ERDC/CERL TR-21-10

Construction Engineering Research Laboratory

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*Installation Technology Transition Program (ITTP)*

# Study of Maintenance of High Performance Sustainable Buildings (HPSB)

James P. Miller, John L. Vavrin, and Samuel Stidwell IV

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Final report



Prepared for Headquarters, Installation Management Command
Fort Sam Houston, TX 78234

Under HQ IMCOM, MIPR No. 11268077, Installation Technology Transition Program

# Abstract

A study was performed by the Energy Branch of the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory, on behalf of the US Army Installation Management Command under the Installation Technology Transition Program. The focus of the study was related to maintainability and operability issues associated with High Performance Sustainable Buildings (HPSBs).

This study was conducted primarily based on information gleaned from telephone and web conference discussions with installation Directorate of Public Works personnel including Operation and Maintenance (O&M) Chiefs, energy managers, maintenance supervisors, and maintenance technicians.

Experiences with HPSBs varied from installation to installation. For example, some installations had very positive experiences with photovoltaic (PV) arrays while other sites questioned their practicality due to maintainability problems. One site noted that PV technologies are changing so rapidly that procuring spare/repair parts becomes difficult or impossible when vendors discontinue supporting their older technologies or manufacturers go out of business.

Based on discussions with the installation O&M personnel, a table of pro and con recommendations for 25 technologies, which are commonly implemented on HPSBs, was prepared and is included in this report.

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# Preface

This study was prepared for the Headquarters, Installation Management Command, under the Installation Technology Transition Program, MIPR Number 11268077.

The work was performed by the Energy Branch of the Facilities Division, US Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL). At the time of publication, Mr. Jedediah Alvey was Chief, Energy Branch; Ms. Vernessa Noye was Acting Chief, Facilities Division; and Mr. Kurt Kinnevan, was the Technical Director for Installations and Senior Scientific Technical Manager. The Acting Deputy Director of ERDC-CERL was Dr. George Calfas, and the Interim Director was Dr. Kumar Topudurti.

Sincere appreciation is expressed to the Operation and Maintenance personnel at Fort Bliss, Fort Bragg, Fort Campbell, Fort Carson, Fort Hood, Fort Leavenworth, Fort Polk, and Fort Riley for providing responses to a paper survey and participating in follow-up telephone conferences.

COL Teresa A. Schlosser was Commander of ERDC, and the Director was Dr. David W. Pittman.

# Executive Summary

Federal statutes such as the Energy Policy Act of 2005 (EPAct 2005), the Energy Independence and Security Act of 2007 (EISA 2007), and various Executive Orders have mandated increasingly challenging energy and water efficiency and sustainability standards for new federal facilities. The Army's policy is to plan, design, and construct high performance sustainable buildings (HPSB) conforming to the Guiding Principles for Federal Sustainable Buildings as detailed in Unified Facilities Criteria (UFC) 1-200-02 (UFC 2016) and the Army's Sustainable Design and Development Policy (Department of the Army 2017). Projects shall validate compliance by achieving minimum Silver level rating through the US Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED), green building certification system.

To meet these stringent requirements, planners and designers of Army facilities have been driven to incorporate new, often more complex, technologies into their designs to save every last unit of energy or water and to receive the necessary LEED credits to achieve at least a Silver rating. Some of these technologies have worked well in the Army environment and have helped the Army reduce its energy and water requirements and improve sustainability of Army facilities. Some technologies, however, have not performed so well in the Army environment, being less energy or water efficient than expected. In other instances, various technologies have been difficult and costly for installations to maintain, to the point of being questionably justifiable for incorporation in Army facilities.

Installation Management Command received feedback from its various installations that certain technologies being included in new Army construction were problematic. Problems cited ranged from systems that were too complicated for installation personnel to effectively operate and maintain to systems that were unnecessarily *fancy*, replaced more frequently than expected, and ultimately more costly than necessary to meet Soldiers' needs. These issues/problems essentially contradict any life-cycle cost analyses that were initially done to support use of these technologies.

This study was conducted on behalf of Headquarters, Installation Management Command, by the Energy Branch of the US Army Engineer

Research and Development Center, Construction Engineering Research Laboratory. The objective of this study was to determine, from the perspective of Army installations' Operations and Maintenance (O&M) and Energy Management personnel, how well various technologies performed in their environment. Due to COVID-19 travel restrictions, the study was conducted by asking installation O&M personnel to provide responses to a paper questionnaire and by making site visits to Fort Campbell, Fort Carson, and Fort Riley followed by telephone discussions with the O&M personnel. Additional installations that were unable to be visited were engaged by requesting responses to the paper questionnaire and follow-up telephone discussions with O&M personnel. These additional installations included Fort Bliss, Fort Bragg, Fort Hood, Fort Leavenworth, and Fort Polk. Input from Mechanical Design Chiefs at two US Army Corps of Engineers districts was received.

During the discussions, installation personnel were asked to provide feedback on their experiences with operating and maintaining HPSB. It was found that installations were, in fact, experiencing difficulties with a number of commonly installed technologies. These technologies were contributing to increased O&M costs, increasing backlogs of maintenance, and customer complaints. The following table summarizes recommendations of the installations to include or not include various technologies in HPSB facilities based on respective O&M experience.

**Summary of installations recommendations to include or not include various technologies in HPSB facilities based on O&M experience.**

| Technology | Recommend | Reason |
|---|---|---|
| **Building Envelopes** | | |
| Continuous external insulation | Y | Very effective at reducing heating/cooling load. This is the current minimum requirement within UFC 1-200-02 (per ASHRAE Std 90.1). |
| Air/moisture/vapor barrier | Y | Very effective at reducing moisture infiltration and latent load on cooling and Dedicated Outdoor Air Systems (DOAS) equipment. |
| Non-operable windows | Y | Very effective at reducing moisture infiltration and controlling unwanted infiltration of sensible load, especially in barracks applications. |

| | | |
|---|---|---|
| **HVAC Systems** | | |
| Variable Refrigerant Flow Systems (VRF) | N | Systems use proprietary controls which are not "open" and do not meet controls UFC requirements or communicate via Army standard protocols. Stringent new Environmental Protection Agency (EPA) leak-rate rules could risk mission impacts. Refrigerant leaks can be difficult to locate and repair. Possible asphyxiation concerns if large refrigerant leaks occur in occupied spaces. |
| Dedicated Outdoor Air Systems (DOAS) | Y | Best means of delivering required quantities of properly conditioned ventilation air and at controlling building dewpoint to avoid moisture and mold issues. |
| Demand Controlled Ventilation (DCV) | N | No assurance of adequate ventilation in occupied spaces. Sensors go out of calibration. HVAC damper failures. |
| Ground Source Heat Pumps | Very location dependent | Good technology in the right climates/soil types/applications. Very poor choice otherwise. Communications with Utility Monitoring and Control System (UMCS) system can be problematic. Heat pumps need to be installed in accessible locations. Difficult to make LCCA work due to high first cost. |
| **Lighting Systems** | | |
| Daylighting systems | N | Frequent occupant complaints. Proprietary controls may be an issue. |
| Electric window blinds | N | Prone to breaking. No added value in Army environment. |
| Occupancy sensors | Y | Occupancy sensors are required by ASHRAE Std 90.1 for lighting. Good technology. Easily understood and maintained. |
| Advanced lighting control systems | N | Proprietary systems are difficult to operate and maintain. Frequent technology changes quickly make systems obsolete and difficult to obtain repair parts. Vendors typically provide poor customer technical support. |
| **Plumbing Systems** | | |
| Hands-Free Lavatory Faucets | N | Battery replacement is an issue. If installed, DPWs prefer wired or solar units with battery backup and units with manual flush backup.<br>When these units ultimately fail, in-kind replacement ranges from $40 to $600. Directorates of Public Works (DPWs) often replace with manual faucets at approximately $60. |
| Hands-Free Soap Dispensers | N | Unnecessary maintenance item. |
| Filtered Water Bottle Stations | N | Bottle fillers are normally popular and avoid use of disposable plastic bottles. Normally there is no need to filter drinking water unless water quality is an issue in older buildings or with older water systems. Filtered water bottle stations require frequent maintenance and should be avoided unless needed. |
| Waterless Urinals | N | Many occupant complaints. Foul odors and clogging. Disallowed by many DPWs due to maintenance and odors. |

| | | |
|---|---|---|
| Tub/Shower Combinations in Barracks | N | Water from overflowing tub causes extensive damage to barracks room, adjacent rooms, and rooms below. |
| Polypropylene Random Copolymer (PPR) Plastic Pipes | N | Poor choice in hot water pressure applications. PPR pipes have burst causing major water damage. Repair parts are hard to obtain. Installations cannot justify the high cost of fusion welding repair tooling. |
| Cleanouts | Y | Cleanouts need to be installed in accessible locations and shown on drawings, not just rely on code for plumber to install. |
| Rainwater Reclaim Systems | Installation dependent | Do not install at installations that are not water constrained. Payback does not justify cost. |
| **Fire Alarm Systems** | | |
| Fire Alarm Systems | Y | To the extent possible, minimize complexity. Prefer vendors who provide strong customer technical support. |
| **Renewable Energy Systems** | | |
| Solar DHW Systems | N | Systems typically do not produce design domestic hot water (DHW) capacity. Systems develop leaks and are susceptible to freezing. Replacement parts can be difficult to obtain. Repair contractors only want to repair their own systems.<br>These systems are not life-cycle cost effective (LCCE) at continental United States installations due to low cost of utilities. The outside continental United States locations are more conducive to payback. DPWs are often unable or disinclined to provide the necessary support to maintain these systems in a useful state. |
| Solar Pool Heating Systems | Y | Good application for solar water heating. |
| Photovoltaic Systems: Ground-Mounted | Y | Designs should carefully consider maintainability, including rapid obsolescence of technologies, availability of repair parts. Depending on utility rates and installation costs, these systems may not be LCCE. |
| Photovoltaic Systems: Roof-Mounted | N | Location adds to maintenance burden. Possible fall hazard to workers. Roof traffic contributes to roof damage. Susceptible to wind damage. |
| Wind Turbine Generators | Location dependent | Only install in select locations, considering environmental concerns, operational issues, and proven wind resources. Wind can be an issue around ranges and airfields. The US Air Force does not normally want them due to hazards. Large wind farms cause issues with airfield radar systems. |

Numerous factors contribute to otherwise promising technologies being less successful in Army usage. Some of these factors include the following:

- Inadequate O&M worker training and skills. Increasingly complex systems require similarly complex O&M skills.

