FINAL REPORT

Technology Transfer: Converting Multizone HVAC Systems from Constant to Variable Volume

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Project Number: EW19-5026

Eileen Westervelt, Joseph Bush, Christopher Battisti, Brianna Morton, Heather FitzHenry, and David Schwenk
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This project promotes awareness and facilitates implementation of a low-cost controls retrofit for multizone air handling systems as an interim solution for energy efficiency that accrues savings while delaying system replacement. Implementation tools support technology evaluation and rapid implementation. Products include the following: fact sheet, technical note, pitch briefing, scoping guide, savings estimator, procurement package templates, commissioning guide, and on-line training. Multiple outreach activities occurred including presentations, journal articles, and contacting potentially interested parties.

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ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
BCxA	Building Commissioning Association
BTU	British Thermal Units
CERL	Construction Engineering Research Laboratory
CONUS	Continental United States
CV	Constant Volume
Cx	Commissioning
DDC	Direct Digital Controls
DG	Design Guide
DoD	Department of Defense
EISA	Energy Independence and Security Act
ERDC	Engineer Research Development Center
ESTCP	Environmental Security Technology Certification Program
FSG	Field Scoping Guide
FY	Fiscal Year
HVAC	Heating Ventilating and Air Conditioning
K	Thousand
M	Million
MZ	Multizone air handling System
MZ-VV	Multizone Variable Volume
N/A	Not Applicable
NAVFAC	Naval Facilities Engineering Systems Command
PROSPECT	Proponent-Sponsored Engineer Corps Training
PVT	Performance Verification Test
PWS	Performance Work Statement
SIR	Savings to Investment Ratio
SOO	Sequence of Operation
SPB	Simple Pay Back Period
TAB	Testing, Adjusting, and Balancing
TME	The Military Engineer
TT	Technology Transfer
UESC	Utility Energy Services Contract
UFGS	Unified Facilities Guide Specification
UMCS	Utility Monitoring Control System
USACE	United States Army Corps of Engineers
USAG	United States Army Garrison
YR	Year
VFD	Variable Frequency Drive
VV	Variable Volume
WBDG	Whole Building Design Guide

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ABSTRACT

Introduction and Objective: The Department of Defense (DoD) has a large inventory of older, inefficient multizone HVAC (heating, ventilation, and air conditioning) equipment, that remains in service due to the high cost and facility disruption of system change out to modern technology. The objective of this project is to promote awareness and facilitate implementation of a low-cost, non-invasive controls retrofit for multizone air handling systems as an interim solution for energy efficiency of existing systems that accrues savings while delaying system replacement.

Technology Transfer Method: A previously demonstrated HVAC retrofit (ESTCP project EW-201152) converts constant volume multizone air handling systems to variable volume for energy savings. This current project (EW-19-5026) makes that retrofit accessible through full spectrum implementation support tools and outreach activities. The stakeholder vetted products include: a fact sheet, a technical note, a pitch briefing, a scoping guide, a savings estimator, procurement package templates, a commissioning guide, and on-line training. Results were published on the Whole Building Design Guide, in industry journals, and presented at technical conferences. Potential DoD users were informed of available resources. These efforts support decision makers in fully evaluating the technology and implementing rapidly and successfully.

Project Performance and Cost Assessment: The project met all performance objectives by obtaining constructive review and enthusiastic feedback from pertinent reviewers throughout the process of developing implementation support tools and conducting outreach to interested parties. Many people are taking steps to implement. Modeling of the retrofit impact for typical applications showed a very favorable 3-5 yr. simple payback. This project cost only a fraction of potential agency-wide annual savings and positions the DoD for significant efficiency success.

Implementation Issues: The COVID pandemic shifted the project schedule and approach due to travel restrictions and team members occupied with the COVID response. The technical journal peer review and quality control coordination of the suite of implementation documents proved challenging but tractable. Project implementers need funding and time to adopt the technology.

Publications:

Westervelt, E., Battisti, C., Morton, B., and D. Schwenk, Feb 2021. *Multizone Air Handler Controls Retrofit for Energy Efficiency,* ASHRAE Transactions – 2021 Virtual Conference, Vol 127, Part 1, VC-21-C009.

Westervelt, E., and C. Battisti, Mar 2021. *Upgrades for HVAC Systems.* The Military Engineer, Pgs. 50-51.

Bush, J., Westervelt, E., Clark, B., Schwenk, D., Battisti, C., Morton, B., and H. FitzHenry, June 2022. *Multizone to Variable Volume HVAC Controls Retrofit – Design and Implementation Suite*. Whole Building Design Guide, https://www.wbdg.org/ffc/army-coe/design-guides.

Westervelt, E., Bush, J., and D. Schwenk, September 2022. *Exploring a Multizone to Variable Volume HVAC Controls Retrofit* ASHRAE Journal, Vol. 64, No. 9 Pgs. 32-47.

EXECUTIVE SUMMARY

INTRODUCTION

The DoD has a large inventory of older (15-40+ yr.) multizone air handling systems which are used for building heating, ventilation, and air conditioning (HVAC). Although these units are quick to respond to changes in temperature needs, they can be very inefficient with energy use. Multizone units deliver a constant volume of air to the building, regardless of actual requirements in the spaces. Further, the conventional dual deck multizone units call for continuous, simultaneous operation of the heating and cooling coils, even when heating or cooling is not needed. Modern alternative system replacements (such as variable air volume systems) help address these inefficiencies but are often cost prohibitive as well as disruptive to building operations to install.

The Engineer Research Development Center's Construction Engineering Research Lab, ERDC-CERL, developed an alternate route to energy savings at a significantly lower cost and with less disruption than a complete system replacement. The multizone variable volume (MZ-VV) retrofit turns heating or cooling down or off when not needed with the addition of two pieces of equipment (a variable speed drive and airflow measurement array) and control scheme changes. Further savings were obtained with the addition of a demand-controlled ventilation option which uses sensors in the spaces to reduce ventilation for empty zones. Figure ES-1 below highlights these control changes on a multizone air handling system. This technology was field tested on five systems in two climate zones and showed 24-60% energy savings at the air handler.

DoD implementers, who typically have limited familiarity with controls, sparse time, and constrained budgets, require support to make an informed application of this promising technology.

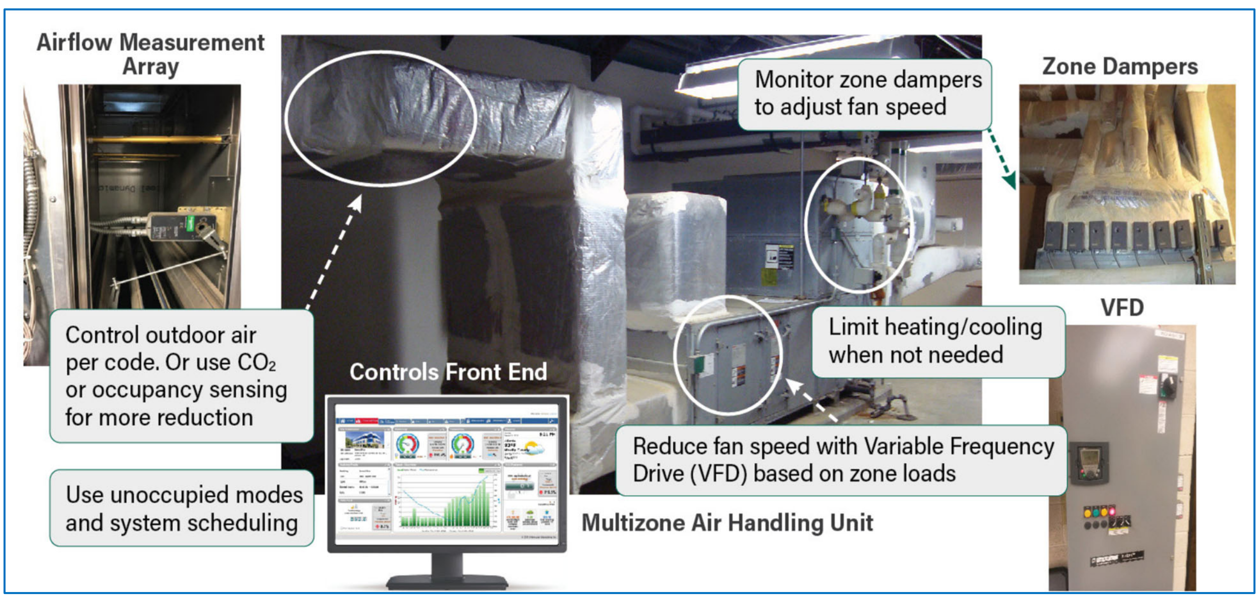


Figure ES-1: Highlights of Control Changes to Multizone Air Handling System

TECHNOLOGY TRANSFER OBJECTIVE

The objective of this technology transfer project is to promote awareness and facilitate implementation of a low-cost controls retrofit for multizone air handling systems as an interim efficiency solution, allowing for accrual of savings now, while delaying full system replacement. This increased efficiency helps to meet facility energy, emissions, and resilience requirements within constrained budgets. Retained cost savings can support additional investments.

TECHNOLOGY TRANSFER METHOD

Technology Adoption Support

To facilitate technology implementation, the team developed a suite of support tools vetted with industry experts and potential users. See Figure ES-2. The implementation resources help a potential user through the entire process of evaluating, implementing, and operating the technology successfully. Ready to use document formats and multiple system configuration options speed technology adoption.

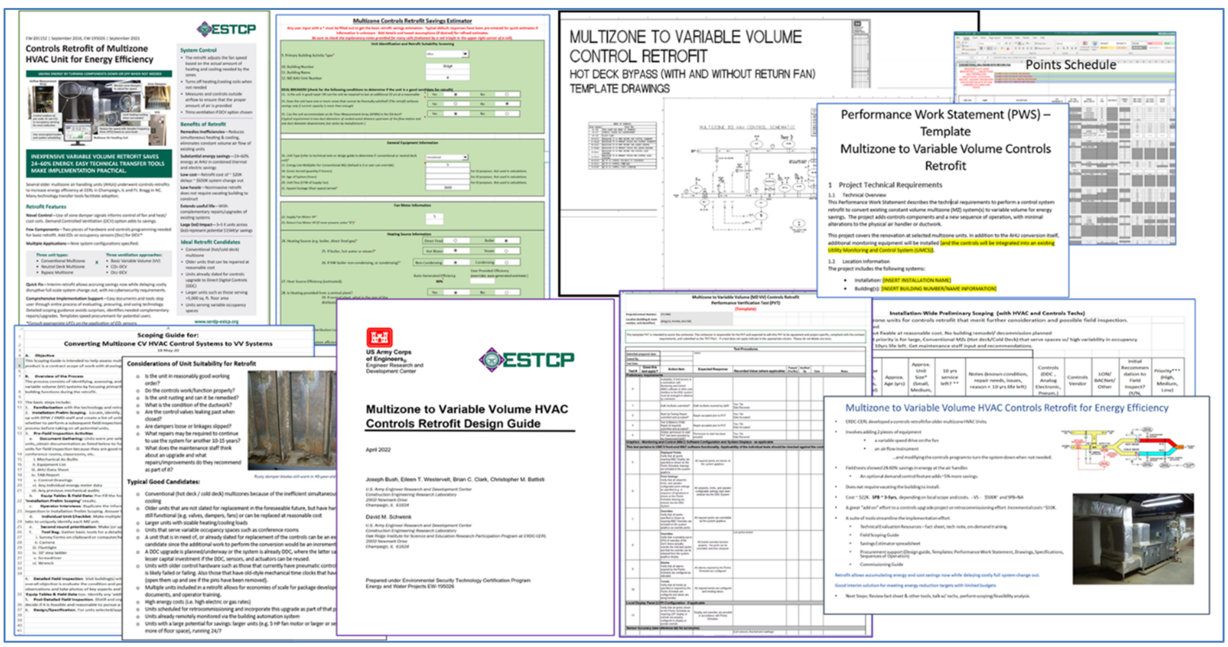


Figure ES-2: Implementation Support Suite of Tools

Products to Evaluate Technology

Several tools were developed to acquaint the assortment of installation stakeholders with the retrofit technology and support applicability determinations to allow a thorough evaluation of the technology by potential users.

- *Fact Sheet:* Provides a 2-page quick introduction to the retrofit, its benefits, applicability, and available resources for general audiences.
- *Technical Note:* Provides 8-pages of pertinent technology details, field demonstration results, and application insights for an engineering audience.
- *Savings Estimator:* Gauges the expected energy and cost impact of retrofit with life cycle cost analysis. Supports early feasibility screening and customized site-specific calculations. Aimed at a joint administrative and technical team.
- *Pitch Briefing:* Supports socializing the retrofit with budgetary and administrative decision makers through a single slide with script. Geared for the executive audience.
- *Field Scoping Guide:* Steps a user through strategic installation-wide screening as well as assessment of an individual unit's operational status and suitability for retrofit. Helps identify complementary repair and upgrade activities that should accompany the retrofit. Aimed at a combined engineering and technician field team.
- *Training:* Delivers a one-hour technical overview of the retrofit and the supporting implementation tools for engineers and technicians. Free, on-demand training on the technology is available at the Whole Building Design Guide, https://www.wbdg.org/continuing-education/dod-courses/estcp/estcp4-4, and on Slipstream's website, https://slipstreaminc.org/estcp. Training for purchase is also available from the Building Commissioning Association, https://www.pathlms.com/bcxa/courses/33553/sections/37765. All are one-hour courses with continuing education units.

Products to Streamline Procurement

The Design Guide and the Procurement Package Templates streamline the design and procurement of the retrofit with a standard procedure that considers best practice and reduces one-off efforts for equipment implementers, designers, and installers.

- *Design Guide:* Lays out a roadmap for implementation that utilizes developed support documents and tools. See Figure ES-3. The guide presents technical explanations and requirements of the retrofit and primary considerations for implementation including: accommodating current or previous DDC upgrades on the system, complementary repair measures, applicable UFGS references for system changes, dehumidification guidance and maintenance recommendations. Developed for project implementers and system designers.

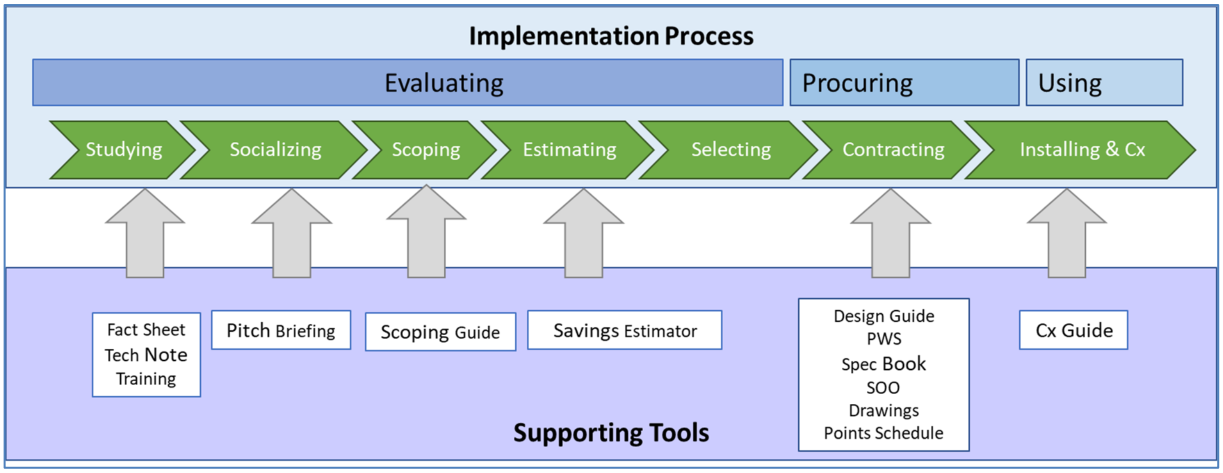


Figure ES-3: Retrofit Implementation Process with Supporting Documents and Tools

- *Procurement Package Templates:* Five templates of drawings, specifications, control sequences of operation, control points schedules, and a performance work statement detail the technical requirements for successful purchase, allow a user to pick and choose needed graphics and text from multiple options, and highlight site specific tailoring needs. Aimed at project implementers.

Products to Use Technology Successfully

The Commissioning Guide and portions of the Design Guide help a user establish and verify proper operation of the system.

- *Commissioning Guide:* Provides project tracking checklists, performance verification test procedures, and a deficiency log. Developed for project implementers and equipment operators.
- *Testing Adjusting and Balancing (TAB) and Maintenance Considerations:* The Design Guide provides insights on TAB and maintenance of the fan speed control and potential humidity issues. Aimed at equipment operators.

Outreach Efforts

To promote awareness of both the technology and the supporting implementation resources, the project team pursued multiple avenues of outreach including the following: 6 conference presentations, 3 on-line training offerings, 4 journal articles, email and/or phone contact with over 90 potential implementers, posting on WBDG of a 47-document design and implementation suite (https://www.wbdg.org/ffc/army-coe/design-guides/mz-vv-hvac-controls-retrofit, and social media postings. See Figures ES-4 through ES-6 and Table ES-1. Additionally, the process for potential incorporation of the control sequences of operation into an applicable UFGS has been initiated.

Figure ES- 4: Six Conference Presentations

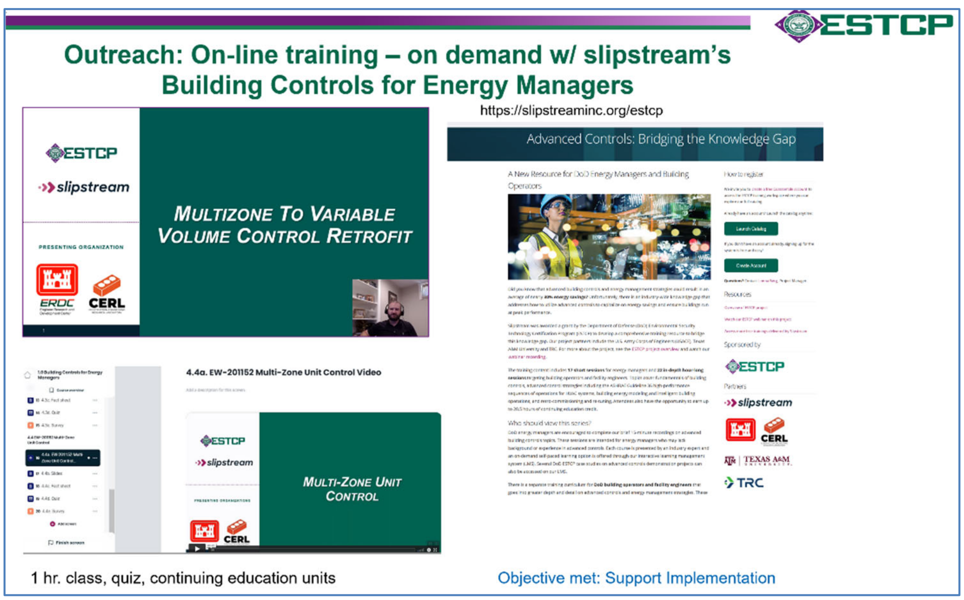


Figure ES-5: On-line Training

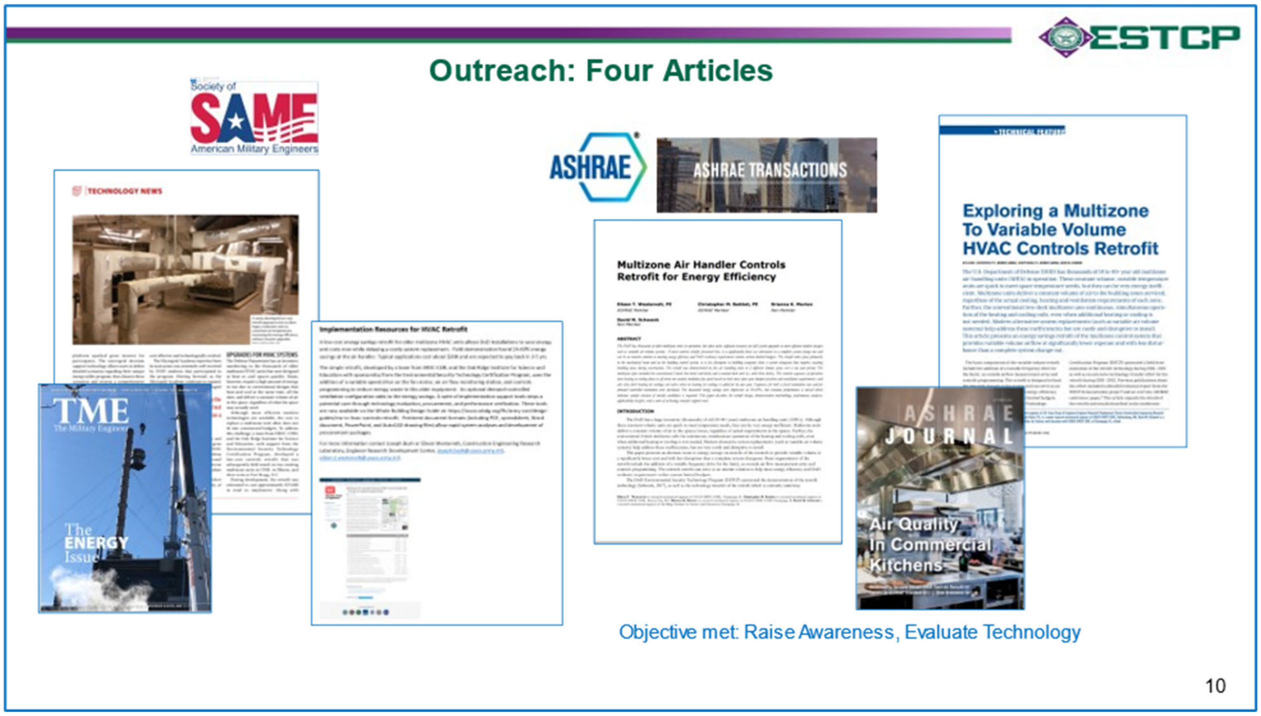


Figure ES-6: Four Journal Articles

Table ES- 1: Multizone Retrofit Design and Implementation Suite Posted on WBDG

TITLE	FORMAT	PAGES	SIZE
01- Multizone to Variable Volume Overview Fact Sheet	PDF	2	1.3MB
02- Multizone to Variable Volume Technical Note	PDF	8	800KB
03- Multizone to Variable Volume Savings Estimator	Excel workbook (xlsx)	19 tabs	6.0 MB
04- Multizone to Variable Volume Pitch Briefing	PowerPoint (pptx)	1 slide	300KB
05- Multizone to Variable Volume Scoping Guide	Excel workbook (xlsx)		2.3MB
06- Multizone to Variable Volume Design Guide with Performance Work Statement, Specifications Book, and Sequences of Operation	MS Word document (docx)	88	683KB
07- Multizone to Variable Volume Points Schedules	Excel workbook (xlsx)	8 tabs	241KB
08.1- Multizone to Variable Volume Bypass Unit Controls Drawings	PDF	12	1.3MB
08.2- Multizone to Variable Volume Conventional Unit Controls Drawings	PDF	12	1.3MB
08.3- Multizone to Variable Volume Neutral Deck Unit Controls Drawings	PDF	12	1.3MB
09- Multizone to Variable Volume Commissioning Guide	Excel workbook (xlsx)	6 tabs	54KB
10.1- Multizone to Variable Volume Bypass Unit AutoCAD Drawings (12 files)	DWG	12	3.2MB
`10.2- Multizone to Variable Volume Conventional Unit AutoCAD Drawings (12 files)	DWG	12	3.3MB
10.3- Multizone to Variable Volume Neutral Deck Unit AutoCAD Drawings (12 files)	DWG	12	3.3MB

TYPICAL RETROFIT ENERGY AND COST IMPACTS

To support understanding of the retrofit's saving potential, the team applied the field results to typical applications. This modeling used the experimental energy improvement along with expected multizone HVAC energy requirements for an office building averaged over three climate zones with average costs for energy, equipment, and labor. The results were very promising, with a 3-5yrs simple pay back (SPB) of investment for typical applications. See **Error! Reference source not found.**. Site specific estimates for particular applications can be developed with the Savings Estimator tool.

