3 iwg (based on an envelope surface area of 19,492 ft^2) and 1.1242 cfm/ft^2 at 0.3 iwg for Bldg 1540B (based on an envelope surface area of 14,476 ft^2). SITA's initial testing was followed by visual inspection and diagnostic evaluation in general accordance with ASTM E1186 (ASTM 2003b) by means of infrared thermography to identify air leakage paths. During the diagnostic evaluation, the building was pressurized to approximately 25 Pa (0.1 iwg) and the building was heated/cooled to achieve a minimum ΔT of 10 °F between interior and exterior conditions. SITA provided the following observations, which were applicable to both Bldgs 1540A&B:

1. All exterior doors should be sealed due to significant heat transfer and leakage located on door perimeters.
2. Significant leakage was present throughout the existing air barrier. One major area of concern was the penetration where the supply and return ductwork leaves the mechanical rooms.

3. On visual inspection above the ceiling, many breaches within the air barrier were evident. All penetrations required sealing and review to achieve the desired leakage rate.

After initial testing and diagnostic evaluation was performed, work was initiated to seal the envelope of Bldg 1540A. All work was done from the interior side of the envelope. The work involved locating and sealing numerous large and small cracks, penetrations, and openings using spray foam, gypsum board, and other materials. Figures 3-1 through 3-5 shows examples of envelope sealing measures.

Figure 3-1. Leakage sources at pipe penetrations and at framing systems.

Figure 3-2. Leaks sealed at pipe hangers in “heated-only” portion of Bldg 1540A.

Figure 3-3. Sealing of conduit penetrations in cavity space above the suspended ceiling of Bldg 1540A (left) and at the mounting location of a 4x4 conduit box (right).

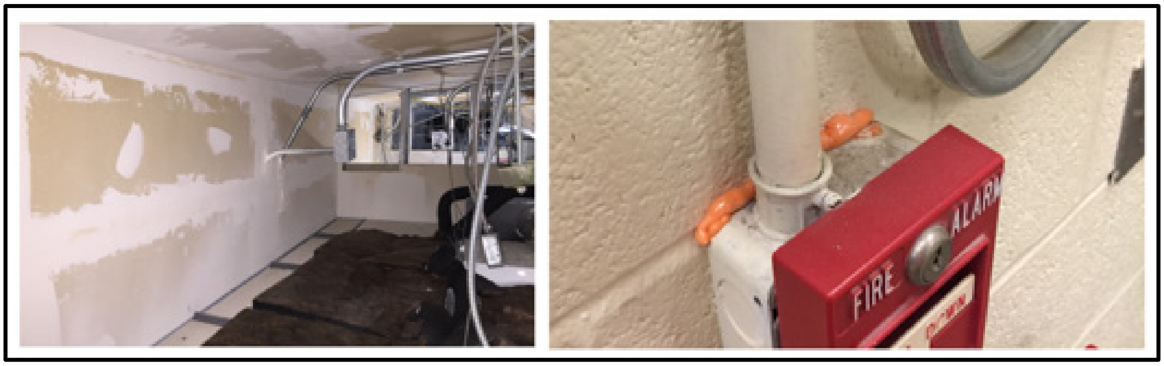


Figure 3-4. Sealing of leaks around an exhaust fan in the mechanical room.

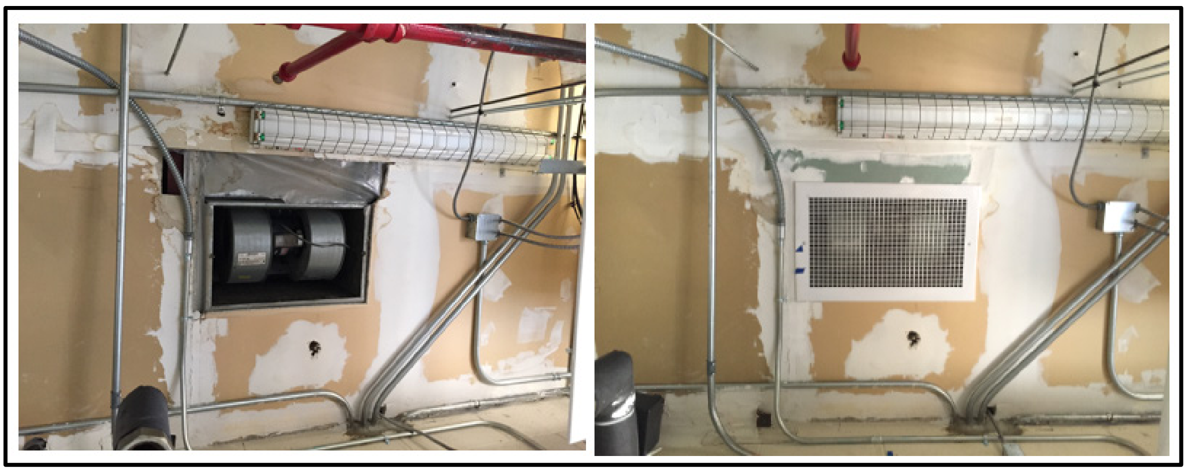


Figure 3-5. Sealing of a major opening above the hard ceiling above the men's latrine.

Throughout the project, the Contractor continued to locate and seal cracks and other penetrations and retested the envelope of Bldg 1540A several times. The Contractor performed post-sealing pressurization testing of Bldg 1540A during the week of 27 Apr 2015 to 1 May 2015 and found the leakiness to be greater than they had hoped. New deficiencies were discovered and subsequently repaired.

Once again, pressure testing of Bldg 1540A was performed during the week of 10 Aug 2015. During this test, additional hidden air infiltration locations were discovered within the secured storage area. These deficiencies were repaired during a Jan 2016 site visit.

A final air barrier test of Bldg 1540A was performed during the week of 4 Jan 2016 to determine effects of additional repairs to areas found in the 10 Aug 2015 tests. The final reported envelope leakage rate for Bldg 1540A was 0.39 cfm/ft^2 at 75 Pa. This leakage rate included the effects of air leakage through the 10 existing 4'x4' single hung windows (Figure 3-6), which were deemed to be quite leaky. Since repair or replacement of the windows was not within the scope of their work, the Contractor did not attempt to remediate leakage through the existing window systems and offered no suggestions on how the existing windows might be improved. Nevertheless, they estimated that, had the windows been upgraded or replaced with currently available window systems, the building's overall leakage rate would have been approximately 0.27 cfm/ft^2 at 75 Pa.

It is possible that the air tightness of these windows could be improved by repairing or replacing any air seals between the moveable sash and the window frame. However, it is likely that there is a greater potential for air leakage around the perimeter of the unit where the frame is installed in the rough opening. Prior to the last couple of decades, the construction industry didn't concern itself with building envelope air tightness to any great extent. As a result, window systems were often installed without much attention paid to achieving a tight air seal at this location. On some projects, this gap would be stuffed with fiberglass insulation or with an expanding foam insulation. Fiberglass insulation in this application is ineffective as an air seal and expanding foam insulation may fill the void between the window frame and the rough opening, but still allow air entry into the wall system.

Figure 3-6. Single hung window (4x4-ft) in Bldg 1540A (typical of 10).

Current best practice is to tape the gap between the interior side of the window frame and the interior air barrier with a high quality, long lasting sealing tape. On the exterior side, windows should be sealed per the manufacturer's instructions. In order to seal these windows in accordance with current best practice would have involved major disruptive repair work on the interior and possibly the exterior sides of the windows.

Although the project did not meet its very aggressive performance objective of <= 0.15 cfm/ft^2 at 75 Pa, the 52% reduction in air leakage rate achieved by this effort was very significant and illustrates the kind of leakage reduction that is possible in many military buildings without impacting the building's exterior finish system.

3.2 Quantitative objective: Reduced energy consumption

- **Definition:** This objective refers to the relative amount of energy required to heat, cool, and ventilate the demonstration building as compared with the baseline facility.
- **Purpose:** The primary purpose of the project was to demonstrate effective means of reducing facility energy consumption and help DoD installations meet Federal and Service requirements to reduce facility energy usage.
- **Metric:** Energy consumption associated with heating, cooling, and ventilation was measured and reported in terms (BTU) for gas usage and kilowatt-hours (kWh) for electricity usage. BTUs were converted to kWh when total energy usage was analyzed.
- **Data:** Thermal energy delivered, mechanical systems electrical usage, and whole building electrical usage.
- **Analytical Methodology:** Measurements of environmental conditions in Bldgs 1540A&B were measured and recorded as well as energy consumption of each facility. Factors such as relative floor size, relative occupancy, and differences in activities within the two facilities were taken into consideration. With consideration that Bldg 1540 is not aligned on the cardinal North-South axis, the differences in building orientation created a minimal difference in the combined heat gain from windows and walls (within 4%). The primary cause for differences in building envelope heat gain was due to roof area differences between Bldgs 1540A&B. The roof area differences and their associated heat gains were proportional to their differences in square footage, with Bldg 1540A being 36% larger than Bldg 1540B.
- **Success Criteria:** Success was contingent on the demonstration facility consuming 20% less energy than the baseline facility. Raw energy data from each of the facilities were adjusted to account for differences in the two facilities such as relative floor size.
- **Results:** *Objective Met*. Overall, Bldg 1540A used 16% less energy than Bldg 1540B. Bldg 1540A consumed 33% more electrical energy than Bldg 1540B; however, it also used 42% less gas energy than Bldg 1540B. Two seasonal observations were made when comparing Bldgs 1540A&B. First, while Bldg 1540A typically used more electrical energy than Bldg 1540B, this gap widened during the summer season. This was attributed to the multitude of components in the radiant panel system (chiller, DOAS, pumps, etc.) that consume electricity, and their

year round operation (excluding the chiller). Second, during the fall and winter periods, the heating system in Bldg 1540B demanded more energy from its boiler compared with Bldg 1540A. This single difference in boiler energy usage drove Bldg 1540B's total energy usage above 1540A's despite the fact that 1540A used more energy in its chiller, HVAC, and electrical systems. The energy savings recorded in Bldg 1540A becomes even more appreciable after incorporating adjustments for the differences in each building's square footage. Bldg 1540B used 30.67 kWh/ft^2 while Bldg 1540A used 18.81 kWh/ft^2. This represented a 39% energy savings for Bldg 1540A on an energy usage per square footage basis compared with Bldg 1540B.

3.3 Quantitative objective: Cost effectiveness

- **Definition:** This objective refers to the relative life-cycle cost effectiveness of the demonstration system as compared with the baseline system, including first cost, operational cost and maintenance cost over its useful life.
- **Purpose:** Cost effectiveness is, or should be, the basis for all facilities-related decisions. Typical economic break points for selecting one technology over a competing technology might be a 10-year simple payback and a SIR greater than 1.0.
- **Metric:** Simple Payback (SP), SIR.
- **Data:** Delta first costs, delta O&M costs, delta energy costs, useful life.
- **Analytical Methodology:** We recorded the costs of installing the demonstration system and compared those costs with the estimated costs to install a conventional all-air HVAC system. In performing our analysis, we considered not only the actual costs of installing the demonstrated system, but projected the costs of installing such a system assuming that the technology were to become broadly accepted within the construction industry. Our analysis is applicable to both a renovation project replacing an existing all-air HVAC system or new construction because we were careful to exclude costs of demolition of existing ductwork, air handlers, VAV boxes and other associated costs in our analysis. As a result, whether for a renovation project or a new construction project, our cost analysis assumed a clean installation of the demonstrated system in a building with no existing systems or equipment hindering installation of the new system.
  We recorded and compared the O&M costs and the energy costs for

both Bldgs 1540A&B. We also estimated the useful life of the demonstration system for use in the SIR calculations.

- **Success Criteria:** SP of less than 5 years as compared with a comparable all-air HVAC system with an SIR on the delta costs greater than 1.2.
- **Results:** *Objective Not Met*. The study indicated a 26.7 year SP and a 23.9 year discounted payback for the radiant panel with DOAS system. The SIR was calculated to be 1.0. Details of these calculations are provided in Section 7.3, "Cost Analysis and Comparison."

3.4 Qualitative objective: Improved comfort

- **Definition:** This objective dealt with the relative perceived comfort of the environment within Bldg 1540A before and after retrofit.
- **Purpose:** The ultimate purpose of conditioning buildings is to provide occupant comfort and satisfaction. It would be easy to save energy by conditioning buildings at levels that are not comfortable, or by not conditioning buildings at all. However, the purpose of buildings is to provide a place for people to live and work. Uncomfortable people cannot be expected to effectively carry out their mission.
- **Metric:** Comfort was determined per the criteria provided in ASHRAE Standard 55-2010, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 2010), Section 5.2.1.1 "Graphic Comfort Zone Method." Note that we also attempted to get occupant satisfaction feedback from Bldg 1540 occupants through a simple one-page survey. However, we got no responses to our survey.
- **Data:** Space dry bulb temperature and RH.
- **Analytical Methodology:** We monitored space temperature and RH in various locations within Bldg 1540A and compared them with the requirements shown in ASHRAE Std 55-2010, Section 5.2.1.1 "Graphic Comfort Zone Method" (ASHRAE 2010).
- **Success Criteria:** Temperature and RH fell within criteria as required by ASHRAE Std 55-2010, Section 5.2.1.1 "Graphic Comfort Zone Method" (ASHRAE 2010). This success criteria is not based on occupant satisfaction, an 80% occupant satisfaction metric, nor any criteria that implies occupant satisfaction.
- **Results:** *Objective Met*. For Bldg 1540A, 95% of the daily temperatures (6 a.m. to 6 p.m.) ranged between 62 and 78 °F, averaging 70 °F. Similarly, 95% of the daily relative humidities (6 a.m. to 6 p.m.) ranged

between 28 and 58% RH, averaging 43%. These parameters for Bldg 1540A were predominantly within the standard's range of acceptability, demonstrating Bldg 1540A's compliance with ASHRAE Standard (STD) 55-2010 (ASHRAE 2010).

3.5 Qualitative objective: reduced relative mold/mildew potential

- **Definition:** This performance objective dealt with the relative reduced risk of developing mold and mildew in the demonstration facility vs. the baseline facility due to system improvements.
- **Purpose:** The DoD has spent millions of dollars trying to mitigate existing mold and mildew and to minimize or eliminate future mold and mildew formation in military facilities. It was important that the systems demonstrated in this project support the DoD's effort to achieve healthful facilities that are free of mold and mildew.
- **Metric:** Mold and mildew potential.
- **Data:** Interior RH levels.
- **Analytical Methodology:** Measurement of interior surfaces at or below 80% surface RH.
- **Success Criteria:** No condensation on "cold" surfaces; interior surfaces at or below 80% surface RH.
- **Results:** *Objective Met*. According to the *2015 ASHRAE Handbook: HVAC Applications*, "a conservative limit for no mold ever, on anything at any temperature, is below 60% RH" (ASHRAE 2015). Bldg 1540A averaged 43% RH during the occupied period (6 a.m. to 6 p.m.) demonstrating the HVAC system's success in mitigating microbial growth potential.

3.6 Qualitative objective: Easily operable and maintainable

- **Definition:** This objective is related to the frequency and extent of operational problems associated with the demonstrated systems and the degree of difficulty that maintenance personnel experience in addressing these problems.
- **Purpose:** Military installations are under increasing pressure to operate with fewer resources (dollars, personnel, etc.). Any proposed systems should be at least as easily operable and maintainable as existing systems.
- **Metric:** Operability and maintainability.

- **Data:** Maintenance records, additional training requirements, discussions with O&M personnel.
- **Analytical Methodology:** We were unable to monitor DPW maintenance records to determine the number of work orders executed to operate and maintain Bldgs 1540A&B as well as the relative cost and time required for O&M in each facility.
- **Success Criteria:** Maintainable by existing staff, no special skills required, reduced O&M burden as compared with the baseline facility.
- **Results:** *Objective Met*. An absence of reported O&M-related issues appears to demonstrate the system's ease of operation and maintainability. The mechanical room components, consisting of a DOAS AHU, pumps and valves, are similar in complexity to a typical AHU and other components of a conventional system. The waterside components of a radiant panel system are similar to those of a chilled water fan coil system. However, the radiant panel systems are less complex than FCUs since they have no fans and require no filters.

4 Facility/Site Description

4.1 Facility/site selection criteria

The following criteria were used to select the demonstration site.

- **Geographic Criteria:** We specifically sought a demonstration site that had both a significant heating season and a significant cooling season. In addition, we sought a location that was considered "wet" or "humid" as a means of addressing concerns that radiant cooling systems will necessarily experience condensation problems in humid areas.
- **Facility Criteria:** We sought a facility that was a reasonable size – big enough to be meaningful, but small enough to feasibly conduct a demonstration. We 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.

  Another criteria was an ability to retrofit the selected building and have a similar building available to use as a baseline for comparison purposes. Fortunately, we found a single building that fit this requirement quite well. Fort Detrick's Bldg 1540 (Figures 4-1 and 4-2) below, is divided into two sub-facilities, Bldg 1540A and Bldg 1540B, which were separated by a very short "common wall" as seen in Figure 4-2. This short plane of separation served as the building envelope demarcation line between Bldgs1540A&B. Bldgs 1540A&B are very similar in size, layout, and occupancy. Each half of the existing building had 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 admin/training facility similar in a number of respects 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 used VAV air handlers to condition the occupied spaces. Finished rooms have gypsum walls with 2x4 lay-in grid ceilings.

Figure 4-1. NE corner of Bldg 1540 (left) and SW corner of Bldg 1540 (right).

Figure 4-2. Floor plan of Bldg 1540A and Bldg 1540B.

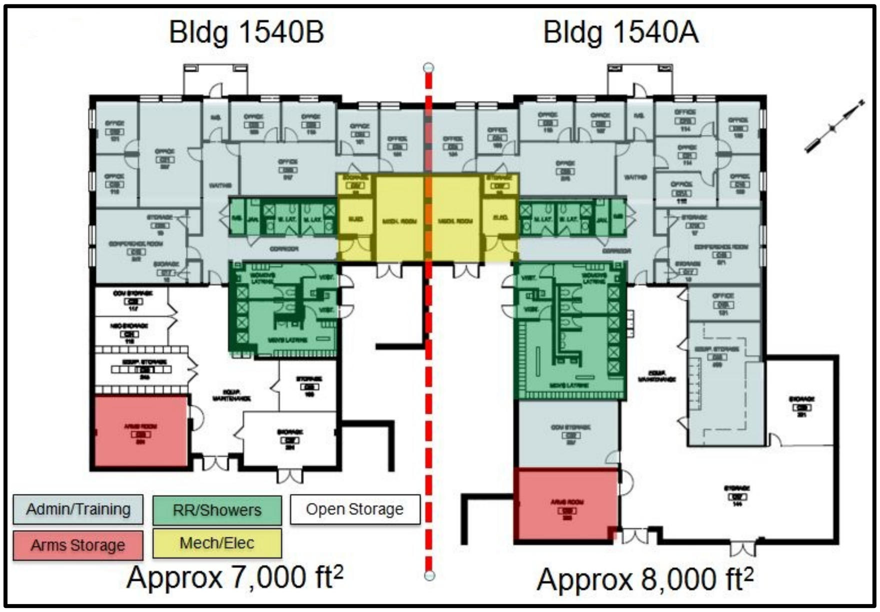
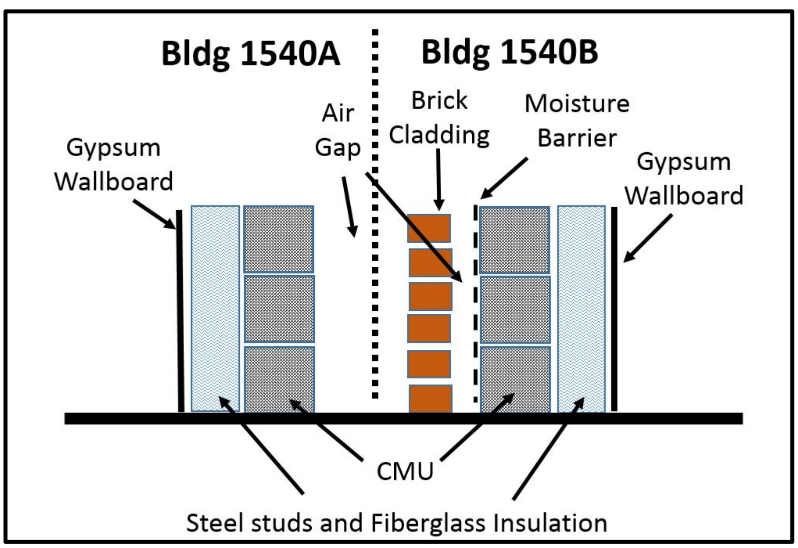


Figure 4-3. Illustration depicting assumed construction details of air gaps separating adjoining walls of Bldgs 1540A and 1540B.



A question arose concerning the possibility of moisture transfer across this "common wall" between Bldgs 1540A and 1540B. Presumably, the interior of Bldg 1540A would need to be maintained at relatively drier indoor air conditions than Bldg 1540B to avoid condensation of moisture on cool radiant panel surfaces. Assuming that Bldg 1540B would not be maintained at similarly dry interior conditions, there would be a vapor pressure difference between conditions in Bldgs 1540A and 1540B that would tend to drive moisture across the "common wall" from Bldg 1540B to Bldg 1540A.

Bldg 1540 actually consists of two distinct buildings under a common roof. Bldg 1540B was constructed first and Bldg 1540A was constructed some time later. We were unable to locate construction drawings showing the details of the adjacent exterior walls of these buildings and we avoided doing any exploratory deconstruction of the exterior wall of Bldg 1540A to discover the details of these walls. Nevertheless, we believe that the "common wall" separating Bldg 1540A and 1540B actually consists of two separate exterior walls separated by air gaps as depicted in Figure 4-3.

Assuming that the air gaps between Bldgs 1540A and 1540B were quite "leaky" with respect to the outdoor ambient air, the "climate" in the air gaps would presumably approach that of the outdoor ambient conditions. If this were to be the case, moisture transport across this section of the exterior wall of Bldg 1540A wouldn't be significantly different than for other portions of its exterior wall. Conversely, if the air gaps were quite "tight" with respect to the outdoor ambient air, conditions in the air gaps would fall somewhere between that of the conditions within Bldgs 1540A and 1540B. If so, this section of the exterior wall of Bldg 1540A would experience a smaller vapor pressure differential than other portions of its exterior walls. As a result, we did not think that moisture transport across this short section of exterior would be a serious concern and we took no actions to mitigate it.

4.2 Facility/site location and operations

- **Demonstration Site Description:** Fort Detrick is located at Frederick, MD, approximately 49 miles northwest of Washington, DC, and about 45 miles west of Baltimore. The installation supports a number of research organizations including the National Institute of Health, the U.S. Department of Agriculture, a biodefense campus and others.

The 21st Signal Brigade is one of the major tenants of the installation. Installation operations primarily consist of administrative or research activities. There are no training ranges at Fort Detrick.

- **Key Operations:** 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 IA training classroom, arms storage rooms, large shower/locker rooms, and unfinished open storage/work areas.
- **Command Support:** The installation's DPW has been very supportive of this project. Fort Detrick's mission is largely to support research in a variety of areas. This willingness to experiment and try new things carries over into the daily operations of the installation engineers.

  The occupants of the facility and their higher organization (21st Signal Brigade) have been very supportive. 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.
- **Communications:** The Contractor's original communications plan was to disconnect the facility's Building Automation Systems (BASs) from the base-wide network and then to arrange with an on-Post internet service provider to provide internet service, allowing the Contractor to remotely access system performance data from the standalone BAS systems. This would have also allowed the Contractor a measure of remote control capability through the existing BAS systems. Unfortunately, the Contractor was unable to secure approval for this approach from the installation's Network Enterprise Command (NEC). The Contractor then suggested the possibility of installing a standalone Energy Monitoring System (EMS) that would have no physical connection to the existing BAS systems. The proposed EMS system (Figure 4-4) shared no data with the existing BAS systems, had no control capabilities, and communicated performance data to the Contractor via a cell phone connection. After lengthy coordination with the NEC, this system was ultimately approved.

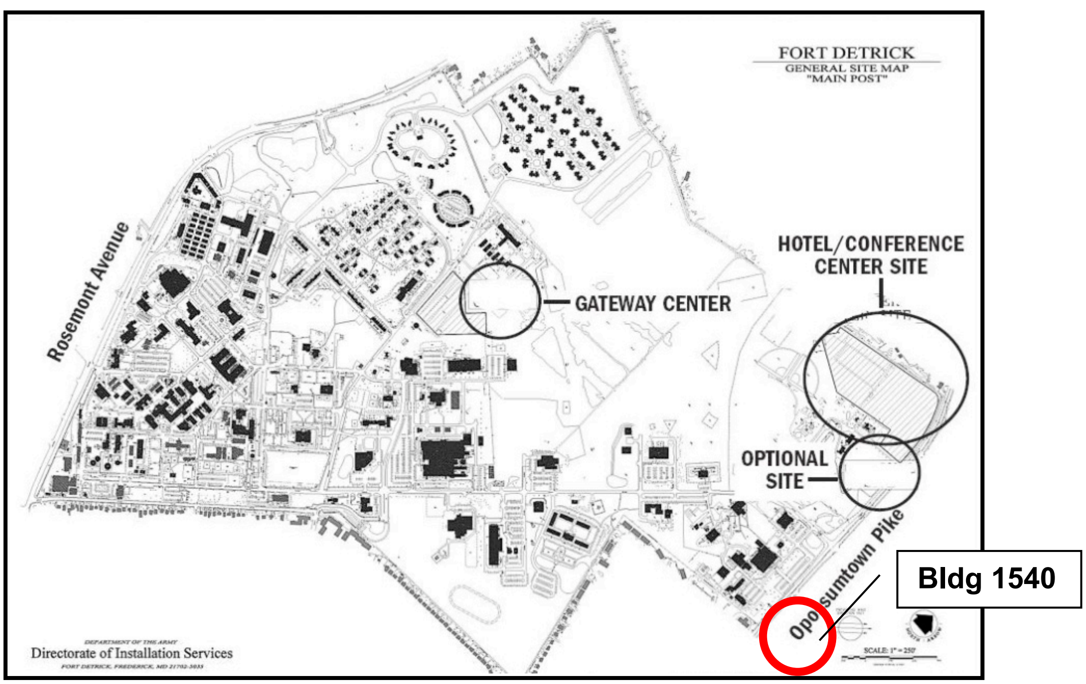
Figure 4-4. Screen capture of the online EnTouch energy management system platform for Bldg 1540.

The inability to negotiate a more convenient means of remotely accessing system performance data with the NEC was unfortunate and costly in several ways. A good deal of time and effort was spent trying to negotiate a method of accessing data that would be acceptable to the NEC. The Contractor expended considerable unanticipated time and funds to purchase and install an EMS system that was completely separate but parallel to the existing BAS system. The Contractor's EMS system was not allowed to share connections to existing sensors with the existing BAS system. As a result, the data inputs to the EMS system were brand new redundant devices installed in parallel with perfectly functional existing devices.

Most significantly, the Contractor's inability to access the existing BAS system meant that the Contractor had no ability to make remote changes in setpoints or start/stop times, or to adjust sequences of operation. Combined with the fact that the Contractor was located in Tampa, FL, and the Fort Detrick DPW also had little or no ability to access the system through the existing BAS, the Contractor's ability to adjust system parameters was extremely limited.

- **Location/Site Map:** Bldg 1540 is located on Porter Street at the location shown in Figure 4-5.

Figure 4-5. Map of Fort Detrick showing location of Bldg 1540.



- **Other Concerns:** One issue that proved to be challenging was the fact that the IA training mission in Bldg 1540A is a critical operation that cannot easily accommodate disruptions. Moreover, alternate locations at Fort Detrick to conduct this training while Bldg 1540A was being renovated were not readily available. Close coordination between the IA training staff and the Contractor was required. All of the occupants of Bldg 1540A were temporarily relocated during the renovation process. Occupants vacated the facility on 15 Jul 2014 and were allowed to reoccupy the facility on 11 May 2015.

Another issue that was somewhat difficult to address was that of complying with the Force Protection requirements of UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*. (HQUSACE, NAVFAC, and AFCESA 2003) Appendix B, Paragraph B-4.1, Standard 16, “Air Intakes,” is intended to minimize the opportunity for aggressors to easily place contaminants where they could be drawn into the air intakes of buildings. The most common means of satisfying this requirement is to elevate the outdoor air inlet to at least 10 ft above ground level. This was the first approach considered by the Contractor. Unfortunately, due to the architecture of the existing exterior brick cladding and the wide roof overhang above the existing outdoor air inlet, there appeared to be no way to cost effectively provide an elevated outdoor air inlet through the mechanical room’s exterior wall.

Per Standard 16, “Air Intakes,” there is an alternative way of satisfying its requirements.

> The requirements of this standard do not have to be applied when air intakes are located within an enclosed mechanical equipment yard or similar area with access control such as an enclosed courtyard.