- Misapplication of technologies. For example, ground source heat pump systems may be very effective in certain climate zones and with the right soil types. Improperly applied, they gradually lose effectiveness over time.
- Rapid technological change causes many complex systems to quickly become obsolete. In some cases, vendors no longer support prior generations of their products, and spare parts become difficult or impossible to obtain.
- Proprietary technologies present unique problems. For example, lighting control systems are difficult or impossible to integrate into base-wide UMCS. In many cases, vendors of these proprietary systems provide little or no technical support to installation O&M technicians, causing DPWs to initiate expensive factory service calls for even minor issues.

In preparing new facility designs, designers conduct a life cycle cost analysis (LCCA). Technologies that are deemed to be life cycle cost effective (LCCE) are retained for possible incorporation into the design and those that are not deemed to be LCCE are dropped from consideration. Of course, an LCCA is only as good as the assumptions upon which it is based. One concern with the LCCA process is the uncertainty with the actual O&M costs used in the analysis for technologies under consideration. Without an adequate estimate of the costs to operate and maintain technologies throughout their expected life, the results of the LCCA are not reliable. A better understanding of actual O&M costs in the Army environment could possibly help avoid selection of technologies that have been problematic in Army applications.

Army planners and designers should carefully consider the implications of technologies proposed for use in new HPSB facilities. Certain technologies have worked well and have moved the Army to a more sustainable future. Other technologies may have performed well in the private sector but have not worked as well in the Army environment. These technologies should be carefully considered before incorporation in future Army projects. Most importantly, the installation’s DPW subject matter experts need to actively participate in planning and design charettes for all military construction/major renovation projects so that their voice is heard on what works/does not work in the facilities they operate and maintain.

# 1 Introduction

## 1.1 Background

The Army has invested in the design and construction of High Performance Sustainable Buildings (HPSB). Army buildings that meet certain Minimum Program Requirements must be verified as being compliant with UFC 1-200-02 *High Performance and Sustainable Building Requirements*. Verification is accomplished by achieving a minimum Silver certification for Building Design and Construction through the US Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED), green building rating system.

Although the intention behind the policies for these HPSBs is to be more cost effective than similar buildings constructed to lesser standards, there have been indications that these buildings may be more difficult to operate and maintain than conventional buildings.

## 1.2 Objective

The study goal was to inform Army leadership of the enduring performance and maintenance requirements of systems incorporated in existing HPSB and their impact on the Army's energy, water, and resilience goals.

## 1.3 Approach

### 1.3.1 Original approach

The original approach taken was to develop a questionnaire or survey to be sent to Operations and Maintenance (O&M) chiefs and/or Energy Managers at a selected number of installations for their input on their experiences with HPSB. The questionnaire, included as an appendix to this report, listed categories of systems and equipment that are commonly installed in Army HPSBs and sought feedback on how well or how poorly these systems and equipment performed at their respective installations. The technical monitor for this project coordinated with personnel within the Fort Hood and Fort Carson Directorates of Public Works (DPW) who provided names and contact information for subject matter experts within these organizations. The plan was to schedule site visits to each of these installations, meet with O&M chiefs, O&M supervisors, O&M technicians, and installation Energy Managers to solicit their input in face-to-face discussions and visit their HPSB facilities to observe issues firsthand.

### 1.3.2 Modified approach

Unfortunately, the outbreak of COVID-19 disrupted the planned approach. Department of Defense (DoD)-imposed travel restrictions hampered the ability to visit one of the two suggested installations. Ultimately, it was possible to conduct site visits and follow-up discussions with Fort Campbell, Fort Carson, and Fort Riley. Although a visit to Fort Hood was not possible, a series of telephone conversations with the installation's Chief of Engineering and O&M chief were conducted.

Besides the installations already mentioned, the Construction Engineering Research Laboratory team expanded its data collection effort to include several additional continental United States CONUS installations, including Fort Bliss, Fort Bragg, Fort Leavenworth, and Fort Polk. These sites were selected because they were known to have a sizable number of HPSBs and they also represented a variety of climate zones. Interactions with these installations were limited to solicitation of responses to the paper questionnaire and telephone or video conferences with people responsible for day-to-day O&M of facilities.

## 1.4 Scope

The scope of this study included HPSB at CONUS Army installations and included both new construction (Design-Build and Design-Bid-Build facilities) and existing buildings that had been renovated/upgraded to HPSB building standards. Information was gathered primarily from discussions with DPW O&M personnel and Energy Managers. Where available, maintenance data were requested and analyzed, but there was no receipt or analysis of individual facility energy performance data or facility plans and specifications. The decision was made that there were enough anomalies and uncertainties in available energy data that made it difficult to draw useful conclusions.

# 2 Observations and Input Data

## 2.1 Problematic systems

### 2.1.1 Proprietary systems

One of the most common issues reported by the installations was proprietary systems that are not maintainable by installation maintenance technicians. For example, several installations mentioned that they had fire alarm systems that were basically inaccessible to the installation's technicians. Although the installation's fire alarm technicians were competent, the vendors for these systems were not willing to provide technical support by phone. When trouble occurred on their system, it was necessary to initiate a credit card purchase to arrange for a site visit by a company technician. Typically, the costs of these site visits came in at the credit card limit so that if anything more than a basic service call was required, it then became necessary to contract for any additional services.

Similar problems were mentioned regarding lighting control systems and the controls for variable refrigerant flow (VRF) systems.

### 2.1.2 Rapid technology obsolescence

Many modern technologies are characterized by rapid technology development and product changes. As a result, upgraded versions or completely new generations of products are developed and introduced to the market. In many cases, vendors stop supporting prior versions of their product line, making it difficult or impossible to get repair/replacement parts or technical support. One installation reported problems with getting spare parts for lighting control systems. The vendor had stopped manufacturing critical parts that the installation needed to maintain its large installed inventory. To address future needs, the installation purchased the vendor's entire remaining inventory of spare parts and put it on its shelves for future use.

Another example of problems associated with rapid obsolescence of technologies pertains to photovoltaic systems. In one installation's experience, when photovoltaic systems became damaged or failed, the necessary repair parts were unavailable because the vendor no longer supported prior generations of its system. In some cases, this has rendered entire photovoltaic arrays inoperable.

Rapid technology change also leads to the need to stock more unique spare and replacement parts because parts that might have been compatible with a previous generation of a given system will no longer fit the current version. The need to stock more unique parts results in more money tied up in spare parts and more warehouse space required to store them.

#### 2.1.3 Unnecessarily complex systems

Overly complex systems were noted as a hindrance to being able to effectively maintain facilities. The heating, ventilating, and air conditioning (HVAC) supervisor at one installation pointed out a facility that was served by numerous dedicated outdoor air systems (DOAS) to condition ventilation air. He noted that these units were frequently shutting down in response to a sensor failure. These particular units incorporated 12 different sensors when, in his opinion, the systems would function adequately and more reliably with much fewer sensors. Unfortunately, in an effort to squeeze every last BTU[1] of energy performance out of a system, designers insert more and more complexity into the system. While this may, in theory, make systems more efficient, it frequently makes them less reliable, more costly to maintain, and as a result, often less energy efficient in the long run.

This same installation reported problems with overly complicated fire alarm systems. The fire alarm system that was installed was capable of supporting a much larger and more complex facility. As a result, the installed system was unnecessarily difficult to operate and maintain.

### 2.2 Best practices and recommendations

Efforts to comply with federal policies and to certify with the USGBC during the design and commissioning phases of projects have often resulted in technologies and equipment being installed that are initially efficient. Unfortunately, many of these same technologies become problematic and ineffective due to O&M difficulties.

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[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

As the Army continues to pursue certification of new construction with the USGBC LEED certification system, currently LEEDv4 with the option to substitute LEEDv4.1 pilot credits, there are specific credits where it is imperative that the O&M teams be involved early in the planning and design process. As illustrated in Figure 1, nearly all of the required and optional credits that might be included in a facility design package for LEED version 4 are noted as requiring input from O&M personnel.

Figure 1. LEEDv4 credits that invite technologies that may not be optimal for an installation are labeled according to the key. For these technologies, input from O&M teams are highly recommended.