Table ES- 2: Economics Impact of Retrofit for Typical Applications

AHU Unit	Incremental Retrofit Cost ($)	Baseline Utility Cost Pre-Retrofit ($)	Energy Savings ($/Yr)	NPV ($)	SPB (Years)	SIR
Typical Conventional MZ in good shape (had equipment schedules)	$10K	$7,100	$2,900	$16K	3.4	2.6
Typical Conventional w/ RCx (had no equipment schedules)	$14K	$10,000	$4,900	$29K	2.8	2.6
Typical Neutral Deck MZ in good shape (had equipment schedules)	$10K	$2,800	$1,900	$6K	5.3	1.6
Typical Neutral Deck MZ w/ RCx (had no equipment schedules)	$14K	$4,200	$3,100	$12K	4.5	1.9

Notes: Office space. Building size=3600sf. Supply fan size = 5HP. Production efficiency corrections for hot water load: distribution losses = 2%, boiler efficiency = 80%. Production efficiency for chilled water load: 1.2kW/ton air cooled. Real discount rate = 3%, life of retrofit=10yrs, Blended energy costs used. Electric unit cost =$0.1054/kwh. Natural Gas unit cost =$0.7213/therm.

PROJECT PERFORMANCE ASSESSMENT

The project met all performance objectives by obtaining acceptable review and constructive feedback from pertinent reviewers throughout the process of scope development, composition of technical description documents, development of the procurement support package, creation of decision and operations support tools, authoring journal articles, giving presentations and training, and conducting outreach to interested parties. See Table ES-3.

Each presentation, article published, call, and posting resulted in new interest in the technology and the implementation documents and tools, and new collaborators to review the products. As of publication of this report:

- The WBDG document suite webpage has had over 450 visitors and ~400 downloads of project related documents.
- Social media postings had over 7.5K views, over 40 positive reactions, and a sharing to another's network.
- One attendee at the ESTCP symposium asked if they could have this process applied to other technologies to foster implementation.
- An IMCOM supervisor has requested that 11 installations review the technology for applicability and feasibility.

- A NAVFAC supervisor asked for a group web meeting to review the technology, and a quadchart technology summary to post on their technical innovation SharePoint.
- An engineering instructor of the PROSPECT HVAC Cx Course will incorporate this work into their training curriculum.
- The BCxA presentation provided scoring by 31 participants and received high ratings and enthusiastic comments.
- A handful of potential HVAC contractors have reviewed the documents and shared favorable impressions.
- One potential contractor has used the estimator as a basis for a 13-site retrofit proposal.
- A college professor attendee at the BCxA remarked that this is an excellent technology to apply during retrocommissioning of existing buildings to optimize energy performance.
- GSA asked for a meeting to review the retrofit process.

Table ES- 3: Technology Transfer Performance Objectives Summary

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
TT Scope Development	Updated tasks and budget numbers	Input from a 10-15 % sampling of potential users. This equates to 4-5 energy managers.	60% satisfaction rating (score ≥ 3 out of 5), or actionable scope adjustment action items.	Avg 97% satisfaction score=4.8/5 **MET**
Reach out to Interested Parties	Satisfaction of Potential Users based on product technical content and ease of use	Feedback from 10% of the 43 interested users (4-5 users).	Responses from ≥ 10%, ≥50% (score of 2.5 out of 5) satisfaction from respondents.	7 respondents Avg 90% satisfaction score=4.5/5 **MET**
Qualitative Performance Objectives				
Develop Technical Description Documents	Acceptable/Unacceptable	Input from two potential users (energy mangers) for accessibility.	Acceptable review, or action items to make document acceptable. Publishing on appropriate website.	**MET**
Develop Procurement Package	Acceptable/Unacceptable	Input from two controls experts, one with intimate understanding of the project, and one new to the technology.	Acceptable review, or action items to make documents acceptable. Publishing on appropriate website.	**MET**
Develop Decision and Operations Support Tools	Acceptable/Unacceptable	Input from two interested energy managers	Acceptable review, or action items to make tools/documentation acceptable.	**MET**
Compose Journal Articles	Acceptable/Unacceptable	Assigned peer reviews. Acceptance/rejection and recommended changes/clarifications	Acceptance of peer reviewed article for publication by esteemed global professional association in HVAC.	**MET**

COST

The cost of this technology transfer project to support retrofit implementation is reasonable and impactful. A major value added by the technology transfer project is development of estimates of the typical economic impact of the retrofit which are very favorable. This is an insight not sought by the field demonstration effort. The technology transfer effort also established the means for applying the experimentally derived savings of the field demonstration to the specific circumstance of potential users. Further its standard approach to implementation provides cost savings to the installation and its contractors in the process of applying the technology and increases the likelihood of quality installations and successful operation. The technology transfer effort costs only a fraction (~2%) of just one year of agency-wide potential annual savings (savings that is expected to accrue as a benefit each year for the anticipated 10-year life) of projects and positions the DoD for significant facility efficiency success.

IMPLEMENTATION ISSUES

The COVID pandemic shifted the project schedule and approach due to travel restrictions and team members called away to assist the COVID response. The technical journal peer review and quality control coordination of the suite of implementation documents proved challenging but tractable. Project implementers need funding and time to adopt the technology.

CONCLUSION

This technology transfer effort is a significant step toward reaping the benefits of a field proven technology in the DoD. The developed full-spectrum implementation tools support a potential user through the entire process of evaluating, implementing, and using the technology. The application of the experimentally determined energy improvement on typical buildings showed expected paybacks of 3-5 yrs. The multi-faceted outreach efforts have been well received by DoD, industry, and academia. Many people have received and reviewed the documents and tools, and several are taking action to implement. Some have used or plan to use the tool for proposals. Others have initiated feasibility reviews or are in the process of socializing the retrofit or seeking implementation funding. The MZ-VV technology is a cost-effective interim solution to accrue savings and meet energy reductions goals. This overall process of technology implementation support can serve as a model for promoting other promising technologies.

1.0 INTRODUCTION

A past ESTCP project (EW-201152) developed and demonstrated a low-cost technique to convert a constant volume (CV) multizone system to a more energy efficient variable volume (VV) multizone system. That project measured and documented the performance of the conversion, along with recommending applicability and implementation requirements for future implementation. This current ESTCP technical transfer project (EW19-5026) builds off the previous demonstration and developed enhanced and additional technical transfer documents and conducted outreach to facilitate implementation of this energy and cost savings conversion at DoD installations.

1.1 BACKGROUND

The DoD has a large existing inventory of CV multizone HVAC systems, an older technology that serves multiple zones and is not efficient with energy use when compared to modern HVAC systems. The demonstration of the conversion from CV to VV was successful, as the results demonstrate the potential for the conversion to meet energy savings, comfort, and maintenance requirements. Cost impacts were mixed compared to anticipated results; however, costs were only a fraction of the cost of alternative approaches. Using multiple sources (a questionnaire distributed to many CONUS installations, the 2009 Base Structure Report, a poll of three large Army Installations, and the energy impacts of the demonstrations), the potential savings from implementing this technique for all MZ systems in the DoD is estimated at over 400,000 million BTU a year (over $15 million per year). This is based on an estimated pool of potential candidates of 3,900 to 5,000 MZ air handlers in use across DoD (Schwenk, 2017).

The MZ-VV conversion focuses on changing the controls of the system rather than extensive changes of physical components such as replacement air handlers and ducting changes.

- <u>Current Technology State of the Art</u>: Typically, when a constant volume multizone system goes through a retrofit, the system is converted to a more modern variable air volume (VAV) system. This consists of changing the central unit and ducting, adding terminal units, adding more hydronic piping and coils, and more controls around the building.
- <u>Current State of Technology in DoD</u>: Currently the DoD keeps older systems such as constant volume multizone systems functioning indefinitely to the best of their ability due to budget constraints. The conversion to VAV is expensive and intrusive, so is usually delayed until catastrophic system failure, or a full facility renovation which vacates the building.
- <u>Technology Opportunity</u>: Rather than going through the expensive, time consuming, disruptive retrofit that industry typically suggests, the controls conversion can provide the system some modernization without high cost or displacement of occupants. The MZ-VV controls conversion occurs mostly in mechanical rooms and in cyberspace through controls programming of the utility monitoring and control system (UMCS), minimizing the effect on the building occupants. The technology transfer products allow for easier and more successful implementation through standard processes for screening, scoping, and commissioning, energy savings calculations, performance work statement verbiage,

specification language, and applicability and sustainment support. Energy savings through system efficiency will lead to lower energy use and costs and increased installation energy resilience.

1.2 OBJECTIVES OF THE TECHNOLOGY TRANSFER

This technology transfer project is a follow on from a previous field demonstration project of the MZ-VV energy efficient controls upgrade for multizone air handling systems. The potential implementers of this technology need support to take advantage of and adopt the technology. The objectives of the technology transfer are as follows:

- Standard Approach Documents and Tools: Facilitate implementation with a standard approach for updating multizone air handling systems with easy and effective technology transfer documents and tools.
- Outreach: Promote awareness with broad-spectrum outreach.

The resulting increased energy efficiency helps to meet facility energy, emissions, and resilience requirements with constrained budgets.

1.3 REGULATORY DRIVERS

This technology transfer will help meet several goals of the Energy Independence and Security Act of 2007 (EISA). These goals of EISA are to move toward greater energy independence and security, increase efficiency of buildings, and improve energy performance of the Federal Government. Additionally, the energy efficiency of this retrofit support E.O. 14057 Federal Sustainability Plan of 2021's energy and emission reduction goals. The output of this effort will provide the DoD with a low-cost way of increasing the efficiency of legacy systems that will support individual services' goals.

2.0 TECHNOLOGY TRANSFER DESCRIPTION

The previously demonstrated MZ-VV technology converts a constant volume multizone air handling system into a variable volume multizone system with instrumentation and controls changes rather than a full system change out which requires demolition and installation of a new air handler, ductwork, piping, coils, and addition of terminal units. The retrofit technology controls the air handler's coils, fans, and dampers more tightly than its original design to provide needed space conditioning with less energy.

The current technology transfer effort developed a suite of implementation support products and conducted outreach to potential users. The design and implementation suite provides the needed help for decision makers and users to evaluate the technology, streamline its procurement and operate it effectively. Outreach efforts have raised awareness and encouraged and supported implementation.

2.1 TECHNOLOGY TRANSFER METHOD

The technology transfer method capitalized on the efforts, insights and contacts identified in the demonstration phase. The technology transfer provides interested parties with readily understood documentation and implementation support tools. Through outreach, the project team has promoted implementation of the technology by making people aware of available resources and making those resources readily accessible.

A collaborative iterative approach has been employed throughout this project, working with subject matter experts and potential users to refine products for accessibility and pertinence. Collaborative review took place during all the project phases from validation of proposed product through final outreach. The following four tasks characterize the effort:

- Validation of Planned Products: The project started with a validation of proposed products to ensure they meet the potential user's needs. The specific tasks of this effort were informed and finalized based on a preliminary scoping survey of potential user needs from the DoD. The team prepared and conducted a preliminary scoping survey of a sampling of potential users from the DoD to determine the technology adoption barriers and needs. The team used this feedback to inform and confirm the proposed materials and project tasks. The project tasks and budget were updated to reflect the insights of this survey.
- Development of Documents and Tools: Building on the original demonstration output, information was reviewed and cross-checked for accuracy and consistency, refined and distilled for accessibility, enhanced with supplemental insights for completeness, and extrapolated for applicability at new sites.
- Collaborative Review: The products were vetted with reviewers possessing a variety of technical and administrative experience (both new and seasoned engineers, technicians, and managers; and possessing either installation, private industry, or research laboratory

perspectives). Review included end user surveys, interviews, detailed document and tool review with tracked changes, as well as in-person equipment visits.

- Outreach: Outreach efforts utilized an assortment of methods to spread awareness and interest, provide ready access to products, and simplify adoption. Methods include posters, articles, conferences, on-line training, user visits, as well as posting documents on applicable websites and announcing on social media.

Most of these efforts occurred in parallel except for the validation of planned products occurring before their development. Figure 1 shows a visual depiction of the workflow.

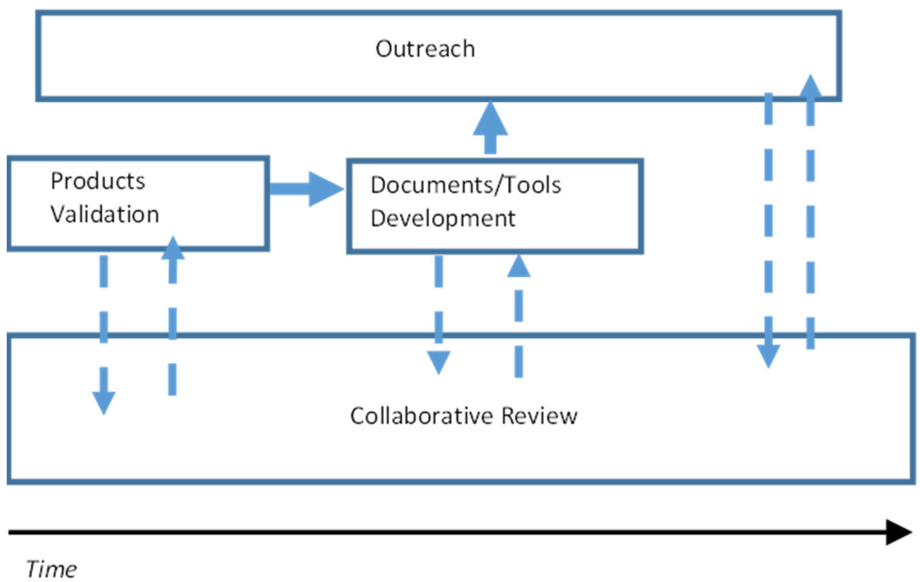


Figure 1: Visual Depiction of Technology Transfer Task Workflow

2.1.1 Task Chronological Summary

The products validation occurred early in FY20. The technology transfer products were developed and refined from mid FY20 through FY22. Outreach and collaboration efforts began at the start of the project in FY20 with the first ESTCP Symposium and continued through the close of the project. Once the products were finalized and shared widely mid FY22, the potential for adoption and application around the DoD, other Federal sectors, and private commercialization was immediately available.

2.1.2 Products to Facilitate Adoption

The products to facilitate adoption allow prospective implementers to evaluate the technology, streamline their procurement, and verify successful operation of their equipment. These products consist of technology description documents (poster, Fact Sheet, Technical Note, and Pitch Briefing), decision support tools (Scoping Guide, Savings Estimator) procurement support tools (Design Guide, Procurement Package Templates for: specifications, drawings, sequences of operation, points schedule, contract language), and an operations support tool (Commissioning (Cx) Guide). They are grouped by the function they support (of evaluating, procuring, or using):

Products to Evaluate Technology

Several tools were developed to acquaint the assortment of installation stakeholders with the retrofit technology and support applicability determinations to allow a thorough evaluation of the technology by potential users. Technology evaluation helps potential users determine if the MZ-VV technology is the right fit for their circumstances. Products include:

- Technical Description Documents and Training:
    - *ESTCP Technology Fact Sheet:* The Fact Sheet provides a 2-page quick introduction to the retrofit, its benefits, applicability, and available resources for general audiences The Fact Sheet is a 2-page ESTCP standard presentation of the technology.
    - *Technical Note:* The Technical Note provides a distillation of the pertinent details of the original demonstration's technical report into an 8-page document. Technology details, field demonstration results, and application insights are presented for an engineering audience.
    - *Pitch Briefing:* The Pitch Briefing is a single PowerPoint slide with script to socialize and convey the retrofit opportunity to budgetary and administrative decision makers. Geared for the executive audience.
    - *Training:* Training delivers a one-hour technical overview of the retrofit and the supporting implementation tools for engineers and technicians. Free, on-demand training on the technology is available at the Whole Building Design Guide, https://www.wbdg.org/continuing-education/dod-courses/estcp/estcp4-4, and on Slipstream's website, https://slipstreaminc.org/estcp. Training for purchase is also available from the Building Commissioning Association, https://www.pathlms.com/bcxa/courses/33553/sections/37765. All are one-hour courses with continuing education units
- Retrofit Decision Support Tools: These tools help potential users gauge the cost and benefits and identify candidate systems for retrofit.
    - *Estimator:* The Estimator gauges the expected energy and cost impact of retrofit with life cycle cost analysis. Supports early feasibility screening and customized site-specific calculations. Aimed at a joint administrative and technical team.
    - *Field Scoping Guide*: The Field Scoping Guide steps a user through strategic installation-wide screening as well as assessment of an individual unit's operational status and suitability for retrofit. Helps identify complementary repair and upgrade activities that should accompany the retrofit. Aimed at a combined engineering and technician field team.

Products to Streamline Procurement

The Design Guide and the Procurement Package Templates streamline the design and procurement of the retrofit with a standard procedure that considers best practice and reduces one-off efforts for designers, installers, and equipment users. This standard approach minimizes disjointed or duplicative acquisition efforts.

- *Design Guide:* The Design Guide lays out a roadmap for implementation that utilizes developed support documents and tools. The guide presents technical explanations and requirements of the retrofit and primary considerations for implementation including accommodating current or previous DDC upgrades on the system, complementary repair measures, applicable UFGS references for system changes, dehumidification guidance and maintenance recommendations. Developed for project implementers and system designers.
- *Procurement Package Templates:* The Procurement Package Templates include five templates for purchasing that detail the technical requirements for success, allow a user to pick and choose needed graphics and text from multiple options, and highlight site specific tailoring needs. Aimed at project implementers.
    - *Specifications Book Template:* The Specifications Template provides technical equipment and operations requirements of the retrofit.
    - *Control Sequences of Operation Template:* The Control Sequences Template provides a step-by-step description of the control scheme functionality and logic for the HVAC equipment.
    - *Performance Work Statement Template:* The Performance Work Statement Template provides sample outcomes-based language for contracting out the retrofit.
    - *Control Drawings Template:* The Drawing Template provides graphical representations of the system layout, control logic schematics, and detailed tables of equipment specifications.
    - *Control Points Schedule Template*. The Controls Points Schedule catalogues the data input and output from sensors and calculations.

  The team worked with industry and installation engineers to enhance the products and coordinated with USACE HVAC Technical Center of Expertise (at U.S. Army Engineering and Support Center, Huntsville, AL) for recommendations to improve these template documents.

Products to Successfully Operate Technology

The Commissioning Guide and portions of the Design Guide help field staff use the system successfully.

- *Commissioning (Cx) Guide:* The Cx Guide is a spreadsheet tool that provides procedures and check lists to establish and verify proper operation of the system. It provides project tracking checklists, performance verification test procedures, and a deficiency log. Developed for project implementers and equipment operators.

- *Testing Adjusting and Balancing (TAB) and Maintenance Considerations:* The Design Guide provides insights on TAB and maintenance of the fan speed control and potential humidity issues. Aimed at equipment operators.

2.1.3 Outreach Tasks

The project team pursued multiple avenues of outreach to promote awareness of both the technology and the supporting implementation resources including the following:

- Conference Presentations: The team presented to an assortment of technical organizations including an American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Conference, the Building Commissioning Association (BCxA) Conference, DoD's Energy Exchange Conference, the USACE Community of Practice Meeting, and two ESTCP Symposiums.
- On-line Training: The team developed a free on-line, on-demand ESTCP training class on the MZ-VV retrofit Additionally, BCxA offers a recording of the conference training presentation for purchase.
- Journal Articles*:* The project team composed an ASHRAE Conference paper published in *ASHRAE Transactions*, an *ASHRAE Journal* peer reviewed article and two articles for *The Military Engineer.*
- Outreach to Interested Parties. The project team contacted the offices of the interested people from the demonstration project survey as well as newly identified interested parties to introduce the technology and implementation support tools and receive feedback.
- Document Posting. The products of this project are posted on the *Whole Building Design Guide* website.
- Standardized Specification. The team initiated potential inclusion of the developed control scheme into an applicable DoD Guide Specification.
- Social Media. Notifications of the project and available implementation resources were posted on social media sites LinkedIn and Facebook.

2.1.4 Technology Stage of Maturity

The Multizone Controls Retrofit technology is in the adoption stage of maturity. The physical components of control are off the shelf products (sensors, actuators, variable frequency drives, and digital control systems). The application and control scheme of these components is new and innovative. The value and risks of this technology are conditionally understood by those intimately involved in the effort from a limited one-year trial of five applications. There is one other partial application of the technology that the team is aware of, but it did not include performance verification. There is no commercial availability of established installers of the technology package or a field vetted application package. There may well be commercial support that could be acquired from the mechanical and controls contractors involved in the demonstration if their risks were limited to the accurate installation and programming of the equipment and not the savings and performance of the system over time.

2.1.5 Future Potential for DoD

The expected application for the DoD is for installation energy managers and/or operations and maintenance staff to use the resources provided to evaluate multizone systems and implement the conversion with standard documents and drawings. These documents are available DoD wide and to the general public and are not specific to any organization.

The documents and tools produced, and the information gathered are useful input to a potential future demonstration of this technology by UESCs. The Scoping Guide, Design Guide, template drawings, specifications, points schedule and performance work statement, as well as the commissioning guidance support contracting out this upgrade.