The Contractor proposed satisfying the Standard 16 requirements by installing a chain link fence and gate enclosing the mechanical equipment yard. This would have been a relatively simple solution to the problem, but the installation Fire Department would not approve it because it could hinder emergency access to the back side of the building.

The Contractor then investigated the possibility of penetrating the standing seam metal roof and installing a vertical air intake above the roof. This approach would have required a specialized roofing Contractor to make this roof penetration. Also, because the building was relatively new, there was concern that any attempts to penetrate or alter the roof would void the roof warranty. Ultimately, it was determined that there was no longer a valid warranty on the roof. By this time, however, the Contractor had fortunately discovered that there was an existing roof penetration above the mechanical room that was large enough for their use and that was no longer being used for its original purpose. Ultimately, this roof penetration was used to accommodate a new outdoor air duct to the new DOAS AHU.

A second aspect of Antiterrorism/Force Protection (AT/FP) pertaining to this project is found in UFC 4-010-01 (HQUSACE, NAVFAC, and AFCESA 2003), Appendix B, Paragraph B-4.3, Standard 18, "Emergency Air Distribution Shutoff," which requires a means of rapidly shutting down air distribution systems and exhaust systems in response to an emergency situation, stating that:

> For all new and existing buildings required to comply with these standards, provide an Emergency Shutoff Switch in the HVAC control system that can immediately shut down the air distribution and exhaust systems throughout the building and close all dampers leading to the outside …
>
> The switch must be capable of shutting down all required systems and closing all required dampers, even if the local hand/off/auto switch is in the hand position, within 30 seconds of switch activation. Locate the shutoff switch (or switches) to be easily accessible by building occupants by locating them similarly to mass notification system (MNS) local operating consoles (LOCs) (see UFC 4-021-01 [HQUSACE, NAVFAC, and AFCESA 2010] for additional information on MNS LOCs) so that the travel distance to the nearest shutoff switch will not be in excess of 200 ft (61 m). Ensure that the shutoff switches are well labeled, and of a different color than fire alarm pull stations.

Appendix B, Paragraph B-4.3.1, “Outside Air Intakes, Relief Air, and Exhausts” establishes leakage ratings for all dampers that must respond in an emergency situation, stating that:

> . . . all outside air intakes, relief air, and exhaust openings with low leakage dampers that are automatically closed when the emergency air distribution shutoff switch is activated. The low leakage dampers will have maximum leakage rates of 3 cfm/square foot (15 liters/second/square meter) with a differential pressure of 1 in. of water gauge (250 Pa) across the damper.

Finally, Appendix B, Paragraph B-4.3.4, “HVAC Replacements and Upgrades” defines the criteria that determine whether the requirements of Standard 18 are required, as follows:

> Where air handling equipment in heating, ventilating, and air-conditioning systems is being replaced or when they are being upgraded, all provisions of Standard 18 will be applied to the building in which the new HVAC system is being installed. This will apply regardless of the major investment trigger . . .

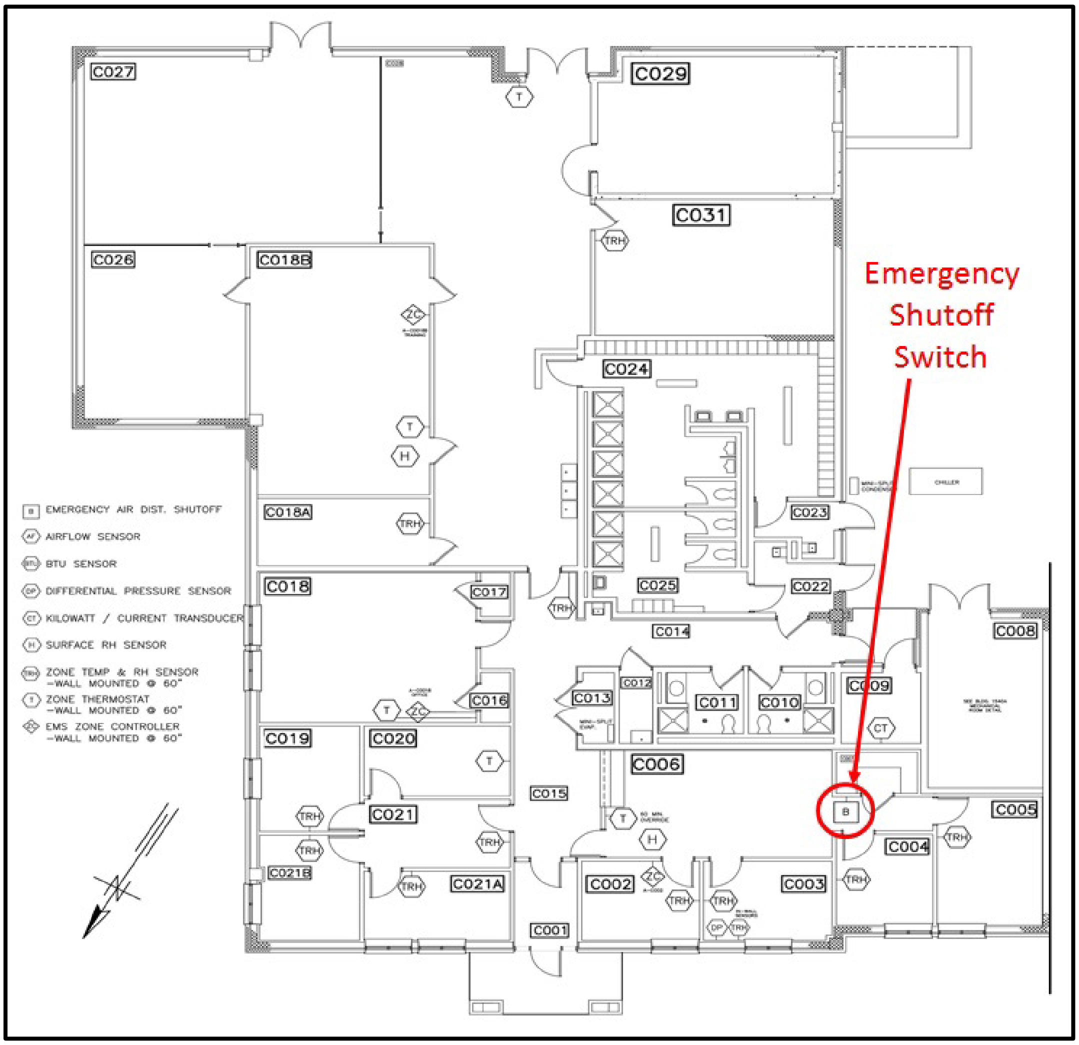
Based on Paragraph B-4.3.4, since the existing air handling equipment was being replaced, it was clear that the requirements of Standard 18 were in force, regardless of the magnitude of the project cost. As a result, the Contractor-provided dampers in compliance with the requirements of Paragraph B-4.3.1. These dampers were all interlocked to be activated by an Emergency Shutoff Switch that, when activated, shuts down all supply fans and exhaust fans and closes all dampers to the outdoors. Figure 4-6 shows the location of the Emergency Shutoff Switch.

Paragraph B-4.3 of UFC 4-010-01 (HQUSACE, NAVFAC, and AFCESA 2012) made mention of an MNS. We determined that there were no mass notification requirements applicable to this project and made no effort to incorporate an MNS in the facility.

4.3 Site-related permits and regulations

- **Regulations:** There were no known regulations that impacted this project.
- **Environmental Permits:** There was no need for any environmental permits.
- **Agreements:** A memorandum of understanding between Fort Detrick and ERDC-CERL was signed in Dec 2012. Signatories included Fort Detrick's Garrison Commander and the ERDC-CERL Director.

Figure 4-6. Emergency shutoff switch location.



5 Test Design

- **Fundamental Problem:** This project attempted to demonstrate the feasibility and efficacy of integrating building envelope improvements with a DOAS system 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 of this demonstration was to provide a cost-effective alternative to the all-air approach to conditioning military buildings.
- **Demonstration Questions:** Questions posed by this demonstration included the following:
- Can the air tightness of existing building envelopes be substantially improved without major disruptive changes to the envelope system?
- Can a DOAS system with energy recovery efficiently and cost effectively provide adequate volumes of conditioned outdoor air to reduce the potential for mold and mildew in the building and prevent formation of condensation of moisture on cool surfaces?
- Can a radiant heating/cooling system satisfactorily condition a military facility?
- Will such an integrated system (improved building envelope, DOAS and radiant heating/cooling) be maintainable in a military environment?
- **Approach:** The approach taken was to identify an operational military facility of reasonable size and with an occupancy and function similar to a large number of existing military facilities. We sought a building in a portion of the United States where the installed systems would be challenged to adequately maintain comfortable and healthful interior conditions under hot and humid conditions as well as winter temperatures. We also looked for a building that had a similar building nearby or that could be subdivided into a demonstration portion and a similar baseline portion. Fort Detrick's Bldg 1540 fit these requirements quite well. The building was about 20 years old and was comparable in design, construction, construction quality, and maintained condition to many buildings of its vintage. The building was divided approximately in half by two floor-to-roof walls and an air gap that completely isolated the two halves of the facility. Each half of the facility had its own independent HVAC system, including boilers, direct expansion (DX)

condensers, and DX VAV AHUs. Each half of the building had its own gas and electric meters. The only shared utility was domestic hot water, which was provided from a dedicated gas hot water heater in the 1540B mechanical room. The energy required to generate domestic hot water was not accounted for in the heating energy requirements of Bldg 1540B. The two halves of the building had similar, but not identical, floor plans and occupancies.

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&B were commissioned and instrumented for energy performance data collection. Because there were many mechanical system deficiencies identified in baseline Bldg 1540B, extensive repairs were made to bring this half of the building up to its design energy performance. Appendix C lists these deficiencies and the associated repairs.

- **Required Data:** The data necessary to perform this demonstration included:
- Envelope leakage data:
- "Before" envelope improvements, Bldg 1540A.
- "After" envelope improvements, Bldg 1540A.
- "Baseline" envelope leakage rate, Bldg 1540B.
- Electrical energy data:
- Total electrical energy, Bldg 1540A.
- HVAC electrical energy, Bldg 1540A.
- Total electrical energy, Bldg 1540B.
- HVAC electrical energy, Bldg 1540B.
- Thermal energy data:
- Total thermal energy, Bldg 1540A.
- Total thermal energy, Bldg 1540B.
- Thermal comfort data:
- Space temperature and RH, Bldg 1540A.
- Space temperature and RH, Bldg 1540B.
- Cost data:
- Cost of building envelope improvements, Bldg 1540A.
- Cost to install demonstrated HVAC systems, Bldg 1540A.
- Estimated cost to install a conventional HVAC system, Bldg 1540A.
- Cost to maintain HVAC systems, Bldg 1540A.
- Cost to maintain HVAC systems, Bldg 1540B.

- Cost of energy, Bldg 1540A.
- Cost of energy, Bldg 1540B.
- Maintainability data:
- Number of HVAC work orders, Bldg 1540A.
- Number of HVAC work orders, Bldg 1540B.
- Number of HVAC work orders requiring special training or skills, Bldg 1540A.
- Local weather data:
- Dry bulb temperature and dewpoint temperature.

5.1 Conceptual test design

"Before" and "after" building envelope air tightness testing involved the following:

- **Independent variable:** Differential pressure (both positive and negative) across the building envelope. Differential pressure is measured in Pascals (Pa) or iwg. For our testing, the building envelope was subjected to differential pressures in the range of 25 to 75 Pa. Testing was completed using the *U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes* (HQUSACE 2012a) as a guideline.
- **Dependent variable(s):** Envelope air leakage rate (cfm). The envelope air leakage rate increased as the differential pressure increased.
- **Controlled variable(s):** The building envelope area (ft^2) was held constant throughout the testing. Also, all "intentional" building openings remained sealed throughout the testing process.
- **Hypothesis:** In situ sealing measures can be applied to the building envelope of a "typical" modern military facility to cost effectively improve the air tightness of the building envelope.
- **Test Design:** The air tightness of Bldg 1540A was tested before and after making physical improvements. The costs to implement the improvements were documented and analyzed to determine the cost effectiveness of the improvements in terms of energy cost savings.
- **Test Phases:** Air barrier testing was performed in accordance with the requirements of ASTM E779 (ASTM 2003a). "Before" testing was conducted to determine the baseline condition of Bldg 1540A and to identify, locate, and characterize leaks. Based on this information, an approach was developed and implemented. After executing the build-

ing envelope improvements, “after” testing was performed to determine the degree of improvement. The costs to design and execute the improvements were calculated and analyzed with respect to the projected energy savings and cost effectiveness.

Effectiveness of the DOAS was determined as follows:

- **Independent variable:** Outdoor ambient dry bulb temperature (DBT) and dewpoint temperature (DPT) are the independent variables.
- **Dependent variable(s):**
- Bldg 1540A interior DBT (°F).
- Bldg 1540A interior DPT (°F).
- Energy requirements of the DOAS system (kWh).
- Controlled variable(s):
- Bldg 1540A supply air flow DBT (°F).
- Bldg 1540A supply air flow DPT (°F).
- Exterior doors and windows were kept closed to prevent infiltration of unconditioned outdoor air.
- The DOAS supply air flow rate and exhaust air flow rate were fixed.
- **Hypothesis:** The DOAS system can deliver sufficient quantities of properly conditioned outdoor air to satisfy the ventilation requirements of Bldg 1540A and to keep the interior of the building dry enough to make Bldg 1540A less susceptible to mold/mildew problems than baseline Bldg 1540B.
- **Test Design:** The outdoor ambient conditions (DBT and DPT), and the condition of the delivered air (DBT and DPT) were measured and recorded. Supply and exhaust air flow rates were fixed. Energy consumed by the DOAS unit was also measured and recorded.
- **Test Phases:** On installation and commissioning of the DOAS system, outdoor ambient conditions, delivered ventilation air conditions, and DOAS energy consumption were measured and recorded for 12 months.

Effectiveness of the radiant heating and cooling system was determined as follows:

- **Independent variable:** Outdoor ambient DBT.
- **Dependent variable(s):**
- DBT (°F) in interior locations of Bldgs 1540A&B.

- Delivered heating and cooling energy (measured in BTU, then converted to kWh):
- Bldg 1540A: Supply water temperature (°F), return water temperature (°F), and flow rate (gallons per minute [gpm]).
- Bldg 1540B: Supply air temperature (°F), return air temperature (°F), and flow rate (cfm).
- Occupant comfort was determined in accordance with the criteria provided in ASHRAE Std 55-2010, Section 5.2.1.1 "Graphic Comfort Zone Method" (ASHRAE 2010)
- **Controlled variable(s):** Exterior doors and windows were kept closed to ensure that building temperature control was maintained via the radiant heating/cooling system. The use of portable heaters or fans to address personal comfort was discouraged.
- **Hypothesis:** The radiant heating/cooling system can be capable of maintaining comfort conditions in the various spaces. The system can be easily operable and maintainable and will be more energy efficient than an all-air system.
- **Test Design:** The outdoor ambient conditions (DBT and DPT) were measured and recorded. The indoor temperatures in occupied spaces were measured and recorded and the energy delivered by the radiant heating/cooling system was measured and recorded.
- **Test Phases:** On installation and commissioning of the radiant heating/cooling system, outdoor ambient conditions and indoor temperatures in various spaces and radiant heating/cooling energy were measured and recorded for 12 months.

5.2 Baseline characterization

This Section defines baseline information necessary for the test design. Data and data interpretation are provided in other sections. Specifics pertaining to baseline performance and cost comparisons can be found in Sections 6.1, "Baseline Performance" and 7.3 "Cost Analysis and Comparison," respectively.

- **Reference Conditions:** Energy data to be collected include:
- Building air tightness data:
- Bldg 1540A baseline air tightness data.
- Bldg 1540A post improvement air tightness data.
- Building environmental conditions:

- Bldg 1540A temperatures and RH (various locations).
- Bldg 1540B temperatures and RH (various locations).
- Building energy consumption:
- Bldg 1540A gas and electric energy consumption.
- Bldg 1540B gas and electric energy consumption.
- Relative first costs:
- Labor and material costs to install demonstrated system.
- Estimated labor and materials costs to install conventional system.
- Relative O&M costs:
- Labor and materials costs to operate and maintain demonstrated system.
- Labor and materials costs to operate and maintain baseline system.
- Baseline Collection Period:
- Bldg 1540A baseline air tightness data – 1 day.
- Bldg 1540B baseline energy performance data – 12 months.
- Bldg 1540B baseline interior environmental performance data – 12 months.
- Bldg 1540B baseline O&M data – 12 months.
- **Existing Baseline Data:** No existing baseline data is known to exist.
- **Baseline Estimation:** The cost to install a conventional system in Bldg 1540A was estimated using RS Means.
- **Baseline Occupancy:** It was also necessary to account for the relative occupancy of Bldgs 1540A&B. Although the building sizes are quite similar, we found that the occupancy of Bldg 1540A was significantly higher than for Bldg 1540B. Although it was not feasible to get an accurate day-to-day count of the number of occupants of each building, it appeared that Bldg 1540B typically had 10 or fewer occupants and Bldg 1540A had 20 or more occupants, especially when IA training classes were in session. These students also brought with them additional computers that added to the cooling load in Bldg 1540A. We also noted that Bldg 1540A had much larger male and female shower rooms, which necessitated considerably higher exhaust (and, hence, ventilation) rates.
- **Building Orientation:** Another consideration is that Bldg 1540's orientation does not lie on a true North-South axis. The differences in building orientation created minimal difference in the combined heat gain from windows and walls (within 4%). The primary cause for differences in building envelope heat gain is due to their differences in roof area. The roof area differences and their associated heat gains are

proportional to their differences in square footage with Bldg 1540A being 36% larger than Bldg 1540B.

- **Data Collection Equipment.** The air barrier testing apparatus (Figure 5-1) consisted of a calibrated blower door system that was installed in the doorway of the facility being tested. The system accurately measured the air being blown into/drawn out of the building while simultaneously measuring the pressure differential (ΔP) across the building envelope. By measuring a number of paired volume/ΔP data points, it was possible to calculate the leakage rate per unit of envelope surface area at a reference differential pressure of 75 Pa. Small, inexpensive temperature and RH dataloggers (Figures 5-2 to 5-4) were easily deployed where needed. Existing utility gas and electric meters (Figures 5-5 and 5-6) were used to measure energy consumption.

Figure 5-1. Air barrier testing apparatus.

Figure 5-2. Typical EnTouch EMS zone thermostat and temperature/humidity logger.

Figure 5-3. Typical temperature and RH dataloggers.

Figure 5-4. Typical room thermostat and RH sensor.

Figure 5-5. Existing utility gas meter for Bldg 1540A.

Figure 5-6. Existing utility gas meter for Bldg 1540B.

5.3 Design and layout of system components

5.3.1 AHUs and/or fan coil units

Table 5-1 lists the test and balance findings on AHUs and/or FCUs.

Table 5-1. Test and balance findings on AHUs and/or FCUs.

Unit	Design CFM	Actual CFM	% of Design	Design OSA*	Actual OSA	% Of Design
AHU-1	1,625	1,659	102%	1,625	1,659	102%
FCU-1	530	370	70%	—	—	—
*Outside Air						

5.3.2 Exhaust fans

Table 5-2 lists the test and balance findings on exhaust fans.

Table 5-2. Test and balance findings on exhaust fans.

Exhaust Fan (EF)#	Design CFM	Actual CFM	% Of Design
1	1,270	(1)	—
2	160	92	58%
	1,100	1,102	100%

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.

Figures 5-7 and 5-8 show partial plan views of radiant panel installation in Bldg 1540A. Note that a number of rooms did not receive radiant panels, including:

- Figure 5-7:
- C023, C024 (men's latrine/shower, existing hot water cabinet unit heaters and exhaust).
- C022, C025 (women's latrine/shower, existing hot water cabinet unit heaters and exhausted).

- C026, C027, C028 (open storage, existing hot water unit heaters only).
- C029 (arms storage, existing hot water unit heater and DX split AC unit).
- Figure 5-8:
- C010/C011 (men's/women's latrines, exhausted only)
- C008 (mechanical room, existing hot water unit heater and exhaust)
- C009 (electrical room, unconditioned).

Figure 5-7. Partial plan view (southwest half) of Bldg 1540A showing radiant panels. Rm C018B (highlighted) shows 11 additional smaller panels installed to address a cooling capacity issue.

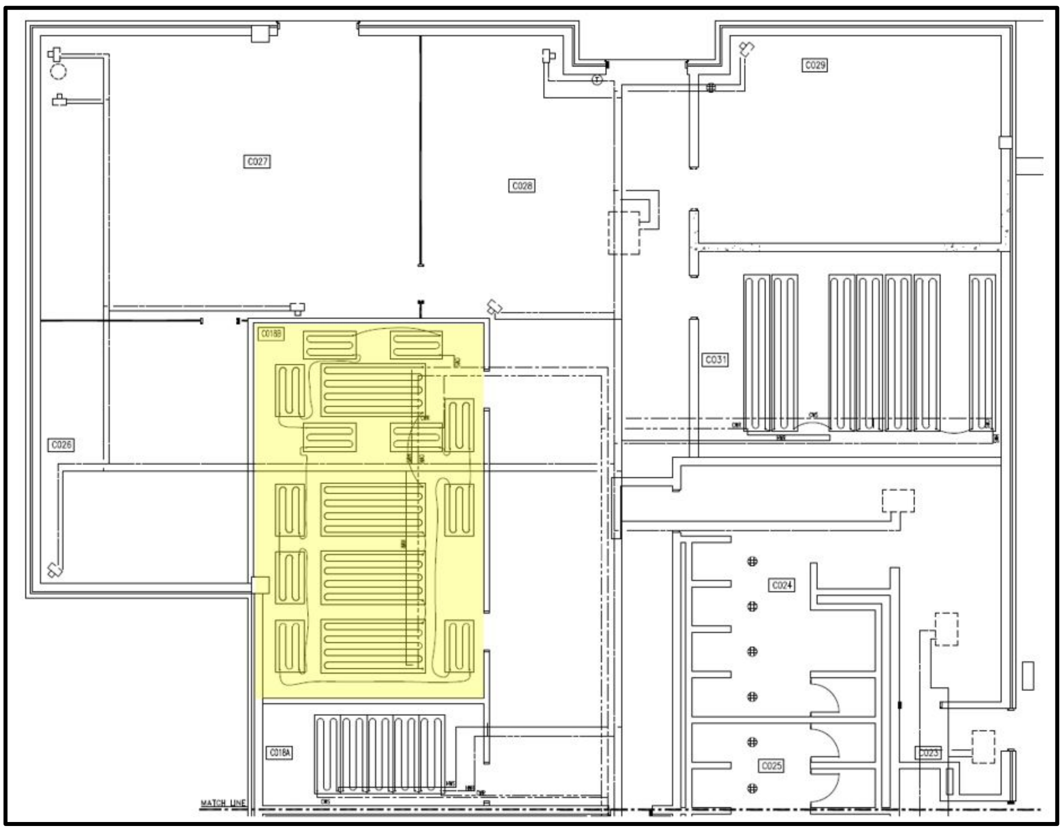
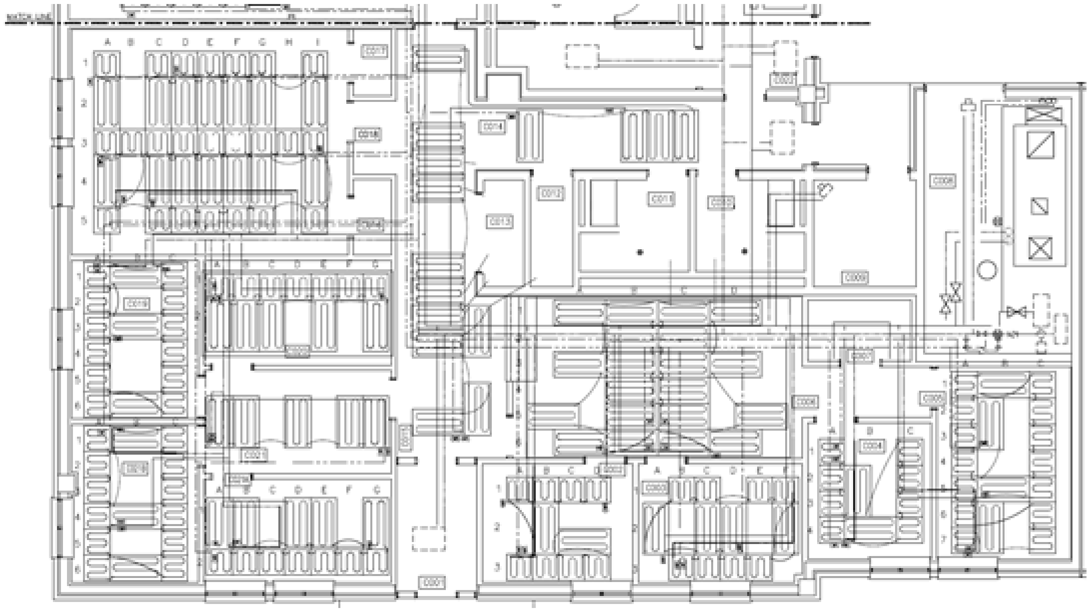


Figure 5-8. Partial plan view (northeast half) of Bldg 1540A showing radiant panels.



The radiant panel system was supplied with hot water from an existing boiler and chilled water from a new air-cooled chiller. Figure 5-9 shows the layout of the hot water system and Figure 5-10 shows a schematic of the chilled water system. Note that chilled water was delivered to the DOAS AHU's 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's cooling coil improved system efficiency by providing a larger 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 DPT of the air in the conditioned spaces.

Figure 5-9. Hot water system schematic.

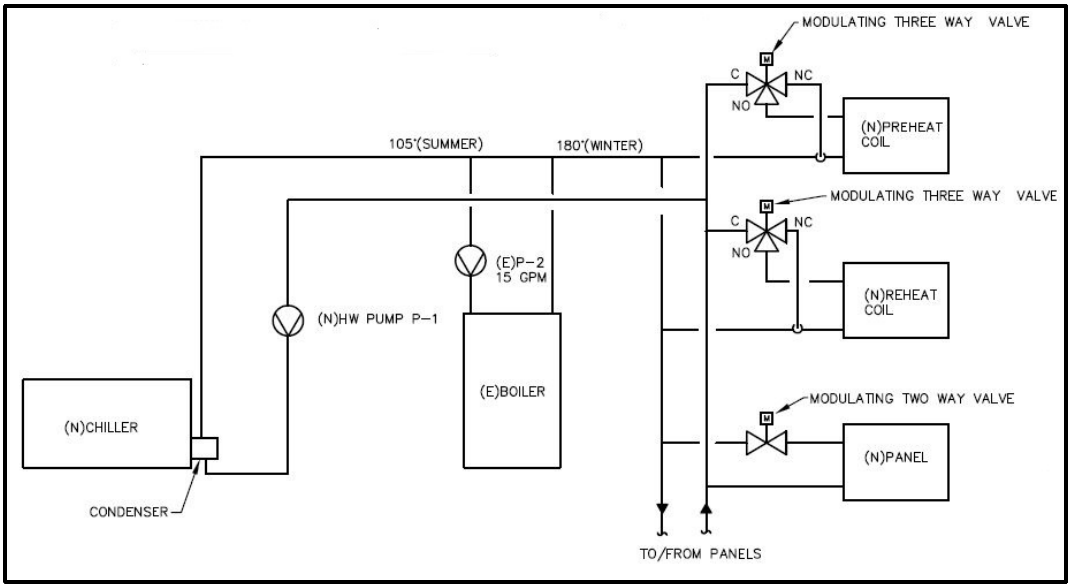


Figure 5-10. Chilled water system schematic.