**LEEDv4 Scorecard for BD+C**

KEY Requires input from Operations & Maintenance ✗

| Y | ? | N | | | | |
|---|---|---|---|---|---|---|
| | | | Credit | Integrative Process | ✗ | 1 |
| **0** | **0** | **0** | | **Water Efficiency** | | **11** |
| Y | | | Prereq | Outdoor Water Use Reduction | ✗ | Required |
| Y | | | Prereq | Indoor Water Use Reduction | ✗ | Required |
| Y | | | Prereq | Building-Level Water Metering | ✗ | Required |
| | | | Credit | Outdoor Water Use Reduction | ✗ | 2 |
| | | | Credit | Indoor Water Use Reduction | ✗ | 6 |
| | | | Credit | Cooling Tower Water Use | ✗ | 2 |
| | | | Credit | Water Metering | ✗ | 1 |
| **0** | **0** | **0** | | **Energy and Atmosphere** | | **33** |
| Y | | | Prereq | Fundamental Commissioning and Verification | ✗ | Required |
| Y | | | Prereq | Minimum Energy Performance | ✗ | Required |
| Y | | | Prereq | Building-Level Energy Metering | ✗ | Required |
| Y | | | Prereq | Fundamental Refrigerant Management | ✗ | Required |
| | | | Credit | Enhanced Commissioning | ✗ | 6 |
| | | | Credit | Optimize Energy Performance | ✗ | 18 |
| | | | Credit | Advanced Energy Metering | ✗ | 1 |
| | | | Credit | Demand Response | ✗ | 2 |
| | | | Credit | Renewable Energy Production | ✗ | 3 |
| | | | Credit | Enhanced Refrigerant Management | ✗ | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Credit | Green Power and Carbon Offsets | | 2 |
| 0 | 0 | 0 | **Indoor Environmental Quality** | | | **16** |
| Y | | | Prereq | Minimum Indoor Air Quality Performance | | Required |
| Y | | | Prereq | Environmental Tobacco Smoke Control | | Required |
| | | | Credit | Enhanced Indoor Air Quality Strategies | | 2 |
| | | | Credit | Low-Emitting Materials | | 3 |
| | | | Credit | Construction Indoor Air Quality Management Plan | | 1 |
| | | | Credit | Indoor Air Quality Assessment | | 2 |
| | | | Credit | Thermal Comfort | | 1 |
| | | | Credit | Interior Lighting | | 2 |
| | | | Credit | Daylight | | 3 |
| | | | Credit | Quality Views | | 1 |
| | | | Credit | Acoustic Performance | | 1 |

The LEED rating system requires projects to prepare and maintain a current facilities requirements and O&M plan that contains the information necessary to operate the building efficiently. This step falls under the Fundamental Commissioning and Verification LEEDv4 prerequisite. This step should be central.

When performing a life cycle cost analysis (LCCA), the O&M team should have an opportunity to review any technologies or equipment under consideration for incorporation into the design to be compliant with federal policy or achieve LEED Silver certification. The O&M team should provide any available historic maintenance records for those technologies to inform the LCCA process. The actual costs derived from the installation's historic maintenance records should be used in the LCCA.

In the case of new technologies for which historical O&M costs are unavailable an attempt should be made to estimate reasonable O&M costs in the Army environment. The O&M cost estimate should consider the availability and cost of adequate technology-specific O&M training, a thorough understanding of maintenance requirements and protocols, and knowledge of the availability of replacement parts in the present and future is critical. For proprietary systems, the costs of contracted O&M support should be part of the O&M cost equation.

## 2.3 Conclusion

The customer, project delivery team (PDT), and O&M team must collaborate to design and deliver a facility solution that is efficient and maintainable. Maintenance records including all costs associated with the equipment, especially problematic equipment, should be prepared for use in the LCCA.

Guidance on LCCA is more detailed in the latest UFC 1-200-02 released on December 1, 2020. This revised guidance should improve the process and begin to eliminate systems that are cost ineffective in the design of future projects.

Maintenance issues should also be discussed in design charrettes and heavily weighted.

# 3 Technologies

## 3.1 Heating, Ventilating, and Air Conditioning (HVAC) Systems

### 3.1.1 Dedicated Outdoor Air Systems (DOAS)

DOAS have become an essential part of modern HVAC systems, especially in hot, humid locations. In these climates, the introduction of unconditioned humid outdoor ventilation air into buildings contributes to perfect conditions to cause mold and mildew infestation of buildings. To avoid this possibility, DOAS systems remove moisture from ventilation air before it enters the facility. In addition, DOAS systems deliver ventilation air in the required quantities to satisfy the ventilation requirements of ASHRAE Standard 62 and to maintain building pressurization. Finally, to promote energy efficiency, most DOAS systems exchange energy (both heat and moisture) between the building's incoming ventilation air stream and the exhaust air stream. This recovery of energy greatly reduces the energy consumed to condition outside air.

To perform these functions, typical DOAS systems incorporate fans, dampers, filters, cooling coils, heating coils, energy recovery wheels, and other components. As a result, DOAS systems involve a greater degree of complexity than one might expect so that it may not be obvious to an untrained observer whether a particular DOAS system is working correctly. DOAS systems typically incorporate sensors to determine whether the system is working properly and to provide an output alarm signal when a fault occurs.

Several installations have experienced serious problems when DOAS systems have failed. Unlike conventional HVAC system components such as air handling units, fan coil units, or packaged air conditioning units, building occupants may not realize that the DOAS system serving their facility is not working properly. As a result, a DOAS system may be malfunctioning for days or weeks before the installation's maintenance staff becomes aware of it. At least two installations reported having buildings seriously damaged by undetected failures of DOAS systems. Within days of a DOAS failure a barracks facility at one installation was heavily contaminated with mold and uninhabitable until the mold was remediated.

Ideally, an alarm signal would be transmitted to the installation's maintenance staff. Although DOAS systems are typically tied in to a facility's building automation system (BAS), which is also connected to the installation's Utility Management and Control System (UMCS), this has not guaranteed that DOAS failures are adequately communicated to the maintenance staff. For one thing, getting DOAS systems approved to operate on an installation's enterprise network can be very difficult. One site reported that its DOAS system was not properly and completely commissioned in the UMCS system at project turnover. No screen was provided in the UMCS system to allow the UMCS system operators to see the status of the DOAS system. To address a lack of connectivity between the DOAS system and the maintenance staff, the DPW at one site installed both outdoor visual and audible alarms and a sign requesting passersby to call the DPW when the alarm was active. This has not always been successful, and facilities have suffered extensive damage from high humidity conditions in the facility.

Some installed DOAS systems have been overly complicated to the point of being very difficult to maintain. For example, the HVAC supervisor at one installation pointed out a facility with multiple Aaon DOAS units that were frequently shutting down. He related that these units incorporated a dozen different sensors, any one of which could cause a shutdown. In his opinion, the system could have performed adequately, and more reliably, with significantly fewer built-in sensors. This appears to be an example of an overly complex design.

Many installations have found that DOAS systems are high-maintenance items. One installation has a number of Munters DOAS units. These units worked well during the first 5 – 7 yr, but then began having issues with controllers. Unfortunately, the manufacturer does not have a retrofit for its old controllers. The same installation has Semco DOAS systems. These units have major issues with corrosion, problems with burnout of Aaon compressors, and failures of desiccant wheels. The Aaon compressors are worked very hard in this application and tend to burn out. When compressors failed, the system did not send an alarm signal to notify the UMCS operators of an inoperable compressor. Consequently, a serious mold problem developed in this barracks facility. A UMCS control protocol is needed to properly interface DOAS compressors and building pressurization controls to installation UMCS systems.

### 3.1.2 Demand controlled ventilation (DCV) systems

DCV is an interesting technology that could conceivably save considerable HVAC energy if properly implemented. Conceptually, DCV systems adjust outdoor air flow rates to maintain indoor carbon dioxide ($CO_2$) concentrations at acceptable levels. When a building is fully occupied, the flow of ventilation air is increased to dilute elevated $CO_2$ levels, and when the occupancy is decreased, the ventilation rate is decreased accordingly. Adjusting ventilation air flow rates greatly decreases the amount of HVAC energy required to condition ventilation air. There are numerous problems associated with DCV systems, mostly associated with sensors and controls. Problems include properly locating $CO_2$ sensors to provide a good indication of the building's actual ventilation requirements and maintaining calibration of $CO_2$ sensors. Other problems are associated with calibration of sensors. It was found that most installations do not have facilities with DCV systems. One installation, however, did have a facility with DCV. Apparently, that system had problems with actuator failures on HVAC system dampers, creating over- and under-pressure situations in the building.

### 3.1.3 Building pressurization controls

Building pressurization controls attempt to maintain proper interior building pressure with respect to the outdoor environment. Ideally, buildings should be maintained at a slight positive pressure to prevent infiltration of unconditioned outdoor air through doors, windows, and other (intentional or unintentional) openings in the building envelope. If a building is too negative, unconditioned outdoor air will infiltrate the building envelope, and it may be difficult or impossible to open exterior doors. Conversely, if a building is over pressurized, exterior doors may not close completely. At least one installation reported problems with pressurization of a gymnasium facility due to issues with damper actuators.

### 3.1.4 Variable refrigerant flow (VRF) systems

A VRF system is defined as any system containing two or more interconnected direct expansion indoor evaporator coils served by a single outdoor condenser unit. They are *ductless* air conditioning or heat pump systems in which refrigerant can be moved from fan-coil unit to fan-coil unit within the occupied facility spaces. VRF systems have become popular within the mechanical design and construction industry because they reduce or eliminate the need for HVAC ductwork within a facility and they use a single outdoor condenser unit to serve multiple indoor fan coil units, simplifying the overall system in some respects. They have the potential to save considerable energy by recovering heat from spaces needing cooling and moving that energy to spaces with a simultaneous heating need.

In spite of these touted potential advantages of VRF systems, DoD has placed special requirements on these systems due to their inherent risks. Three primary risk areas have been identified: (1) VRF systems currently contain proprietary hardware and software in conflict with 10 USC 2867, *Energy Monitoring and Utility Control System Specification for Military Construction and Military Family Housing Activities*. Because of the proprietary nature of these systems, they are not able to communicate with Army UMCS systems so that UMCS operators cannot monitor temperatures inside buildings equipped with VRF systems; (2) VRF systems increase the risk of adverse mission impacts due to new Environmental Protection Agency (EPA) leak-rate rules on HFC refrigerant systems (if 50 lb or greater of refrigerant) and the challenge of locating and repairing a leak in often hard-to-access areas; and (3) VRF systems have uncertain lifecycle costs (LCC) making comparisons with traditional HVAC systems difficult. Although not cited in this list of concerns, note that VRF systems pose a potential safety concern. Because VRF refrigerant systems contain a significant refrigerant charge that typically circulates in piping located above office spaces, a refrigerant leak inside the building could potentially pose an asphyxiation risk to the occupants.