If the site-specific economics are acceptable to potential users, it is expected that limited scale implementation of this technology could be achieved within a year of the completion of this project depending on the status of available ESPC or UESC contracts.

2.2 VALIDATION OF PLAN FOR TECHNOLOGY TRANSFER PRODUCTS

The project team interviewed several potential users of the controls retrofit to review the proposed tools and documentation for presumed utility and desirability. The project scope was adjusted based on the feedback received. The team interviewed 4 energy managers who represent 12% of the people who identified themselves as very or moderately interested in a retrofit. The individual products of the effort were given a 1-5 rating (with 1 being low or least useful and 5 being high or most useful) from each participant (see Table 1). A targeted approval goal of 3 out of 5 (60%) average rating was set for each item, and for the suite of products as a whole. If an item did not reach that benchmark, actionable scope adjustments would be discussed with the participants.

Table 1: Summary of Product Screening Responses

Usefulness of:	Site A	Site B	Site C	Site D	Average score
Technical Note	5	5	5	5	5
Design Guide	5	5	3	5	4.5
Scoping Document		5	5	5	5
Economic Calculator	5	5	5	5	5
Contract Language	5	5	5	5	5
Commissioning and Performance Verification Guidance	5	5	3	5	4.5
Overall Project Utility	5	5	5	5	5

The feedback for the technical transfer project was very positive, with the rating of the overall project approach receiving a 5 out of 5 average rating. The Technical Note, Scoping Guide, Economic Estimator, and standard scoping language all received a 5 out of 5 average rating. The design guide and commissioning/performance verification documents received a 4.5 average rating, with one participant giving both of those documents a 3 out of 5. While that rating is within the average rating goal, the participant stated those documents are not as important or useful to them compared to the other proposed documents and tools. All respondents agreed to review materials for usefulness.

Additional feedback included:

- According to a reviewer from the Air Force (AF), The AF prioritizes project funding by CATCODE in the BUILDER Sustainment Management System based on mission criticality (Rated 1-99 on their mission dependency index). This rating method is used as opposed to energy savings, which is addressed at the organizational level.
- In the AF, impact on energy resilience would be a meaningful selling point for project funding. They suggested language on resilience be incorporated into support tools to promote implementation.
- Reviewers from the Army and the AF said they would like to have more performance data to see if sites similar to their own had success, and if the retrofit is worth their time.
- One reviewer asked if the energy savings could be used to justify a full VAV conversion, and if the tools could help estimate the cost of a full VAV conversion.
- One reviewer observed that there was standard measurement and verification for the Energy Resilience and Conservation Investment Program (ERCIP) which may apply here. They also noted that if the design guidance was not site specific it would not be as important as the cost estimator with the payback analysis.

Based on this feedback, as well as input from the ESTCP review panel and project collaborators, the approach was adjusted as follows:

- The effort continued with the planned tools and documents and added a fact sheet, pitch briefing, and on-line training.
- Resilience justification language was added to the Design Guide as a potential addition to a contract package.
- The team will recommend review of the BUILDER mission dependency index to identify critical facility types to prioritize for retrofit in the Design Guide.
- The products incorporated insights on the cost of a full VAV conversion (e.g., that full conversion is on the order of 25 times the cost of the controls upgrade) but the team recognized that a full conversion calculator is labor intensive and outside of the scope of this work.
- Although the team originally planned to ask any early implementers to gather performance data to help others decide on applicability at their site, no sites implemented during the duration of the project.

This process proved very useful and established that the work is viewed as valuable and useful by the target audience.

2.3 IMPLEMENTATION SUPPORT DOCUMENTS AND TOOLS

The suite of design and implementation tools guides a potential user through the probable steps of implementation with ready information and procedures for use at each stage from technology evaluation, through procurement, to performance verification. Consideration was given to the variety of people involved in these steps and the appropriate level of technical detail for each user. Many of the tools assume implementers will be looking at multiple and varied air handling units for potential application of the technology and allow for review of varied scenarios. The procurement tools are set up as multiple templates that provide an assortment of descriptions and details for common multizone configurations so that the user can select and customize the applicable sections and delete content that does not apply. Pertinent document formats (including PDF, Excel spreadsheet, Word document, PowerPoint and AutoCAD drawing files) allow rapid system analyses and development of procurement packages.

As introduced in Section 2.1.2,the informational documents and training to support technology evaluation include a Fact Sheet, Technical Note, Pitch Briefing, and online training. The decision support tools for technology evaluation include the Savings Estimator and the Scoping Guide. The products to streamline procurement include the Design Guide and Procurement Package Templates. The products to successfully operate technology are the Commissioning Guide and select sections in the Design Guide. Most of these products are discussed in the sections below. The training will be discussed with the outreach in Section 2.4.2.

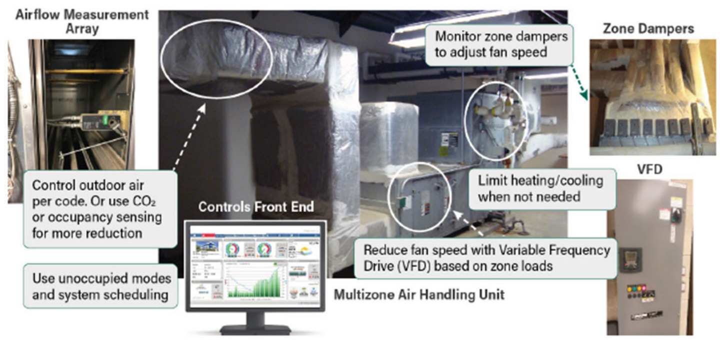
2.3.1 Fact Sheet

The fact sheet is a two-page summary of the technology, the field demonstration results, and a list of available resources in standard ESTCP format. In bulleted lists, key diagrams, and tables, it introduces a potential user to the retrofit features and options, benefits, recommendations for ideal candidates for retrofit, savings from the field demonstration, available technology transfer tools and provides citations for additional resources. See Figure 2Figure 3.

EW-201152 | September 2016, EW-195026 | September 2021

Controls Retrofit of Multizone HVAC Unit for Energy Efficiency

SAVING ENERGY BY TURNING COMPONENTS DOWN OR OFF WHEN NOT NEEDED



INEXPENSIVE VARIABLE VOLUME RETROFIT SAVES 24–60% ENERGY. TYPICAL PAYBACK 3–5 YRS. TECHNOLOGY TRANSFER TOOLS MAKE IMPLEMENTATION PRACTICAL.

Several older multizone air handling units (AHUs) underwent controls retrofits to increase energy efficiency at CERL in Champaign, IL and Ft. Bragg in NC. Many technology transfer tools were developed to facilitate adoption.

Retrofit Features

Novel Control—Zone damper signals adjust fan speed and heating/cooling coil capacity. Demand Controlled Ventilation (DCV) option adds to savings.

Few Components—Two pieces of hardware and controls programming needed for basic retrofit. Add CO_2 or occupancy sensors (Occ) for DCV.*

Multiple Applications—Nine system configurations specified:

Three unit types:		Three ventilation approaches:
• Conventional Multizone • Neutral Deck Multizone • Bypass Multizone	X	• Basic Variable Volume (VV) • CO_2-DCV • Occ-DCV

Quick Fix—Interim retrofit allows accruing savings now while delaying costly disruptive full-scale system change out, with no cybersecurity requirements.

Comprehensive Implementation Support—Easy documents and tools step user through entire process of evaluating, procuring, and using technology. Detailed scoping guidance avoids surprises, identifies needed complementary repairs/upgrades. Templates speed procurement for potential users.

**Consult appropriate UFCs on the application of CO_2 sensors.*

System Control

- The retrofit adjusts the fan speed based on the actual amount of heating and cooling needed by the zones
- Turns off heating/cooling coils when not needed
- Measures and controls outside airflow to ensure that the proper amount of air is provided
- Trims ventilation if DCV option chosen

Benefits of Retrofit

Remedies Inefficiencies—Reduces simultaneous heating & cooling, eliminates constant volume air flow

Substantial energy savings—24–60% energy at AHU in combined thermal and electric savings

Low cost—Retrofit cost of ~ $20K delays ~ $650K system change out

Short payback—SPB = 3–5 yrs. on typical units

Low hassle—Noninvasive retrofit does not require vacating building to construct

Extends useful life—With complementary repairs/upgrades of existing systems

Large DoD Impact—3–5 K units across DoD represent potential $15M/yr savings

Ideal Retrofit Candidates

- Conventional (hot/cold deck) multizone
- Older units that can be repaired at reasonable cost
- Units already slated for controls upgrade to Direct Digital Controls (DDC)
- Larger units such as those serving >5,000 sq. ft. floor area
- Units serving variable occupancy spaces

www.serdp-estcp.org

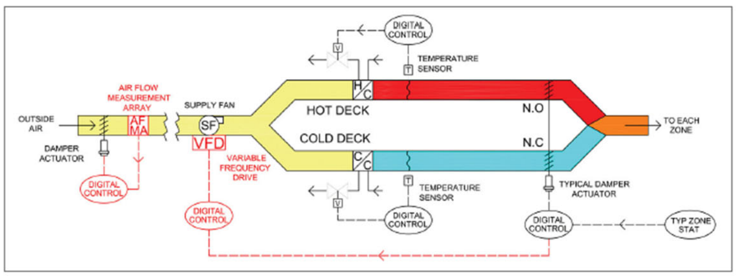
Figure 2: Fact Sheet Page 1

Demonstration sites: Champaign, IL and Ft. Bragg, NC

Three Fort Bragg units were neutral deck multizones original to the 10-yr-old building, serving 3–5 KSF of office or classrooms. The two CERL units were conventional 2-deck multizones, original to the 40-yr-old building, with one serving 2.4 KSF of conference rooms, and the other serving 8.8 KSF of offices, conference/break rooms, and labs. Performance data were collected for 14 months while rotating operation through three different modes, switching daily:

Mode 0: replicated the pre-retrofit constant volume configuration
Mode 1: energy saving variable fan speed (basic VV)
Mode 2: energy saving variable fan speed with demand controlled ventilation (either CO_2-DCV or Occ–DCV)

	VV w/Fixed Ventilation (Mode 1)				VV w/DCV (Mode 2)			
MZ AHU	AHU Energy Savings Percent	Fan Cost Savings Percent	Chiller Cost Savings Percent	Boiler Cost Savings Percent	AHU Energy Savings Percent	Fan Cost Savings Percent	Chiller Cost Savings Percent	Boiler Cost Savings Percent
CERL 1	24%	5%	5%	17%	28%	6%	3%	28%
CERL 2	56%	1%	0%	57%	60%	1%	1%	61%
Bragg 1	47%	45%	14%	2%	50%	45%	14%	7%
Bragg 2	25%	33%	6%	0.4%	N/A			
Bragg 3	32%	37%	8%	5%	32%	36%	8%	5%



Additional Resources

Web Resources:

https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Conservation-and-Efficiency/EW19-5026

https://www.wbdg.org/ffc/army-coe/design-guides

Published Resources:

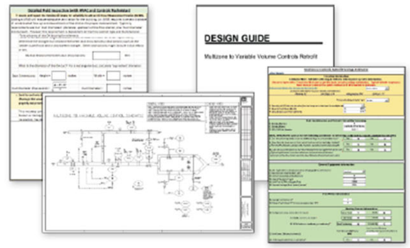
Schwenk, D., Bush, J., Clark, B., Mitsingas, C., and Wallace, S. 2017. *Converting Constant Volume, Multizone Air Handling Systems to Energy Efficient Variable Air Volume Multizone Systems*

Westervelt, E., Battisti, C., Morton, B., and Schwenk, D. 2021. *Multizone Air Handler Controls Retrofit for Energy Efficiency,* ASHRAE Winter Conference Paper

Contact information:

Eileen Westervelt—eileen.t.westervelt@usace.army.mil
Chris Battisti—christopher.m.battisti@usace.army.mil

About ESTCP: The Environmental Security Technology Certification Program (ESTCP) is the U.S. Department of Defense's environmental technology demonstration and validation program. The program's goal is to identify and assess innovative technologies that address DoD's high-priority environmental requirements efficiently and cost-effectively.



Technology Transfer Tools

Evaluate Technology

- Poster—Big picture overview
- Technical Note—Distillation of the original ESTCP technical report
- Field Scoping Guide—Assess status, operation, and suitability for retrofit of units
- Estimator—Energy savings and cost of retrofit
- Pitch Briefing Slides—Inform decision makers

Streamline Procurement

Design Guide, specifications and drawing templates, sequences of operation, points schedule, and performance work statement

Operate and Maintain

Commissioning Guide—Spreadsheet tool for project familiarization, start up, and Performance Verification Test (PVT)

Conclusion

Retrofitting existing units is a simpler and more cost-conscience means of increasing energy efficiency than a full-scale system replacement.

Conventional units had the most significant utility bill savings, with the bulk of the savings in heating. Neutral decks showed adequate savings on 2 of 3 units, with most savings in fan energy. Expected payback on typical multizone applications is 3–5 yrs with SIR ~2.2 at average energy costs of $0.1054/kWh, and $0.72/therm.

The tools and documents developed as part of this project could help facilitate widespread adoption of the technology.

Figure 3: Fact Sheet Page 2

2.3.2 Technical Note

The Technical Note provides a distillation of the pertinent details of the original demonstration's 120-page detailed technical report, as well as additional insights developed during the technical transfer project, in an 8-page document. The goal for this note was to inform energy managers and building operators of the essentials of the retrofit in a condensed, accessible document that can be digested in a reasonable amount of time.

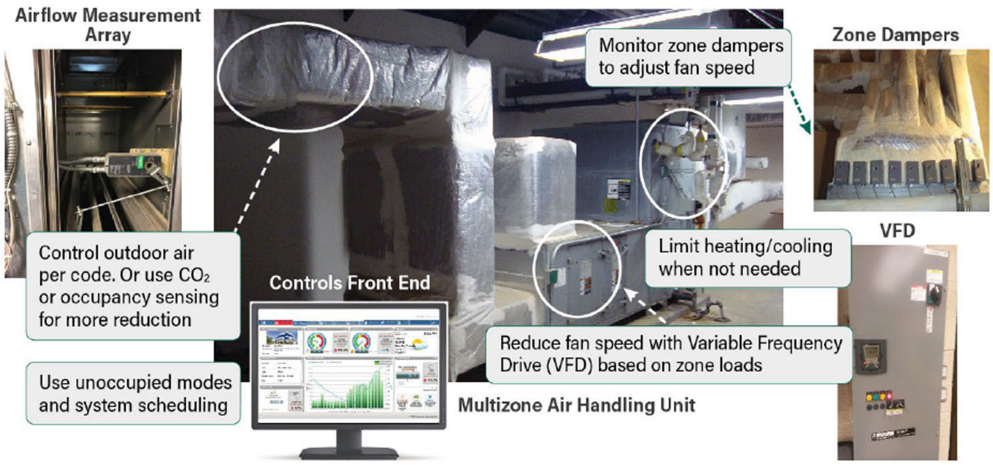
It includes an overview of the efficiency shortcomings of traditional multizone designs and the obstacles to system change out, a description of the retrofit components and the control schemes, schematics and characterizations of typical multizone configurations, the field demonstration methodology and results, extrapolated estimates of energy and cost impacts for typical applications, implementation approaches, benefits of the retrofit, cost drivers, considerations for unit suitability for retrofit, a profile of good candidates for retrofit, common complementary retrofit needs, and a listing of implementation support tools. See Figure 4 through 11.

Technical Note

Multizone to Variable Volume HVAC Controls Retrofit for Energy Efficiency

ESTCP Projects EW 201152 and EW19-5026

April 2022



Highlights of Control Changes to Multizone Air Handler

The Challenge

The DoD has a large inventory of older (10-40+ yr.) multizone air handlers which are used for building heating, cooling, and ventilation. Although these units are quick to respond to changes in temperature needs, they are very inefficient with energy use. Multizone units deliver a constant volume of air to the spaces/zones, regardless of actual requirements in the spaces. Further, the conventional 2-deck multizone units call for continuous, simultaneous operation of the heating and cooling coils, even when additional heating or cooling is not needed. Modern alternative system replacements (such as variable air volume systems) help address these inefficiencies but are very costly and disruptive to install.

Controls Retrofit Solution

The Engineer Research Development Center's Construction Engineering Research Lab, ERDC-CERL, developed an alternate route to energy savings at a significantly lower cost and with less disruption than a complete system change out. A variable volume controls retrofit can serve as an interim solution to help meet energy efficiency and resiliency requirements within limited budgets. The retrofit technique minimally impacts the physical system as it focuses on instrumentation and controls as opposed to the typical demolition and replacement of the central air handling unit and installation of new ductwork and terminal units that would be required for a full system change out. The basic retrofit requires adding two pieces of equipment and controls programming to systems with existing direct digital controls (DDC). An optional demand controlled ventilation (DCV) feature can be implemented using either occupancy or CO_2 sensors in the spaces[1] for more savings.

[1] Currently, the use of CO_2 sensors requires approval in Army and Air Force projects. Occupancy sensors are allowed for DCV.

Figure 4: Technical Note Page 1 of 8

Multizone air handlers mix a zone specific air temperature for each zone, which has its own dedicated duct

Basic Retrofit - *The fundamental improvements needed to implement the variable volume technology:*

1) Variable Frequency Drive (VFD): Installation of a VFD will allow for fan operation at reduced speeds which provides energy savings.
2) Airflow Measurement Array (AFMA): Installation of an AFMA allows monitoring of outdoor air intake to supply the required amounts of ventilation and/or make-up air.
3) Controls Programming: Programming changes to implement the new functionality: variable fan speed control, outside airflow control, on/off heating/cooling coil control and binary hot deck reset.

The retrofit control scheme turns components down or off when not needed. It may be applied to different types of multizone units.

In particular, the scheme adjusts fan speed based on:

- Space Requirements: Dictated by the most critical (most open) zone damper, where fan speed is decreased until one of the (multiple) zone dampers is at fully or near fully open position
- Outside Air Requirements: Through measurement of outside airflow and modulation of the outside air (mixed air) damper(s) to maintain ventilation and/or makeup air requirements.

Additionally, the scheme adjusts coil output capacity to:

- Open/Close Water Valves: Closes hot/cold deck heating (and cooling) coil valves when no heating (or cooling) is called for by any zone. This helps save energy by minimizing the amount of conditioned air that leaks through zone dampers into the supply air to the zone.
- Use a Binary Hot Deck Temperature Reset: Modulates deck temperature to a high or low set point depending on weather. At the warmer setpoint (in colder weather), a 'hotter' deck air temperature allows a lower airflow rate to meet zone heating load. Resulting fan energy savings is typically more beneficial than thermal savings because of the greater cost of electricity versus natural gas. At the cooler setpoint (during warmer weather), excess heating in the coil (and excess standby loss) is reduced as coil capacity better matches warm weather needs.

DCV Option – *This feature uses sensors in the space to detect periods of low or no occupancy and reduces ventilation during those times.*

2

Figure 5: Technical Note Page 2 of 8

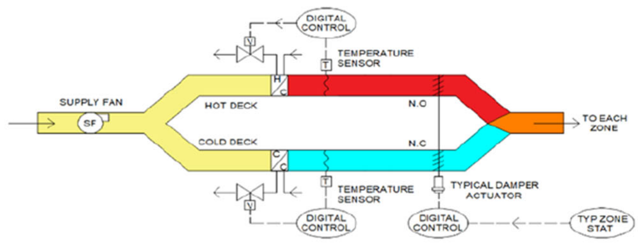
Multizone Configurations

Multizone air handlers have three typical configurations: conventional two-deck, bypass, and neutral deck. Each of these configurations has a supply fan (and sometimes a return fan) that operates at a single speed delivering a constant volume of air and uses zone dampers to mix air streams in the desired proportions. The various types of multizone air handlers differ in the number of decks they have as well as the number and placement of coils. A summary of each configuration follows:

<table>
<tr><th colspan="2">CONVENTIONAL MULTIZONE</th></tr>
<tr><td>

- 2 Decks; 1 hot, 1 cold
- Heating and cooling coils in respective decks
- Both decks typically operated continuously, even when heating/cooling is not needed.
- Typical retrofit efficiency strategies include deck temperature reset, seasonal deck coil shut off, i.e. running only the hot deck coil in winter (with outside air providing needed free cooling) and only the cold deck coil in summer (but has led to mold issues and reduced comfort), and decoupling zone dampers to operate them independently (but is difficult and costly).

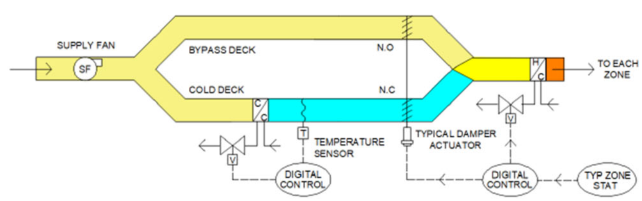
</td><td>



</td></tr>
<tr><th colspan="2">BYPASS MULTIZONE (TEXAS STYLE)</th></tr>
<tr><td>

- 2 decks: Cold and Bypass
- No Coil in Bypass Deck
- Heating coil typically in <u>each</u> zone duct
- Uses mixed air (recirculated and outside air) in bypass deck for "free heating"
- More efficient than Conventional Multizone (by avoiding simultaneous heating and cooling)
- More coils to maintain

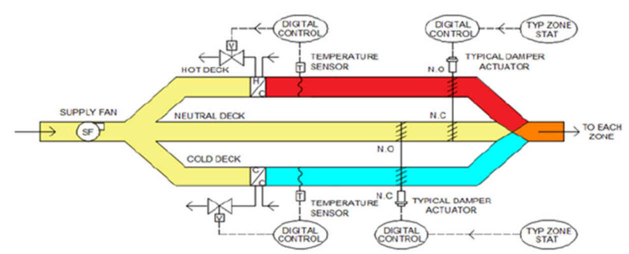
</td><td>



</td></tr>
<tr><th colspan="2">NEUTRAL DECK MULTIZONE</th></tr>
<tr><td>

- 3 Decks: Hot, Neutral, and Cold
- Neutral Deck has no coil and introduces mixed air (recirculated and outside air)
- "Free Heating" from recirculated air in a neutral deck
- More efficient than Conventional Multizone (by avoiding simultaneous heating and cooling)

</td><td>



</td></tr>
</table>

3

Figure 6: Technical Note Page 3 of 8

Demonstration Test

A demonstration of the retrofit technique developed by ERDC-CERL researchers was carried out on five systems at two locations over the course of fourteen months. Three of the five systems were located at Fort Bragg, NC while the remaining two were located at ERDC-CERL in Champaign, IL. The CERL units were conventional multizones, while the Fort Bragg units were neutral deck multizones. As part of the demonstration, systems were evaluated on several aspects, including:

- Energy Savings
- Life Cycle Cost
- Thermal Comfort

Three operational modes were analyzed:

- Base Case: Pre-retrofit state with constant volume fan and typical energy efficiency methods including hot deck temperature reset (based on outside air temperature), air-side economizer control (free cooling using outside air), and time based equipment start/stop scheduling.
- Variable Volume with Fixed Ventilation: Variable fan speed based on the critical zone damper (i.e. the most 'open' damper). Fixed ventilation rate was maintained through measurement of outside airflow and adjusting the outside air damper position. Heating and cooling coils were enabled (*modulating to set point*) or disabled (*valve forced closed*) based on the demand for heating and cooling as indicated by the zone dampers. As with the 'Base Case', economizer control and equipment start/stop schedules were used. Binary Hot deck reset was implemented, keeping the hot deck "hot", to achieve the same load carrying capacity at a lesser airflow rate and thus a reduced fan speed.
- Variable Volume with Demand Control Ventilation: Same as 'Variable Volume with Fixed Ventilation' above, except the ventilation rate was varied based on space ventilation demand (according to CO_2 or occupancy sensors), by adjusting the outside air damper position.