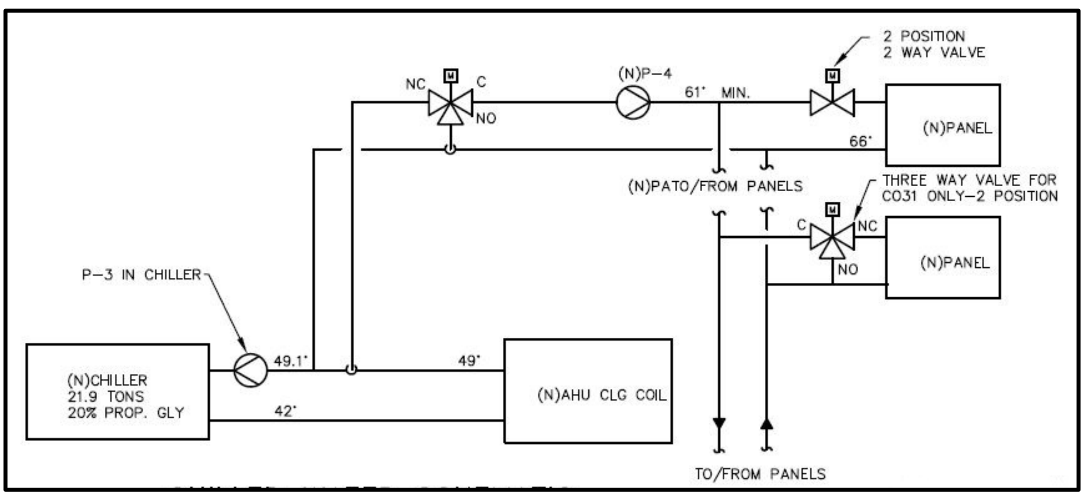
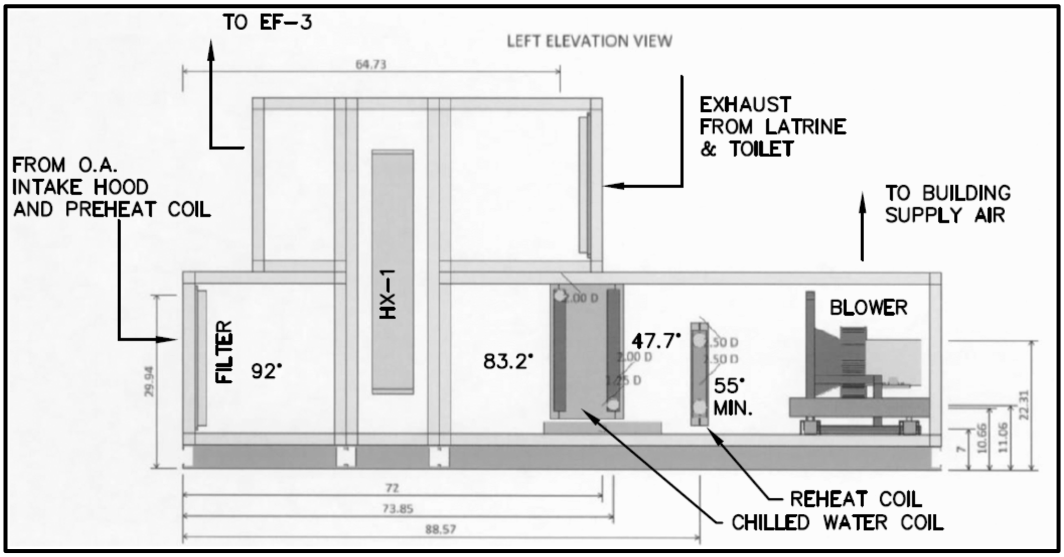


Figure 5-11 shows the DOAS AHU. This was a constant volume device that filtered and preheated (if needed) outside air. The air then passed through an enthalpy wheel where it exchanged energy with building exhaust from the latrines. The ventilation air then passed through a deep cooling coil that cooled and dehumidified it before it entered the reheat coil where it was warmed to a neutral temperature before delivery to the occupied zones.

Figure 5-11. DOAS air handling unit.



5.4 Operational testing

- **Operational Testing of Cost and Performance:** Energy and cost performance data were collected through the course of 12 months of operation under typical outdoor ambient conditions and normal building occupancy. Throughout the course of the year, it was possible to collect performance data during extreme weather events, systems shut downs, periods of high and low occupancy, etc.
- **Modeling and Simulation:** This project did not include modeling and simulation of this building.
- **Timeline:** Operational testing began soon after project kickoff. 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.

  The Contractor began measuring and recording energy consumption of the baseline facility and demonstration facility during the retrofit design phase to obtain baseline energy usage. Post-retrofit testing of the building envelope of the demonstration facility was performed to determine the effectiveness of building envelope sealing activities. 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 Sep 2016.

- **Technology Transfer or Decommissioning:** The Fort Detrick Energy Manager and the 21st Signal Brigade's Facility manager were kept informed throughout the design, installation, testing, and evaluation of this project. Fort Detrick DPW employees were invited to witness and participate in commissioning of this system. All system documentation was turned over to the DPW on project completion. Per prior correspondence with the Director of Public Works, Fort Detrick has no intention to request that the demonstration system be removed at the conclusion of this project and is prepared to provide written acceptance of the demonstration system on receipt of the final deliverable (i.e., the Final Report).

5.5 Sampling protocol

Table 5-3 details the elements of the data sampling, recording, and storage protocol for this demonstration.

Table 5-3. 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	NA*	NA
Temperature	Demo Contractor	Temp loggers	Remote data access	NA	NA
Relative humidity	Demo Contractor	RH loggers	Remote data access	NA	NA
Gas consumption	DPW personnel	Manual recording	Paper and/electronic records	NA	NA
Electric consumption	DPW personnel	Manual recording	Paper and/electronic records	NA	NA
First costs	Demo Contractor	Invoices	Paper and/electronic records	NA	NA
O&M costs	DPW personnel	Work orders	Paper and/electronic records	NA	NA
Occupant satisfaction	Demo Contractor	Temp loggers, Humidity loggers	Data stored in test instrument	NA	NA

*Not Applicable (NA)

5.5.1 Instrumentation plan

Table 5-4 and 5-5 list the elements instrumentation plan for Bldgs 1540A and 1540B, respectively.

Table 5-4. Bldg 1540A instrumentation plan.

Parameter	Data Measurement Method	Data Measurement Frequency	Data Measurement Location	Data Analysis Method
Boiler Flow Rate	Electronic, Badger Meter	Hourly	Immersed in-line with boiler water flow	Numerical tabulation and plotting
Boiler Water Temperature	Electronic, Badger Meter	Hourly	On the exterior of the supply and return boiler water pipes	Numerical tabulation and plotting
Chiller Flow Rate	Electronic, Badger Meter	Hourly	Immersed in-line with chiller water flow	Numerical tabulation and plotting
Chiller Water Temperature	Electronic, Badger Meter	Hourly	On the exterior of the supply and return chilled water pipes	Numerical tabulation and plotting
Electricity Usage	Electronic	24 hour intervals	Main, Chiller, Chilled Water Pumps 3 and 4, Hot Water Pump 2, Pump 1, DOAS Unit Fan, DOAS HX, EF-3, FCU-1	Numerical tabulation and plotting
Air Temperature	Electronic	5 minute intervals	DOAS Cooling Coil Temperature and Heating Coil Temperature, Entering and Leaving Preheat Coil, A-Inside Wall, DOAS-A-HX-EX In and Out, Outside, Rooms: A-C018B Training, A-TH Wall C003, A-C002, AC18-DOAS Airflow	Numerical tabulation and plotting
Air Humidity	Electronic	5 minute intervals	Outside, Rooms: A-C018B Training, A-TH Wall C003, A-C002, AC18-DOAS Airflow	Numerical tabulation and plotting
Pressure	Electronic	5 minute intervals	1540A Conditioned Space	Observed in system alarms
Data Transmission	Electronic (isolated system), EnTouch	5 minute intervals	1540A Mechanical Room	Monthly observation

Table 5-5. Bldg 1540B instrumentation plan.

Parameter	Data Measurement Method	Data Measurement Frequency	Data Measurement Location	Data Analysis Method
Boiler Flow Rate	Electronic, Badger Meter	Hourly	Immersed in-line with boiler water flow	Numerical tabulation and plotting
Boiler Water Temperature	Electronic, Badger Meter	Hourly	On the exterior of the supply and return boiler water pipes	Numerical tabulation and plotting
Electricity Usage	Electronic	24 hour intervals	Main, Hot Water (HW) Pump, DX AHU-4 Fan, DX AHU-4 Condensing Unit, FCU-4, Vault DH/EF	Numerical tabulation and plotting
Air Temperature	Electronic	5 minute intervals	AHU-B-Supply, Rooms: AB GSM B-Airflow, B-C006, B-C018 Conference Room, B-C021, B-TH Wall DP	Numerical tabulation and plotting
Air Humidity	Electronic	5 minute intervals	Rooms: AB GSM B-Airflow, B-C006, B-C018 Conference Room, B-C021, B-TH Wall DP	Numerical tabulation and plotting
Data Transmission	Electronic (isolated system), EnTouch	5 minute intervals	1540B Mechanical Room	Monthly observation

5.5.2 Data acquisition plan

5.5.2.1 System overview

The data communication system and acquisition plan was implemented through a Contractor-provided EMS. The EMS consisted of the EnTouch One System and its wireless components, which was completely separate and not connected in any way to the existing Invensys BAS. The EnTouch system provided the following capabilities needed to satisfy the data collection efforts of this endeavor: metering capabilities (to monitor several system performance metrics), data acquisition/collection and storage, and a method for off-loading data to the Contractor. Figure 5-12 shows a diagram of the system.

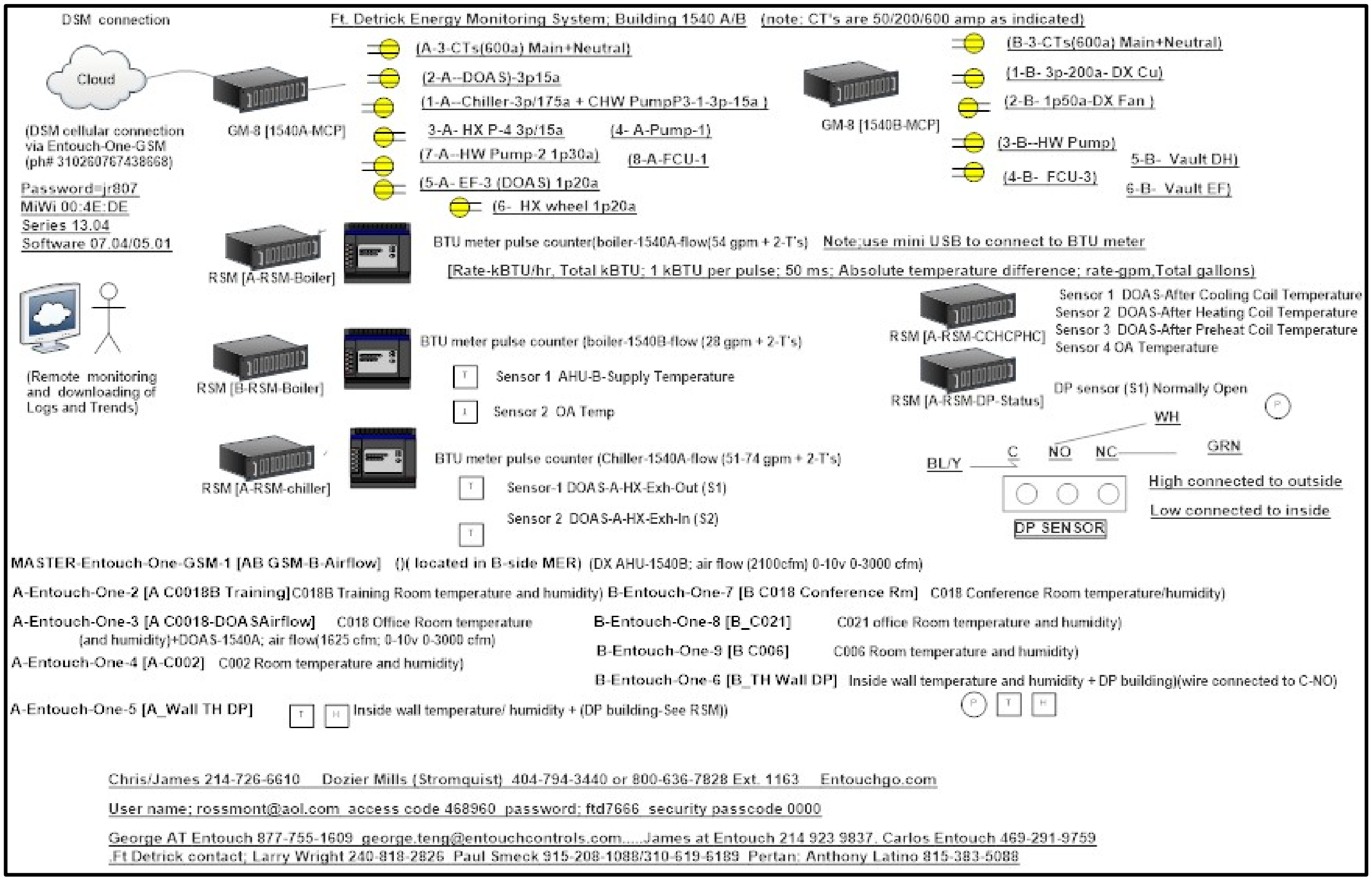
At the time of this project, the existing BAS was not connected to the installation-wide network. This project did not affect the network connection status of the existing BAS system; and the Contractor-provided EMS system did not access, share or communicate information with the existing

BAS or any other Fort Detrick data systems. The EMS only communicated through the Contractor-provided cellular connection, which was solely maintained and managed by the Contractor. Since the proposed EMS will not be necessary or required for normal building operation, when the project is completed and all of the required data are recorded, the proposed EMS will be turned off, removed, and/or abandoned in place on project completion, as determined and directed by the Government.

5.5.2.2 Data collection

Remote monitoring and downloading of data (logs and trends) were achieved through a Global System for Mobile Communications (GSM) cellular connection via an internal device. The EnTouch One Energy Management System (Figure 5-12 and Table 5-6) had an on-board cellular phone connection that connected to EnTouch's data servers (the "Cloud") where the logger and sensor data were downloaded and collected into a personal computer (PC) spreadsheet program. This cellular communication process eliminated the requirement for traditional internet or land line telephone connections. The data were stored at the EnTouch (2017) website, www.entouchgo.com.

Figure 5-12. Diagram highlighting the EnTouch Energy Management System and its components for Bldgs 1540A&B (as updated 13 Jan 2016).



The EMS had individual points that monitored and collected data on the following metrics (which have been outlined in-depth below):

- Energy Consumption – Electrical (kWh) and Thermal (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.
- DP 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.’ If the building interior pressure was less than the outside pressure, or ‘negative,’ untreated outdoor air would infiltrate into the conditioned spaces. If the building interior pressure was greater than the outside pressure, or ‘positive’, conditioned air would exfiltrate to the exterior. These data provided a better understanding of the additional ventilation air heating or cooling loads that the mechanical system had to accommodate, in addition to the plug loads and occupant loads.

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 a metric to compare the differences in energy use of the two HVAC systems.

Table 5-6. Acronym list for the EnTouch Energy Management System diagram.

Term	Definition
AHU	Air Handling Unit
BTU	British Thermal Unit
CHW	Chilled Water Supply
CT	Current Transformer Sensor
DH	Dehumidifier
DOAS	Dedicated Outdoor Air System
DP	Differential Pressure
DX	Direct Expansion Air-Conditioning System
EF	Exhaust Fan
FCU	Fan Coil Unit
HW	Hot Water
HX	Heat Exchanger
OA	Outside Air
P	Pump

5.5.2.3 *Energy monitoring points, Bldg 1540A*

Appendix D to this report includes datasheets for instruments listed in this Section.

Demonstration facility Bldg 1540A was renovated with new mechanical equipment including an air-cooled chiller and chilled water pump, DOAS, radiant panels, and controls. Overall gas and electric consumption data were provided by utility company meters:

1. **kWh (electric)** [Note: The EMS system had individual points that tracked each of the following device data points. These points were monitored via CT clamps and voltage measurements inside the main and branch circuit panels in Electrical Room C009.]:
2. 1540A Main Total (total building power) This was the total kWh for the building that provided more granular datasets than a single monthly electric utility meter reading.
3. Chiller + CHW pump P-3.
4. CHW pump P-4.
5. HW Pump P-2.
6. Pump P-1.
7. DOAS unit fan.

8. DOAS HX.
9. EF-3.
10. FCU-1.
11. **BTU (thermal)** [Note: Points were monitored via BTU pulse meters (flow + supply/return temperatures) in the piping. This did not include domestic hot water supply. The existing boiler and hot water pump in 1540A were retained. Chilled and hot water were in a closed system. See Section 2.2, "Description," for sensor layout and mechanical room layouts.]:
12. Chiller – included chilled water flow rate, supply and return water temperature sensors.
13. Boiler – included hot water flow rate, supply and return water temperature sensors.
14. Flow (airflow) [Note: This point was monitored via an airflow meter located in the supply ductwork of the DOAS unit.].
15. Temperature and Relative Humidity (°F, % RH) [Note: Points were monitored via temperature and relative humidity sensors.]:
16. DOAS unit HX supply and return temperatures.
17. Inside wall temperature and relative humidity (near room C003) – building envelope sensor (a similar T/RH measurement was taken inside the wall of 1540B).
18. Room temperature and RH, Room C0018 (office).
19. Room temperature and RH, Room C018B (IA training).
20. Room temperature and RH, Room C002 (office).
21. Pressure Differential (status):
22. Building DP alarm (located near room C003, alarmed if building pressurization went negative).
23. Ambient:
24. Outside temperature and humidity were per local weather data service (the EnTouch system uses local National Oceanic and Atmospheric Administration [NOAA] reported data)

5.5.2.4 *Energy monitoring system, Bldg 1540A*

The installation of the project's EMS within Bldg 1540A began in Nov 2014 and was substantially completed by Jan 2015. Figures 5-13 to 5-17 show some components of the installed EMS system.

Figure 5-13. EMS panel with monitoring devices installed.

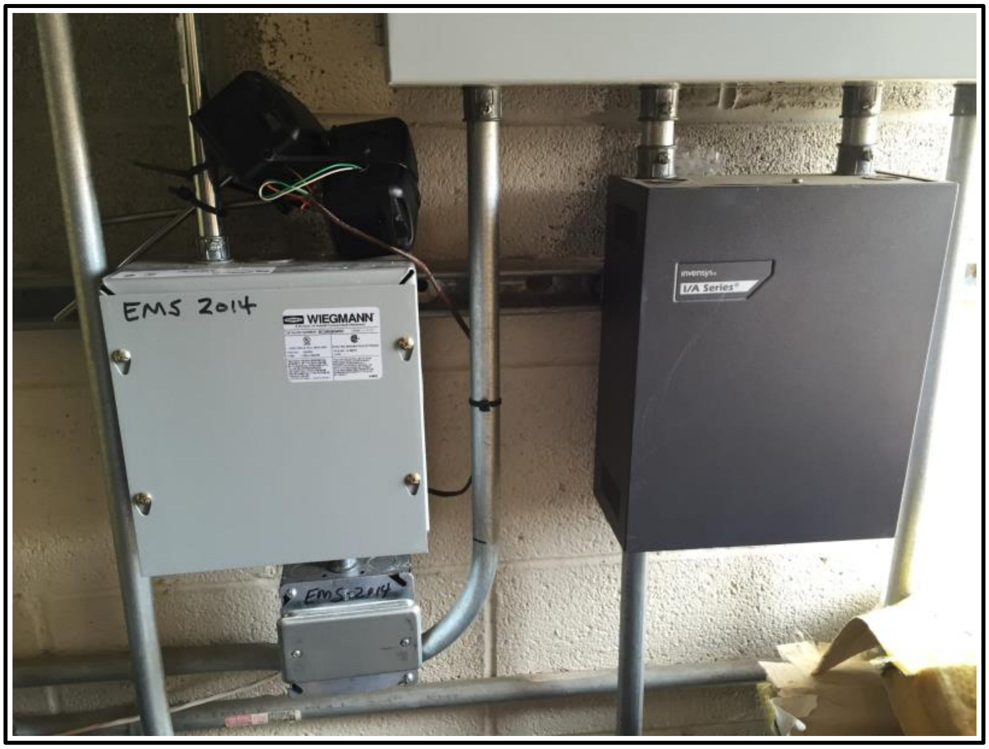


Figure 5-14. Boiler BTU meter connected to programming software.

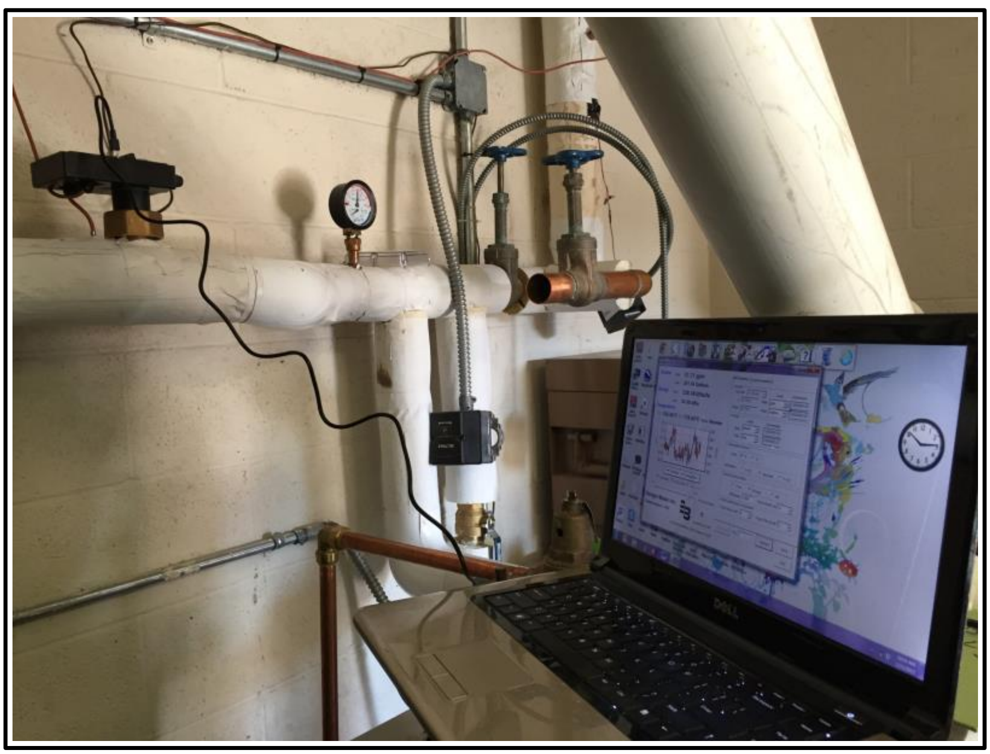


Figure 5-15. Boiler BTU meter as installed.

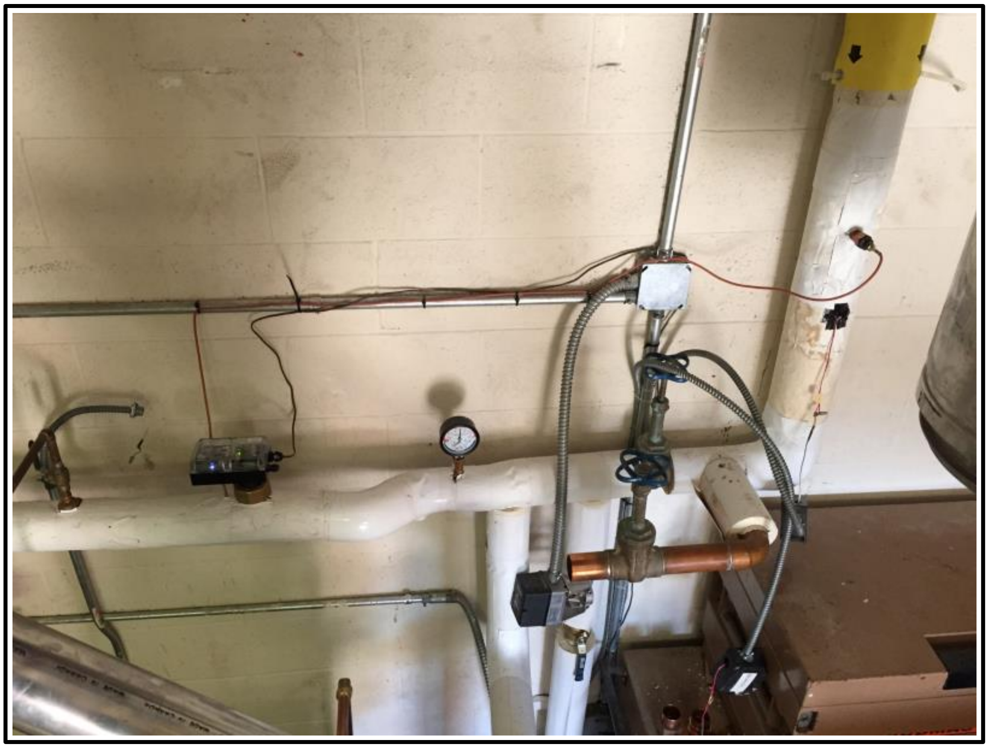
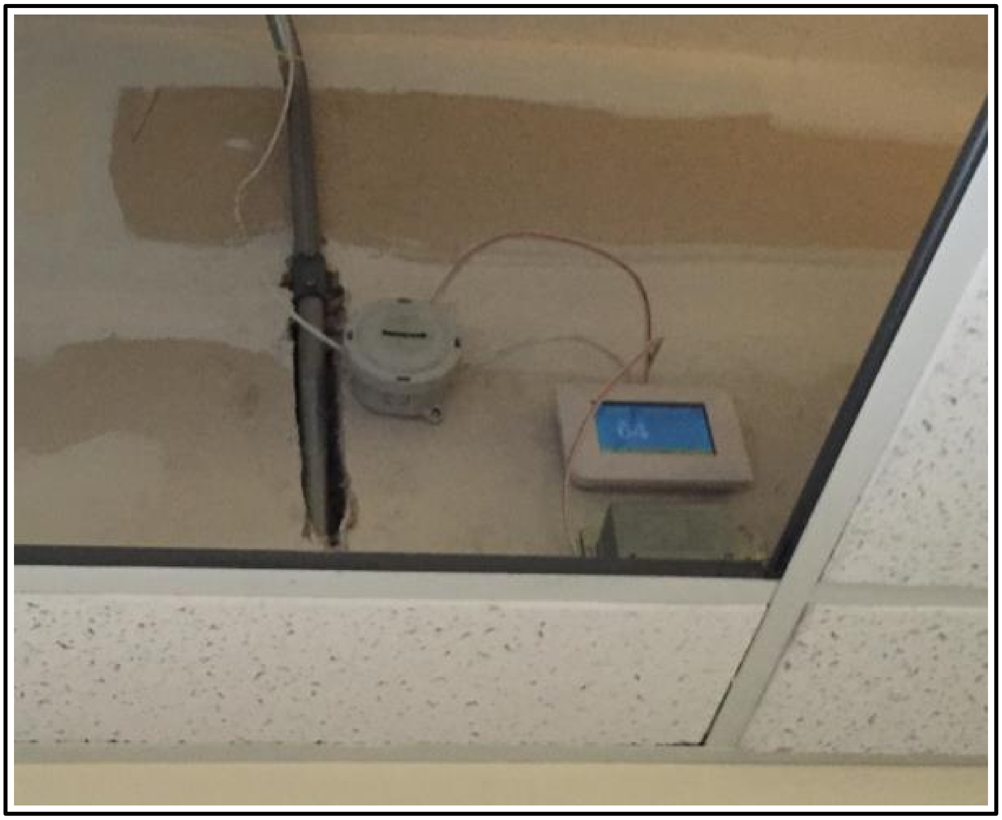


Figure 5-16. Building envelope DP sensor and wall temperature/RH sensors installed above office C003.

Figure 5-17. Building envelope DP sensor (high side inside room, low side outside building) and wall temperature/RH sensor installed above office C003.



5.5.2.5 Energy monitoring points, Bldg 1540B

The existing mechanical systems in Bldg 1540B were retained "as-is" and served as the project control. No new equipment or controls were added or modified. Overall gas and electric consumption data were provided by utility company meters.

1. **kWh (electric)** [Note: Points were monitored via CT clamps and voltage measurements inside the main and branch circuit panels in the electrical room.]:
2. Bldg 1540B Main Total (total building power).
3. HW Pump.
4. DX AHU-4 fan.
5. DX AHU-4 condensing unit.
6. FCU-3.
7. Vault Dehumidifier / Exhaust Fan (different from the A-side).
8. **BTU (thermal)** [Note: Points were monitored via BTU pulse meters (flow + temperatures) in the hot water piping.]:

9. Boiler – included common hot water flow, supply and return water temperature sensors.
10. **Flow (airflow)** [Note: Point was monitored via an airflow meter located in the supply ductwork of AHU-4.].
11. **Temperature and Relative Humidity (°F, % RH)** [Note: Points were monitored via temperature and humidity sensors.]:
12. AHU-4 supply air temperature.
13. Outside air temperature (the outdoor air temperature measured at the site generally tracked the outdoor air temperature recorded by NOAA at the Frederick Municipal Airport, although there were some differences due to the distance between the project site and the airport).
14. Inside wall temperature and RH (near room C006) – building envelope sensor.
15. Room temperature and RH, Room C006 (office).
16. Room temperature and RH, Room C0018 (conference).
17. Room temperature and RH, Room C021 (office).
18. **Differential Pressure (status)**:
19. Differential pressure alarm (alarm on negative pressurization) for the building (near room C006).
20. **Ambient Temperature and RH**:
21. Outside temperature and humidity per local weather data service.

5.5.2.6 Energy monitoring system, Bldg 1540B

The installation of the project's EMS within Bldg 1540B began Nov 2014, and was substantially completed by Jan 2015. Figures 5-18 to 5-24 show some components of the EMS installation.

Figure 5-18. EMS master monitoring device with Global System for Mobile Communications (GSM) communication device.

Figure 5-19. EMS Controller.