Although variable refrigerant flow systems (VRF) are strongly discouraged by UFC 3-410-01, *Heating, Ventilating and Air Conditioning System*, and ECB 2017-7, *Changes to UFC 3-410-01, Heating, Ventilating and Air Conditioning Systems, with Change 3*, they are still proposed for use on new construction projects and renovation projects at design charrettes. Installations typically discourage their use as not preferred.

One installation had at least one facility with VRF systems and reported that due to their moderate climate, the system was unable to adequately heat the facility. Another installation had five similar buildings equipped with Sanyo VRF systems. These five buildings are approximately 8 yr old, and due to maintainability issues, the installation has found it very difficult to keep occupants comfortable. The Sanyo VRF systems have multiple outdoor circuits (condenser units) serving up to 17 indoor head units (evaporator units) per circuit. If one head unit goes down, all the head units on that circuit shut down as well. This causes much of the building to be uncomfortable when only one room should have been affected. This is exacerbated by the fact that the buildings have non-operable windows. Troubleshooting is difficult, in part because these buildings are not on the base-wide UMCS system so that it is not possible to remotely access or diagnose problems with these facilities. An HVAC technician has to drive to the building, enter the Mechanical Room, and plug a laptop directly into the common control panel. The problem is further complicated by difficulties getting the laptop to identify and establish communications with the faulty system. Often this requires the use of trial and error, guesswork, and a good bit of luck to establish communication because the system will only talk to the laptop if the laptop is requesting to communicate to the outdoor circuit with the exact number of head units that the system *thinks* it has on that circuit. A seemingly simple troubleshooting task is unnecessarily frustrating and can be very time consuming. With five such buildings and frequent system failures, a significant amount of the HVAC technicians' time is wasted. Meanwhile, the occupants often suffer with very uncomfortable conditions.

Facilities equipped with VRF systems tend to be very difficult to operate and maintain, in part due to the proprietary nature of the VRF systems and the incompatibility of these systems with Army communications protocols. In general, VRF systems should be disallowed until the problems noted above are adequately addressed.

## 3.2 Chilled beam systems

Chilled beams are a form of HVAC system that has the potential of saving fan energy in buildings. Typical chilled beam systems deliver chilled water to ceiling mounted coils and induce air circulation through the coils either by natural convection or by introducing ventilation air to the coil. Chilled beam systems have the potential of developing condensation on the coils that will drip from the units into the occupied space if humidity conditions in the building are not well maintained. Most of the installations did not have chilled beam systems. At least one installation did have a chilled beam system and complained of a control valve not working properly. They noted that they had condensation problems associated with this system.

## 3.3 Heating systems

The installations had a positive opinion of condensing boilers and furnaces, finding them to be good technologies that are easily maintained.

It was found that radiant heating systems worked well and were well accepted in the right applications, such as in the floor of maintenance facilities. None of the installations mentioned having radiant cooling systems.

Instantaneous domestic hot water (DHW) systems received a mixed review, possibly dependent on the application. For offices that do not need a significant amount of hot water, they appeared to be well accepted as a means of minimizing maintenance of large boilers, tanks, pumps, etc. O&M would be reduced by installing instantaneous DHW systems in these applications. Another installation stated that they did not want instantaneous hot water systems, especially in a barracks application. Presumably this was in reference to small electric units installed in individual barracks rooms. The concern is that these systems are high-maintenance items, resulting in very high demand maintenance order (DMO) counts.

It was also noted that, like storage hot water systems, instantaneous DHW systems tend to accumulate scale in hard water environments.

## 3.4 Renewable energy systems

### 3.4.1 Solar domestic hot water (DHW) systems

Many installations have DHW systems. According to EISA (2007), new federal facilities are required to generate up to 30% of their DHW needs with solar energy "if life cycle cost effective." In many cases, these systems have proven to be a poor investment. They tend to be high-maintenance systems, being prone to leaks and freezing, often fail to deliver their design hot water output, and typically have a short useful life. When they develop leaks or other recurring maintenance issues, many installations decide to bypass and decommission these systems, ultimately removing them altogether.

In general, solar DHW systems do not appear to work well in the Army environment. There are several possible reasons for this:

1. Most solar DHW systems are not sufficiently instrumented to clearly indicate if they are operating as designed. Since it is not obvious by visual inspection if the system is operating per design and if the solar DHW system is not leaking or obviously broken, a maintenance worker might reasonably assume that the system is functioning properly.
2. Most solar DHW systems operate in conjunction with conventional DHW systems with sufficient capacity to meet the design hot water load without reliance on the solar system. Since there is a conventional DHW system providing 100% backup, there are few, if any, complaints of inadequate hot water in the facility. In the Army environment, no complaints often translates into *no service*.
3. Most solar DHW systems are roof mounted, making them difficult or possibly hazardous to service and maintain. Also, being roof mounted, they may be somewhat *out of sight, out of mind*.
4. In some cases, the solar DHW system was not properly handed off to the installation's O&M people. Due to a lack of proper transition to the O&M team, the systems ultimately failed and were taken out of service.
5. In some cases, solar DHW systems suffered irreparable damage from hailstorms and other weather events. It would be possible to harden these systems with ballistic glass, a very expensive option. Repairing these systems is hampered by the fact that the technology and vendors change so fast that it is difficult, if not impossible, to get replacement parts. When seeking repairs, vendors typically will not touch another vendor's proprietary equipment. Instead, they essentially provide quotes for entire system replacement because they are unable to repair another vendor's system.

Except that solar DHW systems are required by EISA (2007), if life cycle cost effective, it might be tempting to disallow these systems altogether. Nevertheless, at least one installation was satisfied with them. That installation's only concern was that the BAS system did not have access to sufficient performance data from the solar DHW system to determine if it was delivering the required percentage of solar hot water. In any event, designers should strongly consider the local installation's preferences regarding solar DHW systems on new construction projects and should be very realistic about the actual life cycle cost of these systems, considering their high maintenance costs and, in many cases, short useful life.

### 3.4.2 Photovoltaic (PV) systems

PV systems are becoming an increasingly important element in installations' toolkits to enhance resilience and reliability. They have been well received by most installations. One problem that has been noted, however, is that the rapid development and evolution of these advanced technologies result in manufacturers terminating support of older generations of their product line. As a result, it can become very difficult to obtain repair parts when failures occur. In some cases, the lack of compatible spare parts can render an entire PV installation inoperable.

Another possible concern with PV systems has to do with how and where they are installed. Rooftop installations have an advantage in that they do not occupy valuable ground space and they are less likely to be shaded by trees, buildings, etc. Nevertheless, rooftop mounting makes it more difficult to maintain these systems, and the need to maintain these rooftop systems may result in increased risk of damage to roofs and safety hazards for workers. Also, in many cases ground-mounted systems might prove to be more cost effective. Rather than mounting a small number of panels on each of several buildings, it might be cheaper to aggregate the same number of panels in a single location at ground level.

Local climate and weather patterns should be considered in decisions to install PV systems. One installation noted that they had experienced winds of approximately 100 mph, causing damage to roofs and roofing materials. Golf ball- and baseball-size hail has caused severe damage to solar panels, windows, and roofs, requiring complete replacement.

### 3.4.3 Wind turbine generation systems

Most of the installations that were interviewed did not have any wind generation systems. One installation, however, had wind turbines on at least one facility. This particular implementation was apparently a very bad application of wind turbines due to turbine height limitations to avoid interfering with radar, the presence of bald eagles, various government rules, and minimal electrical production. The payback for this system was estimated at 100 yr. The wind turbines on this showcase facility at one installation were found to be minimally generating any electricity.

### 3.4.4 Ground source heat pump (GSHP) systems

Ground source heat pump GSHP systems have become a popular technology in recent years. In the right climate zone, with the right soil types and properly designed, installed, and maintained, GSHP systems can save a significant amount of energy to heat and cool buildings. Using the thermal mass of the earth as a big heat capacitor, it is possible to extract heat from the ground during the heating season and reject heat to the earth during the cooling season. In applications with an approximate balance between summer cooling requirements and winter heating needs, these systems can be a very efficient way to condition buildings. Unfortunately, if they are improperly applied, designed, installed, or maintained, they may not live up to expectations and prove not to be cost effective.

Most commonly large GSHP systems utilize vertical well fields to exchange thermal energy with the earth. These well fields can be installed in any open space, including under parking lots. Protecting installed well fields from damage due to vehicle traffic or excavations is critical. The GSHP system circulates a glycol solution through the well field and throughout a building loop. Heat pumps residing on the building loop extract from or reject heat to the building loop. By their nature, GSHP systems may incorporate a number (potentially hundreds) of heat pump units. In any particular system, there will probably be only a limited number of different models of heat pumps which is desirable, keeping the number of unique models of units to be maintained to a manageable level. Nevertheless, potentially large numbers of these electro-mechanical devices can present a significant O&M burden.

GSHPs use proprietary software. Although it may be possible to interface GSHP software to the installation's UMCS system, this may not be successful. One installation reported having a system that used Greensleeves software to interface to its GSHPs. Although the company stated that its software was compatible with the DoD open communications protocol, it appears that their software was not properly implemented at this installation. The DPW stated that they had no visibility to the operation of their GSHP systems and that they were broken about as much as they were operational.