Table 1: Equipment Specifications

MZ AHU	Location	Type	Age of Unit (Yr)	Retrofit Approach*	End Use	Flow Rate (CFM)	Floor Area Served (SF)	# of Zones & spaces	Total Fan HP
CERL 1	Central IL	Conventional	40	Partial	Office	15,190	8800	5 zones 18 spaces	8 (5HP SAF+ 3HP RAF)
CERL 2	Central IL	Conventional	40	Full	Conference rooms	3475	2400	3 zones 9 spaces	3
Bragg 1	Central NC	Neutral Deck	10	Partial	Classrooms	4620	2983	3 zones 3 spaces	5
Bragg 2	Central NC	Neutral Deck	10	Partial	Office	4670	4328	9 zones 20 spaces	5
Bragg 3	Central NC	Neutral Deck	10	Partial	Office	5930	4837	8 zones 19 spaces	7.5

*Notes: *Partial retrofits are variable volume additions to a pre-existing DDC system, and include the addition of a VFD, AFMA and controls programming, Full retrofits are for systems with older failed or failing controls such as pneumatic controls and includes a controls upgrade to DDC, as well as the addition of VFD, AFMA and programming. CERL units had the cold coil disabled in winter. SAF=supply air fan. RAF=return air fan*

Maintenance staff at both sites reported an acceptable level of maintenance. Maintenance staff at CERL even reported one unit as being easier to maintain after retrofit.

Table 2 shows the savings derived from the demonstration. The systems tested attained savings of 24% to 60% reduction in energy usage at the air handler.

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Figure 7: Technical Note Page 4 of 8

Table 2: Energy Savings for the Historic Weather-Normalized Data Set

MZ AHU	Base Case CV	VV w/ Fixed Ventilation		VV w/ Demand Control Ventilation	
	Energy Use (kBtu)	Energy Use (kBtu)	Energy Savings v. Base Case	Energy Use (kBtu)	Energy Savings v. Base Case
CERL 1	514,434	391,676	24%	367,642	29%
CERL 2	581,926	257,910	56%	233,881	60%
Bragg 1	123,991	66,135	47%	61,084	51%
Bragg 2	118,266	88,423	25%	NA	NA
Bragg 3	138,899	94,775	32%	94,086	32%

Notes: CV=Constant Volume, VV=variable volume

Implementation Approaches

There are several approaches for implementing the retrofit which impact the scope and cost of the change and subsequent return on investment:

- Incremental Retrofit: Consists of a variable volume *add-on* to a DDC upgrade project that is underway. Cost analysis only accounts for the addition of a VFD, an airflow measurement array and controls programming. (This approach piggy-backs off the existing DDC project that already covers many administrative/quality assurance costs such as contract set-up, submittals, documentation, training, warranty, travel, and commissioning. This is the least expensive and assumed most likely approach for implementation.)
- Partial Retrofit: Is the same as an incremental retrofit except it is executed as a brand new project on a pre-existing DDC system. (Here all administrative/quality assurance costs are included in the cost of the retrofit package for economic analysis.)
- Full Retrofit: Converts an entire older HVAC control system (e.g., old pneumatic control system) to DDC and incorporates the variable volume technology. (This is the costliest approach and includes hardware material and installation costs as well as administrative/quality assurance costs.)

Benefits of Retrofit

- Improves energy resilience at a fraction of the cost of full system replacement. See Table 5.
- Substantial energy savings (24-60%) at AHU. Savings on older units, like CERL AHU2, can be even greater if the original unit does not have economizer, occupancy schedules, or hot deck reset.
- Quick economic returns (3-5yrs) expected on typical applications for incremental retrofits. See Table 4. Simple Pay Back (SPB) of first costs can be improved in older units with pneumatic controls, or lacking equipment scheduling or economizer. Fits in tight budgets.
- Low impact to occupants — little or no construction in occupied spaces
- Reduced carbon emissions
- Maintains comparable space conditioning and comfort with no observed O&M impact
- Interim measure that allows accruing savings now while deferring major construction

Cost Drivers

- Implementation approach, whether incremental, partial or full will impact cost
- Older systems present additional savings opportunities such as incorporating an airside economizer, time-based scheduled start/stop, or high efficiency motor
- Cost of retrofit remains relatively static regardless of system size, so care should be taken when considering smaller systems for retrofit
- Additional cost related to training will be required to familiarize staff with new sequences
- Cost may be reduced depending on incremental upgrades already made to the units over the course of their lifetimes (such as sensor/ actuator replacements, DDC control upgrades)

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Figure 8: Technical Note Page 5 of 8

Energy and Cost Impact

Table 3: Field Units - Economic Impact of Incremental Retrofit (most with DCV) (See Table 4 for typical applications)

AHU Unit	Incremental Retrofit Cost ($)	Unit Electric Cost ($/kWh)	Unit Gas Cost ($/therm)	Baseline Utility Cost Pre Retrofit ($)	Energy Savings ($/Yr)	Net Present Value, NPV ($)	Simple Pay Back, SPB (Yr)	Savings to Investment Ratio, SIR
CERL 1	$13.8K	0.0636	0.84	$4,561	$1,684	$7K	8	1.5
CERL 2	$9.7K	0.0636	0.84	$6,906	$4,357	$45K	2	5.7
Bragg 1	$7.6K	0.0733	0.62	$1,113	$734	$1K	10	1.2
Bragg 2**	$7.2K	0.0733	0.62	$1,069	$420	($2K)	n/a	0.7
Bragg 3	$7.3K	0.0733	0.62	$1,160	$574	(0.5K)	13	0.9

*Notes: Production efficiency corrections applied to hot water load: distribution losses = 10%, boiler cycling losses = 15%, boiler combustion efficiency = 87%. Production efficiency factors applied to chilled water load: 0.71kW/ton. Real discount rate = 3%, life of retrofit=15yrs, blended energy costs used. Use of occupancy sensors for DCV. ** The Bragg 2 unit has No DCV.*

The demonstration units did not have typical thermal loading because the Conventional units at CERL served entirely interior zones (did not have building shell effects of outside walls, etc.) and the Neutral Deck units at Ft. Bragg had conservative room temperature setpoints (68°F heating, 74°F cooling) that limited the heating and cooling provided. CBECS was used as a source of typical heating/cooling/ventilation requirements by building activity and climate zones. Adjustments were made for the simultaneous heating and cooling of the conventional units. The typical impact presented below represent averages of mixed /humid and cold/very cold climates with US average construction and fuel costs. Typical conditions include a 10 yr. life cycle, a campus of less than 10 buildings served by the central plant, and air cooled chillers.

Table 4: Typical Multizone Retrofits with DCV - Economic Impact

AHU Unit	Incremental Retrofit Cost ($)	Baseline Utility Cost Pre Retrofit ($)	Energy Savings ($/Yr)	NPV ($)	SPB (Years)	SIR
Typical Conventional MZ in good shape (had equipment schedules)	$10K	$7,100	$2,900	$16K	3.4	2.6
Typical Conventional w/ RCx (had no equipment schedules)	$14K	$10,000	$4,900	$29K	2.8	2.6
Typical Neutral Deck MZ in good shape (had equipment schedules)	$10K	$2,800	$1,900	$6K	5.3	1.6
Typical Neutral Deck MZ w/ RCx (had no equipment schedules)	$14K	$4,200	$3,100	$12K	4.5	1.9

Notes: Office space. Building size=3600sf. Supply fan size = 5HP. Production efficiency corrections for hot water load: distribution losses = 2%, boiler efficiency = 80%. Production efficiency for chilled water load: 1.2kW/ton air cooled. Real discount rate = 3%, life of retrofit=10yrs, Blended energy costs used. Electric unit cost =$0.1054/kwh. Natural Gas unit cost =$0.7213/therm.

Table 5: Sample Retrofit Costs and Complete System Replacement Cost

Retrofit Type	Cost
Incremental	$7.2K-$13K
Partial	$20-24K
Full	$48K
Complete HVAC System Replacement w/ VAV AHU and Terminal Units	$550K-750K

Figure 9: Technical Note Page 6 of 8

Table 6 presents the breakout of energy savings. For the conventional units at CERL, boiler plant savings accounted for most of the savings. For the neutral deck units at Ft. Bragg, reductions in fan energy predominated.

Table 6: Breakout of annual energy and cost savings (most w/ DCV)

AHU Unit	Total Cost Savings	Svgs, % Tot Baseline Utility Cost *	Fan Energy Savings			Chiller Plant Savings			Boiler Plant Savings		
			kWh	$	% Tot Baseline Utility $	kWh	$	% Tot Baseline Utility $	Therm	$	% Tot Baseline Utility $
CERL 1	$ 1,684	37%	4,506	$287	6%	2,084	$133	3%	1,506	$1,265	28%
CERL 2	$ 4,357	63%	1,613	$103	1%	563	$36	1%	5,022	$4,218	61%
Typical Conventional Unit	$ 2,900	41%	6,658	$702	10%	2,699	$284	4%	2704	$1948	27%
Bragg 1	$ 734	66%	6,845	$502	45%	2,088	$153	14%	128	$80	7%
Bragg 2	$ 412	39%	4,811	$353	33%	1,042	$76	7%	(28)	($17)	(2%)
Bragg 3	$ 574	49%	5,755	$422	36%	1,295	$95	8%	92	$57	5%
Typical Neutral Deck Unit	$1,900	67%	12,833	$1,350	48%	2,635	$278	10%	337	$245	9%

*Notes: Svgs=Savings, Tot=Total. *Baseline Utility Cost provided in Table 3, Equipment types in Table 1*

Considerations of Unit Suitability for Retrofit

- Is the unit in reasonably good working order?
- Do the controls work/function properly?
- Is the unit rusting and can it be remedied?
- What is the condition of the ductwork?
- Are the control valves leaking when closed?
- Are dampers loose or linkages slipped?
- What repairs may be required to continue to use the system for another 10-15 years?
- What does the maintenance staff think about an upgrade and what repairs/improvements do they recommend?

Rusty damper blades still work in 40-year-old unit.

Typical Good Candidates

- Conventional (hot deck / cold deck) multizones with inefficient simultaneous heating and cooling
- Older units that are not slated for replacement in the foreseeable future, and have hardware that is still functional (e.g., valves, dampers, fans) or can be replaced at reasonable cost
- Larger units with sizable heating/cooling loads
- Units that serve variable occupancy spaces such as conference rooms
- A unit that needs or is slated for a controls replacement since the additional work to perform the conversion would be an incremental cost, and the retrofit will boost overall savings.
- A DDC upgrade is planned/underway, or the system is already DDC, where the latter case may require a smaller capital investment if the DDC sensors, and actuators can be reused.
- Units with older control hardware such as pneumatic controls hardware that is likely failed or failing, or units that have old-style mechanical time clocks that have been disabled.
- High energy costs (i.e., high electric or gas rates), an annual utility bill of at least $2k/yr.

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Figure 10: Technical Note Page 7 of 8

Technical Note

- Units scheduled for retrocommissioning that incorporates this retrofit as part of that process
- Units already remotely monitored via the building automation system
- Units with a large potential for savings: larger units (e.g. 5 HP fan motor or larger or serving 5000 sf or more of floor space), or running 24/7.
- Multiple units included in a retrofit allows for economies of scale for package development, submittal documents, and operator training.

Complementary Retrofit Needs *are system changes which are appropriately conducted along with the retrofit and are dependent on the as-found condition of the unit:*

- DDC Upgrade/Conversion: If the existing controls are pneumatic (or otherwise failed or failing), upgrade of DDC or conversion to DDC is needed. Integration into the controls front end is advantageous.
- Airside Economizer and Start/Stop Scheduling: are cost saving control function additions that might not have been present in the pre-existing system.
- Demand Controlled Ventilation: is a beneficial added controls function where the installation of occupancy sensors or CO_2 sensors in the space(s) relay ventilation requirements to the control system.
- Fan Motor Replacement: In some cases, it may be appropriate to replace the fan motor with a premium efficiency motor. This can provide additional energy savings.
- Controls Upgrade: Installation of new actuators and sensors to support conversion. It is recommended that pneumatic actuators be replaced with electric. Zone thermostats with occupancy mode override buttons or occupancy sensors would afford occupants needed conditioning during unscheduled visits. Zone thermostats with a relative humidity sensor can help monitor occupant comfort.
- Mechanical Repairs: Repair or replace malfunctioning equipment. Examples include dampers/valves in disrepair (loose linkages, water leaks, etc.), leaky ductwork/piping, rusting floors of air handlers that might be able to be repaired (e.g., epoxy), friable insulation, and broken motor mounts.

Implementation Support Tools help user through entire process of evaluating, implementing, and using the technology successfully.

Evaluate Technology: *Determine if the retrofit technology is the right fit for your circumstances:*

- Fact Sheet, Technical Note: Provide distilled technology, demonstration, and application insights
- Field Scoping Guide: Steps user through strategic installation-wide screening as well as assessment of an individual unit's operational status and suitability for retrofit
- Savings Estimator: Gauges the expected energy and cost impact of retrofit with life cycle cost analysis
- Pitch Briefing: Supports discussion with decision makers through a slide with script
- Training: Free on-demand training on the technology is available at: https://slipstreaminc.org/estcp

Streamline procurement:

- Design Guide: Lays out a roadmap for implementation
- Templates for: Drawings, Specifications, Sequences of Operation, Points Schedules, and Performance Work Statement: Detail the technical requirements for success, allows user to pick and choose needed graphics and text.

Establish and verify proper operation of the system:

- Commissioning Guidance: Provides checklists, performance verification test, and deficiency log.

See www.wbdg.org/ffc/army-coe/design-guides for implementation support tools. *For additional information contact: eileen.t.westervelt@usace.army.mil, christopher.m.battisti@usace.army.mil or joseph.bush@usace.army.mil.*

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Figure 11: Technical Note Page 8 of 8

2.3.3 Savings Estimator

This Savings Estimator is designed to help a potential implementer of the Multizone to Variable Volume HVAC Controls Retrofit gauge the life cycle energy and cost impact of the change for their particular application accounting for local weather, costs, and equipment configuration and condition. The estimator employs many default values so that it can be used early in the retrofit decision process using limited user-provided information to help determine if the effort is worth further investigation. These limited required inputs (about a dozen items) allow preliminary calculation of the impact of the basic VV retrofit on a system that is not on a central plant and otherwise functioning correctly. The estimator can also be used after performing more detailed scoping activities, to help refine the cost estimate.

The spreadsheet estimator flags common conditions that would disqualify a unit from retrofit such as extensive required equipment repairs, underlying problematic system layout issues, or inability to accommodate the required air flow measurement. The estimator employs numerous drop-down menus, multiple choice radio buttons, embedded explanatory notes, and logic based conditional formatting that greys-out details that do not apply to current selections or displays warnings or recommendations regarding selections. All assumptions and calculations are viewable and overridable by the user. Technical sources and reasoning are noted throughout. The provided estimator allows for modeling up to five units or scenarios with a single location entry. Additional copies of the estimator can be used for larger applications, or the baseline spreadsheet can be modified by the user for custom conditions, as the spreadsheet cells are not locked. Tabular output is provided by unit or as a combined roll-up of the multiple scenarios described. See Figures 12 through 15 for screenshots of the Savings Estimator.

Multizone to Variable Volume HVAC Controls Retrofit Savings Estimator

User Input

Location information

Estimator Note: All white cells may be filled in with site-specific information.

Items marked with "*" must be filled out to get the basic retrofit savings estimation. Typical default responses have been pre-entered for quick estimates.

*1. Choose your State: Illinois

* 2. Choose Your Representative City: Centralia

Based on your selection of city, your location is in the Mixed-Humid climate zone.

3. (Optional) Choose a Climate Zone if you want to override the assigned climate zone (see map): N/A

NOTE: Make sure that "N/A" is selected for item 3 if you want to use the assigned climate zone.

Example Cities Based on your automatically assigned climate zone (Mixed-Humid):

Atlanta, GA *Washington, D.C.* *Kansas City, MO* *Nashville, TN*

* 4. Quantity of MZ Units to describe (the tool supports data input for up to five configurations, please use tabs in numerical order, e.g. for two units: enter data on tabs: *3-Estimator -Unit 1* and *4-Estimator -Unit 2*, for three units: enter data on tabs: *3-Estimator Unit 1*, *4-Estimator - Unit 2* and *5-Estimator - Unit 3*, etc.: 1

		Escalation Override:
* 5. Electric Cost Rate ($/kWh)	$ 0.1054	
6. (Optional) Assumed Annual Electric Cost Escalation for next 10 yrs.	0.9978	
* 7. Natural Gas Cost Rate ($/therm)	$ 0.721	
8. (Optional) Assumed Natural Gas Cost Escalation for next 10 yrs.	1.0094	

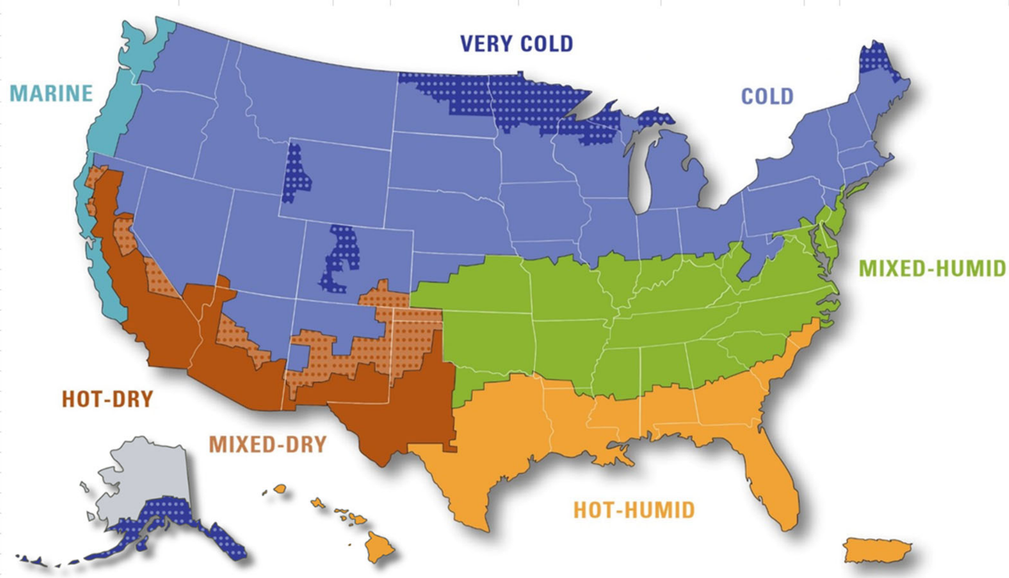
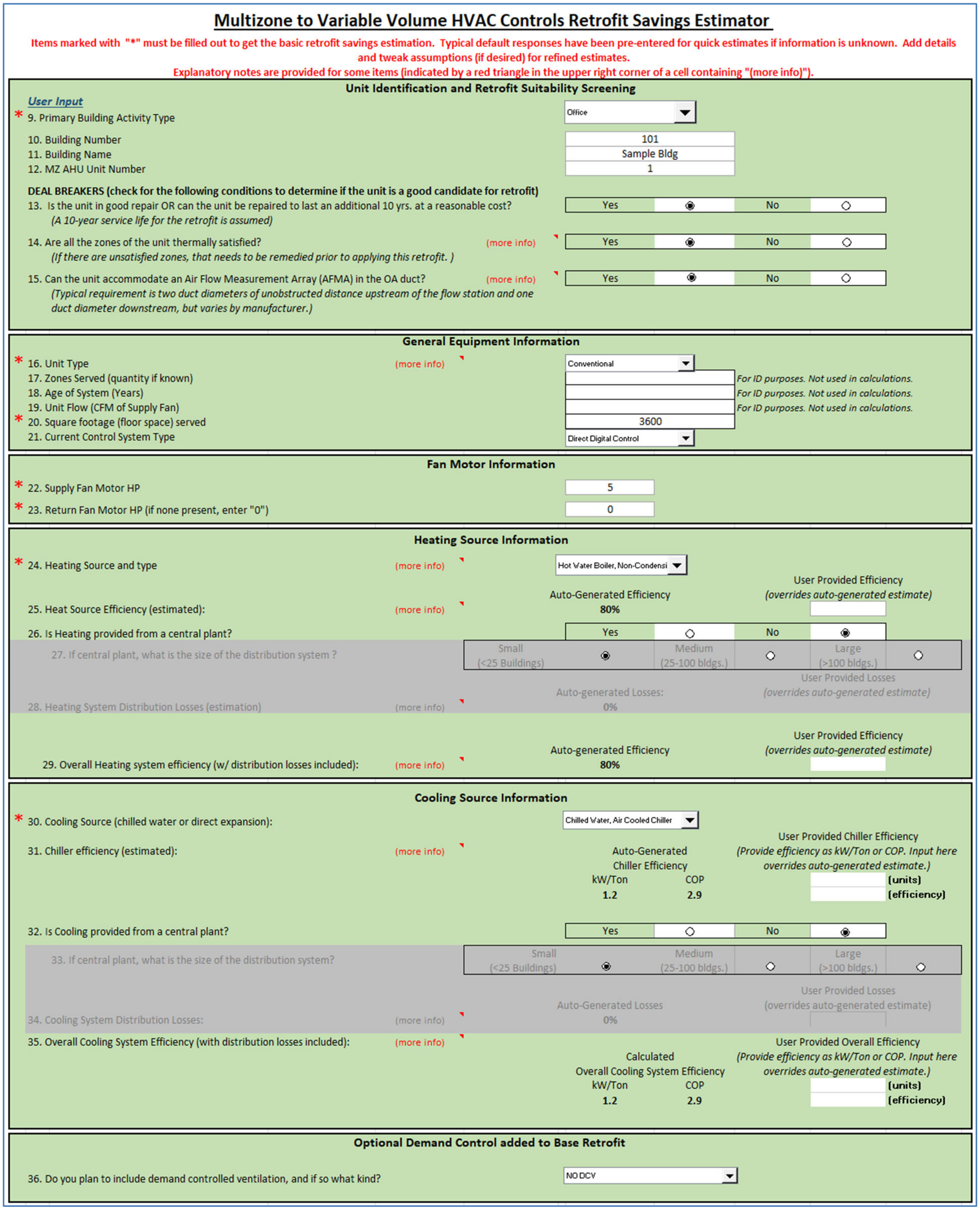


Figure 12: Savings Estimator Location Information Tab



Multizone to Variable Volume HVAC Controls Retrofit Savings Estimator

Items marked with "*" must be filled out to get the basic retrofit savings estimation. Typical default responses have been pre-entered for quick estimates if information is unknown. Add details and tweak assumptions (if desired) for refined estimates.
Explanatory notes are provided for some items (indicated by a red triangle in the upper right corner of a cell containing "(more info)").