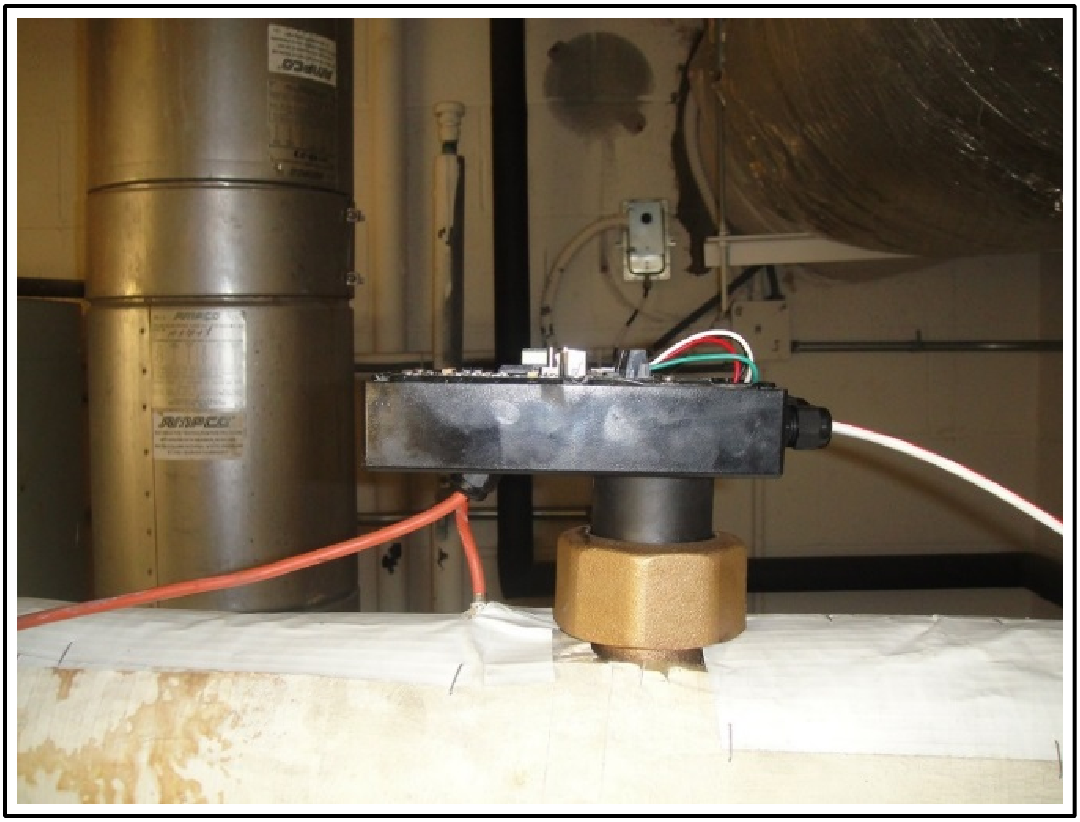
Figure 5-20. EMS installation within the Bldg 1540B mechanical room, showing EMS controller and outside air (OA) temperature sensor.

Figure 5-21. Air flow sensor located in AHU-4 supply air.

Figure 5-22. Outside air temperature sensor.

Figure 5-23. Supply air temperature AHU-4 duct sensor.

Figure 5-24. BTU meter located on Bldg 1540B boiler.



5.5.2.7 General note

For both buildings, electrical sub-meters were not installed on boilers, FCU's, Unit Heaters (UHs), CUH's, EF's, and packaged terminal air conditioners (PTACs). Gas flow monitoring was not included and domestic hot water heating monitoring points were not included.

5.5.2.8 Sensor layout

Figures 5-25 and 5-26 display the sensor layouts for Bldgs 1540A&B, respectively.

Figure 5-25. Sensor layout in Bldg 1540A.

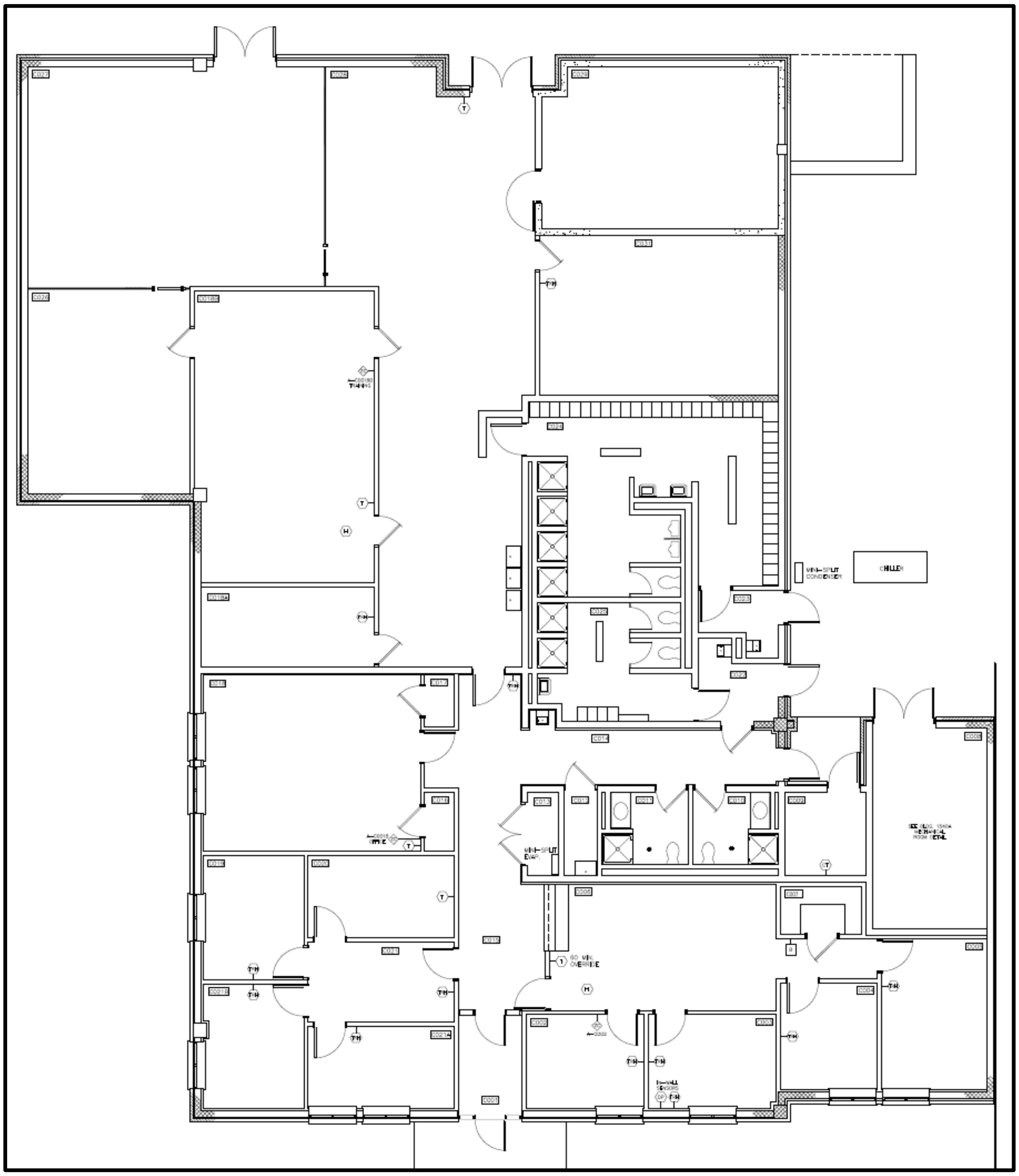
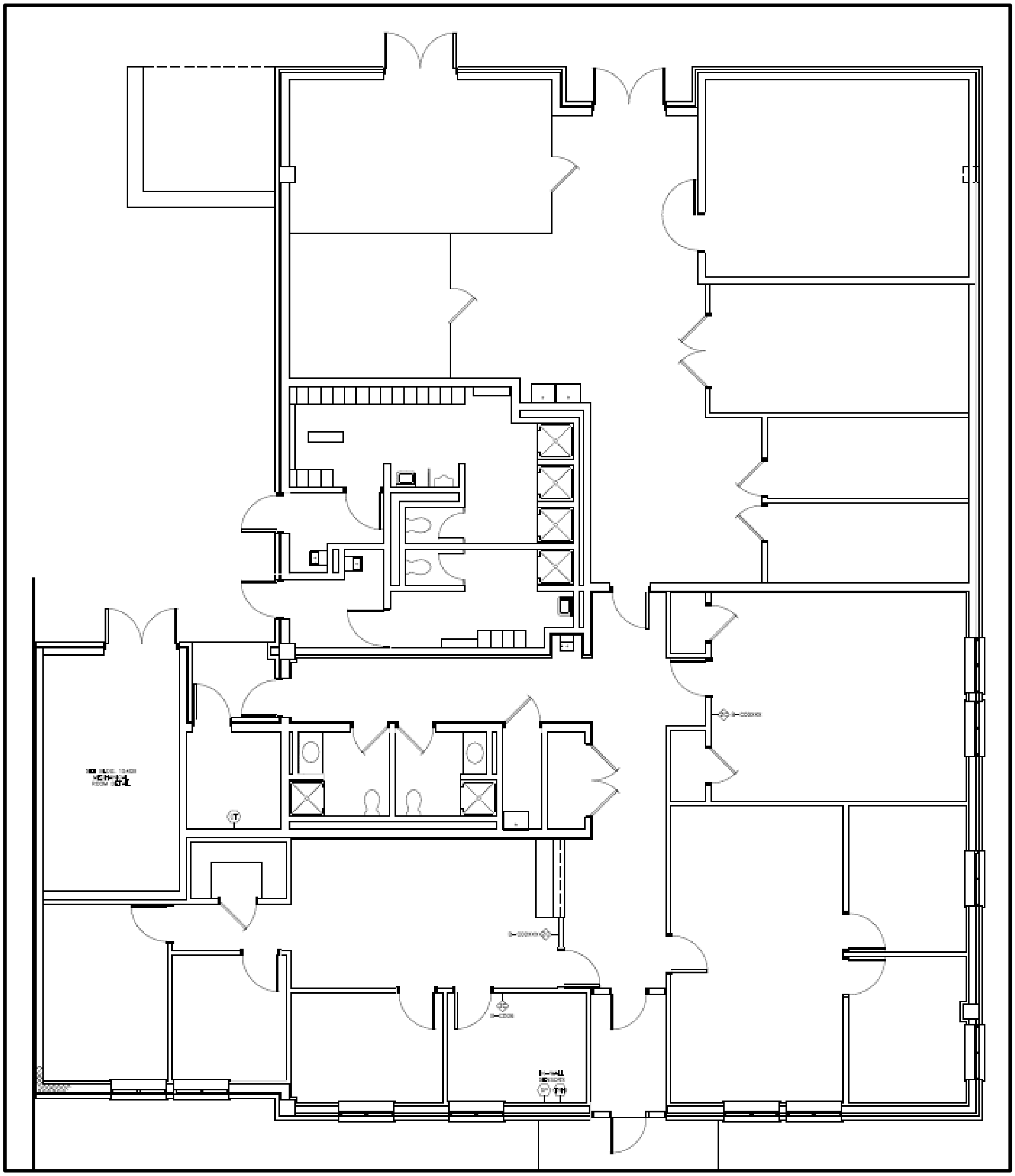


Figure 5-26. Sensor layout in Bldg 1540B.



5.6 Sampling results

Table 5-7 provides an overview of the data sampling, recording, and storage protocol for this demonstration. Chapter 6, "Performance Assessment," and its subsections provide data on the parameters detailed in Table 5-7 (excluding costs). Chapter 7, "Cost Assessment," and its subsections provide cost-related data.

Table 5-7. Data sampling, recording and storage protocol.

Parameters	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	NA	NA
Temperature	Demo Contractor	Temp loggers	Remote data access	NA	NA
Relative humidity	Demo Contractor	RH loggers	Remote data access	NA	NA
Gas consumption	DPW personnel	Manual recording	Paper and/electronic records	NA	NA
Electrical consumption	DPW personnel	Manual recording	Paper and/electronic records	NA	NA
First costs	Demo Contractor	Invoices	Paper and/electronic records	NA	NA
O&M costs	DPW personnel	Work orders	Paper and/electronic records	NA	NA
Occupant satisfaction	Demo Contractor	Temp loggers, Humidity loggers	Data stored in test instrument	NA	NA

5.7 Equipment calibration and data quality issues

- **Equipment Calibration:**
- Blower door apparatus (for testing building envelope air tightness) – to be calibrated by the building envelope air tightness testing Contractor.
- Temperature and RH instruments – factory calibrated.
- Gas meters – factory calibrated.
- Electric meters – factory calibrated. (Installed sensors had their factory calibration checked at the time of installation.)

- **Quality Assurance Sampling:** Temperature and RH data were transmitted in real time to the Contractor's office where it could be reviewed and inspected as frequently as necessary to ensure that all sensors were functioning properly and transmitting plausible data. Gas and electric meter data were checked on a monthly basis to ensure that the meters were functioning correctly.
- **Post-Processing Statistical Analysis:** Datasets were inspected to determine the quality of the collected data. Any missing data points were filled in by interpolation with surrounding data points, if reasonable. When numerous data points appeared to be missing, it was not appropriate or feasible to fill in these points. In such cases, it was necessary to flag such time periods for special consideration.

  Occasional outlier points were considered to be anomalous and were adjusted to conform to the preceding and succeeding data. Extended series of outliers were an indication of unexpected conditions in the sensed environment. Such situations warranted investigation to determine the cause of the anomaly and, if necessary, to take actions to correct it or otherwise account for it.

6 Performance Assessment

This chapter summarizes the data analysis process the investigators used for each performance objective. Section 6.8, "Performance Review" presents and reviews the collected data.

6.1 Baseline performance

A major objective of this project was to compare the baseline (pre-retrofit) energy performance of Bldg 1540A to its post-retrofit performance and to baseline facility Bldg 1540B. We requested access to Fort Detrick DPW's utility records and received the following data for Bldg 1540 for FY2013.

Table 6-1. FY2013 utilities data for Bldg 1540 from Fort Detrick's 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)		

Based on total building areas of 7,618 ft^2 (Bldg 1540A) and 5,590 ft^2 (Bldg 1540B), the calculated Energy Use Intensity (EUI) was 32.9 kWh/ft^2 for Bldg 1540A and 38.9 kWh/ft^2 for Bldg 1540B. Note that there are gaps in the data for both buildings for the months of July, August and September. We are not sure how to address these gaps.

We also hoped to collect several months of operational data in the pre-retrofitted Bldg 1540A while it was occupied under normal operations. Although the Contractor submitted their proposed Energy Monitoring plan on 15 Apr 2014, their proposed system was not approved by the Fort Detrick NEC until 10 Jul 2014. Meanwhile, the Bldg 1540A occupants had vacated the building in early July 2014.

After getting NEC approval, the Energy Monitoring System was ordered, installed and operational by early Sep 2014. As a result, we were unable to collect any pre-retrofit, occupied performance data in Bldg 1540A using our installed Energy Monitoring System as we had hoped. In the end, we used the Energy Monitoring System to collect 24 consecutive months of data for both Bldg 1540A and 1540B. We used this data to compare the first 12 months of Bldg 1540A energy performance data to the first 12 months of Bldg 1540B energy performance data and to the second 12 months of Bldg 1540A energy performance data. We also compared the first 12 months and the second 12 months of energy performance data for Bldg 1540B. The second 12 months of Bldg 1540B data are significant in that we completed repairing and recommissioning Bldg 1540B's mechanical systems just before the start of this second 12-month data collection period.

During the first 9 months of our energy performance data collection, Bldg 1540A underwent a variety of phases related to the renovation process. Tables 6-2 to 6-4 list the electricity and gas utility usage for Bldgs 1540A&B during this first 12-month period (Sep 2014 thru Aug 2015). The Bldg 1540A phases were: (1) an unoccupied, pre-retrofit period (highlighted in pink), (2) an unoccupied retrofit period (highlighted in yellow), and (3) a reoccupied post-retrofit period (highlighted in blue). Section 6.8, "Performance Review," includes comparisons of, and interpretations drawn from this data.

Table 6-2. Energy related baseline parameters for Bldgs 1540A&B.

Building	Preliminary Envelope Air Leakage	Electricity Usage Sep 2014 thru Aug 2015	Gas Usage Sep 2014 thru Aug 2015	Total Energy Usage Sep 2014 thru Aug 2015
1540A	0.82 CFM_{75}/ft^2	97,210 kWh	5,121 Therms	247,292 kWh
1540B	1.12 CFM_{75}/ft^2	51,822 kWh	6,068 Therms	229,658 kWh

Table 6-3. First 12-month energy performance monitoring period for Bldgs 1540A&B (Sep 2014 thru 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)	

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

Table 6-4. Second 12-month energy performance monitoring period for Bldgs 1540A&B (post retrofit, occupied, Sep 2015 thru Aug 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/ft² (based on 7,618 ft²)			30.67 kWh/ft² (based on 5,590 ft²)		

The second 12 months of data (above) were collected after completing mechanical system repairs and recommissioning of Bldg 1540B.

One Action Item raised by ESTCP's Technical Review Panel was to quantify and discuss the impact of solar heat gains on the different sides of the building. The centerline of the wall dividing Bldgs 1540A&B was oriented along a nearly northwest-southeast axis as shown in Figure 6-1. As oriented, Bldg 1540A and 1540B had equal roof and wall surface areas facing northwest, Bldg 1540A had significantly more roof and wall surface area facing northeast and southeast than Bldg 1540B and it had slightly less roof and wall surface area facing southwest than Bldg 1540B. With respect to solar heat gain, southwest facing surface areas would be the most significant, followed by southeast facing surface areas. In Figure 6-1 one can see also that the southwest side of Bldg 1540B appears to be shaded by a number of mature trees while the southwest side of Bldg 1540A faces a paved open courtyard.

Considering these differing relative surface areas and differing orientations, combined with significant shading of the southwest facing walls of Bldg 1540B, it is very difficult to estimate the impact of the building's orientation on the relative energy usage of the demonstration side and the baseline side of the building. We do not believe that relative energy usage was significantly affected by building orientation, but the only way to arrive at a credible estimate of the effect on the relative energy usage would be to model the building, preferably using an hour-by-hour modeling tool such as EnergyPlus™. No such modeling was conducted as part of this project.

Figure 6-1. Satellite view of Bldgs 1540A&B (maps.google.com).

6.2 Reduced building envelope air leakage

- **Performance Objective Analysis Overview:** Building envelope air leakage 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 ASTM E779 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* (ASTM 2003a).
- **Statistical Methodologies:** The methodology uses an unweighted log-linearized linear regression technique, where *Q* is the airflow rate, in m^3/s (ft^3/min), and *dP* is the differential pressure in Pa. In determining the fit to a prescribed equation, the confidence intervals of the derived air leakage coefficient *C* and pressure exponent n are calculated

according to a procedure defined by this Standard. *C* and *n* are calculated separately for pressurization and depressurization. If the pressure exponent is less than 0.5 or greater than 1, then the test is invalid and must be repeated.

- **Graphical Methodologies:** Graphical methodologies were not used.
- **Modeling and Simulation:** Modeling or simulation were not performed as part of this project.
- **Sensitivity Analysis:** Confidence limits for the derived values were determined from the data using the methodology specified in the Standard. The confidence limits of a combined pressurization and depressurization are based on a simple average of pressurization and depressurization values.
- **Industry Standards:** ASTM E779 (ASTM 2003a) is the industry standard for this procedure.
- **Internal Validity:** Test equipment was calibrated, all intentional building envelope openings were sealed, and occupants were prohibited from entering or leaving the building during data collection periods. Data were examined to identify any anomalies that would indicate a possible need to repeat the test.
- **External Validity:** This methodology is broadly applicable to all military installations, regardless of building type, climate zone or other factors.

6.3 Reduced energy consumption

- **Performance Objective Analysis Overview:** Relative energy performance of the retrofitted Bldg 1540A was compared with the baseline energy performance of Bldg 1540B. The electrical and gas energy required to heat, cool and ventilate both buildings was analyzed and compared.
- **Statistical Methodologies:** No statistical analysis was performed.
- **Graphical Methodologies:** Plots of relative energy consumption as a function of time were employed. Other plots illustrated relative energy performance as a function of outdoor weather conditions.
- **Modeling and Simulation:** We did not perform modeling or simulation as part of this project.
- **Sensitivity Analysis:** Building operations during normal daily and seasonal changes in outdoor ambient conditions enabled analysis of the building's sensitivity to outdoor weather conditions in comparison to energy consumption of the baseline facility.

- **Anecdotal Perspectives:** We discussed with energy managers and maintenance personnel their general observations about the function of the retrofitted facility. We also noted typical temperature settings in Bldgs 1540A&B necessary to maintain comfort and any significant changes in occupancy or activities within the baseline and retrofitted facilities that might impact relative energy performance.
- **Industry Standards:** We referenced ASHRAE's *Performance Measurement Protocols for Commercial Buildings: Best Practice Guide* (ASHRAE 2012b), and ASHRAE's Guideline 14-2014, *Measurement of Energy, Demand, and Water Savings* (ASHRAE 2014) or similar guidance.
- **Internal Validity:** We measured energy consumption similarly on both sides of the demonstration building to ensure that the energy required to heat, cool, and ventilate both sides was accurately portrayed. Energy consumption meters were calibrated and checked on a regular basis.

  We had no effective means of tracking significant differences or changes in occupancy or activities in the baseline and retrofitted facilities to account for the effect of occupants. On our various site visits, however, we noted that occupants appeared to be keeping exterior doors and windows closed at all times.

  External Validity: We believe that these integrated technologies are feasible and applicable to all but the most extremely humid locations. These technologies should be ideally suited to dry climates (i.e., locations with low outdoor DPTs) because the ventilation air dehumidification load would be minimal. In such locations, the dehumidification capacity of the DOAS system could be greatly reduced or possibly eliminated altogether. This would reduce the first cost of the system and simultaneously lower the operating cost as well. In such locations, with low outdoor humidity levels, there would be decreased risk of condensation on radiant cooling surfaces. As a result, it might be safe to operate the radiant cooling panels at lower surface temperatures without risk of condensation. If so, this would increase the cooling capacity of the panels and possibly further decrease first costs.

  In hot locations, these technologies would remain technically feasible as long as it would be possible to install sufficient cooling surface area to satisfy the cooling load requirement. In making this determination, the designer would need to consider the expected DPTs within the space and adjust the panel surface temperature accordingly. A panel surface temperature reduction of only a few degrees would significantly increase the system's cooling capacity. For example, in a room with a mean radiant temperature of 78 °F and a panel surface temperature of 62 °F, lowering the panel's surface temperature by 2 °F would increase the radiant cooling capacity by 12%.

These technologies would be quite ideal in locations where the design heating load was significantly larger than the design cooling load. In the heating mode, the ΔT between the hot water supply and return temperatures is much greater than the ΔT between the chilled water supply and return temperatures. As a result, a given radiant panel surface area would have much more heat transfer capacity in the heating mode than in the cooling mode. If the cooling load were substantially smaller than the heating load, the total radiant panel surface could be significantly downsized, making the first cost of the overall radiant heating and cooling system much less expensive.

Radiant heating systems are already being used in large open bay systems such as hangars, garages, and maintenance facilities. These facilities are typically not cooled. Occupancies that are expected to benefit from the combination of radiant heating and cooling would include administrative and barracks facilities. In all applications, adequate provision must be made for delivery of properly conditioned ventilation air.

6.4 Cost effectiveness

- **Performance Objective Analysis Overview:** We tracked the costs to install the proposed systems and 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.
- **Graphical Methodologies:** Cost data for the demonstrated systems vs. a conventional system were presented in a tabular format.
- **Modeling and Simulation:** We did not perform modeling or simulation as part of this project.
- **Sensitivity Analysis:** Sensitivity analysis to determine the impact of increases (or decreases) in system component costs, differing local utility rates and differing climate conditions was not performed.

- **Anecdotal Perspectives:** We were unable to obtain a good breakdown of the construction Contractor's perspective of the relative costs of these technologies vs. more conventional technologies. We were unable to get feedback from the Fort Detrick DPW on the relative costs to maintain the demonstrated system vs. a more conventional system.
- **Industry Standards:** RS Means cost data were used as a reference of comparison of costs to purchase and install these systems.
- **Internal Validity:** We 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. We 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.
- **External Validity:** Cost effectiveness of this technology at other locations will need to consider local utility rates and labor rates in addition to local climate conditions. In a very dry, temperate climate, it might be possible to successfully implement this technology with very little dehumidification capacity and reduced heating and cooling capacity. Conversely, in a humid location with extreme peak heating and increased cooling and dehumidification requirements, use of these technologies might be prohibitively expensive.
- **Building Life-Cycle Cost Program:** To address the System Economics Performance Objective, the USDOE's Life-Cycle Cost tool was used.

6.5 Improved comfort

- **Performance Objective Analysis Overview:** Comfort was analyzed with reference to ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy, Section 5.2.1.1 "Graphic Zone Comfort Method" (ASHRAE 2010).
- **Statistical Methodologies:** No statistical analyses were performed.
- **Graphical Methodologies:** A time dependent scatter plot was used (section 6.8.2). A stock chart was also modified to accommodate the display of temperature and humidity ranges.
- **Modeling and Simulation:** We did not perform modeling or simulation as part of this project.

- **Sensitivity Analysis:** We did not perform a sensitivity analysis to determine how occupant comfort might be impacted by unusual outdoor temperature or humidity conditions.
- **Anecdotal Perspectives:** We attempted to perform a survey of occupants of Bldgs 1540A&B, but the occupants were not responsive to the survey. We did, however, hear about a complaint of uncomfortably warm conditions in Bldg 1540A's Room C018B (the Information Assurance training classroom). 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, we had a brief discussion with the instructor in this classroom. He said that the temperatures in the classroom were still too hot and that they 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. The Contractor's initial design was for an expected classroom cooling load of one instructor, 10 students, their computers, a projector, and the room's lighting. After the occupants returned to the building, we found that the cooling load had essentially doubled (one instructor, 20 students, their computers, a projector, and the room's lighting). As a result, the original radiant cooling system design for this space was wholly undersized to handle the space's actual cooling load. The Contractor worked with the radiant panel manufacturer to attempt to address the problem with the installation of a few additional panels. However, without a major reworking of the entire system in 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. One can see from Figure 5-7 that most of the available ceiling space is currently taken with the installed panels. Apparently the radiant panel manufacturer had some further ideas to increase the cooling capacity, to include mounting cooling panels on the upper walls of the space. It might have been possible to satisfactorily address the problem with further system changes, but this was not attempted. 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.

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

It should also be noted that it was basically 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 they were being very careful to maintain radiant panel temperatures above the space DPT, 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%.

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

- **Industry Standards:** ASHRAE Standard 55-2010, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 2010).
- **Internal Validity:** We discouraged the use of personal electric heaters, personal fans, opened windows and doors, or other means for people to control their personal comfort. We made sure that the temperature and humidity sensors used to ascertain comfort per ASHRAE Standard 55 (ASHRAE 2010) were properly calibrated, located appropriately, and providing credible data.
- **External Validity:** Other than the problem of comfort issues in Room C018B noted above, we verified that the system provides comfort in accordance with ASHRAE Standard 55 (ASHRAE 2010), assuming that the system is designed and installed with adequate heating, cooling, dehumidification, and ventilating capacity.

6.6 Reduced relative mold/mildew potential

- **Performance Objective Analysis Overview:** Of the three necessary ingredients for the formation and growth of mold and mildew (spores, food source, an acceptable temperature range and adequate moisture in the food source), the only one that we can realistically control is the moisture content of the food source. Therefore, our analysis focused on the ability of the retrofitted facility to maintain humidity in the building at levels that will keep building elements and building contents dry enough to discourage mold and mildew formation and growth.
- **Statistical Methodologies:** No statistical analysis was performed.
- **Graphical Methodologies:** We did not use graphical methodologies to analyze this item.
- **Modeling and Simulation:** We did not perform modeling or simulation as part of this project.
- **Sensitivity Analysis:** No sensitivity analysis was planned.
- **Anecdotal Perspectives:** No interviews were conducted.
- **Industry Standards:** "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 below 0.75, our goal was to ensure that no building materials or building contents experienced a water activity greater than 0.75.
- **Internal Validity:** We ensured that temperature and RH data loggers were properly calibrated and delivering accurate data. We also located these devices in the areas that were most susceptible to development of mold and mildew.
- **External Validity:** This performance objective is fully applicable to other locations because it is dependent on maintaining the proper internal environmental conditions that should be attainable with a properly designed system.

6.7 Easily operable and maintainable

- **Performance Objective Analysis Overview:** Because this project replaced a conventional mechanical system, our goal was to demonstrate that the retrofit system was at least 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 O&M of the conventional system within the baseline facility.
- **Statistical Methodologies:** O&M data are sufficiently sparse to be statistically insignificant.
- **Graphical Methodologies:** Graphical methodologies were not used.
- **Modeling and Simulation:** We did not perform modeling or simulation as part of this project.
- **Sensitivity Analysis:** No sensitivity analysis was performed.
- **Anecdotal Perspectives:** We engaged the O&M staff during commissioning of the demonstrated systems. The 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, we attempted to discuss with the installation energy manager and the O&M staff their experiences working with the demonstrated system. As this was an unfamiliar technology, it would have been helpful to identify areas of misunderstanding or concepts that needed to be explained so that maintenance staff could more easily operate and maintain the systems. We were able to discuss maintenance issues with the DPW's Chief of Operations after about 2 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, we believe that the demonstrated system was as at least as operable and maintainable as the conventional VAV system that it replaced.