## 3.5 Lighting control systems

Lighting controls are devices and systems that accept inputs, make decisions about required lighting levels, and control lighting loads as an output. The inputs may be manual (based on human initiative) or automatic (based on time, occupancy, ambient light level, or instructions from a building management system). The outputs are switching, dimming, or data. The unique combinations of inputs and outputs provide a variety of strategies that, when properly matched to the application, can deliver average lighting energy cost savings up to 38+%. The following presents lighting control strategies commonly deployed for new construction, renovation, and retrofit in today's open office spaces:

Time-Based Control. Time-based control involves automatically turning the lights OFF at a certain time of day based on a predictable occupancy schedule. The Lawrence Berkeley National Laboratory (LBNL) estimates average lighting energy savings of 24%.

Manual Control. Manual controls enable occupants to turn lights ON/OFF or to dim the lights in response to visual needs. They can also override scheduled time-based controls.

Commercial building energy codes require light reduction capability. Options range from bilevel switching to dimming, which provides the greatest flexibility and is available as a standard capability of many light emitting diode luminaires. Dimmable luminaires combined with individually addressable luminaires also allow personal control strategies. In this scenario, each user can customize light output levels produced by the luminaire directly overhead. LBNL estimates average lighting energy savings of 31% for personal and 36% for group manual controls.

Vacancy Sensing. Vacancy-sensing controls automatically turn OFF or reduce lighting when the space is vacant. Though ideally suited to smaller enclosed spaces such as private offices, these sensors can be deployed in large open office spaces, either as part of the luminaire or remotely mounted. With more precise luminaire control, higher energy savings can result. LBNL estimates average lighting energy savings of 24%.

Daylight-Responsive Control. Daylight harvesting controls turn OFF or reduce electric lighting in response to daylight falling on work surfaces. In open offices, dimming is preferred to avoid the visual disruption of lights turning ON/OFF. LBNL estimates average lighting energy savings of 28%.

Combining Strategies. These and other lighting control strategies such as task tuning can be economically combined and layered within the same space; LBNL estimates average lighting energy savings of 38%.

Clearly, lighting control systems make much sense from the perspective of potential energy savings. Unfortunately, in everyday practice, lighting control systems are the source of many complaints and, in practice, may be more trouble than they are worth. Some of the problems cited by installations include the following:

- Complexity – Lighting controls typically involve digital controls. Working with digital controls can be challenging, in part because the software packages serving different vendor's systems are all unique. Dealing with digital control systems requires the installation's lighting technicians to be computer technicians as well.
- Proprietary Controls – Because lighting systems involve digital controls, they also require software to interact with them. Lighting technicians need specific software to interact with each brand of lighting control system so that it becomes necessary to have and learn several different software systems. In most cases, learning how to control Vendor A's system will be of little value in learning how to control other vendors' products. Also, unlike HVAC systems, lighting controls have not yet been well integrated into the DoD open communications protocols. Although some lighting controls can communicate via BACNet®, there are numerous other proprietary lighting system control systems in use. A recent effort has been initiated to revise UFGS 26 09 23.00 40 Lighting Control Devices to fully integrate lighting controls into Smart Building controls. Among other things, this effort will have to address cyber security concerns to get authority to operate these systems on enterprise networks.
- Lack of Service Support – Several installations noted that vendors of sophisticated lighting systems offer little or no technical support, and availability of spare and repair parts is limited. When it becomes necessary to troubleshoot lighting control systems, the installation's lighting technicians may quickly find themselves needing technical support. One installation noted that at least one of their lighting control vendors would not even talk to them unless they had had a

relatively high level of training to begin with. In such cases, the installation was forced to purchase a factory service call. Since the factory representative was approximately 500 miles away, it was impractical for the installation to have the factory representative come on site unless they had a number of systems requiring service. As a result, the installation would often wait weeks for a number of systems to fail before arranging for a service visit. Meanwhile, customers suffered from improper or inadequate lighting. Customer complaints are high due to their lighting problems not being addressed in a timely manner.

- Daylight Harvesting Systems – Daylight harvesting systems seem like an excellent way to save energy. These systems, combined with light sensors and lighting control systems, measure the light levels within the space and adjust light fixture output levels to maintain preset light levels in response to available daylight in the space. Unfortunately, they are not without their problems. As a result, daylight harvesting systems are not well liked. Occupants complain of constantly changing light output in their work area. In other cases, it is felt that these systems tend to dim the lights too much. These problems may be a controls issue or general function of the fixtures themselves.
- Occupant Complaints – Workers may require different lighting levels, depending on their assigned tasks, available task and ambient lighting, their age, and other factors. Lighting control systems have the capability to deliver custom lighting levels to suit the needs of individuals throughout the workspace. Unfortunately, the desired lighting level varies from one individual to another, and even the same individual may have differing lighting needs at different times. Even though a lighting control system should be able to satisfy the differing perceived needs throughout a space, those needs are not necessarily static, giving rise to requested lighting level adjustments. Attempting to satisfy individual lighting preferences could become a major O&M burden.
- At a more basic level, occupants become dissatisfied when lighting systems are malfunctioning or inoperable. When installation lighting technicians are unable to address lighting problems in a timely manner due to system complexity or proprietary controls, occupants are understandably dissatisfied.
- Rapid Obsolescence – Lighting systems and lighting controls are rapidly evolving technologies. As such, manufacturers and vendors quickly bring new product lines to market. As that happens, older generations of their product lines are dropped from production and

eventually spare and repair parts become difficult or impossible to obtain. One installation bought out the manufacturer's entire remaining inventory of spare parts for one of their widely used lighting control systems.

- Improper Commissioning, Maintenance, or Usage – In some cases, lighting control systems were never properly commissioned. In other cases, they were not properly maintained after turnover. One installation reported a lighting control system that actually controls lights only one min/day. In some facilities, soldiers never shut the lights off (24/7/365), wearing the systems out in 7 – 8 yr.
- Costly Retrofits – Sometimes installations determine that it is not cost effective to continue to operate or maintain overly complex systems. In such cases, they may decide to convert these systems to much simpler, more maintainable controls. Sometimes, however, this can be complicated by the fact that simple wall switches are connected to the lighting controls via a Cat-5 cable. Installing new control wiring to the wall switches is a non-trivial task with the need to open up wall cavities to install code-compliant conduit and power wiring to a conventional wall switch.

## 3.6 Fire alarm systems

One installation reported having over 100 proprietary fire alarm systems. This results in an almost impossible O&M situation. Certain manufacturers will not talk to installation fire alarm system technicians unless they have had Level II training (which the manufacturer will not provide). The installation's technicians are skilled and competent, but without some vendor technical support or training, it is impossible for them to maintain the system. As a result, when there are problems, it costs the DPW a credit card limit service call just to get a factory representative to make a site visit. Then, if there are any cost issues beyond the credit card limit, the DPW has to go through the contracting process to procure the cost of additional parts or services. This problem also applies to Voice Evacuation systems.

That same installation reporting has a facility with a massively oversized Vigilant fire alarm system (actually three systems), which has over 1000 points. The system is oversized by 200%. If a software failure occurs, it requires a service call. If a soldier vapes or burns popcorn in a room, it causes a trouble alarm, and a credit card limit service call is required.

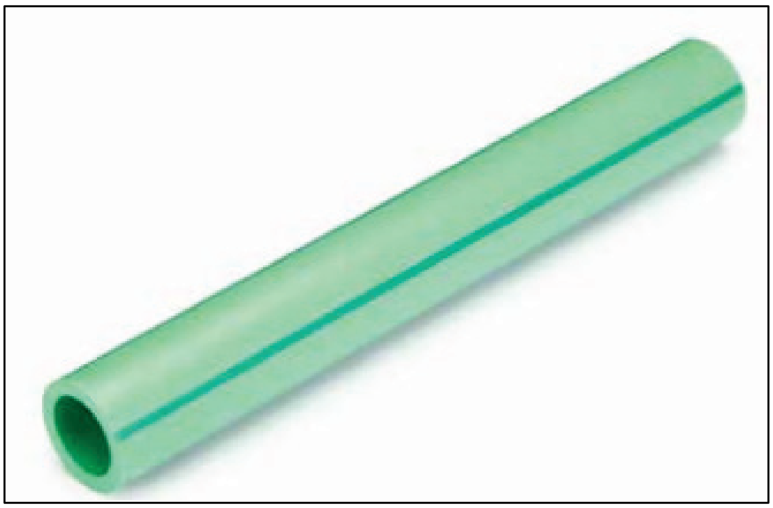
## 3.7 Piping and plumbing systems

### 3.7.1 Piping materials

*3.7.1.1 Polypropylene random copolymer (PPR) piping*

PPR plastic pipes are the latest trends in the construction industry. PPR pipes are specially designed for use with PPR fittings and are joined by a fusion welding process. A major vendor of PPR piping is Aquatherm. Figure 2 is a picture of a section of green PPR piping, which is marketed for potable water applications.

Figure 2. PPR green piping.



Unfortunately, PPR pipes and PPR pipe fittings have some major disadvantages.

- Installation Process – PPR pipes are joined by a thermal fusion process that requires special tooling and skills. Most installations have very few buildings that currently use PPR piping and can hardly justify the $40-$80K cost of the required tools and training to have the capability to install or repair PPR piping in-house.
- Proper Materials for the Application – One installation experienced a major water pipe failure in building where PPR pipe was chosen for a hot water application. This resulted in a major longitudinal split of the piping and significant water damage to the building.
- Proprietary Fittings – In an emergency situation, repair parts or fittings cannot be purchased locally.
- Reaction to Metal – PPR piping should not be allowed to touch metal.

- Product Quality – PPR piping and fittings should only be procured from reputable suppliers as there are manufacturers producing products with inferior qualities.

At least two of the installations interviewed have had very bad experiences with PPR piping. This piping should not be used on Army construction projects, especially in pressurized hot water applications.