Unit Identification and Retrofit Suitability Screening

User Input

* 9. Primary Building Activity Type — Office

10. Building Number — 101
11. Building Name — Sample Bldg
12. MZ AHU Unit Number — 1

DEAL BREAKERS (check for the following conditions to determine if the unit is a good candidate for retrofit)

13. Is the unit in good repair OR can the unit be repaired to last an additional 10 yrs. at a reasonable cost? — Yes ◉ No ○
(A 10-year service life for the retrofit is assumed)

14. Are all the zones of the unit thermally satisfied? (more info) — Yes ◉ No ○
(If there are unsatisfied zones, that needs to be remedied prior to applying this retrofit.)

15. Can the unit accommodate an Air Flow Measurement Array (AFMA) in the OA duct? (more info) — Yes ◉ No ○
(Typical requirement is two duct diameters of unobstructed distance upstream of the flow station and one duct diameter downstream, but varies by manufacturer.)

General Equipment Information

* 16. Unit Type (more info) — Conventional
17. Zones Served (quantity if known) — *For ID purposes. Not used in calculations.*
18. Age of System (Years) — *For ID purposes. Not used in calculations.*
19. Unit Flow (CFM of Supply Fan) — *For ID purposes. Not used in calculations.*
* 20. Square footage (floor space) served — 3600
21. Current Control System Type — Direct Digital Control

Fan Motor Information

* 22. Supply Fan Motor HP — 5
* 23. Return Fan Motor HP (if none present, enter "0") — 0

Heating Source Information

* 24. Heating Source and type (more info) — Hot Water Boiler, Non-Condensi

25. Heat Source Efficiency (estimated): (more info) — Auto-Generated Efficiency: 80% — User Provided Efficiency *(overrides auto-generated estimate)*

26. Is Heating provided from a central plant? — Yes ○ No ◉

27. If central plant, what is the size of the distribution system ? — Small (<25 Buildings) ◉ Medium (25-100 bldgs.) ○ Large (>100 bldgs.) ○

28. Heating System Distribution Losses (estimation) (more info) — Auto-generated Losses: 0% — User Provided Losses (overrides auto-generated estimate)

29. Overall Heating system efficiency (w/ distribution losses included): (more info) — Auto-generated Efficiency: 80% — User Provided Efficiency *(overrides auto-generated estimate)*

Cooling Source Information

* 30. Cooling Source (chilled water or direct expansion): — Chilled Water, Air Cooled Chiller

31. Chiller efficiency (estimated): (more info) — Auto-Generated Chiller Efficiency: kW/Ton 1.2, COP 2.9 — User Provided Chiller Efficiency *(Provide efficiency as kW/Ton or COP. Input here overrides auto-generated estimate.)* **(units)** **(efficiency)**

32. Is Cooling provided from a central plant? — Yes ○ No ◉

33. If central plant, what is the size of the distribution system? — Small (<25 Buildings) ◉ Medium (25-100 bldgs.) ○ Large (>100 bldgs.) ○

34. Cooling System Distribution Losses: (more info) — Auto-Generated Losses: 0% — User Provided Losses (overrides auto-generated estimate)

35. Overall Cooling System Efficiency (with distribution losses included): (more info) — Calculated Overall Cooling System Efficiency: kW/Ton 1.2, COP 2.9 — User Provided Overall Efficiency *(Provide efficiency as kW/Ton or COP. Input here overrides auto-generated estimate.)* **(units)** **(efficiency)**

Optional Demand Control added to Base Retrofit

36. Do you plan to include demand controlled ventilation, and if so what kind? — NO DCV

Figure 13: Savings Estimator Individual Unit Input

Results

This section provides the ability to review specific common retrofit measures as stand-alone activities, or to combine multiple measures into a retrofit package (see Column W), and see the full budget requirements and estimated energy impact accounting for diminishing returns of collective measures.

Building Number 101 **Building Name** Sample Bldg **Unit Number** 1

		Baseline Energy Costs	First Cost Investment	Electric Savings (kWh/yr)	Natural Gas Savings (terms/yr)	Energy Cost Savings ($/yr)	Cost Savings (%)	Fuel Energy Savings (%)	SPB Simple Payback Period (years)	NPV Net Present Value	SIR Savings to Investment Ratio	Insert "x" to include in Selected Measures Package
Individual Measures	VV Upgrade (VFD, AFMA & Programming)	$6,873	$7,190	9,710	1567	$2,153	31%	39%	3.3	$11,493	2.6	x
	Control System Conversion to DDC											
	Implement Equipment Scheduling											
	Fan Motor Upgrade to Premium Efficiency Motor (SF)											
	Addition of Economizer											
	General RCx of Existing Equipment	$6,873	$3,738	6,679	549	$1,100	16%	16%	3	$5,725	2.5	
Packages	**Selected Measures Package**	**$6,873**	**$7,190**	**9,710**	**1,567**	**$2,153**	**31%**	**39%**	**3.3**	**$11,493**	**2.6**	
	All Measures Package	**$6,873**	**$10,928**	**14,835**	**1,865**	**$2,908**	**42%**	**49%**	**3.8**	**$14,228**	**2.3**	

*Selected Measures Package calculates the combined impact of measures selected with an "x" in Col W lines 250-255. All Measures Package is the total of every applicable measure based on input above. This is to allow the user to compare a smaller project against the full project.

Notes/Warnings on Selections:

Figure 14: Savings Estimator Single Unit Results Table

Multizone to Variable Volume HVAC Controls Retrofit Costs and Savings Estimate - Results Roll Up

**Active unit description results are gathered here based on the number of descriptions chosen in the Location information tab.*

NOTE: User does not edit/change the information on this tab. Today's Date: 7/29/2022

Selected Measures Unit Roll Up

Unit #	Baseline Energy Costs	First Cost Investment	Electric Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Energy Cost Savings ($/yr)	Cost Savings (%)	Fuel Energy Savings (%)	SPB Simple Payback Period (years)	NPV Net Present Value	SIR Savings to Investment Ratio
1	$ 6,873	$ 7,190	9710	1567	$ 2,153	31%	39%	3.3	$11,493	2.6
2	$ 15,272	$ 7,190	21577	3481	$ 4,785	31%	39%	1.5	$34,328	5.8
3	$ 6,873	$ 7,190	9710	1567	$ 2,153	31%	39%	3.3	$11,493	2.6
4										
5										
TOTAL	**$ 29,017**	**$ 21,570**	**40996**	**6615**	**$ 9,092**	**31%**	**39%**	**2.4**	**$57,314**	**3.7**

All Measures Unit Roll Up

Unit #	Baseline Energy Costs	First Cost Investment	Electric Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Energy Cost Savings ($/yr)	Cost Savings (%)	Fuel Energy Savings (%)	SPB Simple Payback Period (years)	NPV Net Present Value	SIR Savings to Investment Ratio
1	$ 6,873	$ 10,928	14835	1865	$ 2,908	42%	49%	3.8	$14,228	2.3
2	$ 15,272	$ 7,190	21577	3481	$ 4,785	31%	39%	1.5	$34,328	5.8
3	$ 6,873	$ 7,190	9710	1567	$ 2,153	31%	39%	3.3	$11,493	2.6
4										
5										
TOTAL	**$ 29,017**	**$ 25,308**	**46122**	**6913**	**$ 9,847**	**34%**	**41%**	**2.6**	**$60,050**	**3.4**

Figure 15: Saving Estimator Multiple Unit Results Roll Up

2.3.3.1 Basis of Calculations

The estimator combines multiple inputs:

- User entered information (building activity and floor area, location, existing equipment sizes, configuration, retrofit/repair choices, and local utility costs)
- Typical HVAC requirements for the designated building activity in the local climate zone (from DOE's Energy Information Administration - Commercial Building Energy Consumption Survey (EIA-CBECS) data)

- Experimentally determined technology savings percentages
- Common energy modeling methods
- RS Means Cost Data.

The estimator calculates the expected annual energy and cost savings, and life cycle economics of the improvements for typical building and load applications.

2.3.3.2 Calculation Customization

Several tailoring options for the calculations are available and include:

- Selection of the basic VV retrofit or the version with optional demand-controlled ventilation
- Selection or designation of common complementary activities during upgrade:
    - Retrocommissioning
    - Equipment on/off scheduling
    - Addition of economizer function
    - Conversion from pneumatic controls to direct digital control (DDC),
    - Upgrade of fan motor (s)
    - Init specific repair needs determined by the user (such as cleaning of a fouled heat exchanger)
- Estimates of distribution system energy losses for central plant hydronic or steam systems
- Ability to use auto-generated estimates for energy efficiency, savings percentage and cost; or override these estimates with user provided inputs
- Ability to use a ballpark estimate of costs for retrocommissioning, or develop a refined estimate based on site-specific conditions
- Ability to gauge impact of the most common energy efficiency controls measures of scheduling equipment or adding economizer function
- Ability to review specific common retrofit measures as stand-alone activities or to combine multiple measures into a retrofit package and see the full budget requirements and estimated energy impact accounting for diminishing returns of collective measures.

2.3.4 Pitch Briefing

The pitch briefing is a single Power Point slide with script designed to support discussion with stakeholders and decision makers about the retrofit and potential further exploration. It presents a brief description of the technology and its energy and economic impact, available implementation resources and next steps in retrofit investigation. See Figure 16.

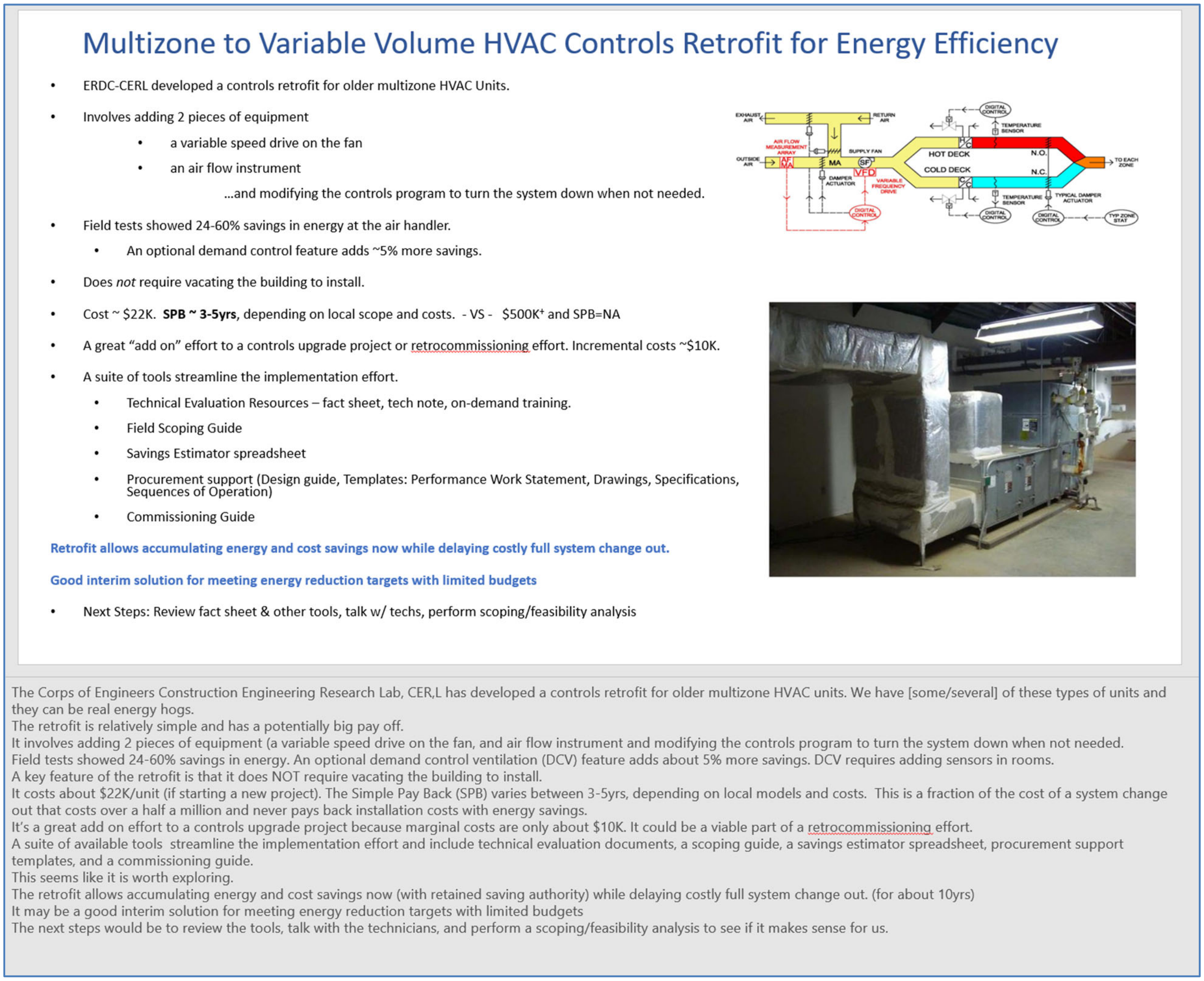


Figure 16: Pitch Briefing Slide with Script

2.3.5 Field Scoping Guide

The Field Scoping Guide helps a user identify reasonable candidates for retrofit from their portfolio of buildings. The approximately 26 pages (2.3MB) of content over 7 spreadsheet tabs walk the user through assessing existing multizone (MZ) air handling units' operational status and their suitability for the MZ-VV retrofit. Both strategic installation-wide screening as well as individual unit evaluation is presented. The results of this scoping effort will inform a contract for retrofit of the selected units.

The guide outlines a step-by-step process that starts with familiarizing the user with the retrofit technology, terminology and potential energy and cost impacts; then moves through an installation or campus level screening that identifies units that merit further consideration based on their size, condition, serviceability, configuration, use profile, and planned upgrades. Once a preliminary list of potential units is assembled, detailed field inspection procedures for individual unit evaluation bring into focus conditions incompatible with the retrofit (such as faulty zone layout, or inability to accommodate airflow measurement equipment) in addition to the operational issues that need to be addressed along with the retrofit to achieve a satisfactory retrofit project outcome. These activities prompt reduction of the field of retrofit candidates to solid contenders. The post field inspection documents the findings and readies the insights gained for application to retrofit design and specification. See Figure 17.

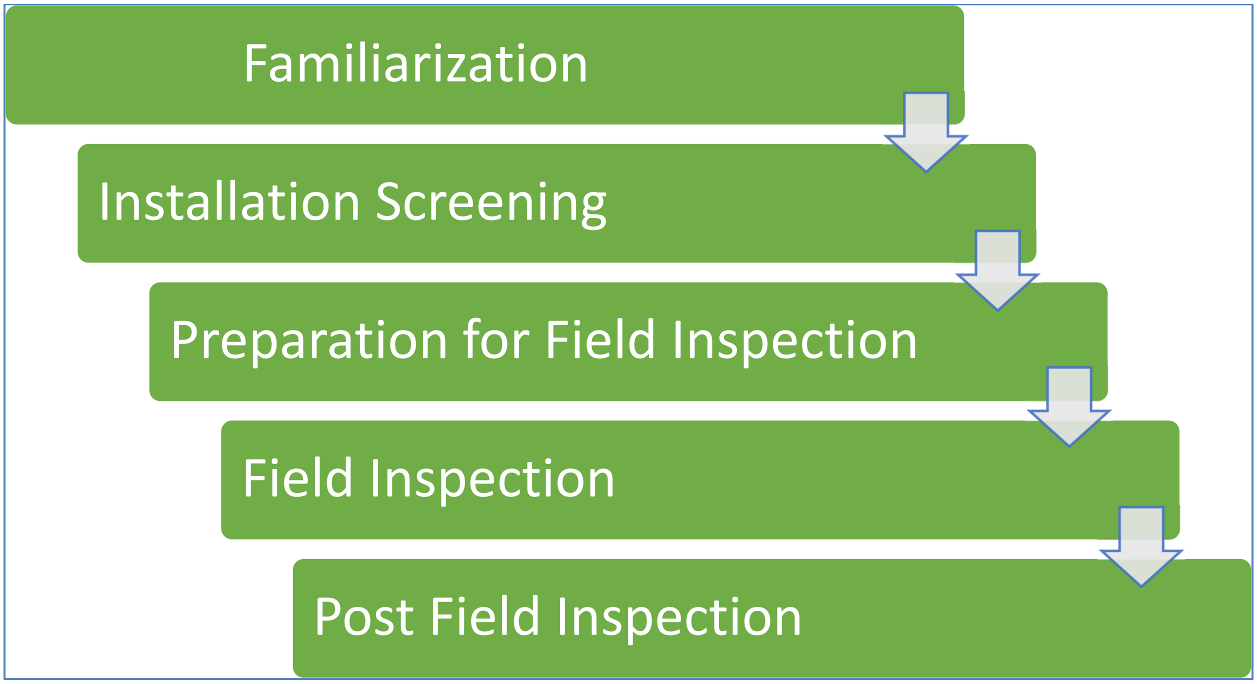


Figure 17: Field Scoping Process

The guide provides ready data forms, technical descriptions, inspection prompts and insights as well as suggested interview questions for maintenance staff. See Figures 18 through 23. The objective is to systematize the scoping process that results in a thorough understanding of conditions of the system which need upgrade or repair beyond the basic variable volume modification to attain a fully functioning system post retrofit that will provide adequate HVAC service. Sample complementary activities might include addressing failed dampers or valves, remedying deteriorating insulation or upgrading actuators and controllers to direct digital control. The complementary activities will increase user satisfaction with the change, maximize savings, and extend service life.

Multizone to Variable Volume HVAC Controls Retrofit Scoping Guide

A. Objective

This Scoping Guide is intended to help assess multizone (MZ) air handling unit operational status and suitability for retrofit. The results of this scoping will inform a contract performance work statement for units selected for retrofit.

B. Scoping Process

The process consists of identifying, assessing, and selecting constant volume (CV) MZ systems suitable for conversion into more energy-efficient variable volume (VV) systems. The retrofit focuses primarily on the HVAC control system, with minimal equipment replacement or disruption of building functions during the retrofit.

The basic steps include:

1. Familiarization

Get familiar with the technology and retrofit. Review Technical Note; *'Multizone to Variable Volume HVAC Controls Retrofit for Energy Efficiency'* included in *'1.Familiarization' tab* for your convenience. Skim 'Reference' tab in this worksheet. You may decide to use the '*MZ to VV Savings Estimator*' spreadsheet tool to determine potential energy and cost impact. See the Whole Building Design Guide website, www.wbdg.org/ffc/army-coe/design-guides, for the savings estimator and other resources.

2. Installation Preliminary Scoping

a. Team up with DPW / OMD staff and create a *first pass* list of units along with their basic characteristics on the 'Installation Prelim Scoping' tab.

b. Locate, identify, and characterize (in a simplified big picture fashion) each multizone unit at the Installation.

c. For each unit, provide an initial recommendation on whether to perform a subsequent field inspection (yes, no, maybe).

d. Pick one or two strong candidates to start with, and work through the entire process before taking on all potential units. This gives you a chance to tailor additional data collection to your needs.

3. Preparation for Field Inspection

a. Document Gathering: For units pre-selected for potential 'field inspection' during the 'Installation Prelim Scoping' step above, obtain *available* documentation as listed below to determine MZ unit type and sizes; where the intent is to help prioritize units for field inspection because they are good retrofit candidates; e.g. conventional MZ units that are large, have big motors, large cfm, large sf served, serve conference rooms, classrooms, or other spaces with highly variable occupancy.

Documents *may* include:

i. Mechanical As-Built Construction (or design) Drawings/Documents *(High Priority Item, Schedules are key)*
ii. Equipment List
iii. AHU Data Sheet
iv. TAB Report
v. Control Drawings
vi. Any individual energy meter data
vii. Any previous mechanical audits

b. Equip Tables & Field Data: *Pre-Fill* the forms under the 'Equip Tables & Field Data' tab using the available documentation and the 'Installation Prelim Scoping' results.

c. DPW-Maint Staff Interviews: Duplicate the information in the 'DPW-Maint Staff interviews' tab for each unit identified for possible field inspection in 'Installation Prelim Scoping'. Answer the questions in coordination with DPW/techs/maintenance staff for each unit. This may be more or different people from the installation preliminary scoping.

d. Second round prioritization: Update priority of units on 'Installation Prelim Scoping' tab for detailed field inspection based on gathered documents and interviews.

e. *Copy* 'Detailed Field Inspection': Make multiple copies of the 'Detailed Field Inspection' tab, one for each unit with enough promise for retrofit to merit a field inspection. Rename the new spreadsheet tabs to uniquely ID each MZ unit.

f. Tool Bag. Gather basic tools for a Field Inspection:

i. Survey Forms on clipboard or computer/tablet
ii. Camera
iii. Flashlight
iv. 10' step ladder
v. Screwdriver
vi. Wrench

4. Field Inspection

a. Visit building(s) with DPW / maintenance staff to 1) complete the forms, 2) guide a decision to retrofit or not, and 3) to document needed repairs to include in a potential retrofit scope of work.

b. Populate 'Equip Tables & Field Data' sheet with nameplate data.

c. Work through the 'Detailed Field Inspection' data sheet to ID suitability for an Air Flow Measurement Station and any 'additional' work beneficial to the unit/system. Complete 'Equip Tables & Field Data' sheet.