- **Industry Standards:** We are unaware of any related industry standards.
- **Internal Validity:** We were unable to analyze operability and maintainability for internal validity.
- **External Validity:** We were unable to evaluate external validity of this performance objective.

6.8 Performance review

6.8.1 Overview of performance review

The data listed Table 6-5 give an overview of the performance objectives of this demonstration.

6.8.2 Thermal comfort

The Graphical Zone Method of ASHRAE STD 55-2010 (ASHRAE 2010) provides a plotted area of temperature and humidity combinations where 80% of occupants in mechanically cooled spaces will be comfortable performing low exertion activities (typing, filing, etc.) (Figure 6-2). 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 a.m. to 6 p.m.) ranged between 62 and 78 °F, averaging 70 °F (Figure 6-3). Similarly, 95% of the daily relative humidities (6 a.m. to 6 p.m.) ranged between 28 and 58% RH, averaging 43%. These parameters for Bldg 1540A were predominantly within the standard's plotted area of acceptability, demonstrating Bldg 1540A's compliance with ASHRAE STD 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, they were often below 67 °F at the start of the "occupied" period (6 a.m. to 6 p.m.) in the winter months (Figure 6-4, Table 6-6).

Table 6-5. Overview of 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 ΔP 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 (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	SP, SIR	First costs, O&M costs, energy costs, and useful life	SP: < 5 yrs. SIR: > 1.2	SP of 26.7 yrs. SIR of 1.0 *Objective not met.*
Qualitative Performance Objectives				
Improved comfort	Occupant satisfaction	Space 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 at or below 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 w/ O&M personnel	Maintainable by existing staff, no special skills required, less O&M burden	*Objective met*

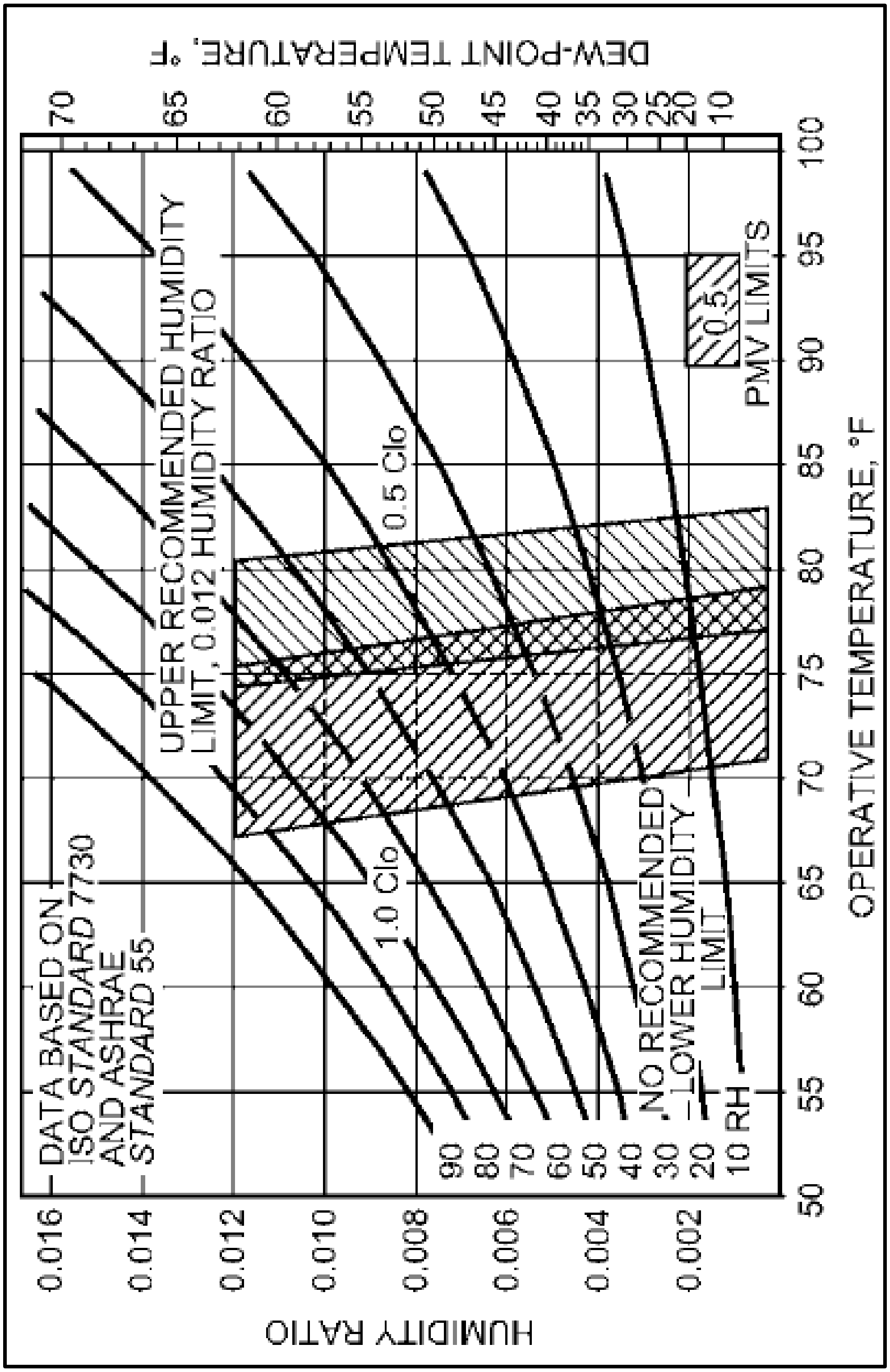


Figure 6-2. A graphical zone method chart derived from ASHRAE Standard 55.

Figure 6-3. Thermal comfort values for Bldg 1540 during occupied hours (6 a.m. to 6 p.m.).

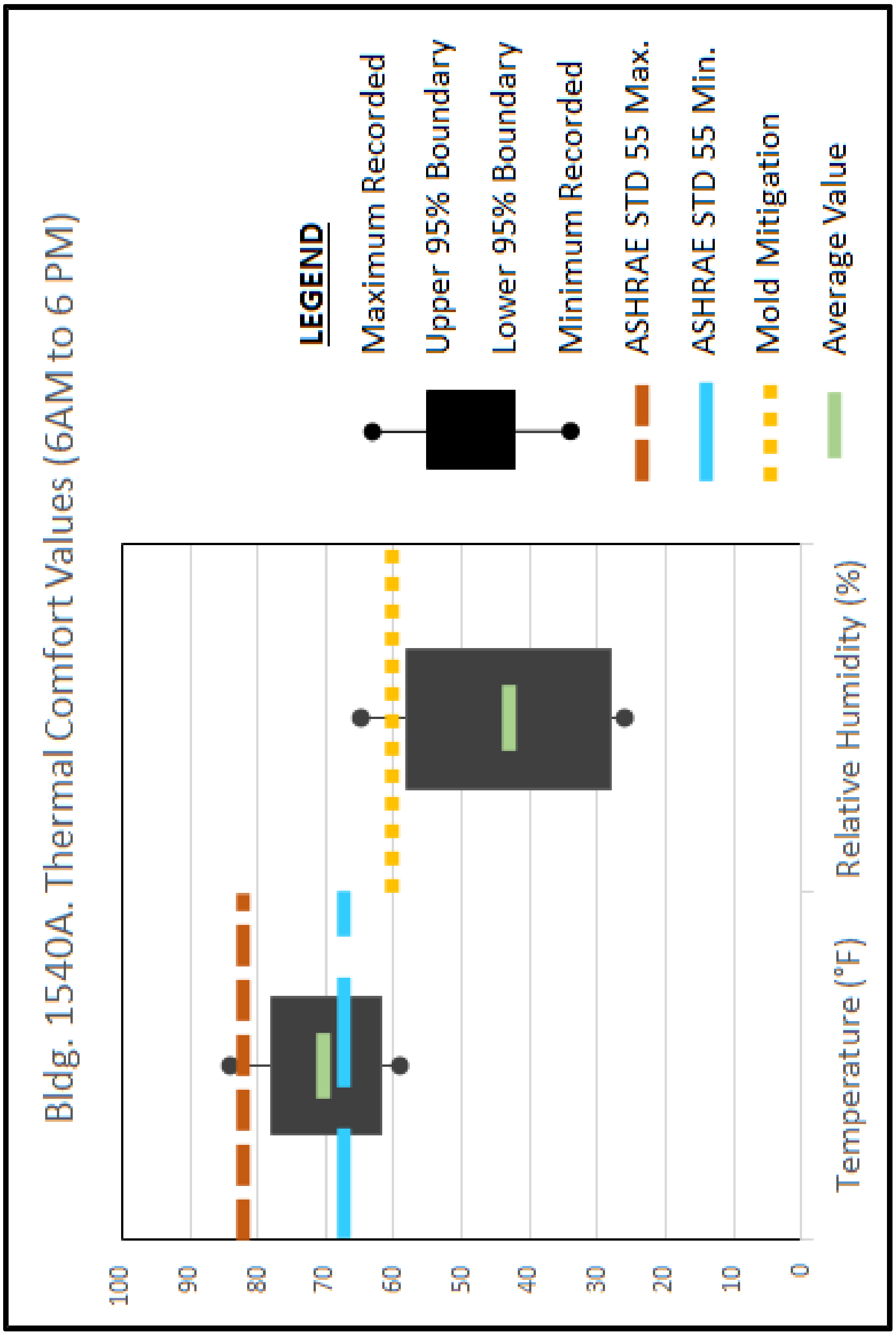


Figure 6-4. Interior temperatures recorded within Bldg 1540A.

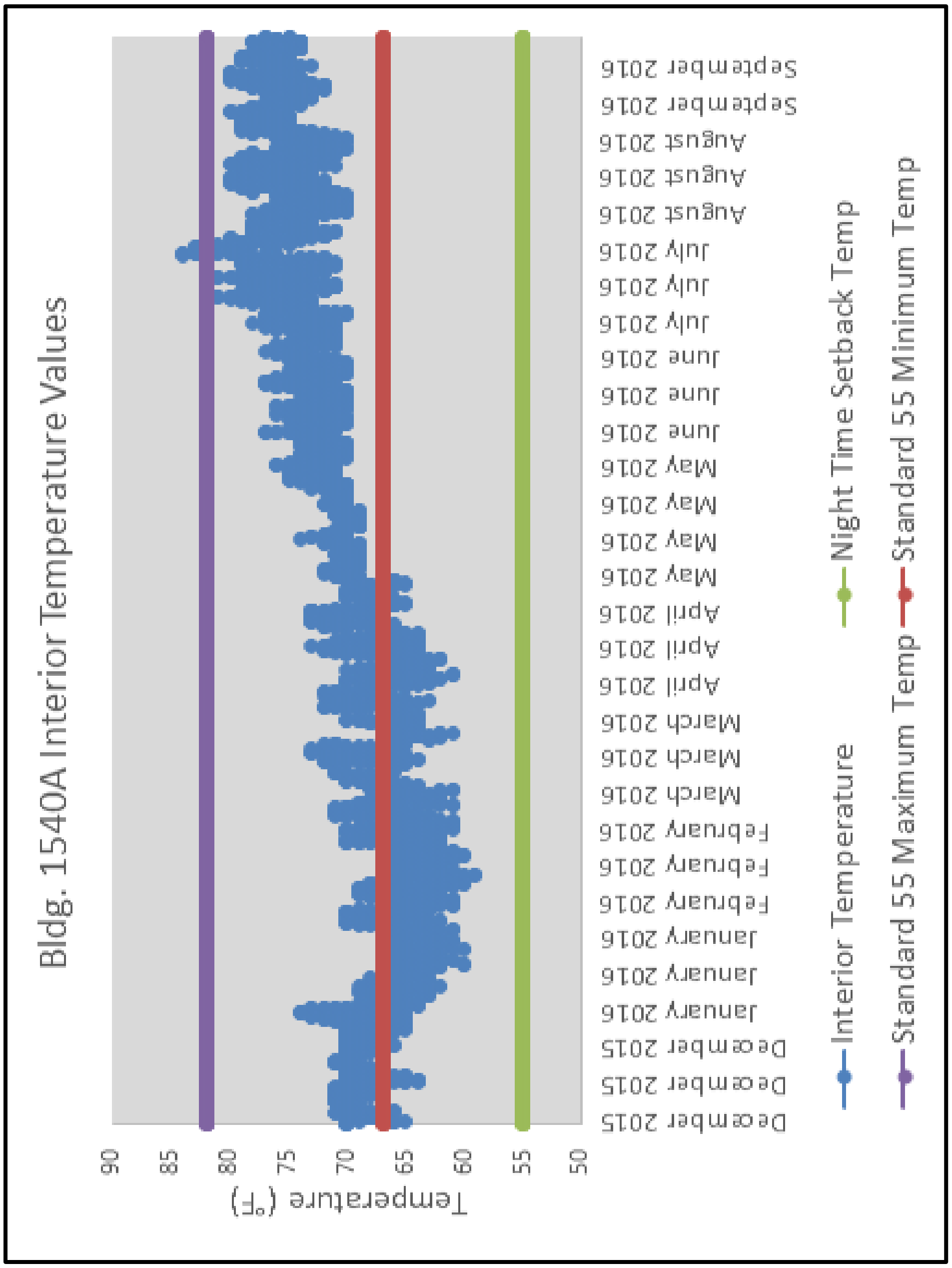


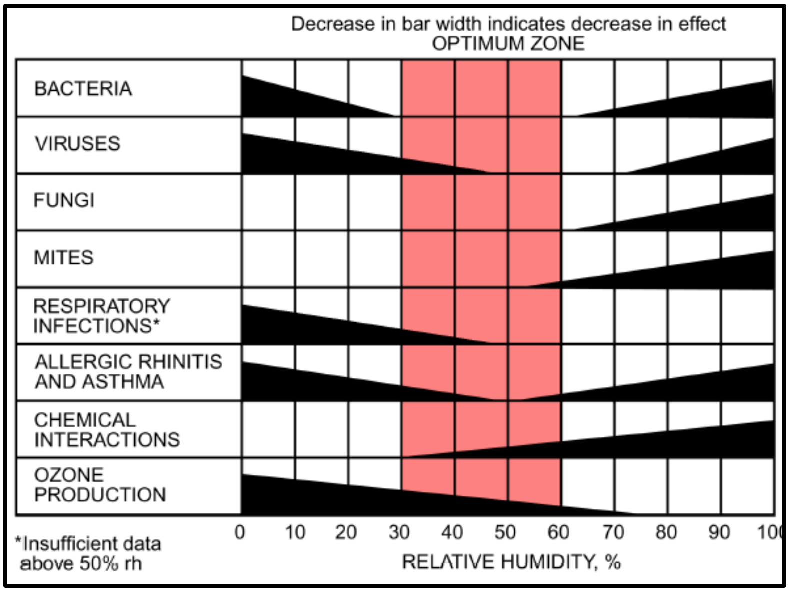
Table 6-6. Monthly outdoor temperatures and interior thermal comfort ranges.

Month	Outside Temperature	1540A Interior Temperature	1540A Interior RH	1540B Interior Temperature	1540B Interior RH
Sep 2015	77 °F	N/A	N/A	N/A	N/A
Oct 2015	65 °F	N/A	N/A	N/A	N/A
Nov 2015	56 °F	55 °F-78 °F	26%-59%	N/A	N/A
Dec 2015	53 °F	64 °F-75 °F	29%-66%	N/A	N/A
Jan 2016	30 °F	60 °F-74 °F	27%-47%	N/A	N/A
Feb 2016	35 °F	59 °F-71 °F	25%-45%	N/A	N/A
Mar 2016	48 °F	61 °F-73 °F	33%-52%	N/A	N/A
Apr 2016	50 °F	61 °F-73 °F	30%-54%	69 °F-74 °F	29%-57%
May 2016	63 °F	64°-75 °F	35%-57%	69 °F-76 °F	33%-65%
Jun 2016	72 °F	70 °F-77 °F	40%-57%	70 °F-77 °F	40%-60%
Jul 2016	78 °F	70 °F-85 °F	40%-60%	71 °F-80 °F	49%-68%
Aug 2016	78 °F	70 °F-81 °F	41%-58%	71 °F-82 °F	54%-69%

6.8.3 Microbial growth potential

In addition to thermal comfort, ASHRAE has also published recommendations for indoor humidity levels for mitigating mold growth and promoting human health. 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 and 60% RH (Figure 6-5). Bldg 1540A averaged 43% RH during the occupied period (6 a.m. to 6 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 system combination to maintain temperature and humidity for indoor health and comfort.

Figure 6-5. The optimum humidity range for human comfort and health (30 to 60%), as published in the 2012 *ASHRAE Handbook on HVAC Systems and Equipment*.



6.8.4 Comparison with baseline energy Performance

This project demonstrated energy savings for Bldg 1540A's radiant system over the original all-air system. Overall energy consumption (electric + gas) in Bldg 1540A for the period Sep 2015 through Aug 2016 decreased 42% compared with the prior 12 months (Sep 2014 through Aug 2015) (Figure 6-6 and Table 6-7). This was due to a 20% decrease in electricity usage, and a 56% decrease in gas usage (Figures 6-7 and 6-8). Section 6.8.5 compares the energy performance of Bldgs 1540A&B.

Table 6-7. Monthly electric and gas usage data for Bldg 1540A during the periods of Sep 2014 through Aug 2015 and Sep 2015 through Aug 2016. Also shown are monthly HDD and CDD (base 60).

	Sep 2014 through Aug 2015				Sep 2015 through Aug 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

	Sep 2014 through Aug 2015				Sep 2015 through Aug 2016				
Month	HDD_{60}	CDD_{60}	Electric (kWh)	Gas (Therms)	Month	HDD_{60}	CDD_{60}	Electric (kWh)	Gas (therms)
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	5,121	Total	3282.9	1909.1	78,036	2,229
Total			247,292		**Total**			143,362	

In Table 6-7, note that Bldg 1540A was unoccupied during the shaded months while the demonstration system was being installed. Table 6-7 also includes Heating Degree Days (HDD) and Cooling Degree Days (CDD) using a balance point of 60 °F. Weather data were obtained from a Global Surface Observation Data (GSOD) data file from the Frederick Municipal Airport, which is approximately 1 mile to the Southeast of Bldg 1540. The data consist of daily averages of DBT data, dew point temperature data, and several other weather data parameters. HDD and CDD calculations are based on daily average DBT data only. From a quick review of Table 6-7, one can see that there were 14% more HDDs and 4% more CDDs in the period of Sep 2014 to Aug 2015 than for the period Sep 2015 to Aug 2016. These greater HDDs and CDDs are not significant enough to account for the considerably more electrical and gas energy consumed in the period of Sep 2014 to Aug 2015.

In reviewing Table 6-7, it is puzzling to note that, although Bldg 1540A was unoccupied from Sep 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 year. The Contractor went to great efforts to account for these anomalies, including checking the calibration of meters and instrumentation and reviewing sequences of operation and operational schedules and verifying conversion factors on gas meters.

It is possible that construction contractor activities consumed an inordinate amount of electricity during the unoccupied period, but this is considered to be unlikely. The Contractor also 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. They 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.

Figure 6-6. Bldg 1540A total energy usage (electric + gas) for the period Sep 2015 to Aug 2016 vs. the period Sep 2014 to Aug 2015.

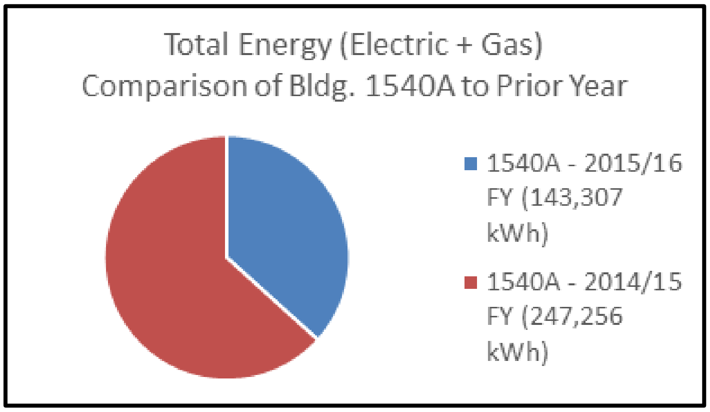


Figure 6-7. Bldg 1540A realized a 20% decrease in electrical usage for the period Sep 2015 to Aug 2016 vs. the period Sep 2014 to Aug 2015.

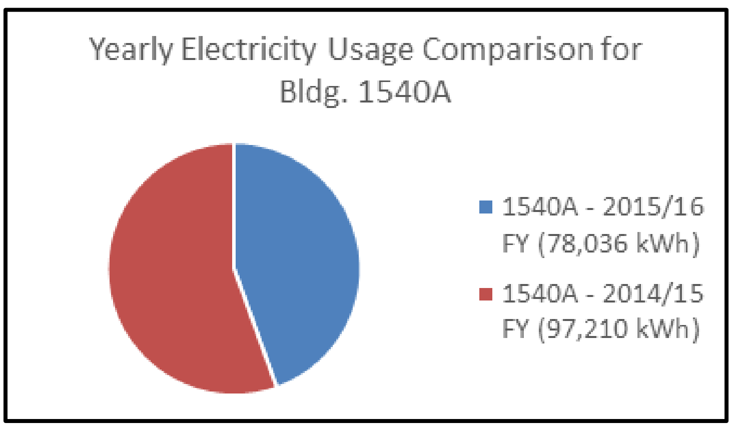
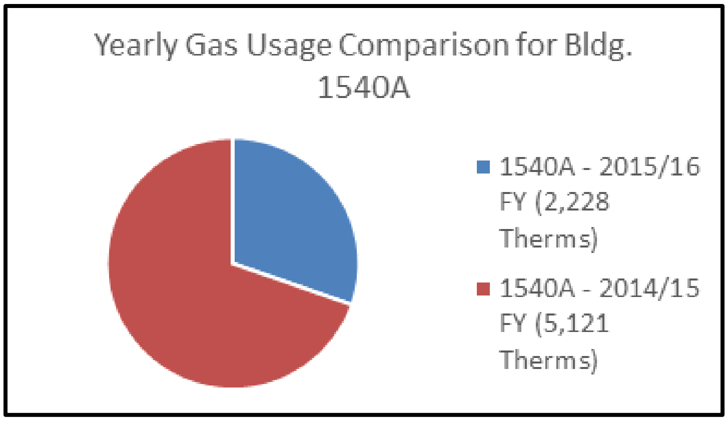


Figure 6-8. Bldg 1540A realized a 56% decrease in gas usage for the period Sep 2015 to Aug 2016 vs. the period Sep 2014 to Aug 2015.



Bldg 1540B's energy usage shared similarities with the previous year. Overall energy consumption (electric + gas) in Bldg 1540B decreased 25% compared with the prior year (2014/2015 FY) (Figure 6-9 and Table 6-8). This was due to a 14% increase in electricity usage being offset by a 37% decrease in gas usage (Figures 6-10 and 6-11).

Table 6-8. Bldg 1540B monthly electric and gas usage data for the periods of Sep 2014 through Aug 2015 and Sep 2015 through Aug 2016.

Month	Electric (kWh)	Gas (therms)	Month	Electric (kWh)	Gas (therms)
Sep 2014	4,332	432	Sep 2015	5,359	139
Oct 2014	6,317	373	Oct 2015	4,449	323
Nov 2014	6,071	710	Nov 2015	4,096	411
Dec 2014	6,366	754	Dec 2015	4,540	485
Jan 2015	6,679	792	Jan 2016	4,853	771
Feb 2015	6,152	957	Feb 2016	4,621	697
Mar 2015	677	606	Mar 2016	4,929	445
Apr 2015	45	495	Apr 2016	4,665	281
May 2015	5,779	423	May 2016	4,296	225
Jun 2015	2,234	259	Jun 2016	4,830	43
Jul 2015	3,374	133	Jul 2016	5,990	10
Aug 2015	3,796	133	Aug 2016	6,235	12
Total	51,822	6,068	Total	58,863	3,842
Total	**229,686 kWh**			**171,461 kWh**	

The decreased energy usage in baseline Bldg 1540B is also somewhat difficult to explain. As with Bldg 1540A, the 14% more HDDs and 4% more CDDs in the period of Sep 2014 to Aug 2015 than for the period Sep 2015 to Aug 2016 do not appear to be sufficient to explain the building's reduced energy usage from Sep 2015 to Aug 2016. One possible explanation for the reduced energy usage might be that the repairs and recommissioning work (see Appendix B) completed in Aug 2015 improved the building's overall energy efficiency. Although some energy efficiency improvements may have resulted, it seems unlikely that the building would have seen such a significant improvement in energy efficiency. A more plausible explanation would seem to be that occupancy and/or activities within Bldg 1540B were significantly reduced during the latter period as compared to the prior year. We were unable to verify relative occupancies or activity levels between these two periods.

Figure 6-9. Bldg 1540B total energy usage (electric + gas) for the period Sep 2015 to Aug 2016 vs. the period Sep 2014 to Aug 2015.

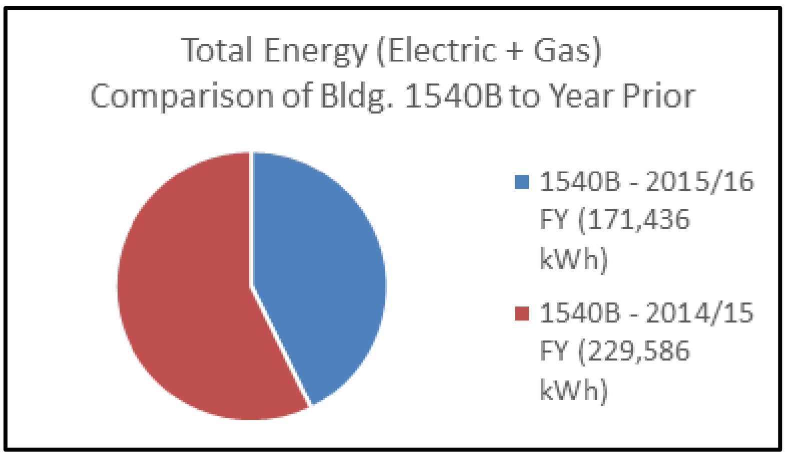


Figure 6-10. Bldg 1540B realized a 14% increase in electrical usage for the period Sep 2015 to Aug 2016 vs. the period Sep 2014 to Aug 2015.

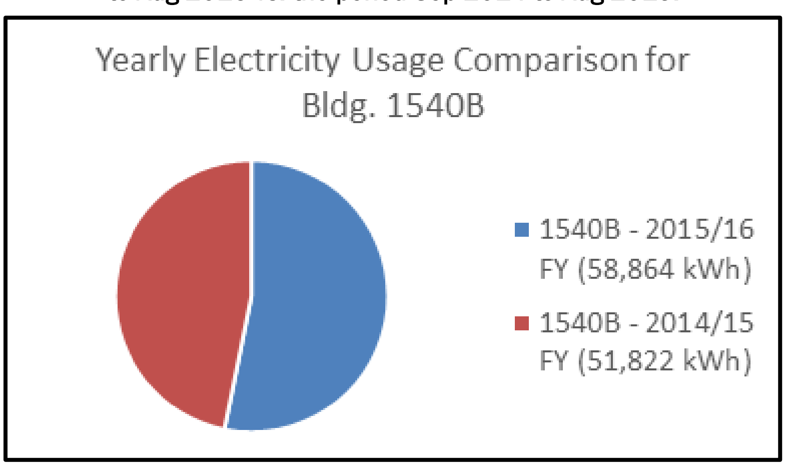
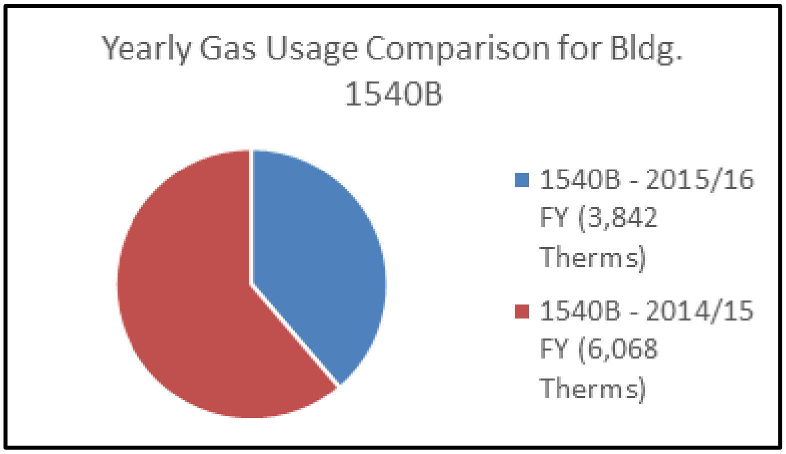


Figure 6-11. Bldg 1540B realized a 37% decrease in gas usage for the period Sep 2015 to Aug 2016 vs. the period Sep 2014 to Aug 2015.