#### *3.7.1.2 Chlorinated polyvinyl chloride (CPVC) piping*

CPVC is a high-temperature plastic pressure piping system introduced for potable plumbing in 1959. It has been used extensively in fire sprinkler systems since 1985. This material is also used for many industrial and process piping applications. CPVC pipe is available in nominal sizes from ½ in. to 24 in. and is approved for hot- and cold-water applications in all model plumbing and mechanical codes across the United States and Canada. Per UFGS 22 00 00 Plumbing, General Purpose (11/2015)[1], CPVC pipe is acceptable for hot- and cold-water distribution systems. Nevertheless, several installations have had problems with it. One installation recommended it not be referenced in RFPs for risers or any other application in buildings. Apparently, CPVC piping becomes brittle, especially when exposed to highly chlorinated water. It also reacts poorly when in contact with spray foam insulation, which causes deterioration of the CPVC piping. CPVC should not be connected to polyvinyl chloride (PVC) piping. Ruptures of CPVC piping have not been uncommon, with catastrophic results. CPVC failures have led to class action lawsuits in the private sector.

One installation noted that they were in the process of changing its installation design guide to disallow use of CPVC pipe. Another installation recommended against use of CPVC in any building, preferring copper for risers, transitioning to crosslinked polyethylene piping for distribution.

#### *3.7.1.3 Copper*

Per UFGS 22 00 00, Type L copper piping is recommended as an acceptable material in Army plumbing systems for cold- and hot-water pressure piping applications. Even in these applications, however, copper

[1] https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs/ufgs-22-00-00

piping can develop pin holes due to corrosion, creating potentially major water leaks.

#### 3.7.2 Touch-free lavatory faucets

Touch-free lavatory faucets have become increasingly popular in recent years and are commonly found in commercial and public facilities such as big box stores, schools, and airport terminals. One of the advantages of touch-free faucets is sanitation. One does not need to touch the faucet handle and risk the spread of germs – probably the most significant advantage of these devices in this age of Covid. Another advantage is that they conserve water, at least in theory, compared to manual faucets.

A possible disadvantage of touch-free faucets is that they typically deliver water at a single temperature. This is not a significant problem in the proper application, such as a lavatory in a public restroom.

The biggest concern with touch-free faucets is that they require maintenance, and the costs over time can be significant. Typically touch-free faucets require AA battery power or are hard wired. If battery powered, they require occasional battery replacement. While this is not particularly difficult, it takes time. If sensors, solenoids, or control circuitry fails and it becomes necessary to replace the fixture, the repair or replacement cost can amount to hundreds of dollars. When touch-free faucets fail, at least one installation's approach has been to replace failed units with $65 commercially available standard replacement faucets rather than invest approximately $400 to $650 to replace with a new touch-free faucet.

#### 3.7.3 Filtered water bottle stations

These systems require replacement of filters at $100 each. Some places require monthly filter replacement. The filters are often located next to the unit's control board, and as a result, control boards often get damaged at great expense.

#### 3.7.4 Shower mixing valves

One installation recommended avoiding scald-free shower mixing valves. Apparently, there is no need for the added expense and complexity of installing these scald-free mixing valves in barracks facilities since the temperature of hot water delivered to the soldiers' rooms is regulated to safe temperatures in the mechanical room.

#### 3.7.5 Waterless urinals

Waterless urinals may seem like a good idea for conserving water. However, most installations are dissatisfied with these fixtures. They are high preventive maintenance items, requiring filter changes to stay sanitary and in working order. If not well maintained, they have a foul odor and tend to clog. In summary, waterless urinals are not recommended.

#### 3.7.6 Water efficient plumbing

Water efficient plumbing is generally desirable, saving thousands of gallons of potable water each year. However, even good technologies can have some unintended consequences. By reducing the volume of potable water required in modern facilities, less water flows through the system, making it difficult to maintain chlorine residuals and proper disinfection. At least two installations reported this problem. One installation has had to open and flush several fire hydrants on post for 8 hr per week just to maintain proper chorine residual in the water, amounting to 576,000 gal/week/hydrant. When this becomes necessary, it would seem to negate the benefit of installing water efficient fixtures.

Other problems sometimes associated with water efficient plumbing systems include clogging of low-flow toilets and corrosion and clogging in pipes.

Several installations mentioned problems with flexible joints in piping in both heating and cooling systems. When these joints fail, it is a major problem to repair the system. This is a significant design issue. To the extent possible, flexible piping joints should be avoided.

#### 3.7.7 Rainwater reclaim systems

At least one installation claimed that these systems are more trouble than they are worth. A particular system at this installation was determined to be illegal because it was reclaiming water from a Mechanical Room and attempting to use the reclaimed water to flush toilets. They find that these systems do not work and eventually are taken out of service. Possibly, the system in question was improperly designed or constructed. Nevertheless, the DPW would not recommend using these systems at installations where water is not scarce.

## 3.8 Plumbing – general

Proper design and installation of showers in barracks are critical. When leakage or overflow problems occur, it is not just that particular barracks unit that is damaged. Typically, the water damage extends to other units as well, making mitigation a major undertaking.

Surprisingly, at least one installation said that it had barracks rooms with bathtub/shower combinations. It was reported that soldiers sometimes fall asleep in the tub and the water overflows, resulting in damage to that unit and units in lower floors as well. It would seem that bathtub/shower combinations should be avoided.

Comments were received in regard to the inaccessibility of plumbing system cleanouts. Cleanouts need to be recessed in a wall or otherwise easily accessible. Rather than allowing the plumbing contractors discretion to locate cleanouts wherever they wish, the location should be clearly shown on the construction drawings.

## 3.9 Combined heat and power (CHP)

CHP is a relatively new technology on Army installations. One installation reported having a new system that was near to commissioning. It was too soon to know how well this system would work.

## 3.10 Building automation systems and utility monitoring and control systems

Several installations reported that some of their BAS controls are not properly or completely integrated into the enterprise UMCS system. In some cases, many buildings can be viewed from the installation's UMCS front end, but UMCS operators have little or no ability to adjust or troubleshoot the building systems beyond that.

In general, common issues related to BAS and UMCS systems could be summarized as follows:

- Overly complex sequences of operation are probably more of a detriment than a benefit. With all the pressures to make Army facilities more and more energy efficient, designers understandably look for any way to reduce annual building energy budgets by a few more BTUs. Unfortunately, as designs become more complex the odds of those designs being properly installed and commissioned in the field and properly operated and maintained after turnover diminish rapidly.
- Proper project commissioning, turnover, and training of O&M personnel remains an issue. Project commissioning is an increasingly complex task. Although the US Army Corps of Engineers (USACE) has been aggressively training commissioning team members across the project delivery life cycle, the need for training has not been exhausted. Also, project schedule pressures can interfere with proper execution and completion of the commissioning process. The proper commissioning of BAS and UMCS systems requires very specific skills and remains a concern.
- Numerous buildings are not yet on the installations' base-wide UMCS system. Progress is being made, but in some cases there is a long way to go. At least one installation reported less than half of its facilities were on the base-wide UMCS system.
- Major technologies are not able to be fully integrated into a Smart Building network. While BAS systems in compliance with UFC 3-410-02 *Direct Digital Control for HVAC and Other Building Control Systems* can be properly integrated into UMCS systems, there are numerous systems that are not yet in compliance with these requirements, such as lighting control systems, geothermal systems, and VRF systems. Until these systems can be fully integrated into base-wide UMCS systems, they will be unnecessarily burdensome to operate and maintain and the value of a base-wide integrated Smart Building network will not be fully realized.

## 3.11 Building envelopes

Generally, there were no complaints about building envelopes. More stringent building envelope air tightness requirements have been very successful at reducing the infiltration of humid air into conditioned spaces, thereby greatly reducing incidences of mold and mildew contamination within facilities.

Non-operable windows are good for saving energy, maintaining building pressurization, preventing uncontrolled infiltration of unconditioned outdoor air, and avoiding mold and mildew problems. However, they can be a problem when buildings experience extended power outages or HVAC problems. For example, one installation experienced a loss of power for 5 days following a hurricane. Due to inoperable windows in barracks facilities, it had to set up tents to shelter the troops because the buildings were uninhabitable due to hot and humid interior conditions.

There were no remarks concerning issues related to building insulation systems.

# 4 Operations and Maintenance (O&M) Processes and Procurement

## 4.1 Customer involvement in planning and design

Engagement of O&M personnel early and throughout the planning and design process to review and provide feedback on proposed designs is very important. It was found that most installations felt that they were able to participate in early planning and design, but some did not feel that O&M personnel were adequately engaged or felt that their recommendations were not used. At times, there may not be enough O&M personnel available to assign to participate in these planning and design reviews. Nevertheless, it seems that most installations prioritize planning and design reviews and participate to the maximum extent that they are able.

## 4.2 Training and hiring

As technologies become increasingly complex and software driven, many older O&M personnel are very challenged to develop or maintain the skills to effectively troubleshoot and maintain these systems. Younger employees often are more adaptable to software-driven technologies. However, attracting and retaining younger workers with the necessary technical skills to effectively operate and maintain these increasingly complex systems poses an additional challenge as they often find more lucrative opportunities in the private sector.

At least one installation noted that this past year (2020) posed unique problems getting its people trained due to Covid travel restrictions. Hopefully, this is a temporary problem.

## 4.3 Design issues

Planning or design deficiencies are sometimes a problem. For example, concerns were heard about confined spaces, inadequate access to equipment, and designs that incorporated code infractions. Overly complex designs are not appreciated and should be discouraged, whenever possible. For example, a showcase facility at one installation had the following issues:

- A complex system design incorporating five ground source heat pumps. The heat pumps were installed too closely together, making

these systems very difficult to maintain. The five original heat pumps have since been replaced with three larger units.
- Wind turbines which were found to be barely generating electricity. No doubt, the wind turbines looked good on paper but were actually a poor choice at this location.

Another installation mentioned that it had facilities with electric blinds. These systems were broken, and the soldiers resorted to putting up paper to cover windows. This was a good example of excess complexity. Manual blinds would have cost less and probably worked better.