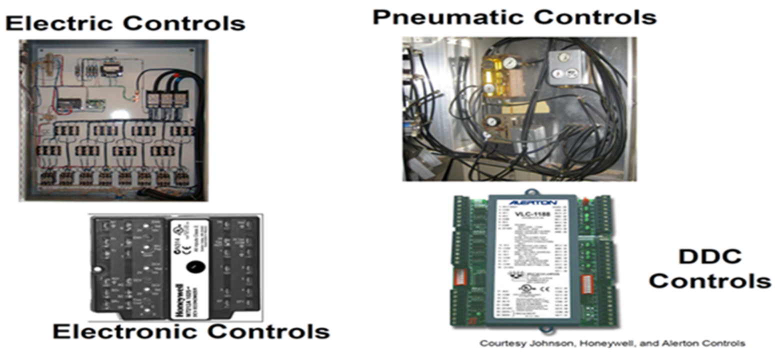
d. Log pertinent observations and take photos of key aspects and components.

Figure 18: FSG: Overview Tab Excerpt

Pneumatic, Electric, Electronic, and DDC Controls

Identifying the type of controls on the multizone AHU will help determine if the controls need to be replaced.
The controls retrofit requires a Direct Digital Control (DDC) system. The controls sequence is too complex for other control methods.

The illustrations below show examples of the different types of control systems.



Some defining characteristics of the control system types are:

Pneumatic Control System
Uses compressed air to power the controllers, sensors, and actuators. The compressed air is carried in copper or plastic tubes.
The controllers use pneumatic (compressed air) to make logic/control decisions and to move actuators to the desired position.
The sensors also transmit their sensed process values via pneumatic signal. Dampers and values are actuated by pneumatic signal.
Note: A system that *only* has pneumatic actuators (for valves and dampers) is not a pneumatic control system. (See below)
It usually has electric devices used to start/stop motors and to provide safeties for equipment protection (such as a freeze stat).

Electronic / Electric Control System
Uses electricity to power the control system. The controllers use semiconductor solid state circuitry to make logic/control decisions. The sensors transmit their sensed process values via electronic (often 4-20 mA) signal. Dampers and values can be actuated by electronic signal or by pneumatic signal via a pneumatic signal transducer.
It usually has electric devices used to start/stop motors and to provide safeties for equipment protection (such as a freeze stat).

Direct Digital Control (DDC)
The same as an Electronic Control System but the controller also has a microprocessor to make logic/control decisions. The controllers also have a network interface to communicate (e.g. share data) with other controllers and/or a supervisory system.

Figure 19: FSG: Reference Tab Excerpt

Installation -Wide Preliminary Scoping (with HVAC and Controls Techs)

Purpose: Identify candidate multizone units for controls retrofit that merit further consideration and possible field inspection.

* Consider cfm, motor size, sf served (e.g. Small: SF < 5hp or CFM < 3000; Medium: 5hp < SF < 15hp or 3000 < cfm < 10000; Large: SF > 15hp or cfm > 10,000)

** Fair to good condition, or poor but fixable at reasonable cost. No building remodel/ decommission planned

*** Assign priority to all units where highest priority is for large, Conventional MZs (Hot deck/Cold Deck) that serve spaces w/ high variability in occupancy (conference rooms, classrooms) w/ 10yrs life left. Get maintenance staff input and recommendations.

Complete information as available:

	Bldg Name/ Number	Unit ID# and/ or location	MZ Type (Conv, Bypass, Neutral)	Approx. Age (yrs)	Approx. Unit Size* (Small, Medium, Large)	10 yrs service left? **	Notes (known condition, repair needs, issues, reason < 10 yrs life left)	Controls (DDC , Analog Electronic, Pneum.)	Controls Vendor	LON/ BACNet/ Niagara/ Other	Initial Recommendation to Field Inspect? (Y/N, Maybe)	Priority*** (High, Medium, Low)
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												

Figure 20: FSG: Installation-Wide Screening Datasheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
1	Equip Tables & Field Data																					Equip Tables & Field Data														
2			AHU Information			Fan Motor Information																Zone Information														
3						Supply Fan Motor							RA	Return or Exhaust Fan Motor										Variable occupancy spaces_ Approximate portion of 'Total Area Served' (SF) by end use (%)											Cooli	
4	Bldg Name/ Number	Unit ID# and/ or location	MZ Type (Conv, Bypass, Neutral)	Approx. Age (yrs)	Supply Fan CFM	Mfg.	Model/ Part Number	HP	Eff.	Voltage	Date/ Age	OK for VFD?	Plenum or ducted return air?	Mfg.	Model/Part Number	HP	Eff.	Voltage	Date / Age	OK for VFD ?	Air Side Economizer ? (Y/N)	Total Area Served (SF)	Number of Zones	Classroom (%)	Conference / Assembly (%)	Rest Room (%)	Gym (%)	Shop (%)	other (%)	other (specify)	Observed Balancing Damper (%Open) Position	Scheduling Eqpt? (mechanical time clock, electro	Is unit currently running 24/7?	Is 24/7 operation needed?	Cooling Type (ChW, Dir Expn)	Capacity (Btu/hr)
5																																				
6																																				
7																																				
8																																				
9																																				
10																																				
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Figure 21: FSG: Detailed Field Data Form

Detailed Field Inspection (with HVAC and Controls Technician)

3d **MZ Unit __________________________ Date__________________________**

b Locate and inspect the Outside Air intake for suitability to add an Air Flow Measurement Station (AFMS).

Adding a AFMS will ensure adequate ventilation for the building. An AFMS requires a certain distance of unobstructed flow up and downstream of the station for proper measurement. Typically requirements are two' Duct Diameters' (distance) upstream of the flow station, one 'Duct Diameter' downstream. However this requirement is dependent on the flow station type and manufacturer.

-Take pictures of the OA ducting for reference.

-What is the available length (distance) in the OA duct to install an AFMS? Specifically; determine the straight-duct distance between duct disturbances (obstructions) such as the intake louver/hood and a downstream damper. Other obstructions might include a duct elbow or tee.

OA Duct Distance between duct disturbances: [ ] feet

What is the diameter of the OA duct? For a rectangular duct, calculate 'equivalent' diameter:

Duct Dimensions: Height = [ ] inches Width = [ ] inches

Duct Diameter (Equivalent) = $\frac{(W + H)}{2}$ Duct Diameter = [ ] inches

c Look for and note damage on the ducting or equipment that appears significant enough to warrant repair. (Damage that would hinder AHU operation would hurt the ability of the AHU to condition the space properly and prevent energy savings)

This includes corrosion (ducts, dampers, heating/cooling coils, drain pan, motor mounts, etc.), broken or damaged ductwork (e.g. split seams), loose, degraded or missing AHU or duct insulation, flex ducts not connected to diffusers, flex ducts that are flattened or distorted:

d Review drawings to inspect the Outside Air, Supply Air, and Return Air ducting path. Does the ductwork run through any unconditioned spaces for a distance over 50 feet? (If so, insulation or duct leakage may be a concern.)

Yes [ ] No [ ]

Figure 22: FSG: Inspection Prompts Example

DPW-Maint Staff Interview

3	**MZ Unit ___________________________ Date__________________________**
a.	**Known issues with the AHU and the spaces it conditions.** Examples include fan operational issues (too loud, vibrates, etc.), valve/damper issues, duct/coil/damper/AHU floor corrosion/microbial growth, space conditioning capacity or accuracy, repeated complaints. Note below:
b.	**What is the general condition of the HVAC mechanicals?** What needs to be fixed? Be open to improving and fixing any existing problems as a part of the retrofit. Does this unit have 10 yrs of life in it? Can needed repairs be made at a reasonable cost? Note below:

Figure 23: FSG: Technician Interview Questions Excerpt

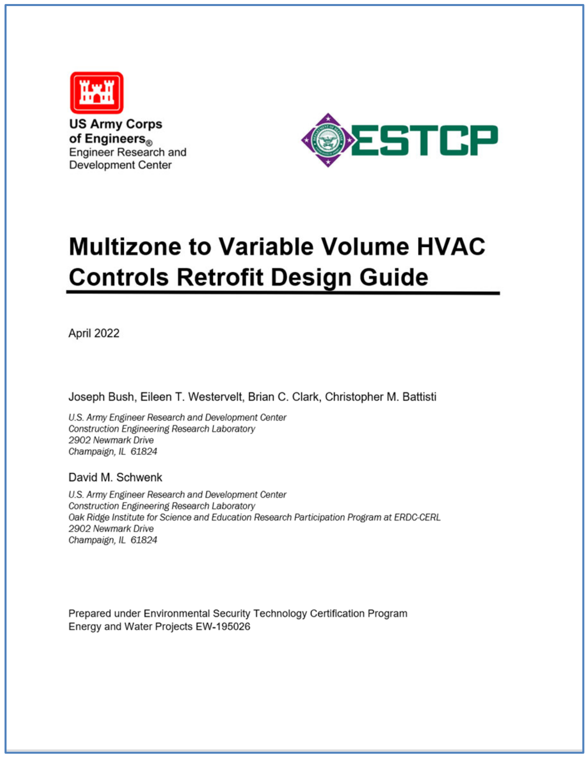
2.3.1 Procurement Support Tools

The procurement support tools consist of the Design Guide (with appendices that contain templates for a Performance Work Statement, Specifications Book, and Controls Sequences of Operation), the template Control Drawings Set and template Control Point Schedule to facilitate procurement efforts. Many of the documents are provided in template fashion by presenting language and drawings for multiple common equipment configurations to allow the user to pick and choose the text or graphics that matches their situation and strike out or delete what does not apply. Resources are provided in ready-to-use format such as MS Word documents, AutoCAD drawings and Excel spreadsheets. These ready formats help the user to quickly produce procurement packages that systematically consider best practices, and to minimize one-off efforts.

2.3.1.1 Design Guide

This Design Guide serves as an overall roadmap to support implementation of a variable volume retrofit. Described activities range from selecting which air handling unit(s) (AHUs) are good candidates for retrofit, through preparing contract documents for award, to performing inspections and tests leading to system acceptance and turnover. See Figure 24. This document includes technical requirements along with a process for implementation that make use of supporting tools (e.g., text documents, procedures, spreadsheets and drawings) developed in conjunction with the guide[1].

[1] See the Design Guide appendices and the whole building design guide, www.wbdg.org/ffc/army-coe/design-guides for accompanying files.



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Multizone to Variable Volume HVAC Controls Retrofit Design Guide

April 2022

Joseph Bush, Eileen T. Westervelt, Brian C. Clark, Christopher M. Battisti

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
2902 Newmark Drive
Champaign, IL 61824

David M. Schwenk

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
Oak Ridge Institute for Science and Education Research Participation Program at ERDC-CERL
2902 Newmark Drive
Champaign, IL 61824

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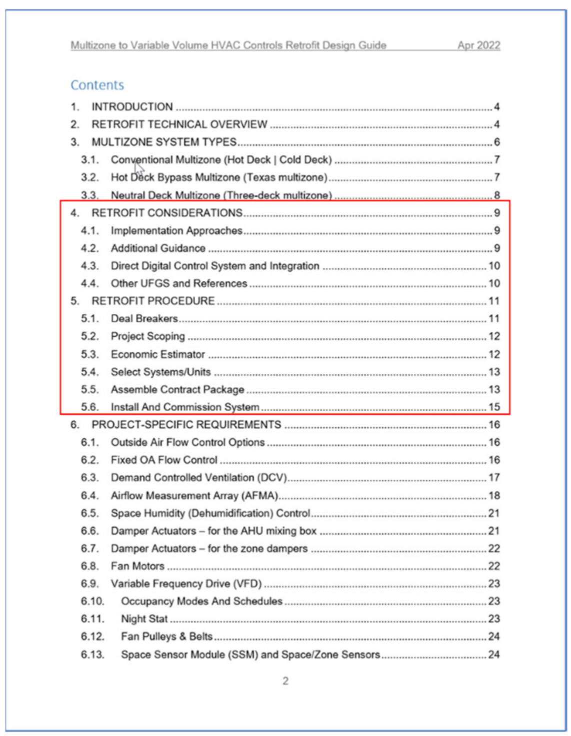
Figure 24:DG Cover



Multizone to Variable Volume HVAC Controls Retrofit Design Guide Apr 2022

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   6.11. Night Stat 23
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2

Figure 25: DG Foundational Sections

The foundational portion of the nearly 90-page guide are the 7 pages of Sections 4 and 5 that describe key implementation considerations and the retrofit process See Figure 25. The other information is either introductory, reference, or supporting template documents. The primary considerations presented include implementation approaches that account for and interact with current or previous DDC upgrades on the system, and applicable UFGS references for DDC upgrade and HVAC system repair, monitoring, tuning and cybersecurity. The retrofit process includes project scoping, estimating, system selection, contracting, installation and commissioning. This process and the supporting tools are show in Figure 26.

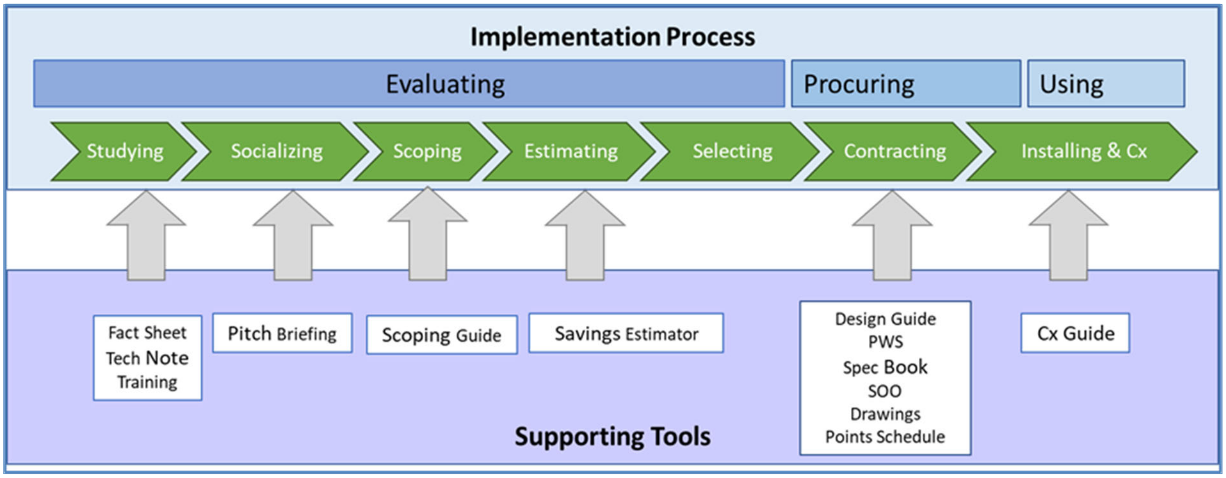

Figure 26: Retrofit Implementation Process with Supporting Documents and Tools

Implementation support contents includes a technical explanation of the retrofit, features of typical system types, requirements for project-specific equipment, control strategies, recommendations on DDC integration, dehumidification guidance, and maintenance considerations. The appendices provide the templates for the PWS, specifications book, control sequences of operation, as well as overviews of the scoping guide and savings estimator.

2.3.1.2 Procurement Package Templates for PWS, Specifications Book, Sequences of Operation, Drawings, and Points Schedule

The Performance Work Statement, Specifications Book, Sequences of Operation, Drawings and Points Schedule complement each other to fully describe the required work. They need to be developed and tailored and coordinated with each other by the designer/specifier as a combined package.

The Performance Work Statement (PWS) template provides sample outcomes-based contracting language for the MZ-VV retrofit implementation at an installation. This includes editable language for the project technical requirements based on the retrofit specifics at an installation as well as additional language beyond the retrofit to incorporate complementary repairs and upgrades. The template flags content that will need to be provided, edited, or tailored with highlighted text in square tailoring brackets. See Figure 27. It also references other implementation support documents to use on contract package preparation and lists typical needed attachments.

Performance Work Statement (PWS) – Template Multizone to Variable Volume Controls Retrofit

1 PROJECT TECHNICAL REQUIREMENTS

1.1 TECHNICAL OVERVIEW

This Performance Work Statement describes the technical requirements to perform a control system retrofit to convert existing constant volume multizone (MZ) system(s) to variable volume for energy savings. The project adds controls components and a new sequence of operation, with minimal alterations to the physical air handler or ductwork.

This project covers the renovation at selected multizone units. In addition to the AHU conversion itself, additional monitoring equipment will be installed [and the controls will be integrated into an existing Utility Monitoring and Control System (UMCS)].

1.2 LOCATION INFORMATION

The project includes the following systems:

- Installation: [INSERT INSTALLATION NAME]
- Building(s): [INSERT BUILDING NUMBER/NAME INFORMATION]

Figure 27:PWS Template Excerpt

The Specifications Book template provides sample technical equipment and operations requirements for the VV retrofit project. See Figure 28. Requirements cover materials and workmanship, quality requirements for the products, and specifics of how the products are incorporated into the work including equipment labeling, startup procedures, performance verification, and system training. The sections that need to be tailored are flagged in square tailoring brackets. Designer/Specifier notes are provided throughout. Language for common complementary system repairs and upgrades beyond the standard retrofit is provided for the specifiers benefit including motors, sensors, controllers, and actuators. Additional requirements and specification sections may be needed and added at the designer’s discretion.

2.2 Motors

****

Designer/Specifier Note:

Determine if supply and/or return fan motor(s) are to be replaced. Typically, an existing fan motor can be reused when a VFD is added to the system but it is best to consult with an electrical engineer or other motor specialist. You can use the 'Execution' section of this spec or keyed note in the control system drawing to indicate/list the motor(s) that are to be replaced.

****

[Motors must meet NEMA specifications for "Premium Efficiency Motor" and must be capable of being safely and reliably driven by a VFD. Motors must be selected based on high efficiency characteristics relative to typical characteristics and applications as listed in NEMA MG 10. In addition, continuous rated, polyphase squirrel-cage medium induction motors must meet the requirements for premium efficiency electric motors in accordance with NEMA MG 1, including the NEMA full load efficiency ratings. Motor must be open drip proof.]

2.3 Variable Frequency Drive

2.3.1 The VFD must control the speed of induction motor(s) by converting the input AC mains power to an adjustable frequency and voltage using Pulse Width Modulation (PWM).

2.3.2 The drive must have an efficiency of at least 96% at rated speed and load. The displacement power factor must be at least 0.95 under any speed or load condition.

2.3.3 Electrical and electromechanical components of the Variable Frequency Drive (VFD) must not cause electromagnetic interference to adjacent electrical or electromechanical equipment while in operation.

Figure 28: Specifications Book Excerpt

The Control Sequences of Operation template provides a step-by-step description of the control scheme functionality and logic for the HVAC equipment. See Figure 29. Schemes are presented by multizone type (Bypass, Conventional Hot Deck/ Cold Deck, and Neutral Deck). Specifiers notes and tailoring selections (in square brackets) are provided throughout to accommodate systems with return fans and systems where the demand-controlled ventilation option is chosen.

G. OUTSIDE AIR (OA) FLOW CONTROL

(1) DISABLED: WHEN THIS LOOP IS DIABLED THE OA DAMPER IS CLOSED.

(2) ENABLED: WHEN THIS LOOP IS ENABLED THE OA DAMPER IS CONTROLLED BASED ON:

i. [FIXED FLOW SETPOINT: MODULATE THE OA DAMPER TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT THE FIXED OCCUPIED SETPOINT (OA-F-SP) SCHEDULED FLOW.]

ii. [OCCUPACY SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE OCCUPANCY AS SENSED BY THE CEILING MOUNT OCCUPANCY SENSORS IN ROOMS/ZONES [ ] ACCORDING TO THE FOLLOWING SCHEDULE:

OCC SENSOR STATUS	OA FLOW SETPOINT
NO ROOMS/ZONES OCCUPIED	[ ] CFM
ANY ROOM/ZONE OCCUPIED	[ ] CFM]

iii. [CO2 SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE MAXIMUM ZONE C02 (MAX-ZONE-CO2) SENSED IN ANY AREA/SPACE SERVED BY THE AHU ACCORDING TO THE FOLLOWING OA-F-SP LINEAR RESET SCHEDULE:

MAX-ZONE-CO2	OA FLOW SETPOINT
[ ] PPM	[ ] CFM (LOWER LIMIT)
[ ] PPM	[ ] CFM (UPPER LIMIT)]

Figure 29: Sequence of Operation Excerpt

The Control Drawings Template provides graphical representations of the system layout, control logic schematics, and detailed tables of equipment specification. See Figure 30. Drawings are provided in 12 drawing sets for the three common system types (bypass, conventional and neutral). Specific sheets include control schemes, ladder diagrams, control logic diagrams, and placeholder pages for sequences of operation and DoD format Points Schedules that are developed from the Sequences of Operation and Point Schedule templates.

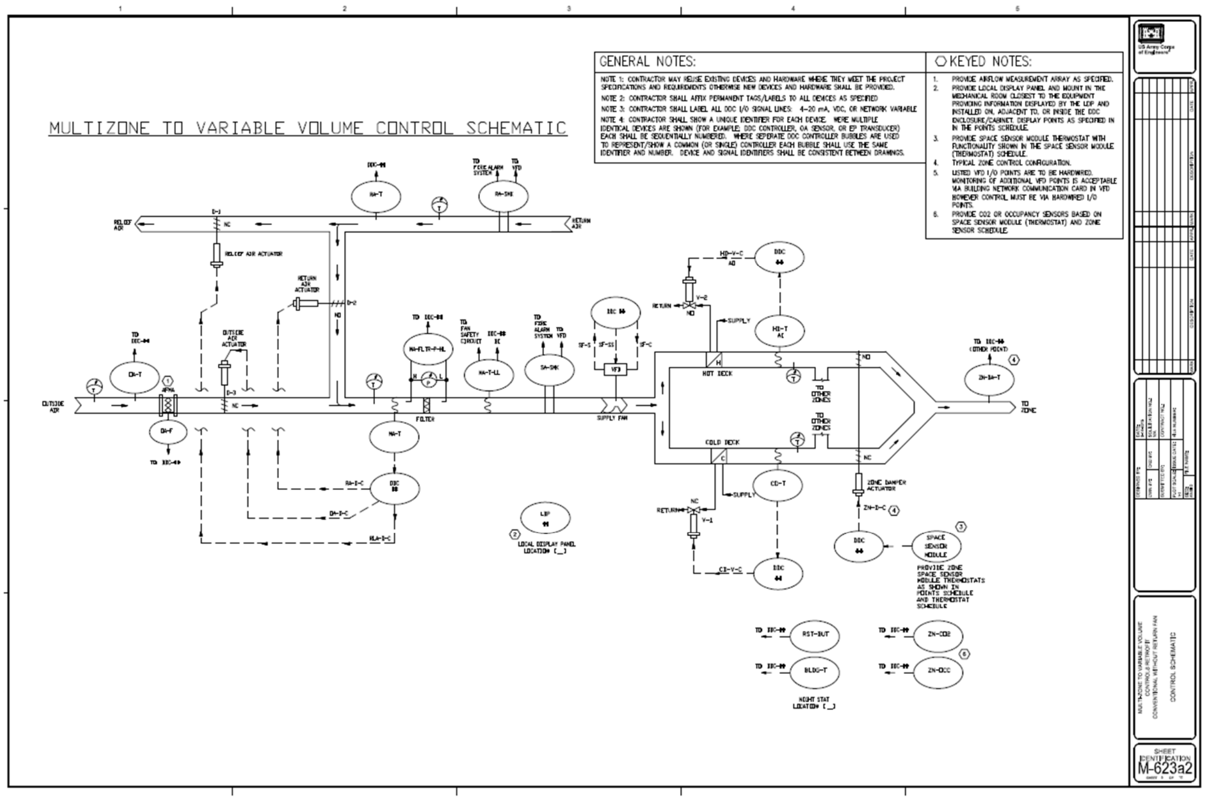

Figure 30: Design Drawings Excerpt

2.3.2 Commissioning Guide

The Commissioning (Cx) Guide is a spreadsheet tool that provides procedures and check lists to establish and verify proper operation of the system, to ensure the equipment operates as designed and provides the needed space conditioning. See Figure 31. The Performance Verification Test in the Cx Guide can be repeated over time to ensure ongoing correct and efficient operations.