6.8.5 Energy performance comparison of Bldgs 1540A&B for monitoring periods Sep 2014 to Aug 2015 and Sep 2015 to Aug 2016

Table 6-9 lists electricity and gas utility usage for Bldgs 1540A&B during the post-retrofit monitoring period (Sep 2015 to Aug 2016). Overall, Bldg 1540A used 16% less energy than Bldg 1540B (Figure 6-12). Bldg 1540A consumed 33% more electrical energy than Bldg 1540B (Figure 6-13), however, Bldg 1540A also used 42% less gas energy than Bldg 1540B (Figure 6-14). Two seasonal observations were made when comparing Bldgs 1540A&B. First, while Bldg 1540A typically used more electrical energy than Bldg 1540B, this gap widened during the summer season. This was attributed to the multitude of components in the radiant panel system (chiller, DOAS, pumps, etc.) that consume electricity and that operate year round (with the exception of the chiller). Second, during the fall and winter periods, the heating system in Bldg 1540B demanded more energy from its boiler compared with Bldg 1540A. This single difference in boiler energy usage drove Bldg 1540B's total energy usage above 1540A's despite 1540A using more energy in its chiller, HVAC, and electrical systems. The energy savings recorded from Bldg 1540A becomes even more appreciable after incorporating adjustments for the differences in each building's square footage. Bldg 1540B used 30.67 kWh/ft^2 while Bldg 1540A used 18.81 kWh/ft^2. This represented a 39% energy savings for Bldg 1540A on an energy usage per square footage basis compared with Bldg 1540B.

Table 6-9. Post-retrofit monitoring period (Sep 2015 to Aug 2016) electricity and gas utility usage for Bldgs 1540A&B.

	Bldg 1540A		Bldg 1540 B	
Month	Electric (kWh)	Gas (therms)	Electric (kWh)	Gas (therms)
Sep 2015	8,087	49	5,359	139
Oct 2015	6,203	166	4,449	323
Nov 2015	5,711	231	4,096	411
Dec 2015	5,370	251	4,540	485
Jan 2016	5,163	529	4,853	771
Feb 2016	4,665	425	4,621	697
Mar 2016	4,664	228	4,929	445
Apr 2016	5,233	158	4,665	281
May 2016	6,326	100	4,296	225
Jun 2016	8,086	32	4,830	43
Jul 2016	8,719	29	5,990	10
Aug 2016	9,809	31	6,235	12
Total	**78,036**	**2,228**	**58,864**	**3,842**
Total (kWh)	**143,307**		**171,436**	

Figure 6-12. Fiscal year 2015/2016 overall energy usage comparison for Bldgs 1540A&B (electricity + gas). Overall, Bldg 1540A used 20% less energy than Bldg 1540B.

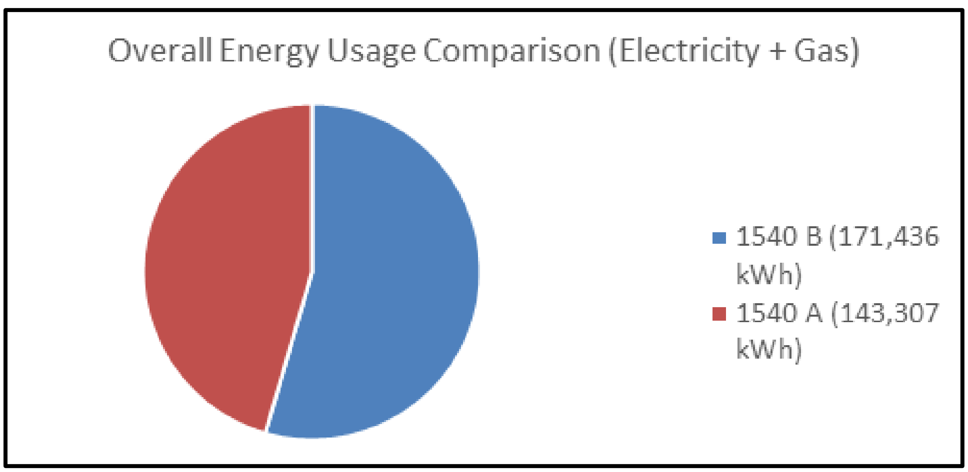


Figure 6-13. Fiscal year 2015/2016 electricity usage comparison for Bldgs 1540A&B. Bldg 1540A consumed 30% more electrical energy than Bldg 1540B.

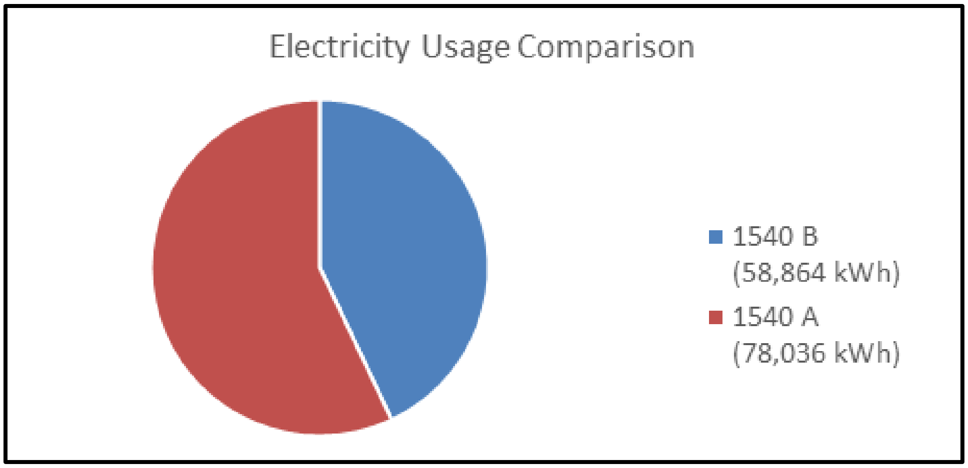


Figure 6-14. Fiscal year 2015/2016 gas utility usage comparison for Bldgs 1540A&B. Bldg 1540A consumed 43% less gas energy than Bldg 1540B.

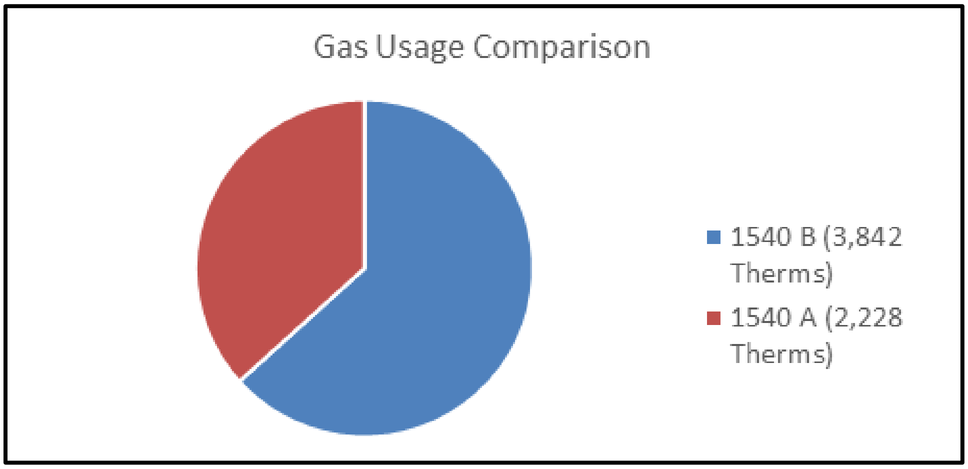


Table 6-10. Summary table of energy performance.

	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

6.8.6 Operations and maintenance

In discussions with the installation's Operations and Maintenance Chief, he stated that he was unaware of any maintenance issues with the installed system. An absence of O&M-related issues demonstrated the system's ease of operation and maintainability. The waterside components of a radiant panel system are similar to those of a hot/chilled water fan coil system. However, the fact that a radiant panel system has no need for FCUs results in a system with fewer moving parts and filters.

6.8.7 Distinct building issues and differences

Additional differences between Bldgs 1540A&B include:

1. A much greater volume of conditioned outside air is required for Bldg 1540A, primarily driven by its much larger latrine size and the fact that the current ventilation rate was based on current ASHRAE standards.
2. The fully conditioned area (heated and cooled) area (square feet) of Bldg 1540A is 1.63 times greater than that of Bldg 1540B. The total area of Bldg 1540A is 1.36 times larger than Bldg 1540B.
3. The total wall length separating heated-only spaces from fully conditioned spaces is nearly 1.4 times greater for Bldg 1540A than for Bldg 1540B.
4. The envelope of Bldg 1540A encloses a volume (cubic feet) that is 1.36 times larger than that of Bldg 1540B.
5. The mission in Bldg 1540A is different from that of Bldg 1540B. In particular, Bldg 1540A has the Information Assurance training mission, which appears to have ongoing classes of approximately 20 students and their computers. Bldg 1540B does not appear to have anything comparable as far as operational intensity. Also, Bldg 1540A has a much larger shower/locker room.

6.8.8 Other issues

1. During periods of cool nighttime temperatures, Bldg 1540A temperatures did not fall to the 55 °F nighttime setback temperature during unoccupied mode. The programming for the 55 °F night setback temperature was verified during a Jan 2016 site visit. It was also discussed with Control Systems, Inc., Fort Detrick's controls contractor, in Mar 2016, at which time the BAS was reprogrammed so that the boilers should not operate when the indoor temperatures are above 55 °F during unoccupied periods. Therefore, the system appears to have been influenced/manipulated onsite

by occupants during the after-hours period (6:00 p.m. to 6:00 a.m.). Despite the Mar 2016 reprogramming efforts by the controls Contractor, the HVAC system did not reach the nighttime setback temperature as intended.

2. We also noted that:
3. There is one heating VAV coil in Bldg 1540B that has been nonfunctional for the past 7 months. This could account for an approximate 5-10% absence of heating energy from Bldg 1540B. The VAV coil concern is on a DPW repair list awaiting corrective action.
4. The mechanical air handling equipment serving Bldg 1540B is substantially smaller than the comparable system in Bldg 1540A.
5. In Bldg 1540A, the dehumidification discharge air temperature setpoint was raised from 45 to 50 °F. Additionally, the Entering Air Humidity sensor was programmed with a 10% RH deadband. These adjustments were made because it was suspected that the DOAS reheat was a major energy consumer during the cooling season.
6. In Mar 2016, the BAS programming / logic of Bldgs 1540A&B was modified so that the boilers would not operate when the indoor space temperature is above 55 °F during unoccupied periods.

7 Cost Assessment

- **Building Life-Cycle Costing:** Completed using "User Friendly" Building Life-Cycle Costing (Addison 1999), a Department of Energy funded program that is a derivative of efforts described in the National Institute of Standards and Technology (NIST) Handbook 135 (Fuller and Petersen 1995).
- **Life-Cycle Cost Table:** See Table 7-1.
- **Life-Cycle Cost Elements:** See Table 7-1.
- **Life-Cycle Cost Timeframe:** The life-cycle cost estimate was conducted during the course of the project. First costs (material and equipment purchases and installation labor) were compiled during the course of system installation that occurred within approximately the first 8 months of the project. Operational costs, including energy costs and O&M costs, were gathered during the 12-month data collection period.

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, plumbing, 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 vs. baseline data.	$2,746
Maintenance	Frequency of required maintenance. Labor and material per maintenance action.	$220
Hardware lifetime	Estimate based on components degradation during demonstration.	0 Years
Operator training	Estimate of training costs.	$2,500

7.2 Cost drivers

HVAC systems are sized and selected 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 (ASHRAE 2015). The largest anticipated cost driver for a retrofit project would be the installation of a continuous air barrier within the facility. 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, it would have added a large cost to this project to install a new air barrier.

A second major cost driver could be the required mechanical room space to install the DOAS. The DOAS AHU is configured to be approximately 50% taller than a conventional AHU to accommodate the desiccant energy recovery wheel. Care should be taken in selecting an existing mechanical equipment room so that it can accommodate the physically larger DOAS equipment. Chapter 5, “Test Design,” and Appendix B, “Equipment Schedules,” provide equipment-related information. Chapter 4, “Facility/Site Description,” provides site information.

7.3 Cost analysis and comparison

A life-cycle cost analysis was performed comparing the project installation cost including materials and equipment costs, labor costs, energy costs and operation and maintenance 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 RS Means.

Costs included:

- Base: (conventional chilled/hot water VAV system)
- Estimated first cost of system (using RS Means): $259,250
- Estimated yearly utility cost (derived from scaling 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:

- USDOE/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 Life-Cycle Cost [LCC] analysis): 25
- Number of Years before Project Occupancy or Operation: 0
- USDOE Fuel Price Escalation Region: 3
- Analysis Sector: 2.

The present value life-cycle costs for 25 years were:

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

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

Efforts were made to improve the condition of both buildings (Table 7-2). The $3,500.00 spent in labor and materials to improve the air tightness of Bldg 1540A yielded $87.58 in annual energy savings (electric + gas). The SP on these sealing efforts is 40.0 years. A total of $48,996 was invested in the retrocommissioning of Bldg 1540B. Comparison of the 2014/2015 and 2015/2016 fiscal years revealed that the retrocommissioning 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 SP. Accounting for the annual finances associated with envelope leaks did not materially change the life-cycle cost analysis (Table 7-3).

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 a $43.66/ft^2 for the radiant panel system with DOAS and $34.03/ft² 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 (Table 7-5 through Table 7-7). Therefore, the cost savings metric (less than 1%) 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 Chapter, 6 "Performance Assessment," provide motivation for adopting the radiant panel system.

Table 7-2. Financial overview of the efforts made to improve the condition of Bldgs 1540A&B.

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

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

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/ft²	$34.03/ft²

Table 7-5. Life-cycle cost analysis (Tbl. 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. Life-cycle cost analysis (Tbl. 2 of 3).

		Maintenance		Total	Total	
		1st Year	LCC	Undiscounted LCC	LCC	
Case	Description	$	PV $	PV $	PV $	Net Savings
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. Life-cycle cost analysis (Tbl. 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%
*Adjusted Internal Rate of Return							

8 Implementation Issues

8.1 Issues

This demonstration project used a typical existing DoD facility to validate the performance of an integrated system of an improved building envelope, a DOAS, and a radiant heating and cooling system. The project assumed that the facility's original construction was performed in reasonable accordance with the original design intent. Therefore, it was imperative that the building be actually constructed in accordance with the original design intent and that the existing building be accurately depicted in as-built construction documents. Locating the original design documents proved to be a difficult task and we were frustrated to learn that there were no as-built documents.

The demonstration facility incorporated an air barrier system built with drywall encompassing the entire interior of the building. Much of this drywall air barrier system was hidden from view by installed HVAC equipment and interior partitions so as to prevent thorough inspection of the existing drywall air barrier system.

During removal of the existing HVAC equipment we 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. In fact, two areas of the existing drywall air barrier in the wall adjacent to the mechanical equipment room were never closed where the supply and return air ductwork passed through the mechanical room enclosure into the occupied spaces. Apparently these two areas were never sealed during the original construction. These deficiencies were identified when tests on the existing air barrier system were unable to achieve proper pressurization.

After performing an initial air barrier test and being unable to pressurize the building due to excessive envelope penetrations, we sealed numerous ceiling drywall air barrier penetrations and two other large drywall air barrier penetrations. Upon repeating the air barrier tests, the building once again failed to achieve proper pressurization. This time, we determined that wall and ceiling air barriers located in an almost inaccessible location behind a hard drywall interior ceiling of the locker rooms had never been completed as required by the original design construction documents. This location (shown in Figure 3-5) allowed direct uncontrolled infiltration of outdoor air into the interior of the building. When this area was eventually sealed, air barrier tests were able to achieve proper pressurization of the building to determine the baseline air tightness of the original design intent.

8.2 Lessons Learned

- In planning retrofit projects, one should not assume that existing construction complies with the original design intent.
- In future construction projects, after the building envelope construction has been completed, air barrier tests should be performed to demonstrate that the building has been properly sealed before installing interior finishes.

  During initial HVAC system testing, we found that the existing control system was undocumented, hindering our ability to perform in situ tests of the existing HVAC system. To overcome this handicap, we located and used the original HVAC controls subcontractor to determine the control points and proper operation of the HVAC controls system. When the HVAC system tests were performed, we determined that various system components were not operating properly and that they required additional DPW maintenance to get the existing HVAC system operating in accordance with the design intent. As this research effort was originally proposed for execution at a different Army installation, the project was not planned in advance with Fort Detrick's DPW. Therefore, maintenance personnel and system's components were not programmed or coordinated in advance. Additional unanticipated coordination with the DPW and the installation was required to accommodate this request before implementation of the Energy Monitoring System.

- For retrofit projects, one should not assume that the existing HVAC system complies with the original design intent.

  Our original design concept for the Energy Monitoring System assumed that a new base-wide utility monitoring and control system (UMCS) being installed by Fort Detrick would be available for our use to remotely monitor data points for this HVAC demonstration project. However, we learned that current network security requirements disallowed our access to Army data, including building operational data. As a result, an unplanned standalone Energy Monitoring System had to be designed and implemented within the confines of our project budget and schedule. Our Energy Monitoring System allowed us to remotely access system operational data, but gave us no ability to remotely control or adjust our systems. This problem was further exacerbated by the fact that even Fort Detrick's DPW had no ability to make system adjustments on our behalf. Any control system changes or adjustments had to be separately procured through Fort Detrick's control system contractor. These network security restrictions cost our project a lot of time and money that could have been used more productively elsewhere. They also severely limited our ability to adjust system parameters, setpoints and schedules in an effort to optimize system performance.

- Network security policies will probably require installation of standalone data acquisition systems to remotely obtain operational data on future demonstration projects. Also, it will probably be impossible to remotely adjust or control demonstrated systems.

During the design of the demonstration HVAC system, interior occupant loads were based on existing program requirements and the existing number of occupants in the space. For example, the student count in the IA training room (C018B) was initially determined to be 10 students in the classroom. However, during design and/or construction, the classroom program was doubled to accommodate 20 students. This necessitated redesign and renovation of the classroom HVAC radiant panels including installation of additional radiant cooling panels to accommodate the cooling load of 20 additional students and their corresponding computer equipment.

- Unanticipated programming requirements may change occupancy loads during an ongoing project.
- As with any other HVAC system, the ability of a radiant heating and cooling system to accommodate unanticipated additional loads is limited to the excess capacity designed into the system. Consider providing oversized supply and return piping from zones which might be subject to increased loads.

When conducting demonstration projects involving buildings, the number of building occupants and their day-to-day activities can significantly affect results. This was problematic for this project because we had no means of tracking the number of people using the buildings on a daily basis or of knowing what kind of activities were occurring.

We had excellent support from the Unit's maintenance officer, but he was already seriously overworked so we tried to limit asking for his assistance to only the most essential matters.

- Onsite support by a person who has the time, flexibility, and technical knowledge to make observations, report findings, coordinate with local personnel, and make minor adjustments or corrections can be very valuable.

We had great difficulty accessing background energy consumption data because Fort Detrick facilities were not metered on a building-by-building basis. Currently Fort Detrick is executing a separate program to install a new base-wide networked UMCS system to monitor and collect facility data, including Bldg 1540. Unfortunately, the lack of available energy performance data for Bldg 1540 forced us to make very rudimentary assumptions of Bldg 1540's energy performance before this project. Although we were able to get monthly utilities data from Fort Detrick, the data had unexplained gaps, which reduced the value of the datasets.

- Quality historic energy data may not be available for baseline comparisons.

The energy consumption of the radiant heating and cooling system is greatly affected by the amount of ventilation air required to offset exhaust air and positively pressurize the facility. Currently there is no accepted industry method to precisely calculate this requirement. The volume of outside air required above building exhaust quantities is based on the experience and judgment of the designer. In actual use, we recommend adjustment of outside air volumes to that required to satisfy the actual ventilation and pressurization requirements of the building.

- Outside air flow should be adjusted to that required to satisfy the actual ventilation and pressurization requirements of the building.

This project used the existing gas utility meters installed at each half of the building to measure gas consumption. An onsite USACE employee emailed us a photograph of each meter's display at the start of each month. Since we had no ability to make remote adjustments of system parameters, schedules, or set points, this may have been adequate for our needs. However, if we had had an ability to remotely control the system, it would have been helpful to be able to measure and record gas usage in near real time.

- When attempting to optimize system performance, near real time data is essential.

In addition to estimating the outside air requirement, it is necessary to specify the dehumidification coil's leaving air temperature in the DOAS system to satisfy the anticipated humidity load of the building. This is usually based on the experience and judgment of the designer. In this project, we had planned to adjust the dehumidification coil leaving air temperature to determine the actual leaving air temperature required to satisfy the actual humidity load of the building. Unfortunately, since our Energy Monitoring System was prohibited from having any control capabilities, we were unable to adjust this parameter. We recommend adjusting the dehumidification coil's leaving air temperature to satisfy the actual humidity load of the building. This capability could save considerable energy.

- The DOAS dehumidification coil's leaving air temperature should be adjusted to satisfy the actual humidity load of the building.

All the equipment and design expertise required to implement the use of 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 their 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.

Another common concern is that a radiant cooling system will experience condensation on the cool surface of the radiant panels. By properly dehumidifying ventilation air through the DOAS system, 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, we demonstrated that it is possible to implement radiant cooling without risk of condensation problems within the facility.

Typical decision-making factors include "known" technology and avoiding risky ("unknown") technologies. However, common "known" HVAC technologies are high risk with respect to maintenance costs. In an era of decreasing maintenance budgets and reduced maintenance staffing, radiant heating and cooling systems, which are relatively maintenance free, thus require reduce maintenance costs and personnel.

8.3 Other possible Lessons Learned to consider

- 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 as best as possible.
- For retrofit applications, it is best to plan to replace the entire existing ceiling grid system. Attempting to work around existing fire sprinklers and light fixture locations proved to be very difficult. In some cases, "cloud" radiant panels might be a good option (vs. 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.
- An accurate estimate of the number of individuals who typically occupy a given space is crucial for proper load calculations of the radiant system.

Appendix A: Points of Contact

Point of Contact	Organization	Phone & E-mail	Role in Project
James P. Miller	U.S. Army ERDC-CERL	217-373-4566 James.P.Miller@usace.army.mil	Project Manager, Contracting Officer's Representative
Patrick Tanner	The PERTAN Group	217-351-4330, x201 patrick.tanner@pertan.com	Principal
Anthony Latino	The PERTAN Group	217-356-1348 anthony.latino@pertan.com	Project Manager
Raymond Patenaude	The PERTAN Group	727-369-0881 ray@TheHolmesAgency.com	Technical Lead
Ross Montgomery	The PERTAN Group	941-729-4496 rossmont@aol.com	Commissioning Provider
Christopher Martinez	The PERTAN Group	chrismartinez@tampabay.rr.com	Energy Consultant
Gary Stenlund, P.E.	Engineering Professionals, Inc.	813-251-6848 stenlund@engrpros.com	Design Engineer of Record
Paul Smeck	Fort Detrick, 21st Signal Brigade	301-619-6189 Paul.D.Smeck.civ@mail.mil	Bldg 1540 User's Representative
Chris Nygard	Fort Detrick DPW, Energy Manager	301-619-0506 christian.p.nygard.civ@mail.mil	Installation Energy Manager
Carl B. Pritchard	Fort Detrick DPW, Director	301-619-2454 carl.b.pritchard.civ@mail.mil	DPW
Glenn Murphey	USACE Baltimore District	Glenn.N.Murphey@usace.army.mil	Construction Inspector
Katie Brown	USACE Baltimore District	Katharine.L.Brown@usace.army.mil	Commissioning Specialist
Sarah Medepalli	ESTCP	703-610-2158 sarah.medepalli@noblis.org	Technical Monitor

Appendix B: Equipment Schedules

Table B-1. Bldg 1540A mechanical equipment schedule.

Item #	Description	Brand	Model	Location	Circuit #
AHU-1	Air Handling Unit	Daikin	CAH006GDGC	C008-MER	2
B-1	Boiler (existing)	HydroTherm	KN-4	C008-MER	12
CH-1	Chiller	Carrier	30RAP020	Mech Courtyard	1
CUH-1	Cabinet Unit Heater	EXISTING		C001-Vestibule	14
CUH-2	Cabinet Unit Heater	EXISTING		C022-W. Vestibule	14
CUH-3	Cabinet Unit Heater	EXISTING		C023-M. Vestibule	14
CUH-5	Cabinet Unit Heater	EXISTING		C025-W. Latrine	14
CUH-6	Cabinet Unit Heater	EXISTING		C024-M. Latrine	14
CUH-7	Cabinet Unit Heater	EXISTING		C024-M. Latrine	16
CUH-8	Cabinet Unit Heater	EXISTING		C014-Corridor	18
DH-1					9
EF-1	Mechanical Room Exhaust Fan	EXISTING		C008-MER	7
EF-2	Electrical Room Exhaust Fan	EXISTING		C009-Elect Room	7
EF-3	AHU/Latrine Exhaust Fan	Cook	135SQN-hp	C008-MER	6
FCU-1	Fan Coil Unit; only supplies heating	EXISTING		C028-Loading Area	5
Glycol Sys	Glycol System	Advantage Controls	GF	C008-MER	23
HX-1	Energy Recovery Wheel	Daikin	ECW 364-3A	C008-MER AHU	15
LP-1	Electrical Sub-Distribution Panel	EXISTING		C009-Elect Room	11
MS-1	Mini-Split System for Comm/Information Technology (IT) Closet	Daikin	INDOOR-FTXS12LVJU OUTDOOR-RXS12LVJU	Mech Courtyard/C013	24 & 26
P-1	Pump	Bell & Gossett	B&G SERIES 80 1-1/2 X 1-1/2 X 9-1/2	C008-MER	4
P-2	Pump	EXISTING		C008-MER	17
P-3	Pump - located within Chiller	Carrier		Mech Courtyard	1
P-4	Pump	Bell & Gossett	B&G SERIES 80 1-1/2 X 1-1/2 X 7B	C008-MER	3
UH-1	Unit Heater	Existing		C008-MER	16
UH-2	Unit Heater	Existing		C009-Elect Room	16
UH-4	Unit Heater	Existing		C029-Arms Vault	16
UH-5	Unit Heater	Existing		C028-Loading Area	18

Item #	Description	Brand	Model	Location	Circuit #
UH-6	Unit Heater	Existing		C028-Loading Area	18
UH-7	Unit Heater	Existing		C027-Gen. Storage	18
UH-8	Unit Heater	Existing		C027-Gen. Storage	18
UH-9	Unit Heater	Existing		C027-Gen. Storage	18
UH-10	Unit Heater	Existing		C026-Gen. Storage	18
VAV	ALL REMOVED				

Table B-2. Air handler unit schedule.

Air Handling Unit Schedule		
Mark	AHU	AHU-1
Supply Air	CFM	1625
Outside Air	CFM	1625
Static Pressure In. H2o	EXT./TOTAL	1.0/2.7
Max. Fan Speed	RPM	3300
Motor	Horsepower (hp)	2.0
Fan Wheel Type	—	Plenum
Filter	—	MERV8
Electrical	V/Ø/Hz	208V/3Ø
Location	—	Mech. Room
Manufacturer	—	DAIKIN
Model	—	CAH006GDGC
Area Served	—	Offices
Cooling Coil		
Total Capacity	BTUH	114,750
Sensible Capacity	BTUH	63,000
Cooling Coil	Rows/Fins	11 FPI
Cooling Coil Max. Face Vel.	feet/minute (FPM)	286
Cooling Coil Max. Press. Drop	IN. H_2O	0.45
Entering Air Temp. (Db/Wb)	°F/°F	83.2/70.8
Leaving Air Temp. (Db/Wb)	°F/°F	47.7/47.5
Chilled Water Flow	GPM	33.2
Chilled Water Temp. (Entering/Leaving)	°F/°F	42/49
Max. Water Press. Drop	FT. H_2O	8.2
Heating		
Total Capacity	BTUH	57,275
Heating Coil	ROWS/FINS	2/13 FPI
Heating Coil Max. Face Vel.	FPM	433
Heating Coil Max. Press. Drop	IN. H_2O	0.29
Entering Air Temp.	°F	48
Leaving Air Temp.	°F	80

Air Handling Unit Schedule		
Hot Water Flow	GPM	11.4
Hot Water Temp. (Entering/Leaving)	°F/°F	105/94.9
Max. Water Press. Drop	FT. H_2O	1.3
Notes	-	1, 2, 3
20% Prop. Glycol		
Disconnect Switch By Div. 16. Factory Variable Speed Drive (VSD) for Fan and HX.		
OA Motor Operated Low Leakage Damper and Actuator, Spring Return, and Interlock to EF-3 Operation Mounted in Outside Air Intake Duct in Attic.		