Other comments about maintainability and accessibility issues were heard. Besides instances where equipment was installed with inadequate maintenance clearances, there were maintainable items located in inaccessible places (e.g., variable air volume [VAV] boxes mounted high above the floor, requiring a tall ladder to reach them). Also, designs should minimize or altogether avoid installing maintainable items behind locked doors where maintenance personnel must get someone to unlock the door to give them access. This is especially true of barracks facilities.

In spite of these issues, installations felt that their voices were being heard on design issues.

## 4.4 Construction issues

At least one installation suggested that problems with DOAS systems and other ventilation systems (economizer controls and building pressurization controls) are related to deficiencies in the commissioning process. The suggestion was that these systems were not properly set up or commissioned initially.

In at least one case, the UMCS system was not properly completed with no screens installed to allow the UMCS system operators to *see* the building. UMCS systems are critical and need to be properly and fully commissioned, including graphic displays.

Sometimes the construction phase gets squeezed due to schedule constraints. On some projects, functional performance testing has been rushed by units wanting to occupy the facility early. The PDT, including USACE, the contractor, and the installer, need to work together to make sure that the commissioning process is complete.

Turnover of HVAC systems is usually accomplished satisfactorily. Full warranty support should be provided from date of building turnover rather than the date of equipment installation.

## 4.5 O&M issues

### 4.5.1 Training/skills

In some cases, maintenance technicians are improperly or inadequately trained. Generic HVAC training does not cover vendor-specific training. If possible, it would be helpful to ensure that brand-specific training is available prior to installation. Depending on the specific equipment installed, training options may be very limited or not very thorough. Installations tend to search for training on equipment that has proven to be problematic.

### 4.5.2 Overly complex systems

Overly complex systems require installations to contract for specialized services to maintain facilities. Systems that require specialized contracted support should be disallowed in favor of systems that can be maintained with the installation's government or contracted staff. Sustaining facilities with credit card projects is costly and often not very timely. It would be beneficial to preferentially select systems and equipment that do not require a contractor with a laptop to come out and troubleshoot and that offer outstanding technical support and training for installation technicians.

### 4.5.3 Lack of manufacturer support

Vendors that are customer friendly should be favored over vendors that provide poor customer support after sale. Often, installations cannot get telephone support when needed and have to resort to an authorized vendor for a certain manufacturer, thus costing more money, DMOs, and premature Facilities Engineering Work Requests (DA Form 4283).

### 4.5.4 Unique spare and repair parts

Spare/repair parts for complex systems tend to be unique and often expensive. At times, there are very long lead times to take delivery of these items. When that occurs, DPW O&M personnel are ineffective in meeting their objectives and are unable to meet their customers' expectations. This also causes premature DA4283 requests and raises costs for specialty parts.

Unique repair parts require more space for warehousing. For example, one installation had 38 different models of shower mixing valves. They suggested standardization to the maximum extent practical.

#### 4.5.5 Buy American Act

The Buy American Act exacerbates the difficulty of purchasing spare/repair parts. For a system that that satisfied the Buy American Act (at least 51% sourced in the United States), one installation found that certain spare/repair parts for that system were actually from China. These parts were inherently inferior and very difficult to purchase. As the Buy American Act involves fairly complex regulatory issues, a solution is elusive.

# 5 Recommendations and Path Forward

## 5.1 Planning phase

The planning phase is an excellent time for the project team to become familiar with the installation's technology preferences. Table 1 is a summary of technology preferences gleaned from discussions with the installations that were interviewed for this study. A review of this table with an installation's O&M chief would be a good place to start this discussion. In addition, O&M subject matter experts should review and provide input into points determined for LEED certification, most importantly, the technologies incorporated.

Table 1. Summary of installations' recommendations to include or not include various technologies in HPSB facilities based on O&M experience.

| Technology | Recommend | Reason |
|---|---|---|
| **Building Envelopes** | | |
| Continuous external insulation | Y | Very effective at reducing heating/cooling load. This is the current minimum requirement within UFC 1-200-02 (per ASHRAE Std 90.1). |
| Air/moisture/vapor barrier | Y | Very effective at reducing moisture infiltration and latent load on cooling and Dedicated Outdoor Air Systems (DOAS) equipment. |
| Non-operable windows | Y | Very effective at reducing moisture infiltration and controlling unwanted infiltration of sensible load, especially in barracks applications. |
| **Heating, Ventilating, and Air Conditioning HVAC Systems** | | |
| Variable Refrigerant Flow Systems (VRF) | N | Systems use proprietary controls which are not "open" and do not meet controls UFC requirements or communicate via Army standard protocols. Stringent new EPA leak-rate rules could risk mission impacts. Refrigerant leaks can be difficult to locate and repair. Possible asphyxiation concerns if large refrigerant leaks occur in occupied spaces. |
| Dedicated Outdoor Air Systems (DOAS) | Y | Best means of delivering required quantities of properly conditioned ventilation air and at controlling building dewpoint to avoid moisture and mold issues. |
| Demand Controlled Ventilation (DCV) | N | No assurance of adequate ventilation in occupied spaces. Sensors go out of calibration. HVAC damper failures. |
| Ground Source Heat Pumps | Very location dependent | Good technology in the right climates/soil types/applications. Very poor choice otherwise. Communications with Utility Monitoring and Control System (UMCS) system can be problematic. Heat pumps need to be installed in accessible locations. Difficult to make LCCA work due to high first cost. |

| | | |
|---|---|---|
| **Lighting Systems** | | |
| Daylighting systems | N | Frequent occupant complaints. Proprietary controls may be an issue. |
| Electric window blinds | N | Prone to breaking. No added value in Army environment. |
| Occupancy sensors | Y | Occupancy sensors are required by ASHRAE Std 90.1 for lighting. Good technology. Easily understood and maintained. |
| Advanced lighting control systems | N | Proprietary systems are difficult to operate and maintain. Frequent technology changes quickly make systems obsolete and difficult to obtain repair parts. Vendors typically provide poor customer technical support. |
| **Plumbing Systems** | | |
| Hands-Free Lavatory Faucets | N | Battery replacement is an issue. If installed, DPWs prefer wired or solar units with battery backup and units with manual flush backup.<br>When these units ultimately fail, in-kind replacement ranges from $40 to $600. Directorates of Public Works (DPWs) often replace with manual faucets at approximately $60. |
| Hands-Free Soap Dispensers | N | Unnecessary maintenance item. |
| Filtered Water Bottle Stations | N | Bottle fillers are normally popular and avoid use of disposable plastic bottles. Normally there is no need to filter drinking water unless water quality is an issue in older buildings or with older water systems. Filtered water bottle stations require frequent maintenance and should be avoided unless needed. |
| Waterless Urinals | N | Many occupant complaints. Foul odors and clogging. Disallowed by many DPWs due to maintenance and odors. |
| Tub/Shower Combinations in Barracks | N | Water from overflowing tub causes extensive damage to barracks room, adjacent rooms, and rooms below. |
| Polypropylene Random Copolymer (PPR) Plastic Pipes | N | Poor choice in hot water pressure applications. PPR pipes have burst causing major water damage. Repair parts are hard to obtain. Installations cannot justify the high cost of fusion welding repair tooling. |
| Cleanouts | Y | Cleanouts need to be installed in accessible locations and shown on drawings, not just rely on code for plumber to install. |
| Rainwater Reclaim Systems | Installation dependent | Do not install at installations that are not water constrained. Payback does not justify cost. |
| **Fire Alarm Systems** | | |
| Fire Alarm Systems | Y | To the extent possible, minimize complexity. Prefer vendors who provide strong customer technical support. |

| Renewable Energy Systems | | |
|---|---|---|
| Solar DHW Systems | N | Systems typically do not produce design domestic hot water (DHW) capacity. Systems develop leaks and are susceptible to freezing. Replacement parts can be difficult to obtain. Repair contractors only want to repair their own systems.<br>These systems are not life-cycle cost effective (LCCE) at continental United States installations due to low cost of utilities. The outside continental United States locations are more conducive to payback. DPWs are often unable or disinclined to provide the necessary support to maintain these systems in a useful state. |
| Solar Pool Heating Systems | Y | Good application for solar water heating. |
| Photovoltaic Systems: Ground-Mounted | Y | Designs should carefully consider maintainability, including rapid obsolescence of technologies, availability of repair parts. Depending on utility rates and installation costs, these systems may not be LCCE. |
| Photovoltaic Systems: Roof-Mounted | N | Location adds to maintenance burden. Possible fall hazard to workers. Roof traffic contributes to roof damage. Susceptible to wind damage. |
| Wind Turbine Generators | Location dependent | Only install in select locations, considering environmental concerns, operational issues, and proven wind resources. Wind can be an issue around ranges and airfields. The US Air Force does not normally want them due to hazards. Large wind farms cause issues with airfield radar systems. |

## 5.2 Design phase

The planning and design phase offers the greatest opportunity to deliver Army facilities that will be maintainable and life cycle cost effective. Selection of technologies to be incorporated into facility designs should carefully consider the ability of the installation's O&M staff to successfully operate and maintain the facility.

Designers should seek realistic estimated O&M costs when performing life cycle cost analyses. Although industry sources such as RS Means facility maintenance cost estimating tools are helpful, O&M cost data from the installation could be a more reliable source of what it costs to operate and maintain the facility in the Army environment. At any rate, installation O&M personnel should review the realism of data and assumptions used in LCC analyses before design documents progress to the point of selecting technologies to be incorporated in the design.

Design reviewers should pay attention to accessibility and maintainability issues. For example, VAV boxes that are installed high above a ceiling or requiring a tall step ladder to access can constitute a safety hazard for maintenance workers. Mechanical and electrical equipment that does not provide adequate room for maintenance should be avoided. Maintenance items in soldiers' rooms of barracks facilities should be minimized or eliminated entirely. Plumbing cleanout locations should be shown on drawings and not left to the contractor's discretion.