The guide is intended to assist with the execution of a MZ-VV retrofit project to help ensure that the specified equipment has been correctly acquired, installed as required, and is functioning properly. It is designed to help the Contracting Officer's Quality Assurance Representative work through project familiarization, start up, performance verification, deficiency resolution, and turnover. Since each project is unique and has its own specific circumstances and requirements, this document is meant to be edited for each specific project based on the contract documents. This guide is intended to work along with the MZ-VV Design Guide, Control Drawings and Specifications Book.

The Cx Guide provides a step-by-step process for commissioning the retrofit to ensure correct operations. It includes project progress tracker checklist, startup checks, performance verification testing, and deficiency log.

The performance verification test is a point-by-point check to ensure the retrofit operates as intended. Every aspect and portion of the control sequence is tested including the following:

sensor accuracy, fan variable speed operation, economizer operation, water valve operation and demand-controlled ventilation.

Test Procedures								
Submittal prepared date:			notes:					
Tested By:								
Test Date:								
Test #	**Does this test apply?**	**Action Item**	**Expected Response**	**Recorded Value (where applicable)**	**Passed (Yes/No)**	**Verified By**	**Date**	**Notes**
Supply Fan VFD Basic Operation								
21		From the Supply Fan VFD, turn the H-O-A switch to Off	The VFD should stop the fan.					
22		From the Supply Fan VFD, turn the H-O-A switch to Hand	The VFD will start the fan and slowly ramp it up to speed					
			Optional (if specified): An Alarm will be generated through the BAS for Hand Position					
23		From the Supply Fan VFD, adjust the frequency reference to 75% (45Hz)	The VFD will drive the fan to the reference frequency					
		From the Supply Fan VFD, adjust the frequency reference to 1%. Once fan speed reaches a minimum record minimum fan speed.	Fan speed ramps down to the specified minimum fan speed typically between 35% to 50% but check specified minimum.					
24		From the Supply Fan VFD, turn the H-O-A switch to auto	The VFD will return to automatic control, and operate according to the fan capacity control loop according to a subsquent test.					
25		Simulate restart from power loss	Power down VFD at disconnect, then reenergize disconnect after one minute and confirm VFD and fan start and control to setpoint.					
26		Reset all alarms						

Figure 31:Cx Guide: PVT Excerpt

2.4 OUTREACH

2.4.1 Conference Presentations and Networking

The project team gave six conference presentations and attended one additional conference for networking. Team representatives attended the 2020 ASHRAE Winter Conference to network with conference personnel and advocate for a future presentation of the work. The team participated in two virtual conferences (the 2021 DOE Energy Exchange and the 2021 ASHRAE Winter Conference) and two in-person conferences (USACE Community of Practice 2021 meeting and the Building Commissioning Association 2021Conference), to present the demonstration results and technical transfer suite of products. See Figure 32.

The ASHRAE Conference provided valuable feedback on the work from HVAC industry practitioners and industry standards committee representatives. Over 3,000 buildings-related industry professionals attend this event, with the AHR Expo being the world's largest HVAC&R marketplace. The Building Commissioning Association (BCxA) Conference alerted an international group of building managers, academics, and potential installers of the implementation resources. The Energy Exchange Conference, the USACE Community of Practice meeting, and the two ESTCP Symposiums provided instruction and networking to DoD Energy Managers, USACE Engineers and related DoD stakeholders. The Energy Exchange is the largest training and trade show event for the Department of Energy. Thousands of attendees from the Federal, State, and Local Government attend the Energy Exchange every year, along with other industry technical experts in the private and public sectors of energy management.

A physical project poster (2019) and a PowerPoint presentation (2020) offered a big picture overview of the project. They were used at the ESCTP Symposiums to generate awareness and interest in the retrofit. PowerPoint presentations and question and answer sessions were offered at the conference meetings. The conferences also utilized quizzes in addition to session participation for the attendees to earn continuing education units.

Figure 32: Six Outreach Presentations

2.4.2 On-line Training

The team developed a free on-line, on-demand ESTCP training class on the MZ-VV retrofit that is offered on SlipStream's website https://slipstreaminc.org/estcp and the WBDG website, https://www.wbdg.org/continuing-education/dod-courses/estcp/estcp4-4. See Figure 33 through 34. Additionally, BCxA offers a recording of the 2021 conference training presentation as part their Track 2: *Commissioning Essentials* training course available for purchase, https://www.pathlms.com/bcxa/courses/33553/sections/37765. Each training offering is one hour of instruction. All three training sources provide the opportunity for receiving continuing education unit credit with lesson viewing and successful completion of the content quiz.

This training covers and introduction to multizone types, the retrofit details and benefits, the field demonstration results, and the implementation support tools.

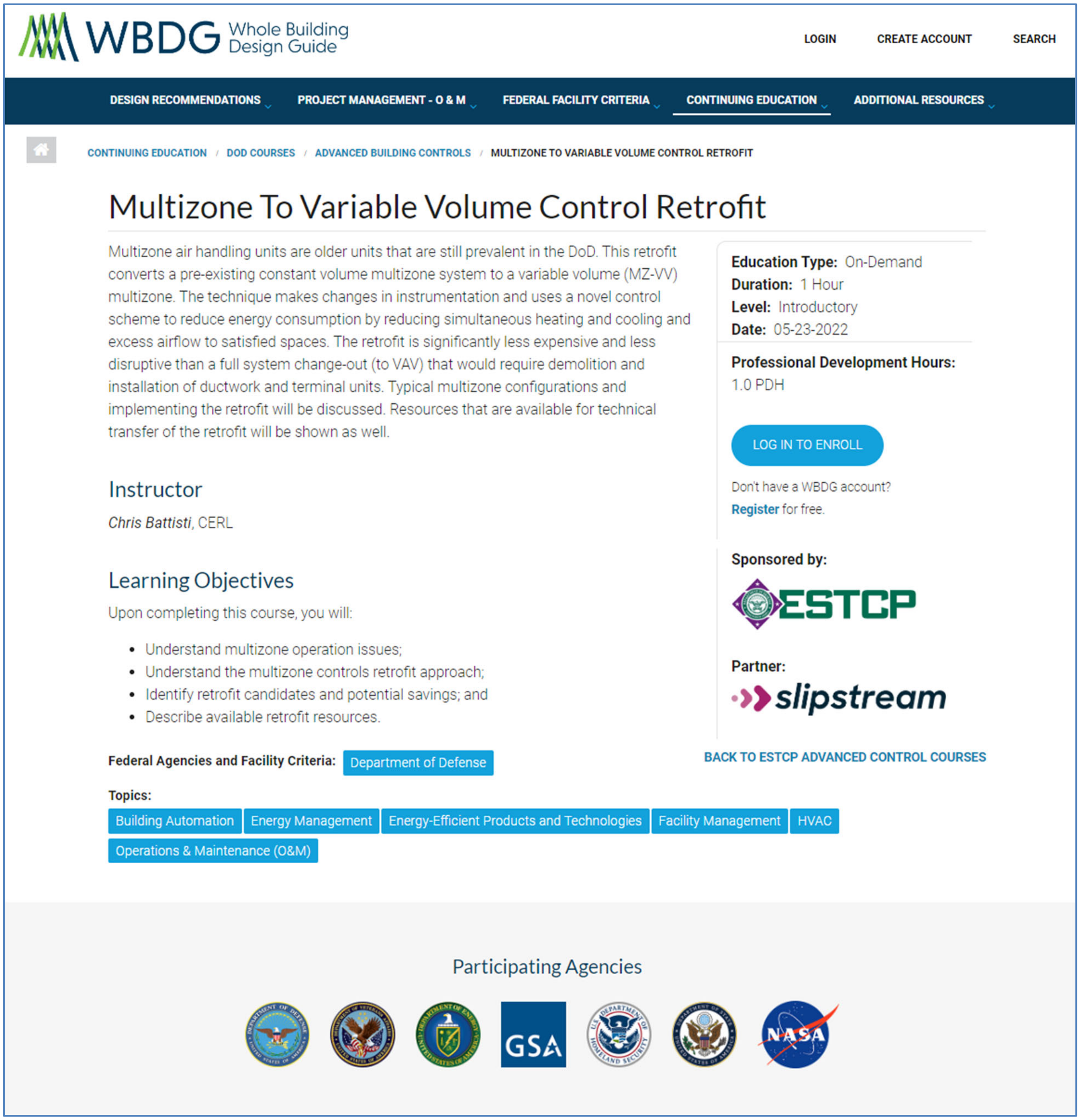

Figure 33: On-line Training at WBDG

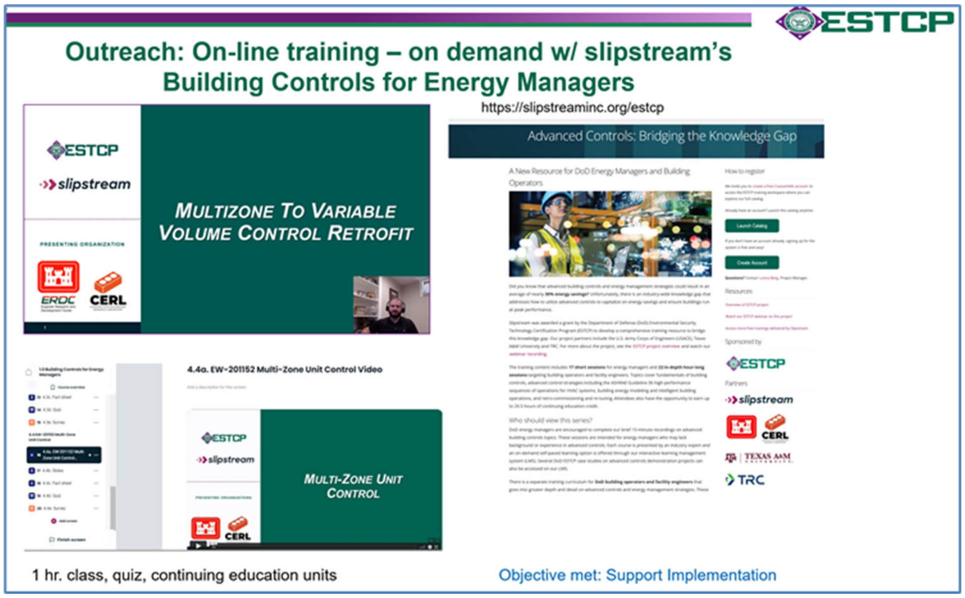

Figure 34: On-line On-demand Training on Slipstream

2.4.3 Journal Articles

Utilizing the technical richness of the original demonstration's Final Report, as well as new insights developed during the technology transfer phase, four journal articles were composed to convey the demonstration methods, the technology analysis procedures, the results of the demonstration test and the technology transfer effort. Publications included *ASHRAE Transactions*, *ASHRAE Journal*, and the Society of American Military Engineers' periodical, *The Military Engineer*. Individual service periodicals originally targeted for publications including *Navy Currents*, *AF Engineer*, and the Army's *DPW Digest* are no longer in operation. Organizational websites for each service have been contacted to publicize the work.

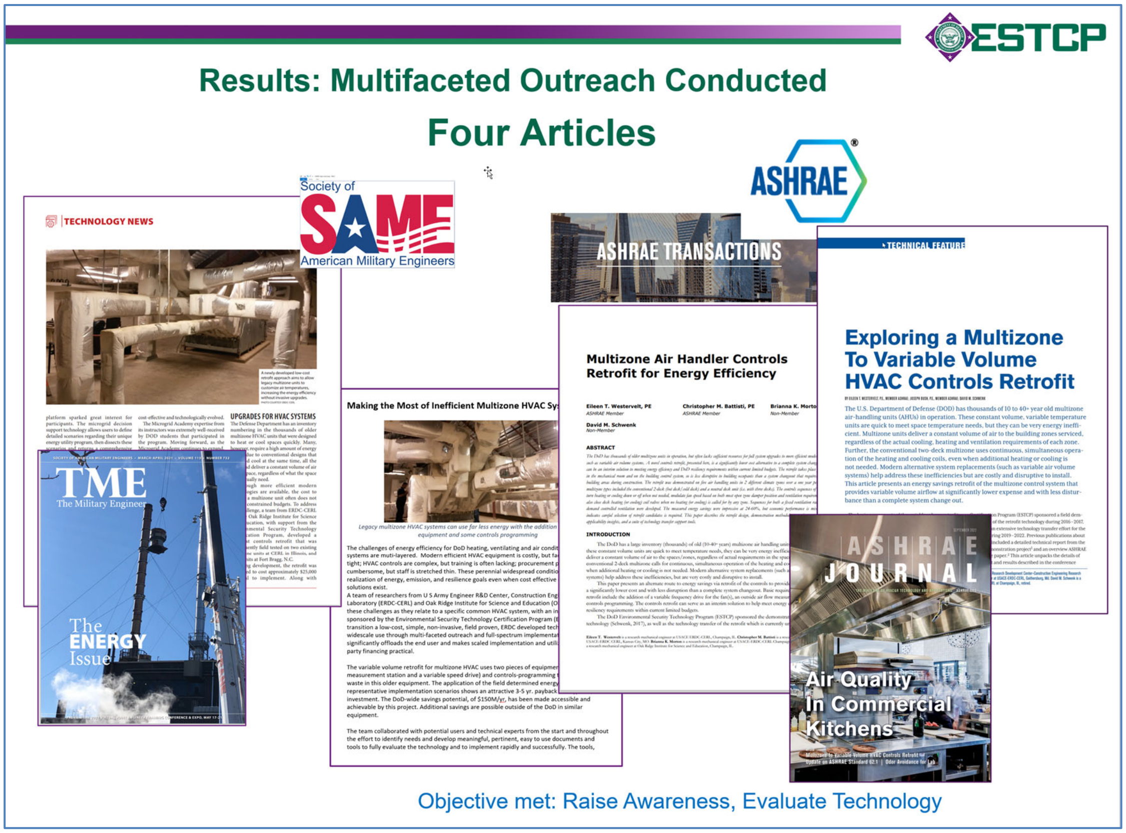

Figure 35: Four Outreach Articles

2.4.4 Potential User Contact

Leveraging the demonstration phase identification of parties interesting in learning more about the technology, the project team contacted the offices of the forty-three interested people from the demonstration project survey to introduce the technology, provide links to the documents and tools and offer follow-on discussion. The team also contacted parties that had identified themselves as interested in the technology from the assorted presentations and articles, and parties recommended by primary contacts. Over ninety people were contacted. The group represented primarily energy and building managers from military installations, but also included HVAC controls contractors and HVAC retrocommissioning providers.

The team made additional contacts to the military installations in this group to grain additional insights on their systems, needs, priorities, interest in moving forward with technology adoption, desired assistance and barriers to implementation.

2.4.5 Document Posting

The implementation support products of this project (totaling 47 documents) were posted on the *Whole Building Design Guide* website for ready access by potential implementers, https://www.wbdg.org/ffc/army-coe/design-guides/mz-vv-hvac-controls-retrofit. See Figure 36.

Although other websites were originally considered for duplicate postings, the team determined that posting on multiple sites would introduce undesirable quality control issues. Instead, publication notices were sent to energy managers and pertinent media (including ESTCP).

WBDG Whole Building Design Guide

LOGIN CREATE ACCOUNT SEARCH

DESIGN RECOMMENDATIONS | PROJECT MANAGEMENT - O & M | FEDERAL FACILITY CRITERIA | CONTINUING EDUCATION | ADDITIONAL RESOURCES

ARMY - COE / DESIGN GUIDES / MULTIZONE TO VARIABLE VOLUME HVAC CONTROLS RETROFIT – DESIGN & IMPLEMENTATION SUITE

US Army Corps of Engineers®

Multizone To Variable Volume HVAC Controls Retrofit – Design & Implementation Suite

Date: 06-29-2022

This retrofit converts an existing constant volume multizone HVAC system (MZ–CV) to a variable volume (MZ–VV) system for increased energy efficiency. The technique makes limited changes in instrumentation and uses a novel control scheme to reduce fan speed and coil use when not needed. A demand controlled ventilation option also reduces ventilation when spaces are unoccupied. The retrofit is significantly less expensive and less disruptive than a full system change-out (to VAV). This retrofit can be an interim solution to meet energy reduction targets and accrue savings now while postponing large capital investment. Field demonstration found 24–60% energy savings at the air handler. Typical applications are expected to pay back in 3–5 yrs.

A suite of design and implementation support tools steps a potential user through technology evaluation, procurement, and performance verification. The files are numbered roughly in the probable order of use. Pertinent document formats (including PDF, Excel spreadsheet, Word document, PowerPoint, and AutoCAD drawing files (zipped)) allow rapid system analyses and development of procurement packages.

TITLE	DATE	VIEW
01- Multizone to Variable Volume Overview Fact Sheet	02-17-2022	PDF
02- Multizone to Variable Volume Technical Note	04-14-2022	PDF
03- Multizone to Variable Volume Savings Estimator	08-01-2022	XLSX
04- Multizone to Variable Volume Pitch Briefing	04-07-2022	PPTX
05- Multizone to Variable Volume Scoping Guide	04-05-2022	XLSX
06- Multizone to Variable Volume Design Guide with Performance Work Statement, Specifications Book, and Sequences of Operation	04-13-2022	DOCX
07- Multizone to Variable Volume Points Schedules	02-15-2022	XLSX
08.1- Multizone to Variable Volume Bypass Unit Controls Drawings	02-14-2022	PDF
08.2- Multizone to Variable Volume Conventional Unit Controls Drawings	02-14-2022	PDF
08.3- Multizone to Variable Volume Neutral Deck Unit Controls Drawings	02-14-2022	PDF
09- Multizone to Variable Volume Commissioning Guide	04-05-2022	XLSX
10.1- Multizone to Variable Volume Bypass Unit AutoCAD Drawings (12 files)	02-14-2022	DWG/ZIP
10.2- Multizone to Variable Volume Conventional Unit AutoCAD Drawings (12 files)	02-14-2022	DWG/ZIP
10.3- Multizone to Variable Volume Neutral Deck Unit AutoCAD Drawings (12 files)	02-14-2022	DWG/ZIP

A technology field demonstration was conducted, and these design and implementation technology transfer tools were developed by the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) under the DoD Environmental Security Technology Certification Program (ESTCP).

Retrofit Project Links

- ESTCP Multizone Variable Volume Retrofit Field Demonstration Project
- ESTCP Multizone Variable Volume Retrofit Technology Transfer Project
- Multizone to Variable Volume HVAC Control Retrofit Training

Federal Facility Criteria: Army - COE | Design Guides

Related Links

- U.S. Army Corps of Engineer Headquarters
- Centers of Standardization
- Model Request for Proposal (RFP)
- Tri-Services Sustainability Program

See the Department of Defense library for more information and criteria.

Participating Agencies

GSA NASA

Figure 36: Implementation Suite on WBDG

The team initiated potential inclusion of the developed control scheme into an applicable DoD Guide Specification. The team submitted a Criteria Change Request on the Whole building Design Guide to recommend potential inclusion of the developed MZ-VV control sequences in the Unified Facilities Guide Specification UFGS 23 09 93, *Sequences of Operation of HVAC Controls,* https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs/ufgs-23-09-93. See Figure 37. Feedback from the Specifications and Criteria group indicated that the targeted guide specification is scheduled for update by the tri-services in the next few years and the group will consider if this addition is appropriate.