Table B-3. Air-cooled scroll chiller schedule.

Air-Cooled Scroll Chiller Schedule		
Mark	—	CH-1
Capacity	TONS	16.0
Chiller Ambient	—	95
Water Flow	GPM	50.6
Max. Water Press. Drop	FT. H_2O	24
Water temp. entering/leaving	°F/°F	50.6/42.0
KW/Cond. Fans	#/KW	2/2.89
Unit Total Energy Efficiency Rating (EER)	—	9.9
Refrigerant	—	R-410A
Compressors Power	KW	19.2
Total Power Input	KW/FLA	31.5/140
Electrical	V/Ø/Hz	208/3Ø/60Hz
Integrated Part Load Value (IPLV)	KW/TON	14.38
Weight	LBS.	1296
Location	—	Pad Mount
Integral Pump Min TDHD	FT. H_2O	65
# Pumps/hp Each	—	(1)3 hp
Pump RPM	—	1750
Manufacturer	—	CARRIER
Model	—	30RAP020

Notes:
1. Provide single point power connection & unit mounted disconnect. 20% Prop. Glycol
2. Provide factory integral chilled water pump and min. 75 gallon water storage
3. Accessories and Installed Options:

- Cooler Heater
- Non-Fused Disconnect
- Micro Channel, E-Coat
- Ultra Low Sound
- Single Pump, 3 hp
- Digital Compressor
- Low Ambient Head Pressure Control
- BACnet Communications
- Single Point
- Chilled Water Storage Tank
- Wind Baffle

Table B-4. Enthalpy heat exchanger schedule.

Enthalpy Heat Exchanger Schedule				
HX-1 (SUMMER OPERATION)		Outside Air	Wheel	Supply Air
Airflow	SCFM*	1651 CFM	0.8	1625 CFM
Temperature	°F db/wb	92/77	IN.W.C.	83.2/70.8
Humidity Ratio	GR/LB	116	523	92
Static Pressure	IN.W.C.	-0.25	FPM	1.05
Heat Recovered	BTUH	—	—	43,900
		Exhaust Air	Wheel	Building Air
Airflow	SCFM	1126 CFM	0.5	1100 CFM
Temperature	°F db/wb	90.0/75.7	IN.W.C.	77/65
Humidity Ratio	GR/LB	115	—	79
Static Pressure	IN.W.C.	1.0	1/2 hp	-0.5
Notes	—	DAIKIN	1.	MOD. ECW 364-3A
1. Complete with variable speed drive, 120V/1Ø. BUILT INTO AHU-1 *standard cubic feet per minute				

Table B-5. Preheat coil schedule.

Preheat Coil Schedule					
COIL #	CFM	BTUH	SIZE	WATER GPM (180°-160°)	# REQUIRED
1	1625	71,700	24X15	7.4	1

Table B-6. Fan schedule.

Fan Schedule				
Tag	—	(E)EF-1	(E)EF-2	(N)EF-3
Service	—	Mech.	Elect.	Latrines
Air Quantity	CFM	1270	160	1,100
Ext. Static Press.	IN. H_2O	1/4	1/4	1.2
Fan Type	-	Prv	Prv	In-Line
Drive	-	Existing	Existing	Belt
Sones	-	Existing	Existing	15.0
Motor	H.P./WATTS	1/2	1/12	1/2
Fan Speed	RPM	Existing	Existing	1639
Power	V/1Ø	115V/1Ø	115V/1Ø	115V/1Ø
Control	-	T-Stat	T-Stat	W/AHU-1
Location	-	Roof	Roof	Mech.
Manufacturer	-	Existing	Existing	Cook
Model	-	Existing	Existing	135SQN-hp
Notes		1	1	2
1. Existing Fan To Remain.				

Fan Schedule
2. Complete with Disconnect Switch, Vibration Isolators, Motor Operated Low Leakage Damper and Actuator, Spring Return, and Interlock to AHU-1 Operation.

Table B-7. Hood schedule.

Hood Schedule								
Qty	Mark	Throat Size	Hood Size	Height	CFM	Throat Velocity	Press. Drop	Accessories
		L x W	L x W	H				
1	OA Int. Hood	42x12	78x36	14	1625	464	0.02	3

Table B-8. Minimum code required outside air ventilation rates.

Minimum Code Required Outside Air Ventilation Rates (per ASHRAE Standard 62.1-2010)															
Area Served	Occup. Cat.	Default Occupant Density	Net Area Az	Area Outdoor Air Rate Ra	Code Req'd Based On Floor Area		# People Pz	People Outdoor Air Rate Rp	Code Req'd Oa Based On People	Code Req'd OA Total VBz AzRa+PzRp		Zone Air Distrib. Effec. Ez		Total Oa Req'd by Code Voz
		P/1000 SF	SF	CFM/SF	CFM		Person(s)	CFM/person	CFM	CFM				CFM
Office	Office	Count	1470	0.06	88	+	20	5	100	188	/	0.8	=	235
Conf/ Training	Conf	Count	1256	0.06	75	+	22	5	110	185	/	0.8	=	231
Total Req'd													=	466
Total Provided													=	1625

Table B-9. Pump schedule.

Pump Schedule									
Symbol	Type	Service	Location	Flow (gpm)	Total Head (ft)	Rpm	Power (hp)	Elect. (V/Ø/Hz)	Model
P-1	In-Line	Hot Water	C008	45	60	1750	3 hp	208/3/60	B&G Series 80 1-1/2 X 1-1/2 X 9-1/2
P-2	In-Line	Boiler Loop	C008	15	10	1750	1/4 hp	115/1/60	Existing
P-3	In-Ch-1	Ch Water	Chiller	50.6	65	1750	3 hp	208/3/60	In Chiller
P-4	In-Line	Ch Water	C008	15.1	46	1750	3/4 hp	208/3/60	B&G Series 80 1-1/2 X 1-1/2 X 7B

Table B-10. Expansion tank schedule.

Expansion Tank Schedule					
Tag	Location	Total Volume (gal)	Accept. Vol. (gal)	Type	Remark
ET-1	C008	10	5	Diaphragm	Horizontal Mounted
ET-2	C008	10	5	Diaphragm	Horizontal Mounted

Table B-11. Boiler schedule (existing).

Existing Boiler Schedule		
Mark	—	B-1
Service	—	Heating
Type	—	Cast Iron
Burner Data		
Type	—	Forced
Fuel	—	Nat. Gas
Output	MBTUH	369
Input	MBTUH	399
Fuel Consumption	CFH	399
Boiler Data		
Working Pressure	PSIG	60
Test Pressure	PSIG	100
Minimum Heating Surface	SQ.FT.	Existing
Minimum Efficiency	%	90%
Electrical Data		
Power	(V/Ø/Hz)	150V/1Ø
Model	Hydrotherm	KN-4
Notes		To Remain
Combustion air required: 399,000 BTUH gas input divided BY 1 SQ.IN/3,000 BTUH equals 133 sq.in. opening. 864 sq.in. opening provided.		
*pound-force per square inch gauge		

Table B-12. Fan coil unit schedule (existing).

Existing Fan Coil Unit Schedule						
		Heating			Fan Motor	
Tag	Nominal Airflow Rating (CFM)	Minimum (BTUH)	EWT (°F)	Water Flow (GPM)	Power (hp)	Elect. (V/Ø/Hz)
FCU-1	530	34,490	180	3.4	1/4	115/1/60

Table B-13. Cabinet unit heater schedule (existing).

Existing Cabinet Unit Heater Schedule									
						Fan Motor			
Symbol	Capacity (BTUH)	EAT (°F)	EWT (°F)	LWT (°F)	Water Flow (GPM)	hp	Elect. (V/Ø/Hz)	Type	Location
CUH-1	6140	55°	180°	160°	0.63	1/12	115/1/60	C.C. MOUNT	C001
CUH-2	6140	68°	180°	160°	0.63	1/12	115/1/60	R.C. MOUNT	C022
CUH-3	11270	68°	180°	160°	1.6	1/12	115/1/60	R.C. MOUNT	C023
CUH-5	850	68°	180°	160°	0.1	1/12	115/1/60	R.C. MOUNT	W. TOILET
CUH-6	850	68°	180°	160°	0.1	1/12	115/1/60	R.C. MOUNT	M. TOILET
CUH-7	850	68°	180°	160°	0.1	1/12	115/1/60	R.C. MOUNT	M. TOILET
CUH-8	11270	68°	180°	160°	1.6	1/12	115/1/60	C.C. MOUNT	C014

Table B-14. Unit heater schedule (existing).

Existing Unit Heater Schedule									
					Water	Fan Motor			
Symbol	Capacity (BTUH)	EAT (°F)	EWT (°F)	LWT (°F)	Flow (GPM)	hp	Elect. (V/Ø/Hz)	Type	Location
UH-1	27320	55°	180°	160°	3.5	1/20	115/1/60	VERTICAL	C008
UH-2	~~3415~~	~~55°~~	~~180°~~	~~160°~~	~~0.8~~	~~1/25~~	~~115/1/60~~	~~HORIZONTAL~~	~~C009~~
UH-3 (REMOVED)	~~3415~~	~~55°~~	~~180°~~	~~160°~~	~~0.8~~	~~1/25~~	~~115/1/60~~	~~HORIZONTAL~~	~~C031~~
UH-4	3415	55°	180°	160°	0.8	1/25	115/1/60	HORIZONTAL	C029
UH-5	3415	55°	180°	160°	0.8	1/25	115/1/60	HORIZONTAL	C028
UH-6	10245	55°	180°	160°	1.0	1/20	115/1/60	HORIZONTAL	C028
UH-7	6830	55°	180°	160°	0.95	1/20	115/1/60	HORIZONTAL	C027
UH-8	3415	55°	180°	160°	0.8	1/25	115/1/60	HORIZONTAL	C027
UH-9	3415	55°	180°	160°	0.8	1/25	115/1/60	HORIZONTAL	C027
UH-10	3415	55°	180°	160°	0.8	1/25	115/1/60	HORIZONTAL	C026

Table B-15. Radiant panel cooling schedule.

Manufacturer: TWA							
Panel Type	Description	Coil Passes	Output (BTUH)/ft)	TWA Panel Code	Nominal Width (in.)	Min Flow Rate (GPM)	0.8
RP-1	Cloud	8	96	SHSASASASASASASASASH	48	ΔT (°F)	5.0
RP-1 Cloud	Cloud	4	48	SHSPSPSPSPSH	24	Mean Fluid Temp (°F)	63.5
RP-2/D	Linear	4	48	MOD	24	Room Temp (°F)	75
RP-2/S	Linear	4	48	MOD	24		
RP-4/D	Linear	4	48	MOD	24		
RP-4/S	Linear	4	48	MOD	24		
RP-5/D	Linear	4	48	SHSASASASASH	24		
RP-5/S	Linear	4	48	SHSASASASASH	24		

Room #	Panel Type	Panel Tag	Wall-Wall Length (in)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft Of Head)
C002	RP-2/D	A1	24	2.00	96	4	1	T-BAR	0.46	0.44
	RP-2/D	A3	24	2.00	96	4				
	RP-2/D	B1	24	2.00	96	4				
	RP-4/S	B2	48	4.00	192	4				
	RP-2/D	B3	24	2.00	96	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-4/S	C2	48	4.00	192	4				
	RP-2/D	C3	24	2.00	96	4				
	RP-2/D	D1	24	2.00	96	4				
	RP-2/D	D3	24	2.00	96	4				
C003	RP-4/D	A2	48	4.00	192	4	1	T-BAR	0.61	0.94
	RP-2/S	B1	24	2.00	96	4				

Room #	Panel Type	Panel Tag	Wall-Wall Length (in)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft Of Head)
	RP-2/D	B3	24	2.00	96	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-4/S	C2	48	4.00	192	4				
	RP-2/D	C3	24	2.00	96	4				
	RP-2/D	D1	24	2.00	96	4				
	RP-4/S	D2	48	4.00	192	4				
	RP-2/D	D3	24	2.00	96	4				
	RP-2/S	E1	24	2.00	96	4				
	RP-2/D	E3	24	2.00	96	4				
	RP-4/D	F2	48	4.00	192	4				
C004	RP-2/D	A1	24	2.00	96	4	1	T-BAR	0.46	0.44
	RP-2/S	A2	24	2.00	96	4				
	RP-2/S	A3	24	2.00	96	4				
	RP-2/D	A4	24	2.00	96	4				
	RP-4/D	B2	48	4.00	192	4				
	RP-4/D	B3	48	4.00	192	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-2/S	C2	24	2.00	96	4				
	RP-2/S	C3	24	2.00	96	4				
	RP-2/D	C4	24	2.00	96	4				
C005	RP-2/D	A1	24	2.00	96	4	1	T-BAR	0.84	2.21
	RP-2/S	A2	24	2.00	96	4				
	RP-2/D	A3	24	2.00	96	4				
	RP-2/S	A4	24	2.00	96	4				
	RP-2/D	A5	24	2.00	96	4				
	RP-2/S	A6	24	2.00	96	4				
	RP-2/D	A7	24	2.00	96	4				
	RP-4/S	B1	48	4.00	192	4				
	RP-4/S	B3	48	4.00	192	4				
	RP-4/S	B5	48	4.00	192	4				
	RP-4/D	B7	48	4.00	192	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-2/S	C2	24	2.00	96	4				
	RP-2/D	C3	24	2.00	96	4				
	RP-2/S	C4	24	2.00	96	4				
	RP-2/D	C5	24	2.00	96	4				
	RP-2/S	C6	24	2.00	96	4				
	RP-2/D	C7	24	2.00	96	4				
C006	RP-4/D	A1	48	4.00	192	4	1	T-BAR	0.77	1.71
	RP-4/S	A3	48	4.00	192	4				
	RP-4/S	A4	48	4.00	192	4				
	RP-4/D	A6	48	4.00	192	4				
	RP-4/S	B1	48	4.00	192	4				
	RP-4/S	B2	48	4.00	192	4				
	RP-4/S	B3	48	4.00	192	4				

Room #	Panel Type	Panel Tag	Wall-Wall Length (in)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft Of Head)
	RP-4/S	B4	48	4.00	192	4				
	RP-4/S	B5	48	4.00	192	4				
	RP-4/S	B6	48	4.00	192	4				
	RP-4/S	C1	48	4.00	192	4	1	T-BAR	0.77	1.71
	RP-4/S	C2	48	4.00	192	4				
	RP-4/S	C3	48	4.00	192	4				
	RP-4/S	C4	48	4.00	192	4				
	RP-4/S	C5	48	4.00	192	4				
	RP-4/S	C6	48	4.00	192	4				
	RP-4/D	D1	48	4.00	192	4				
	RP-4/S	D3	48	4.00	192	4				
	RP-4/S	D4	48	4.00	192	4				
	RP-4/D	D6	48	4.00	192	4				
C014	RP-4/D	A	48	4.00	192	4	1	T-BAR	1.15	5.09
	RP-4/S	B	48	4.00	192	4				
	RP-4/D	C	48	4.00	192	4				
	RP-4/S	D	48	4.00	192	4				
	RP-4/D	E	48	4.00	192	4				
	RP-4/S	F	48	4.00	192	4				
	RP-4/D	G	48	4.00	192	4				
	RP-4/S	H	48	4.00	192	4				
	RP-4/D	I	48	4.00	192	4				
C015	RP-4/D	A	48	4.00	192	4				
	RP-4/S	B	48	4.00	192	4				
	RP-4/D	C	48	4.00	192	4				
	RP-4/S	D	48	4.00	192	4				
	RP-4/D	E	48	4.00	192	4				
	RP-4/S	F	48	4.00	192	4				
C018	RP-4/D	A2	48	4.00	192	4	1	T-BAR	0.81	1.95
	RP-2/D	B1	24	2.00	96	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-4/S	C2	48	4.00	192	4				
	RP-2/S	D1	24	2.00	96	4				
	RP-4/S	D2	48	4.00	192	4				
	RP-2/S	E1	24	2.00	96	4				
	RP-4/D	E2	48	4.00	192	4				
	RP-2/S	F1	24	2.00	96	4				
	RP-4/S	F2	48	4.00	192	4				
	RP-2/S	G1	24	2.00	96	4				
	RP-4/S	G2	48	4.00	192	4				
	RP-2/D	H1	24	2.00	96	4				
	RP-4/D	I2	48	4.00	192	4				
	RP-2/D	A3	24	2.00	96	4	1	T-BAR	1.15	5.09
	RP-4/D	A4	48	4.00	192	4				
	RP-2/D	B3	24	2.00	96	4				

Room #	Panel Type	Panel Tag	Wall-Wall Length (in)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft Of Head)
	RP-2/D	B5	24	2.00	96	4				
	RP-2/S	C3	24	2.00	96	4				
	RP-4/S	C4	48	4.00	192	4				
	RP-2/D	C5	24	2.00	96	4				
	RP-2/S	D3	24	2.00	96	4				
	RP-4/S	D4	48	4.00	192	4				
	RP-2/S	D5	24	2.00	96	4				
	RP-2/S	E3	24	2.00	96	4				
	RP-4/D	E4	48	4.00	192	4				
	RP-2/S	E5	24	2.00	96	4				
	RP-2/S	F3	24	2.00	96	4				
	RP-4/S	F4	48	4.00	192	4				
	RP-2/S	F5	24	2.00	96	4				
	RP-2/S	G3	24	2.00	96	4				
	RP-4/S	G4	48	4.00	192	4				
	RP-2/S	G5	24	2.00	96	4				
	RP-2/S	H3	24	2.00	96	4				
	RP-2/D	H5	24	2.00	96	4				
	RP-2/S	I3	24	2.00	96	4				
	RP-4/D	I4	48	4.00	192	4				
C018A	RP-5/D	A	72	6.00	288	4	1	T-BAR	0.58	0.79
	RP-5/S	B	72	6.00	288	4				
	RP-5/D	C	72	6.00	288	4				
	RP-5/S	D	72	6.00	288	4				
	RP-5/D	E	72	6.00	288	4				
C018B	RP-1	A	96	8.00	768	8	1	CLOUD	1.23	6.06
	RP-1	B	96	8.00	768	8				
	RP-1	C	96	8.00	768	8				
	RP-1	D	96	8.00	768	8				
	RP-1 CLOUD	C1	48	4.00	192	4	1	CLOUD	0.84	3.44
	RP-1 CLOUD	A1	48	4.00	192	4				
	RP-1 CLOUD	A2	48	4.00	192	4				
	RP-1 CLOUD	A3	48	4.00	192	4				
	RP-1 CLOUD	A4	48	4.00	192	4				
	RP-1 CLOUD	A5	48	4.00	192	4				
	RP-1 CLOUD	A6	48	4.00	192	4				
	RP-1 CLOUD	C6	48	4.00	192	4				
	RP-1 CLOUD	C4	48	4.00	192	4				
	RP-1 CLOUD	C3	48	4.00	192	4				
	RP-1 CLOUD	C2	48	4.00	192	4				
C019	RP-2/D	A1	24	2.00	96	4	1	T-BAR	0.69	1.29
	RP-2/D	A2	24	2.00	96	4				
	RP-2/D	A3	24	2.00	96	4				
	RP-2/D	A4	24	2.00	96	4				
	RP-2/D	A5	24	2.00	96	4				

Room #	Panel Type	Panel Tag	Wall-Wall Length (in)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft Of Head)
	RP-2/D	A6	24	2.00	96	4				
	RP-4/S	B1	48	4.00	192	4				
	RP-4/S	B3	48	4.00	192	4				
	RP-4/S	B6	48	4.00	192	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-2/D	C2	24	2.00	96	4				
	RP-2/D	C3	24	2.00	96	4				
	RP-2/D	C4	24	2.00	96	4				
	RP-2/D	C5	24	2.00	96	4				
	RP-2/D	C6	24	2.00	96	4				
C020	RP-2/S	A1	24	2.00	96	4	1	T-BAR	0.65	1.10
	RP-4/D	A2	48	4.00	192	4				
	RP-2/S	B1	24	2.00	96	4				
	RP-2/S	C1	24	2.00	96	4				
	RP-4/S	C2	48	4.00	192	4				
	RP-2/S	D1	24	2.00	96	4				
	RP-4/S	D2	48	4.00	192	4				
	RP-2/S	E1	24	2.00	96	4				
	RP-4/S	E2	48	4.00	192	4				
	RP-2/S	F1	24	2.00	96	4				
	RP-2/S	G1	24	2.00	96	4				
	RP-4/D	G2	48	4.00	192	4				
C021	RP-4/D	A	48	4.00	192	4	1	T-BAR	0.38	0.17
	RP-4/S	B	48	4.00	192	4				
	RP-4/S	C	48	4.00	192	4				
	RP-4/S	D	48	4.00	192	4				
	RP-4/D	E	48	4.00	192	4				
C021A	RP-4/D	A1	48	4.00	192	4	1	T-BAR	0.65	1.10
	RP-2/D	A2	24	2.00	96	4				
	RP-2/D	B2	24	2.00	96	4				
	RP-4/S	C1	48	4.00	192	4				
	RP-2/D	C2	24	2.00	96	4				
	RP-4/S	D1	48	4.00	192	4				
	RP-2/D	D2	24	2.00	96	4				
	RP-4/S	E1	48	4.00	192	4				
	RP-2/D	E2	24	2.00	96	4				
	RP-2/D	F2	24	2.00	96	4				
	RP-4/D	G1	48	4.00	192	4				
	RP-2/D	G2	24	2.00	96	4				
C021B	RP-2/D	A1	24	2.00	96	4	1	T-BAR	0.69	1.29
	RP-2/D	A2	24	2.00	96	4				
	RP-2/D	A3	24	2.00	96	4				
	RP-2/D	A4	24	2.00	96	4				
	RP-2/D	A5	24	2.00	96	4				
	RP-2/D	A6	24	2.00	96	4				

Room #	Panel Type	Panel Tag	Wall-Wall Length (in)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft Of Head)
	RP-4/S	B1	48	4.00	192	4				
	RP-4/S	B3	48	4.00	192	4				
	RP-4/D	B6	48	4.00	192	4				
	RP-2/D	C1	24	2.00	96	4				
	RP-2/D	C2	24	2.00	96	4				
	RP-2/D	C3	24	2.00	96	4				
	RP-2/D	C4	24	2.00	96	4				
	RP-2/D	C5	24	2.00	96	4				
	RP-2/D	C6	24	2.00	96	4				
C031	RP-5/S	A	144	12.00	576	4	1	T-BAR	0.92	2.79
	RP-5/S	B	144	12.00	576	4				
	RP-5/S	C	144	12.00	576	4				
	RP-5/D	D	144	12.00	576	4				
	RP-5/S	E	144	12.00	576	4	1	T-BAR	0.69	1.29
	RP-5/D	F	144	12.00	576	4				
	RP-5/D	G	144	12.00	576	4				

Table B-16. Radiant panel heating schedule.

Manufacturer: TWA							
Panel Type	Description	Coil Passes	Output (BTUH/ft)	TWA Panel Code	Nominal Width (in.)	Min Flow Rate (gpm)	0.44
RP-1	Linear	8	363	SHSASASASASASASASASH	48	ΔT (°F)	20.0
RP-2/D	Linear	4	200	MOD	24	Mean Fluid Temp (°F)	130.0
RP-4/D	Linear	4	200	MOD	24	Room Temp (°F)	70.0
RP-5/D	Linear	4	214	SHSASASASASH	24		

Room #	Panel Type	Panel Tag	Wall-Wall Length (in.)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# Of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft of Head)
C002	RP-2/D	A1	24	2.00	400	4	1	T-BAR	0.32	0.12
	RP-2/D	A3	24	2.00	400	4				
	RP-2/D	B1	24	2.00	400	4				
	RP-2/D	B3	24	2.00	400	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C3	24	2.00	400	4				
	RP-2/D	D1	24	2.00	400	4				
	RP-2/D	D3	24	2.00	400	4				
C003	RP-4/D	A2	48	4.00	800	4	1	T-BAR	0.40	0.22
	RP-2/D	B3	24	2.00	400	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C3	24	2.00	400	4				
	RP-2/D	D1	24	2.00	400	4				
	RP-2/D	D3	24	2.00	400	4				
	RP-2/D	E3	24	2.00	400	4				
	RP-4/D	F2	48	4.00	800	4				

Room #	Panel Type	Panel Tag	Wall-Wall Length (in.)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# Of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft of Head)
C004	RP-2/D	A1	24	2.00	400	4	1	T-BAR	0.32	0.12
	RP-2/D	A4	24	2.00	400	4				
	RP-4/D	B2	48	4.00	800	4				
	RP-4/D	B3	48	4.00	800	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C4	24	2.00	400	4				
C005	RP-2/D	A1	24	2.00	400	4	1	T-BAR	0.40	0.22
	RP-2/D	A3	24	2.00	400	4				
	RP-2/D	A5	24	2.00	400	4				
	RP-2/D	A7	24	2.00	400	4				
	RP-4/D	B7	48	4.00	800	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C3	24	2.00	400	4				
	RP-2/D	C5	24	2.00	400	4				
	RP-2/D	C7	24	2.00	400	4				
C006	RP-4/D	A1	48	4.00	800	4	1	T-BAR	0.32	0.12
	RP-4/D	A6	48	4.00	800	4				
	RP-4/D	D1	48	4.00	800	4				
	RP-4/D	D6	48	4.00	800	4				
C014	RP-4/D	A	48	4.00	800	4	1	T-BAR	0.64	0.8
	RP-4/D	C	48	4.00	800	4				
	RP-4/D	E	48	4.00	800	4				
	RP-4/D	G	48	4.00	800	4				
	RP-4/D	I	48	4.00	800	4				
C015	RP-4/D	A	48	4.00	800	4				
	RP-4/D	C	48	4.00	800	4				
	RP-4/D	E	48	4.00	800	4				
C018	RP-4/D	A2	48	4.00	800	4	1	T-BAR	0.80	1.46
	RP-2/D	A3	24	2.00	400	4				
	RP-4/D	A4	48	4.00	800	4				
	RP-2/D	B1	24	2.00	400	4				
	RP-2/D	B3	24	2.00	400	4				
	RP-2/D	B5	24	2.00	400	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C5	24	2.00	400	4				
	RP-4/D	E2	48	4.00	800	4				
	RP-4/D	E4	48	4.00	800	4				
	RP-2/D	H1	24	2.00	400	4				
	RP-2/D	H5	24	2.00	400	4				
	RP-4/D	I2	48	4.00	800	4				
	RP-4/D	I4	48	4.00	800	4				
C018A	RP-5/D	A	72	6.00	1284	4	1	T-BAR	0.39	0.19
	RP-5/D	C	72	6.00	1284	4				
	RP-5/D	E	72	6.00	1284	4				
C018B	RP-1	A	96	8.00	2907	8	1	CLOUD	1.16	4.45

Room #	Panel Type	Panel Tag	Wall-Wall Length (in.)	Active Length (ft)	Actual Output (BTU)	# of Coil Passes	# Of Circuits	Panel Install Type	Flow Rate (gpm)	Press. Drop (ft of Head)
	RP-1	B	96	8.00	2907	8				
	RP-1	C	96	8.00	2907	8				
	RP-1	D	96	8.00	2907	8				
C019	RP-2/D	A1	24	2.00	400	4	1	T-BAR	0.48	0.37
	RP-2/D	A2	24	2.00	400	4				
	RP-2/D	A3	24	2.00	400	4				
	RP-2/D	A4	24	2.00	400	4				
	RP-2/D	A5	24	2.00	400	4				
	RP-2/D	A6	24	2.00	400	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C2	24	2.00	400	4				
	RP-2/D	C3	24	2.00	400	4				
	RP-2/D	C4	24	2.00	400	4				
	RP-2/D	C5	24	2.00	400	4				
	RP-2/D	C6	24	2.00	400	4				
C020	RP-4/D	A2	48	4.00	800	4	1	T-BAR	0.16	0.01
	RP-4/D	G2	48	4.00	800	4				
C021	RP-4/D	A	48	4.00	800	4	1	T-BAR	0.16	0.01
	RP-4/D	E	48	4.00	800	4				
C021A	RP-4/D	A1	48	4.00	800	4	1	T-BAR	0.44	0.29
	RP-2/D	A2	24	2.00	400	4				
	RP-2/D	B2	24	2.00	400	4				
	RP-2/D	C2	24	2.00	400	4				
	RP-2/D	D2	24	2.00	400	4				
	RP-2/D	E2	24	2.00	400	4				
	RP-2/D	F2	24	2.00	400	4				
	RP-4/D	G1	48	4.00	800	4				
	RP-2/D	G2	24	2.00	400	4				
C021B	RP-2/D	A1	24	2.00	400	4	1	T-BAR	0.56	0.55
	RP-2/D	A2	24	2.00	400	4				
	RP-2/D	A3	24	2.00	400	4				
	RP-2/D	A4	24	2.00	400	4				
	RP-2/D	A5	24	2.00	400	4				
	RP-2/D	A6	24	2.00	400	4				
	RP-4/D	B6	48	4.00	800	4				
	RP-2/D	C1	24	2.00	400	4				
	RP-2/D	C2	24	2.00	400	4				
	RP-2/D	C3	24	2.00	400	4				
	RP-2/D	C4	24	2.00	400	4				
	RP-2/D	C5	24	2.00	400	4				
	RP-2/D	C6	24	2.00	400	4				
C031	RP-5/D	D	144	12.00	2568	4	1	T-BAR	0.77	1.23
	RP-5/D	F	144	12.00	2568	4				
	RP-5/D	G	144	12.00	2568	4				

Appendix C: Bldg 1540B Deficiencies List

The PERTAN contract was modified on 17 Jun 2015 to add additional Task 5 to correct deficiencies in the baseline facility, Bldg 1540B. The following paragraph summarizes requirements for Task 5.