## 5.3 Construction phase

During submittal reviews, attention should continue to be given to accessibility and maintainability issues. Shop drawings should be inspected with an eye towards any details that might prove to be a hindrance to maintenance personnel.

As construction progresses, inspectors should assure that pipes, ducts, valves, panels, and other equipment is properly labeled. The entire project delivery team should work together to minimize delays that can create pressure to complete the work before commissioning is properly completed.

An excellent opportunity for O&M personnel to obtain hands-on training is to involve themselves in the commissioning process. To the extent that they are able to do so, O&M personnel should be invited to participate in commissioning inspections, performance verification testing, and functional performance testing.

## 5.4 Other possible opportunities

Operability and maintainability requirements should be addressed in UFCs/UFGSs. A review of Installation Design Guides (IDGs) from several installations made it quite clear that IDGs do not adequately address operability and maintainability of electrical, mechanical, plumbing, and architectural systems for which DPW personnel are responsible. This is an Army-wide (actually, DOD-wide) issue and merits being addressed at the Tri-Service level.

# Appendix: Questionnaire

US Army Corps of Engineers®

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

**High Performance Sustainable Buildings Questionnaire**

Interviewed on ___________ 2020

**Installation:**

**Maintenance by In-House or Contract?**

**POC Name:**

**POC Phone:**

**POC Email:**

Please list any High Performance Sustainable Buildings (HPSB) or LEED Silver certifiable buildings, particularly, any that have proven to be difficult to operate or maintain or have performed below expectations. Typically HPSB/LEED Silver buildings were constructed in the last 10 years or so.

| Building Number | Facility Type / Primary Use | Month / Year Completed | Total Area ($ft^2$) |
|---|---|---|---|
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<u>**Types of problematic systems (indicate any/all that apply)**</u>

- **Ventilation Systems**
  - Dedicated outdoor air systems (DOAS):
  - Economizer controls:
  - Demand controlled ventilation systems (DCV):
  - Building pressurization controls:
- **Heating/Cooling Systems**
  - Condensing boilers or furnaces:
  - Radiant heating or cooling systems:
  - Chilled beam systems:
  - Variable refrigerant flow (VRF) systems:
  - Recommend hydronic system instead of air (AHU) throughout a building?
- **Building Envelope:**
- **Plumbing, Domestic Hot Water and Irrigation Systems**
  - Low-flow toilets and fixtures:
  - Waterless urinals:
  - Solar domestic hot water systems:
  - Instantaneous hot water systems:
  - Water metering integrated to base-wide UMCS system:
  - Bathtubs in Barracks:
  - Fire Protection:
  - Irrigation system metering:
  - Water efficiencies have created another problem with maintaining chlorine residuals / disinfection.
  - Alternative Water systems:
  - Piping:
  - Flex Joints Failing in both heating and cooling systems:
  - Point of Use Mixing Valve:
  - Cleanouts:
  - High temp hot water recirculation line:

  - Shower Mixing Valves:
  - Education and training:
- **Lighting Systems**
  - Lighting control systems:
  - Daylight harvesting systems:
- **Renewables and Energy Recovery**
  - Renewable energy systems (PV, wind, etc.):
  - Ground-source heat pump (GSHP) systems:
  - Energy recovery systems:
- **Controls and Information Systems**
  - Local Building Automation Systems (BAS):
  - Energy/Utility Monitoring and Control Systems (E/UMCS):
  - Meter Data Management Systems (MDMS):
- **Historic Buildings (those on the National Historic Registry)**
- **Buildings Unoccupied due to Deployments, etc.**
- **Other (please describe)**
  - **Aircraft Hangers:**

**<u>Types of problems encountered:</u>**

- **Planning & Design Issues**
  - RFP:
  - Project doesn’t satisfy owner’s requirements:
  - Project siting issues:
  - Planning or design deficiencies:
  - Overly complex design:
  - Materials selection issues:
  - Renovations:
  - UFC/UFGS:
  - Connex Facilities:
- **Construction Issues**
  - Construction deficiencies:

    - Improperly or inadequately commissioned:
    - Air or water systems not properly balanced:
    - Inadequate as-built documentation:
    - Inadequate O&M systems manual documentation:
    - Warranty support issues:
    - Turnover:
    - Quality control an issue:
- **Operational Issues**
    - Costly to operate or maintain:
    - Poor energy performance:
    - System capacity issues:
    - Air or water infiltration:
    - Mold or mildew:
    - Inadequate occupant comfort:
    - Not meeting performance expectations:
    - Insufficient domestic hot water supply:
    - Inadequate performance of water conserving showers and plumbing systems:
    - BAS/UMCS inadequately documented correctly:
    - Proprietary, non-open, non-interoperable control systems:
    - Building controls not properly integrated into enterprise UMCS system:
    - The more fancy you get:
    - The more unique your parts are:
    - Advanced technology spare parts:
- **Maintenance Issues**
    - Maintenance staff improperly/inadequately trained:
    - O & M costs:
    - Accessibility/maintainability issues:
    - Specialized services must be contracted to maintain the facility:

- Excessive service calls:
- Inadequate manufacturer support:
- Spare/repair parts are unique and/or difficult to procure:
- Due to changing technology (i.e. PV, solar water heating):
- Using high efficient fixtures, if they end up breaking:
- Filters get replaced frequently:
- Natural Gas Meters:

- **Other (please describe)**

______________________________________________________

______________________________________________________

_________________________________________________

**For these facilities:**

- Is EMCS / MDMS data available?
- Is GFEBS data available?

**What above listed systems have worked well?**

- ________________
- ________________
- ________________
- ________________
- ________________
- ________________

**Final thoughts/concerns/commendables/recommendations on HPSBs?**

- ________________
- ________________
- ________________
- ________________
- ________________
- ________________

**Photos (optional, but helpful):**

# References

Department of the Army. 2017. *Sustainable Design and Development Policy Update*. Washington, DC.

EISA 2007 (H.R.6 - Energy Independence and Security Act of 2007). 110th Congress (2007–2008). Washington, DC. https://www.congress.gov/bill/110th-congress/house-bill/6

EPAct 2005 (H.R.6 - Energy Policy Act of 2005). 2005. 109th Congress (2005–2006). Washington, DC. https://www.congress.gov/bill/109th-congress/house-bill/6

UFC 2016 (Unified Facilities Criteria 2016). 2016. *Unified Facilities Criteria (UFC) 1-200-02 High Performance and Sustainable Buildings Requirements, 1 Dec 2016*. Washington, DC: Department of Defense.

# Acronyms and Abbreviations

| | |
|---|---|
| BAS | building automation system |
| CHP | combined heat and power |
| $CO_2$ | carbon dioxide |
| CONUS | Continental United States |
| CPVC | chlorinated polyvinyl chloride |
| DCV | demand controlled ventilation |
| DHW | domestic hot water |
| DMO | demand maintenance order |
| DOAS | dedicated outdoor air systems |
| DoD | Department of Defense |
| DPW | Directorates of Public Works |
| DX | direct expansion |
| EPA | Environmental Protection Agency |
| GSHP | ground source heat pump |
| HPSB | High Performance Sustainable Buildings |
| HVAC | heating, ventilating, and air conditioning |
| LBNL | Lawrence Berkeley National Laboratory |
| LCC | lifecycle costs |
| LCCA | life cycle cost analysis |
| LEED | Leadership in Energy and Environmental Design |
| O&M | Operations and Maintenance |
| PDT | project delivery team |
| PPR | Polypropylene random copolymer |

| | |
|---|---|
| PV | photovoltaic |
| PVC | polyvinyl chloride |
| UMCS | Utility Management and Control System |
| USACE | US Army Corps of Engineers |
| USGBC | US Green Building Council |
| VRF | variable refrigerant flow |
| LCCE | life-cycle cost effective |
| UFC | Unified Facilities Criteria |

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



| 1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | 3. DATES COVERED (From - To) |
|---|---|---|
| March 2021 | Final Technical Report (TR) | |

**4. TITLE AND SUBTITLE**
Study of Maintenance of High Performance Sustainable Buildings (HPSB)

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT**

**6. AUTHOR(S)**
James P. Miller, John L. Vavrin, and Samuel Stidwell IV

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
US Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005
Champaign, IL 61826-9005

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ERDC/CERL TR-21-10

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Headquarters, Installation Management Command
Fort Sam Houston, TX 78234

**10. SPONSOR/MONITOR'S ACRONYM(S)**
HQ IMCOM

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**
MIPR No. 11268077

**14. ABSTRACT**
A study was performed by the Energy Branch of the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory, on behalf of the US Army Installation Management Command under the Installation Technology Transition Program. The focus of the study was related to maintainability and operability issues associated with High Performance Sustainable Buildings (HPSBs). This study was conducted primarily based on information gleaned from telephone and web conference discussions with installation Directorate of Public Works personnel including Operation and Maintenance (O&M) Chiefs, energy managers, maintenance supervisors, and maintenance technicians. Experiences with HPSBs varied from installation to installation. For example, some installations had very positive experiences with photovoltaic (PV) arrays while other sites questioned their practicality due to maintainability problems. One site noted that PV technologies are changing so rapidly that procuring spare/repair parts becomes difficult or impossible when vendors discontinue supporting their older technologies or manufacturers go out of business. Based on discussions with the installation O&M personnel, a table of pro and con recommendations for 25 technologies, which are commonly implemented on HPSBs, was prepared and is included in this report.

**15. SUBJECT TERMS**
Buildings—Energy conservation, Buildings—Performance, Photovoltaic power systems—Technology, Sustainable buildings—Materials

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR | 57 | James P. Miller |
| | | | | | 19b. TELEPHONE NUMBER (include area code) 217-373-4566 |