C.10.f. Task 5 – Correct Deficiencies in Bldg 1540B: A number of unforeseen deficiencies were identified in baseline Bldg 1540B that will impact its energy consumption and the ability to fairly compare the energy performance of the demonstration facility (Bldg 1540A) with the baseline facility (Bldg 1540B). This task is added to restore comparability to baseline facility. Task 5 shall be completed no-later than 45 days after award of contract modification P00001. The Contractor shall complete the subtasks listed in Table C-1.

Table C-1. Required contractor subtasks.

Item	Required Action	Final Status
B-1	Replace sheaves and belt on AHU-4 to cause this unit to deliver design air flow.	COMPLETED – 26 Jun 2015.
B-2	VAV terminal units 1, 8, 11, 13, 14, 16, 15, and 18 are not operational. Troubleshoot and repair or replace as necessary.	COMPLETED – 30 Jul 2015. VAV's were replaced and tested.
B-3	Exhaust fans 8 and 9 are not operational. Troubleshoot and repair or replace as necessary.	COMPLETED – 26 Jun 2015. Fans made operational by mechanical Contractor.
B-4	Perform point-to-point verification of proper functioning of VAV reheat coil valves. For any reheat coil valves that are not functioning properly, provide a recommendation of repair vs. replacement.	COMPLETED – 30 Jul 2015. Two (2) reheat valves were found not functioning. Recommend replace actuators in Rooms C007 and C005.
B-5	Verify and update the time schedule within the BAS.	COMPLETED – 07 Aug 2015. Implemented same time schedule as Bldg 1540A, the building schedule operates 0600-1800 Monday to Sunday.
B-6	Verify proper operation of Boiler High Limit Safety controls. If High Limit Safety controls are found to be nonfunctional, provide a recommendation of repair vs. replacement.	COMPLETED – 07 Aug 2015. Boiler is interlocked with pump and shuts down when pump is shut down (In Auto). Flow switch should be added to prevent boiler operation in Hand without pump.
B-7	Boiler lockout OA temp has been changed to 85 °F, which leaves the boiler running all the time. Adjust boiler lockout temperature so unit shuts down when not needed.	COMPLETED – 07 Aug 2015. No action was taken as the boiler is needed for VAV reheat coils.

Item	Required Action	Final Status
B-8	Hot water system still operates when Invensys system is shut off. Provide necessary controls so that hot water system shuts down when not needed.	COMPLETED – 07 Aug 2015. No action was taken as the existing Invensys control system controls the operation of the boiler system in both 1540A&B, and it has been verified to work.
B-9	THIS ITEM IS DELETED. NO ACTION REQUIRED.	NO ACTION REQUIRED.
B-10	UH-10 has been removed. Remove associated active sensor and relay.	COMPLETED – 30 Jul 2015. The corresponding controls were removed.
B-11	Operation and temperature control should be connected to the Invensys system for the two new PTAC systems installed during renovation. Interconnect new PTAC units to Invensys system or provide other appropriate means of controlling these units.	COMPLETED – 30 Jul 2015. PTAC units were connected to system and are on the building schedule.
B-12	The UH's & CUH's are not connected to the Invensys time schedule. Incorporate these into the time schedule.	COMPLETED – 30 Jul 2015. Units are connected to building schedule.
B-13	THIS ITEM IS DELETED. NO ACTION REQUIRED.	NO ACTION REQUIRED.
B-14	Control valve actuators for baseboard units in restrooms are not connected. Connect actuators and make them operational.	COMPLETED – 30 Jul 2015. Valve actuators are connected to system and are operational with bathroom units.
B-15	Change out high limit thermostat automatic reset for manual device.	COMPLETED – 26 Jun 2015. As the coil was busted, the valve was in closed position. Replaced coil and system operates as designed.
B-16	Determine why FCU-3 water return and supply are turned off and correct problem as needed.	COMPLETED – 26 Jun 2015. Coil unit was leaking and was replaced by mechanical Contractor.
B-17	AHU-4 face and bypass dampers are not documented in the design or controls sequence. The damper is modulated with the same signal as the preheat valve. Provide a proper control signal to this system so that it functions appropriately.	COMPLETED No action was taken. No need to change the sequence of operation for the face and bypass dampers and the heating valve.

Item	Required Action	Final Status
B-18	AHU. Preheat sensor is not reading correctly and is mounted in an incorrect location. The sequence for the preheat valve uses the common supply duct temp in its control algorithm in lieu of the sensor. Repair, replace and/or relocate this device to provide a proper control signal to the AHU.	COMPLETED There is not a place in the unit to properly place the preheat sensor. The preheat coil and the DX coil are side by side with no access in between. A sensor cannot be located on the leaving side of the preheat coil and beside the original Standing Operating Procedure (SOP) call for the heating coil to be controlled by the supply air sensor.
B-19	THIS ITEM IS DELETED. NO ACTION REQUIRED.	NO ACTION REQUIRED.
B-20	Verify proper operation of Power Logic KW meter. If unit if found function incorrectly, provide recommendation of recalibration, repair and/or replacement.	COMPLETED – 30 Jul 2015. Meter appears to be operating correctly.
B-21	Provide a written report documenting completion of above corrective actions and resulting outcomes.	COMPLETED Submitted and Accepted by CERL Contract Officer Representative (COR) – 17 Sep 2015.
B-22	On completion of all corrective actions identified above, perform Test and Balance (TAB) of Bldg 1540B and document in a written TAB report.	COMPLETED Submitted and Accepted by CERL COR – 17 Sep 2015.

Appendix D: Product Datasheets

Figure D-1. EnTouch Remote Sensor Module (RSM-100) datasheet.

RSM-100

REMOTE SENSOR MODULE

THE ENTOUCH ONE REMOTE SENSOR MODULE

The EnTouch Remote Sensor Module is designed to work with our EnTouch One EMS family. Monitor your facilities through our cloud based system using your computer, tablet, or mobile device.

Monitor energy critical systems in your facility and reduce the risk of a facility crisis with the EnTouch Remote Sensor Module.

TECHNICAL SPECIFICATIONS

Power Requirements

- 24V AC from wall mounted 120-24 VAC transformer

Measurements

- Four temperature input port
- Supported sensors: 10K Type 2, 10K Type 3, 20K type 4
- Two wire NTC passive sensors. *(Sensors sold separately)*
- Digital input: Any of the temperature inputs can also be configured to sense opening or closing of a dry contact
- Pulse input: Accumulated pulse count in certain time. Software support will be deployed in the future for water and gas metering applications

Wiring Connection

- Mating connector provided with the unit
- 1 Terminal Block, Pluggable, 3.50mm, 6POS – Power Supply
- 2 Terminal Block, Pluggable, 3.50mm, 8POS – Measurement/Control Inputs

Terminal Designation

- Sensor 1 – Sensor 4: Temperature Input or Digital Input . Polarity insensitive.
- Pulse In: Pulse Counter Input. Requires isolated open collector / relay input

Physical and Environmental

- Size: 5″ x 1.6″ x 4″
- Weight: 4.5 Oz
- Mounting: Wall mounted with hardware provided
- Compliance: FCC, CSA

RSM FEATURES

Multiple Facility Monitoring

Our monitoring platform is designed for commercial applications. It can monitor energy usage, temperature or can act as a contact sensor to monitor door openings and closings. The RSM gives total system visibility over all of your facilities.

Configurable Features

The system is flexible, allowing it to monitor the most complex applications. From simple contact closure inputs to thermal sensing inputs, the RSM can handle them all. Adapt and expand as your facility needs grow.

Refrigeration Monitoring

The EnTouch EMS can monitor refrigeration temperatures and defrost cycles, allowing business owners to become more energy efficient, detect hidden maintenance issues and benchmark energy performance across locations.

Support for External Inputs

The system can accept inputs from static switches, motion detectors, and thermal sensors. Use these inputs to facilitate problem alerts, safety features and system performance.

Designed For Retrofit Applications

Unlike traditional wired systems, the EnTouch Remote Sensor Module is easy to install and don't require extensive communication wiring or programming. In fact there is no programming required. Easy to use, quick to get started, and cost effective for your business.

Pulse Metering

The Remote Sensor Module also supports pulse input, which allows it to track water, electricity and gas consumption. With this functionality, a restaurant can track real-time utility consumption and compare multiple facilities from a cloud based management portal.

ENTOUCH CONTROLS
TOTAL FACILITIES INTELLIGENCE

MANAGEMENT OF:

HVAC LIGHTING REFRIGERATION 24/7 CLOUD MONITORING

Sales: 800-820-3511 • www.entouchcontrols.com • Support: 877-755-1609

Figure D-2. GreenTrol airflow sensor datasheet.

GreenTrol Automation, Inc.

Model **GF-2100A**

Technical Data Sheet

Single Probe Air Flow Measurement with PID Control Output and Alarm - Analog Output

GreenFlow 2000 Series

GF-2100A OVERVIEW

GreenTrol model GF-2100A is a high quality economical programmable single probe dual-output airflow/temperature measurement and control solution with options for analog air flow, temperature and corresponding PID output (for control of airflow set point) and alarm features. It is designed for installation in critical applications where precise air flow and temperature measurement (down to zero flow), and available PID control of air flow set point are required. The GF-2100A includes one factory calibrated probe and an advanced programmable microprocessor controlled transmitter. A simple user interface and LCD permit selection of analog output options for airflow, and for temperature measurement or for corresponding PID control signal output to maintain airflow set point. Airflow sensor accuracy is typically 3% of reading (4% max) from 0 to 2,000 FPM [10.16 m/s], and temperature accuracy is ± 0.36°F [± 0.2°C] from -20 to 160°F [-28.9°C to 71.1°C]. Probes are equipped with high reliability bead-in-glass heated thermistors, factory calibrated to NIST traceable standards over the entire operating range. A Field Calibration Wizard feature permits field adjustment of factory calibration if required. A programmable alarm feature includes options for low/high limit and hysteresis; dead band alarm with upper/lower alarms as a percentage of flow; or as a sensor trouble alarm. The alarm condition is shown locally on the LCD display and can be configured as dry relay contacts or as an external LED driver (15mA typical). Analog outputs are field-configurable for 0-10VDC, 0-5VDC or 2-10 VDC (20 mA max.) for communication with virtually all modern controls and building automation systems (BAS).

APPLICATIONS

- Available for applications where accurate monitoring/control of low airflow and temperature is required.
- Maximize system efficiency by accurately measuring and controlling airflow with a single instrument.
- Key in the acquisition of **LEED®** credits for **Energy and Atmosphere** and **Indoor Environmental Quality** when applied in OA applications.

SYSTEM FEATURES

- Advanced Thermal Dispersion (TD) technology ensures accurate, repeatable airflow measurement from zero flow (still air).
- Proprietary sensor design features high reliability bead-in-glass heated thermistors factory calibrated in wind tunnels to NIST traceable standards for placement in more locations than other sensing technologies.
- Variable airflow signal integration to minimize airflow fluctuations (transient wind gusts) at low air flows.
- Programmable local and remote relay or LED alarms for low/high limit, and deadband.
- Versatile Field Calibration Wizard for simple field adjustment if required.
- Simple push-button user interface for simple field configuration.
- Innovative universal mounting bracket and adjustable insertion mount bracket available.

GF-2100A SPECIFICATIONS

System

Sensor Accuracy*: Airflow: ± 3% of reading typical (4% max)
Temperature: ± 0.36°F [± 0.2°C]

Calibrated Range: ....0 to 2,000 fpm [10.16 m/s]

Operating Temperature: ....Sensor: -20 to 160°F [-28.9 to 71.1°C]
Xmtr: -20 to 120°F [-28.9 to 48.9°C]

Operating Humidity: ....0 to 99% non-condensing; Transmitter must be protected from exposure to precipitation

Programmable Modes: ....Independently configurable outputs for flow, temperature, control, alarm or disabled

Power Requirements: ......24 VAC (22.8-26.4 VAC) at 8VA max

Transmitter Enclosure

Enclosure Material: ....Durable housing with cover

Enclosure Rating: UL94V-0

Transmitter Dimensions: ...3.570 x 6.006 x 1.502 in (HxWxD) [90.68 x 152.55 x 38.15 mm], with integral 0.502 [12.75 mm] flanges.

Sensor Probe

Probe Construction: ....6063 alum standard (316 SS optional)

Mounting Brackets: ....Universal and Insertion available

Probe Diameter: ....0.75 in [19 mm]

Standard Size: ....8 and 16 inches (203.2, 406.4 mm)

Probes / Sensing Nodes: ...1 probe per transmitter; 1 sensing node per probe

Probe/Transmitter Cable: ..10 ft [3.05m] Plenum rated FEP cable (Other lengths avail.)

Output Interface

Analog Outputs: ....Dual non-isolated analog 0-10VDC, 0-5VDC or 2-10 VDC (20 mA max)

Output Resolution: ....0.21% of full scale (0-10/2-10VDC)
0.42% of full scale (0-5VDC)

Output Load: ....500 ohm minimum (20 mA max)

Programmable Alarm: .....Low limit, High limit or dead band alarm (percentage above or below a specified flow)

Alarm type: ....LCD indication and dry relay contacts (30VDC/24VAC @ 3 amp max) or direct LED drive (15 mA typical).

Field Cal Wizard: ....Simple field adjustment of factory calibration if required

Standard Warranty: ....12 months

* Sensor accuracy is the accuracy of the individual sensor. Installed accuracy of the overall airflow station is application-dependent based on application size and resulting sensor density and is typically better than 15% of reading.

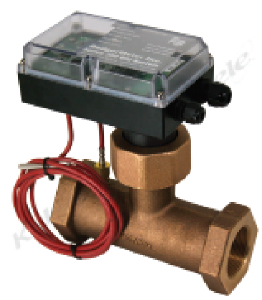
Figure D-3. Badger BTU meter datasheet.

FLOW

BTU METER
380 SERIES

DESCRIPTION

The **Badger Meter 380 Series BTU meters** provide an inexpensive solution to monitoring thermal energy consumption in cold or hot water systems. The integrated flow and temperature sensors along with the internal metering components make installation and commissioning easy. With on-board Modbus and BACnet communication and a compact design that will fit in a wall, the **380 Series** is perfect for networking and multi-tenant billing applications.



380CS07

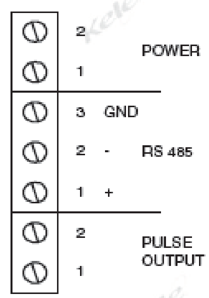
FEATURES

- ***AC or DC power***
- ***Field programmable***
- ***Scaled pulse or RS-485 (Modbus and BACnet) output standard***
- ***Two temperature sensors included***
- ***Compact, fits within a standard 2X4 stud wall***
- ***Compatible with potable water and water/glycol mixtures***

APPLICATION

- ***Strip Malls***
- ***Multi-tenant buildings***
- ***Office buildings***
- ***Thermal storage systems***
- ***Sustainable design buildings***

WIRING



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FLOW

SPECIFICATIONS

Supply Voltage	12-28 VAC or 12-35 VDC
Supply VA	5 VA
Supply Current	200 mA maximum
Sensor Input	0.24" diameter RTD probe, meets IEC751 Class B; 6.5' (2 m) cable for remote sensor, custom fitting for 1/8" NPT pipe tap included
Output	Scaled pulse: 10, 50, 150, 200 or 250 ms
Wiring	Two cable glands, PG6 and PG9
Wiring Terminations	Screw terminals inside enclosure
Communication	Modbus RTU, BACnet
Repeatability	±0.5%
Size	3/4", 1", 1-1/4", 1-1/2", 2"
Connections	FNPT
Velocity Range	1 to 15 fps
Accuracy	± 2% of range

Operating Temperature	-4° to 149°F (-20° to 65°C)
Media Temperature Range	
Cold service	-4° to 140°F (-20° to 60°F)
Hot service	39° to 257°F (4° to 125°C)
Materials Of Construction	Cast bronze tee, 316 SS impeller, PEEK flow sensor, polyurethane potting material, polycarbonate housing
Enclosure Rating	NEMA 4
Weight	
3/4"	6 lb (2.7 kg)
1"	7 lb (3.2 kg)
1-1/4"	8 lb (3.6 kg)
1-1/2"	9 lb (4.1 kg)
2"	13 lb (5.9.kg)
Warranty	1 year

Figure D-4. Honeywell humidity/temperature sensor datasheet.

Honeywell

H7625, H7635, H7655 Humidity/Temperature Sensors

The H7625, H7635, and H7655 are highly accurate, stable humidity transducers designed for use with HVAC controllers such as the T7350 Thermostat, H775 Remote Humidity Controller, and W7760 Direct Digital Controllers. The Ceramic Technology humidity sensor is not affected by condensation and provides excellent long-term stability.

SPECIFICATION DATA

FEATURES

- **Ceramic Technology overcomes the limitations of other resistance based humidity sensors that use water soluble polymer coatings.**
- **Ceramic Technology allows sensors to recover fully from condensation, fog, and high humidity.**
- **Highly accurate, repeatable, stable output with negligible hysteresis.**
- **Temperature compensated output**
- **Zero and span trimmers, and increment/decrement recalibration feature.**
- **All units have selectable 4-20mA, 0-10Vdc, or 0-5Vdc output.**
- **NIST traceable 2%, 3%, and 5% calibration, every sensor calibrated at 3 different points.**

SPECIFICATIONS

Models:
❑ See Table 1.

Dimensions:
❑ See Fig. 1 through 3.

Operating RH Range:
❑ 0 to 100% RH.

Humidity Accuracy:
❑ ±2%, ±3% or ±5% from 20 to 95% RH.

20K Ohm Temperature Accuracy:
❑ ±0.4°F at 77°F (±0.2°C at 25°C).

20K Ohm Temperature Output Range:
❑ Room: 40° to 110°F (4° to 43°C).
❑ Duct/Outdoor: -40° to 240°F (-40° to 116°C).

Hysteresis:
❑ Less than ±0.4% RH.

Supply Voltage:
❑ 18 to 36 Vdc or 24 Vac.

Maximum Impedance Load:
❑ 2.42K ohms at 60 Hz.

Maximum Supply Current:
❑ Current Mode: 22 mA.
❑ Voltage Mode: 5 mA.

Finish:
❑ Room Enclosure: ABS Plastic (UL94-HB rated).
❑ Duct Enclosure: ABS Plastic (UL94-5VA rated).
❑ Outdoor Enclosure: ASA Plastic (UL-94V0 rated).

Compensated Temperature Range:
❑ -10 to 160°F (-23 to 71°C).

Humidity Response Time:
❑ 30 seconds.

Saturation Response Time:
❑ 10 minutes.

Sensitivity:
❑ 0.1%RH.

Interchangeability:
❑ Less than ±3% RH nominal.

Repeatability:
❑ 0.5% RH.

Long term drift:
❑ Less than 2% RH drift/5 years.

Table 1. Models.

Model Number	RH Accuracy	Mount	Output Signal	Voltage Supply	Temperature Sensor
H7625A	2%	Room	Selectable: 4-20 mA, 0-10 Vdc, or 0-5 Vdc	18-36 Vdc or 24 Vac	20K ohm
H7635A	3%				
H7625B	2%	Duct			
H7635B	3%				
H7655B	5%				
H7635C	3%	Outdoor			

Appendix E: Criteria Change Request for UFC 3-410-01

E.1 Problem

UFC 3-410-01, Paragraph B-8 suggests considering the use of infrared radiant heating in high bay areas or where spot heating is required. Except in these specific instances, UFC 3-410-01 currently assumes that space heating will be provided by the mechanical delivery of warmed air and that the sensible component of space comfort cooling will be satisfied by mechanical delivery of cooled air. These assumptions ignore the fact that, in combination with a well-sealed building envelope and a dedicated outdoor air system (DOAS), a radiant heating and cooling system can successfully satisfy both the space heating and cooling requirements of many military facilities.

UFC 3-410-01, paragraphs 3-2 and 3-3 require provision of a DOAS system to condition the ventilation air when the total outdoor air requirements for a building (either new buildings or ones undergoing major renovation) exceed 1,000 CFM. The DOAS separates the ventilation function from the space heating and cooling functions. As a result, a completely separate system must be installed to meet the space heating and cooling requirements. These separate systems typically are VAV systems, fan coil units (FCUs), or other all-air system types. Current criteria does not recognize the alternative possibility of satisfying space heating/cooling requirements with a radiant system.

Radiant systems have been widely used in Europe and other parts of the world. They are simple in design, quiet, clean, and easily maintained. They cost effectively enable individual temperature control in small spaces because all that is required is a small two-position control valve connected to a simple room thermostat. Unlike FCUs, no air filters are required so that filter maintenance is reduced and confined to the DOAS unit in the mechanical room. Radiant systems can take advantage of lower temperature heating water and higher temperature cooling water. This facilitates the possibility of piping chilled water leaving the DOAS system's cooling coil to supply the radiant cooling panels. As a result, the chiller sees a higher chilled water return temperature, improving the chilled water system's efficiency and capacity.

E.2 Solution

Incorporate criteria allowing broader consideration of low temperature radiant heating systems in administrative facilities, barracks facilities, and other building types with either high or low ceilings. In applications requiring no cooling, ventilation air can be provided by a dedicated ventilation air system delivering neutral or slightly warmed air with the bulk of comfort heating provided by radiant systems installed in the floor slab or ceiling. Slab mounting facilitates the use of the slab mass as thermal storage in addition to being a radiating surface. Ceiling-mounted radiant systems may be radiant mat systems incorporated in ceiling finish systems, radiant metallic “cloud” panels suspended from the structural ceiling or radiant metallic panels for mounting in a suspended ceiling grid.

In dry locations requiring combined heating and cooling (but no dehumidification), incorporate criteria allowing consideration of radiant heating and cooling systems in administrative facilities, barracks facilities, and other buildings with high or low ceilings where ventilation air requirements are provided by a separate ventilation system delivering neutral or partially tempered air. Combined radiant heating and cooling systems may be installed in the floor slab or ceiling. Slab mounting facilitates using the slab mass as thermal storage in addition to being a radiating surface. Ceiling-mounted radiant systems may be radiant mat systems incorporated in ceiling finish systems, radiant metallic “cloud” panels suspended from the structural ceiling, or radiant metallic panels for mounting in a suspended ceiling grid.

In humid locations requiring combined heating, cooling and dehumidification, incorporate criteria allowing consideration of radiant heating and cooling systems in administrative facilities, barracks facilities and other buildings with high or low ceilings. Candidate facilities in humid locations should have tight building envelopes to prevent infiltration of humid unconditioned outdoor air. Ventilation air requirements shall be provided by a DOAS system delivering neutral or partially tempered air. In the cooling mode, all latent cooling shall be handled by the DOAS system and the radiant system should provide sensible cooling only. Combined radiant heating and cooling systems may be installed in the floor slab or ceiling. Slab mounting facilitates using the slab mass as thermal storage in addition to being a radiating surface. Ceiling-mounted radiant systems may be radiant mat systems incorporated in ceiling finish systems, radiant metallic “cloud” panels suspended from the structural ceiling or radiant metallic panels for mounting in a suspended ceiling grid.

A radiant heating/cooling system and a DOAS system were retrofitted into a Company HQ facility, successfully demonstrating that comfort conditions could be satisfied without experiencing problems with condensation forming on radiant cooling surfaces. This demonstration was performed in a hot, humid location (Frederick, MD). The installed system was found to be quiet, simple to operate and maintain, and capable of satisfying occupant comfort. Besides this project, the Army Corps of Engineers recently completed construction of a new six story cadet barracks facility using radiant heating and cooling systems embedded in the floor slab of cadet rooms. Low temperature radiant heating has also been used successfully in a deep energy retrofit project at the Presidio of Monterrey's Bldg 630 barracks facility. Low temperature radiant heating systems have also been successfully installed at a number of U.S. Army maintenance facilities and hangars in Germany.

Low temperature radiant heating systems facilitate taking full advantage of the potentially higher efficiency of condensing boilers because return water temperatures from these systems are low enough to extract latent heat from flue gases. Radiant heating and cooling systems may also be a useful alternative to all-air HVAC systems in the renovation of facilities with minimal available overhead space for both ventilation and space conditioning air ducts.

As with any system, a thorough engineering analysis and life-cycle cost analysis should be performed before deciding to install a radiant heating/cooling system. We believe that a radiant heating/cooling system may be life-cycle cost competitive with traditional all-air systems, especially in locations with low to moderate sensible and latent cooling loads.

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Acronyms and Abbreviations

Term	Definition
AC	Alternating Current
AHU	Air Handling Unit
AIRR	Adjusted Internal Rate of Return
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
AT/FP	Antiterrorism/Force Protection
BAS	Building Automation System
BLCC	Building Life-Cycle Cost
BRAC	Base Realignment and Closure
BTU	British Thermal Unit
BTUH	British Thermal Unit per Hour
BV	Besloten Vennootschap (Dutch: Limited Company)
C&P	Cost and Performance
ccSPF	Closed-Cell Spray Polyurethane Foam
CDD	Cooling Degree Day
CERL	Construction Engineering Research Laboratory
CFM	Cubic Feet per Minute
CFH	Cubic Feet per Hour
CHW	Chilled Water
CMU	Concrete Masonry Unit
CONUS	Continental United States
COR	Contract Officer Representative
COTS	Commercial off-the-Shelf
CRCP	Ceiling Radiant Cooling Panel
CT	Current Transformer
CUH	Cabinet Unit Heater
DB	Dry Bulb
DBT	Dry Bulb Temperature
DH	Dehumidifier
DOAS	Dedicated Outdoor Air System
DoD	U.S. Department of Defense
DP	Differential Pressure
DPT	Dew Point Temperature
DPW	Directorate of Public Works
DX	Direct Expansion
ECB	Engineering and Construction Bulletin
EER	Energy Efficiency Rating

Term	Definition
EF	Exhaust Fan
EISA	U.S. Energy Independence and Security Act of 2007
EMS	Energy Monitoring System
EO	Executive Order
EPAct	Energy Policy Act
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESTCP	Environmental Security Technology Certification Program
ET	Expansion Tank
EUI	Energy Use Intensity (kWh/ft^2)
EW	Energy and Water
EWT	Entering Water Temperature
FCU	Fan Coil Unit
FEMP	Federal Energy Management Program
FLA	Full Load Amps
FP	Force Protection
FPM	feet/minute
FY	Fiscal Year
GHG	Greenhouse Gas
GPM	Gallons per Minute
GSM	Global System for Mobile Communications
HDD	Heating Degree Day
HGL	HydroGeoLogic, Inc.
hp	Horsepower
HVAC	Heating, Ventilating, and Air-Conditioning
HW	Hot Water
HX	Heat Exchanger
IA	Information Assurance
IPLV	Integrated Part Load Value
ISO	International Standards Organization
IT	Information Technology
Iwg	inches of water gauge
kW	Kilowatt
kWh	Kilowatt Hour
LCC	Life-Cycle Cost
LEED	Leadership in Energy and Environmental Design
LOC	Local Operating Consoles
LWT	Leaving Water Temperature
MIPR	Military Interdepartmental Purchase Request
MNS	Mass Notification System

Term	Definition
MOU	Memorandum of Understanding
NA	Not Applicable
NEC	Network Enterprise Command
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSN	National Supply Number
O&M	Operations and Maintenance
OA	Outside Air
OMB	Office of Management and Budget
OSA	Outside Air
Pa	Pascal
PC	Personal Computer
PSIG	pound-force per square inch gauge
PTAC	Packaged Terminal Air Conditioner
PV	PhotoVoltaic
RH	Relative Humidity
ROI	Return on Investment
RPM	Revolutions per Minute
RSM	Remote Sensor Module
SAR	Same as Report
SCFM	standard cubic feet per minute
SERDP	Strategic Environmental Research and Development Program
SF	square feet
SIR	Savings-to-Investment Ratio
SITA	Southern Independent Testing Agency, Inc.
SOP	Standing Operating Procedure
SP	Simple Payback
STD	Standard
TAB	Test and Balance
TR	Technical Report
UFC	Unified Facilities Criteria
UH	Unit Heater
UMCS	Utility Monitoring and Control System
USACE	U.S. Army Corps of Engineers
USDOE	U.S. Department of Energy
VAV	Variable Air Volume
VSD	Variable Speed Drive
WBDG	Whole Building Design Guide

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14. ABSTRACT
The 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&B) 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 Supply (DOAS) system 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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