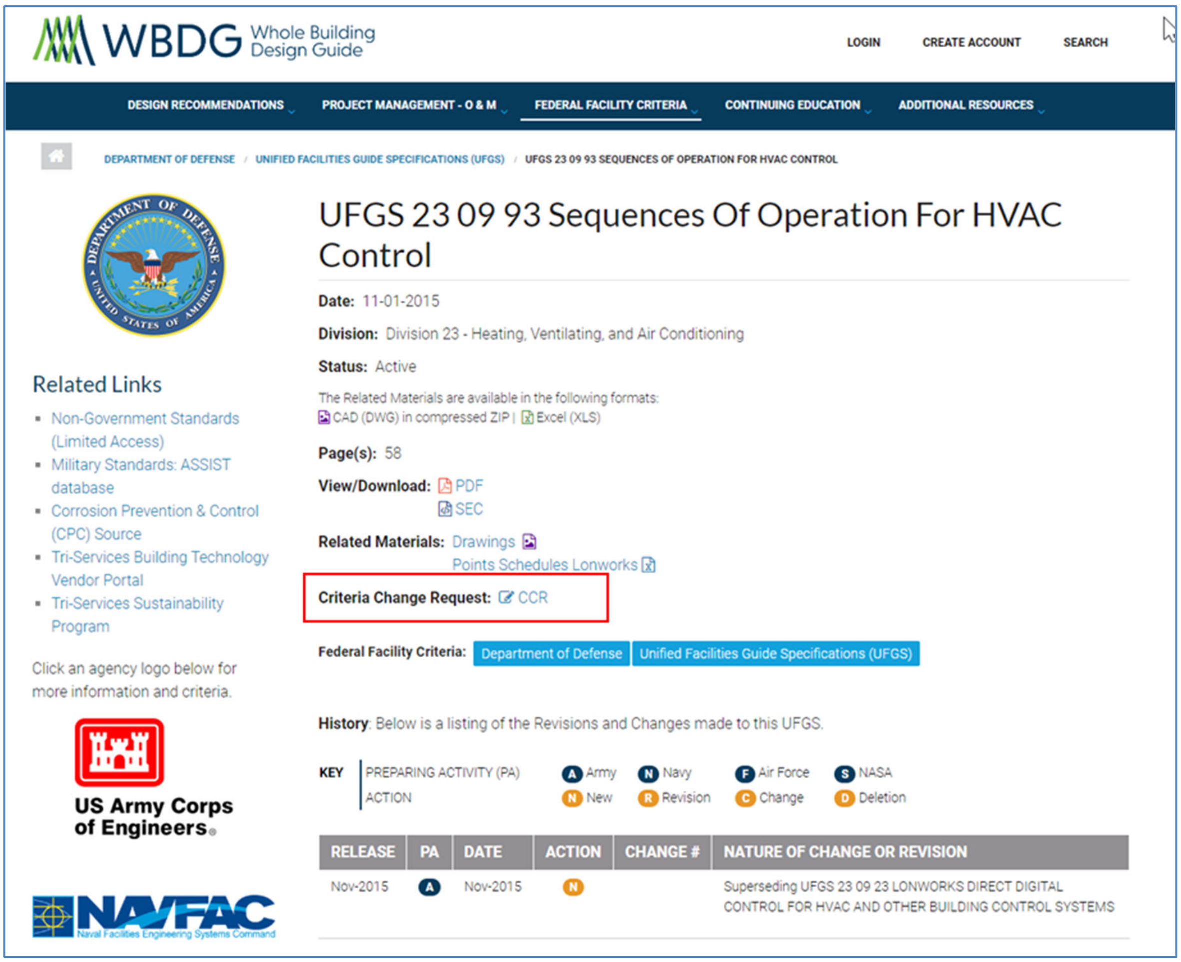

Figure 37: Criteria Change Request on WBDG

2.4.6 Social Media

Notifications of the project and available implementation resources were posted from LinkedIn personal profiles and LinkedIn groups for: the Association of Energy Engineers, SERDP-ESTCP, the Building Commissioning Association and ASHRAE. A notification was also posted on the SERDP-ESTCP Facebook page. Website statistics that were available to the project team show over 6.5K views, and 30 positive reactions ("likes" or "applause"). The largest exposure occurred on the Association of Energy Engineer's group page, which is targeted to building energy professionals. See Figure 38.

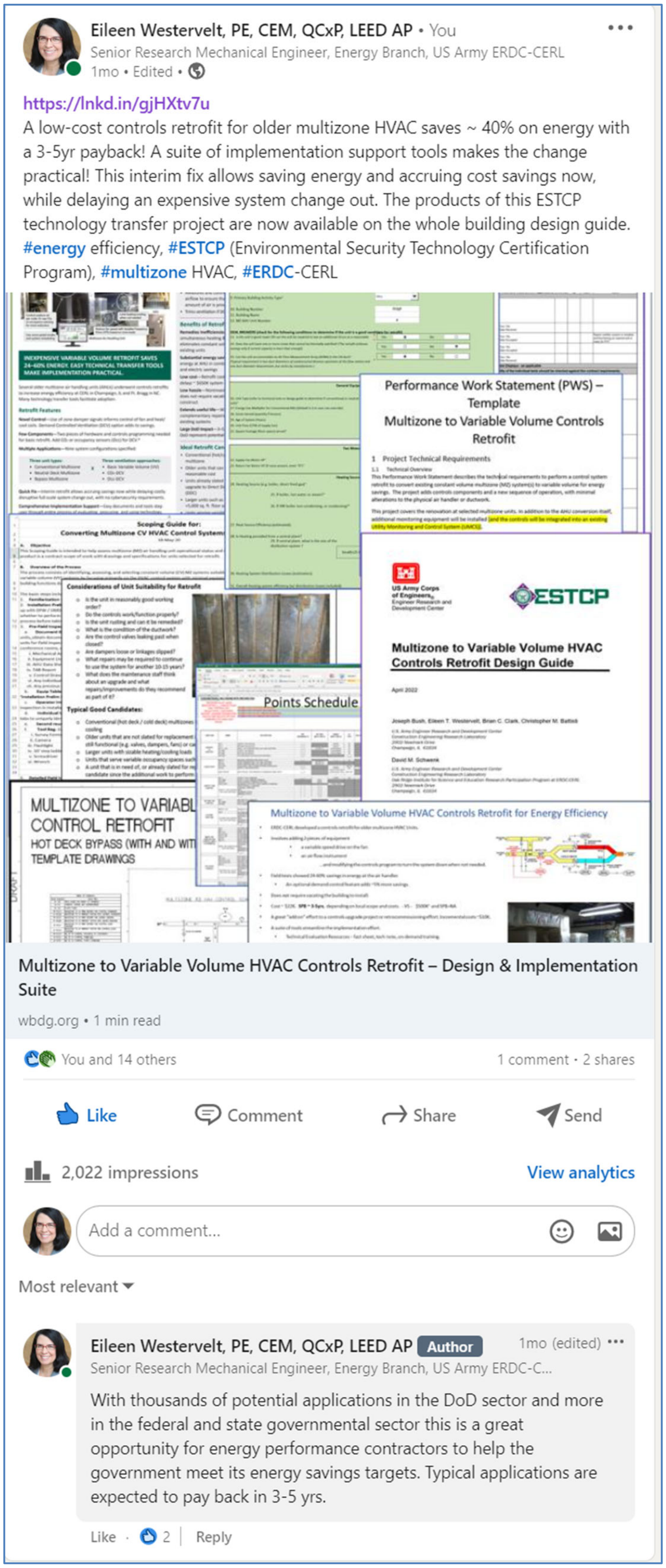

Figure 38: LinkedIn Posting

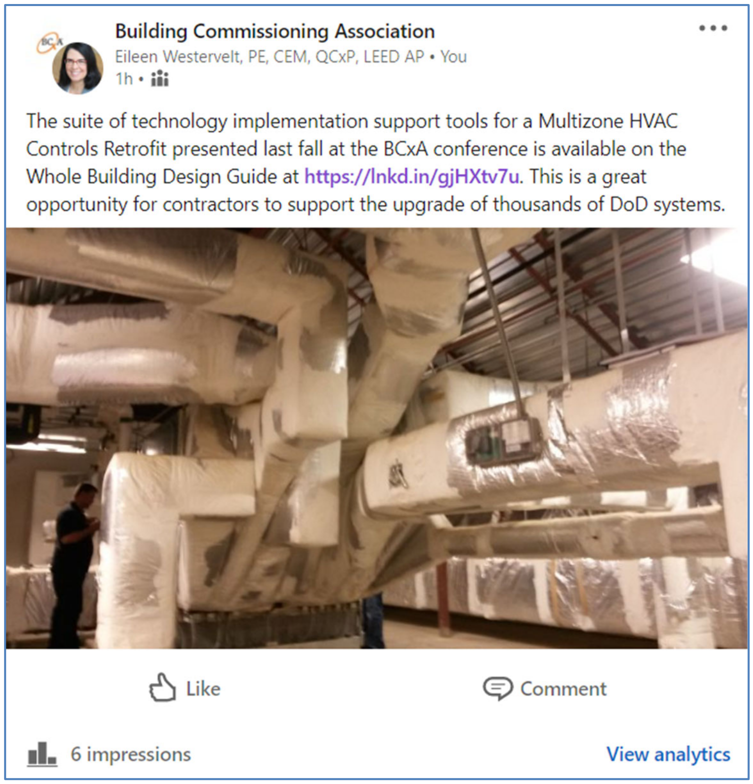

Figure 39: Additional LinkedIn Posting

2.5 DEVELOPMENT OF TYPICAL RETROFIT ENERGY AND COST IMPACTS

The demonstration units did not have typical thermal loading because the Conventional units at CERL served entirely interior zones (did not have building shell effects of outside walls, etc.) and the Neutral Deck units at Ft. Bragg had conservative room temperature setpoints (68°F heating, 74°F cooling) that limited the heating and cooling provided.

To support understanding of the retrofit's saving potential, the team applied the field results to typical applications. This modeling used the experimental energy improvement along with expected multizone HVAC energy requirements for an office building averaged over three climate zones with average costs for energy, equipment, and labor. CBECS was used as a source of typical heating/cooling/ventilation requirements by building activity and climate zones. Adjustments were made for the simultaneous heating and cooling of the conventional units. The typical impact presented below represent averages of mixed /humid and cold/very cold climates with US average construction and fuel costs. Typical conditions include a 10 yr. life cycle, a campus of less than 10 buildings served by the central plant, and air-cooled chillers.

The results were very promising, with a 3-5yrs SPB of investment for typical applications. See **Error! Reference source not found.**. Site specific estimates for particular applications can be developed with the Savings Estimator tool.

Table 2: Economic Impact of Retrofit for Typical Applications

AHU Unit	**Incremental Retrofit Cost ($)**	**Baseline Utility Cost Pre-Retrofit ($)**	**Energy Savings ($/Yr)**	**NPV ($)**	**SPB (Years)**	**SIR**
Typical Conventional MZ in good shape (had equipment schedules)	$10K	$7,100	$2,900	$16K	3.4	2.6
Typical Conventional w/ RCx (had no equipment schedules)	$14K	$10,000	$4,900	$29K	2.8	2.6
Typical Neutral Deck MZ in good shape (had equipment schedules)	$10K	$2,800	$1,900	$6K	5.3	1.6
Typical Neutral Deck MZ w/ RCx (had no equipment schedules)	$14K	$4,200	$3,100	$12K	4.5	1.9

Notes: Office space. Building size=3600sf. Supply fan size = 5HP. Production efficiency corrections for hot water load: distribution losses = 2%, boiler efficiency = 80%. Production efficiency for chilled water load: 1.2kW/ton air cooled. Real discount rate = 3%, life of retrofit=10yrs, Blended energy costs used. Electric unit cost =$0.1054/kwh. Natural Gas unit cost =$0.7213/therm.

2.6 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY TRANSFER METHOD

2.6.1 Advantages

This effort provides a decidedly more deliberate, collaborative, and expansive approach to technology transfer than many public sector research efforts that concentrate on technical outcomes. This work picks up the admirable work of the demonstration team and attempts to bridge the gap between the experimental findings and scientific explanations, and real-world implementation. It makes the work accessible and pertinent to the military installation implementer accommodating their limited time, money, and depth of familiarity with HVAC equipment controls.

The resulting implementation products distill technical documents into manageable summaries, bulleted list, and tables as asked for by building operators.

The discussions with an assortment of practitioners produced application insights that were captured for the potential technology user.

The development of the savings estimator led to deeper understandings of how the field demonstration calculations captured the energy impact of the technology upgrade but did not represent typical use applications. The extrapolation of experimental results to typical facility application scenarios shows the variable volume technology as significantly more promising economically than originally presumed by the field tests. Further, it allows an interested party to explore the economic impact of the retrofit given their local climate; costs of energy, materials, and labor; and specific facility end use. The multi-level calculations allow early screening approximations in addition to detailed cost estimates that reflect the full scope of the retrofit effort. The widespread options for user overrides of assumptions empower the user to easily adapt the tool as desired.

The template approach to the many procurement package tools provides speed of development with minimized tailoring for particular circumstances.

The ready access documents in usable form: Word documents, Excel spreadsheets, PowerPoint presentations and AutoCAD drawing files reduce the time and costs of implementation activities.

The method received enthusiastic reviews from multiple audiences and can be a model that inspires other efforts to maximize the use of proven technologies.

2.6.2 Limitations

The limitations of the technology transfer approach include the vast diversity of circumstance of potential retrofits, and the commencement of the technology transfer efforts only after the field demonstration was complete.

All retrofits are unique. Every multizone has its own history of maintenance and modifications, and specific physical configuration and access constraints of the building layout. The developed tools do not provide the full scope of insights needed for any particular application; local engineering judgment is still needed for success.

The extrapolated savings is based on a sample of five field demonstrations. No locations have comparable data sets for expansion of a performance data base. Metering energy flows is costly and time consuming.

The project did not complete design or secure funding for potential users. Those steps remain for the user to address.

The project was planned for a shorter than ideal duration. No budget was planned for on-going support. Implementation takes significant time in government facilities. The full impact of these efforts is not yet apparent.

3.0 TECHNICAL TRANSFER PERFORMANCE

This effort goes a long way toward moving the technology to a more mature state and adoption. It gets the word out, helps people understand the implications of the change, and provides the documentation and support products for the implementation, verification, and maintenance of the retrofit.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES AND ATAINMENT

A summary of the project performance objective and their attainment status is provided in **Error! Reference source not found.Error! Reference source not found.**. All objectives were met.

Table 3: Technical Transfer Project Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
TT Scope Development	Updated tasks and budget numbers	Input from a 10-15 % sampling of potential users. This equates to 4-5 energy managers.	60% satisfaction rating (score ≥ 3 out of 5), or actionable scope adjustment action items.	Avg 97% satisfaction score=4.8/5 **MET**
Reach out to Interested Parties	Satisfaction of Potential Users based on product technical content and ease of use	Feedback from 10% of the 43 interested users (4-5 users).	Responses from ≥ 10%, ≥50% (score of 2.5 out of 5) satisfaction from respondents.	7 respondents Avg 90% satisfaction score=4.5/5 **MET**
Qualitative Performance Objectives				
Develop Technical Description Documents	Acceptable/Unacceptable	Input from two potential users (energy mangers) for accessibility.	Acceptable review, or action items to make document acceptable. Publishing on appropriate website.	**MET**
Develop Procurement Package	Acceptable/Unacceptable	Input from two controls experts, one with intimate understanding of the project, and one new to the technology.	Acceptable review, or action items to make documents acceptable. Publishing on appropriate website.	**MET**
Develop Decision and Operations Support Tools	Acceptable/Unacceptable	Input from two interested energy managers	Acceptable review, or action items to make tools/documentation acceptable.	**MET**
Compose Journal Articles	Acceptable/Unacceptable	Assigned peer reviews. Acceptance/rejection and recommended changes/clarifications	Acceptance of peer reviewed article for publication by esteemed global professional association in HVAC.	**MET**

3.2 PROJECT PERFORMANCE OBJECTIVES DESCRIPTIONS

As was shown in **Error! Reference source not found.** above, there are six performance objectives for this technical transfer that are a mixture of quantitative and qualitative metrics. These performance objectives are described in detail in the following sub-paragraphs.

3.2.1 Technology Transfer Scope Development

Purpose: Review proposed tools and documentation with potential users, and adjust scope based on feedback to produce meaningful assistance to potential users. The proposed tools and documentation to be reviewed are the following:

- Fact Sheet
- Technical Note
- Field Scoping Guide
- Spreadsheet Estimator
- Procurement Support Tools (Design Guide, Specifications, Drawings, Sequence of Operation, Points & PWS Contracting Language)
- Commissioning Guidance

Metric: The metric is a usefulness rating.

Data: Interview/survey data is required to evaluate the proposed scope of work.

Analytical Methodology: Collect perspectives through interviews or surveys with energy managers and other potential users from military installations. Items under review will be given a 1-5 rating from each participant.

Success Criteria: 60% satisfaction rating, or actionable scope adjustment action items. **CRITERIA MET.**

3.2.2 Develop Technical Description Documents

Purpose: Gather feedback on technical description documents including the posters, technical note, fact sheet and pitch briefing.

Metric: The metric is a binary acceptability rating, acceptable or unacceptable.

Data: Review rating from two potential users.

Analytical Methodology: Gather perspectives and document reviews from potential users. Reviewed documents will be given an acceptable or unacceptable rating from each participant. Document will be revised until acceptable rating is achieved.

Success Criteria: Acceptable review, or action items to make documents acceptable. Publishing on appropriate website. **CRITERIA MET.**

3.2.3 Develop Procurement Package

Purpose: Gather feedback on developed Design Guide, Drawings, and Specification Templates, and sample contracting language for contracting out the retrofit.

Metric: The metric is a binary acceptability rating, acceptable or unacceptable.

Data: Review rating from two controls experts, one with intimate understanding of the project, and one new to the technology.

Analytical Methodology: Gather perspectives and document reviews from controls experts. Reviewed documents will be given an acceptable or unacceptable rating from each participant. Document will be revised until acceptable rating is achieved.

Success Criteria: Acceptable review, or action items to make documents acceptable. Publishing on appropriate website. **CRITERIA MET.**

3.2.4 Develop Decision & Operations Support Tools

Purpose: Gather feedback on developed Decision & Implementation Support Tools. Support tools for review include:

- Field scoping guide for use by energy managers of building operators to assess the operational status of their facilities and readiness for retrofit.
- Spreadsheet calculator to allow facilities personnel to review their particular circumstances for viability.
- Commissioning guidance.

Metric: The metric is a binary acceptability rating, acceptable or unacceptable.

Data: Review rating from two interested parties.

Analytical Methodology: Gather perspectives and document reviews from potential users. Reviewed documents/tools will be given an acceptable or unacceptable rating from each participant. Document will be revised until acceptable rating is achieved.

Success Criteria: Acceptable review, or action items to make documents/tools acceptable. Publishing on appropriate website. **CRITERIA MET.**

3.2.5 Compose Journal Articles

Purpose: As part of the communication of the technical transfer package, publish an article in a journal of a professional association in HVAC such as ASHRAE Journal. Additionally, the team will reach out to service journals as to expand impact.

Metric: The metric is a binary acceptability rating, acceptable or unacceptable.

Data: Acceptance by journal.

Analytical Methodology: Peer reviewed article process. Address concerns and recommendations of reviewers.

Success Criteria: Acceptable review, with publication. **CRITERIA MET.**

3.2.6 Reach out to interested parties

Purpose: As part of the communication of the technical transfer package, reach out to interested parties for review and feedback.

Metric: Satisfaction of Potential Users based on technical content and ease of use.

Data: Survey results.

Analytical Methodology: Input from a sampling of potential users.

Success Criteria: Greater than 10% response, greater than 60% satisfaction from respondents. **CRITERIA MET.**

3.3 TECHNOLOGY TRANSFER FEEDBACK

The project team determined the performance of the project through reviews by technical experts, and interviews and surveys with potential users of the implementation tools. The success of technology transfer depends on the accuracy and pertinence of the developed products and their accessibility and ease of use to stakeholders with varying technical knowledge.

There were emails, interviews and surveys with DoD stakeholders who were identified in the original demonstration project as well as well as newly identified interested parties to introduce the technology and implementation support tools and receive feedback.

Interactions reviewed the technology transfer products and asked for feedback on the utility of the products, how much they could facilitate their execution of the MZ to VV conversion, and what additional implementation support is desired.

The feedback from facility administrators and energy management staff at military installations on the implementation support tools is provided in Table 4. Reviewers were asked if they had looked at and used the tools, and their opinions on the quality and applicability of the individual tools by rating them between 1 and 5, with 5 being the highest score. Of those that responded, 6 of 7 had looked at the tools, one has already put them into use. The predominant opinion on the tools was that they are great. The overall average rating received was 4.5 of 5 or 90% of potential high score. One reviewer remarked that they thought the single slide Pitch Briefing would be the most important tool in the whole package to obtain buy-in and get funding with its short, sweet, and to the point presentation of essential ideas.

Table 4: Post Product Release Review

	Reviewer 1	Reviewer 2	Reviewer 3	Reviewer 4	Reviewer 5	Reviewer 6	Reviewer 7	Average
Fact Sheet	Looked at	Used, great, 5	Looked at, great, 5	Looked at, great, 5	Looked at, OK, 3	-	Looked at	4.5=90%
Technical Note	Looked at	Used, great, 5	Looked at, great, 5	Looked at, great, 5	Looked at, OK, 3	-	Looked at	4.3=86%
Savings Estimator	Looked at	Used, great, 5	Looked at, great, 5	Looked at, great, 5	Looked at	-	Looked at	5=100%
Pitch Briefing	Looked at	Looked at, great, 5	Looked at, great, 5 Most useful tool!	Looked at, great, 5	Looked at, OK, 3	-	Looked at	4.3 =86%
Scoping Guide	Looked at	Used, great, 5	Looked at, great, 5	Looked at, great, 5	Looked at, OK, 3	-	Looked at	4.3= 86%
Procurement Package Templates	Looked at	Used, great, 5	Looked at, great, 5	Looked at, great, 5	Looked at, OK, 3	-	Looked at	4.3=86%
Cx Guide	Looked at	Used, great, 5	Looked at, great, 5	Looked at, great, 5	Looked at, OK, 3	-	Looked at	4.3=86%

Table 5 presents the responses of the reviewers regarding the multizone equipment at their installation, their perceived overall usefulness of the suite of implementation tools, the merits of the retrofit, their implementation status, and plans.

The quantity of multizones reported was about 40 units per site, with them all being conventional (hot deck/cold deck) units. The repair needs of these units was described as minor to moderate. The type of controls of the units is predominately DDC with one location reporting a mixture of both DDC and pneumatic controls. The perceived usefulness of the implementation support tools was strong, with an average score 3.6 of 4 or 90% of the highest rating. The perceived merits of the retrofit ranged from OK (3 points) to great (5 points), with an average score of 3.8 of 5 or 77% of the highest rating. Five of six of the respondents (83%) state that they plan to continue to investigate the retrofit. Regarding their stage of implementation of the retrofit, five reported that they are interested in investigating. Of the remaining two respondents, one stated that they are in the familiarization and socializing stages, the other reported that they are seeking funding. When responding to the question regarding what they need to proceed with implementation, the most common response was funding, additionally time to investigate and leadership approval were also mentioned. Three respondents reporting expectation or plan to seek third party financing with ESPCs or UESCs, two reported expecting to seek ERCIP funds, and two reported expecting to seeking SRM funds.

Table 5: Post Product Release Survey/Interview

	Reviewer-1	Reviewer-2	Reviewer-3	Reviewer-4	Reviewer-5	Reviewer-6	Reviewer-7	Average /Summary
Number of Units	41-50 Conv	91-100 Conv	11-20 Conv	31-40 Conv	Not sure	Not sure	5 conv	38/site
Repair Needs	Minor	Minor	Moderate	Don't know	-	-	moderate	Minor-moderate
Type of Control	DDC	DDC	Mix of DDC & pneumatic	DDC	-		Don't know	DDC
Perceived usefulness of tools	Some help 3	Significant help 4	Significant help 4	Significant help 4	Some help 3			3.6/4 = 90%
Perceived merits of retrofit	OK. Fan savings looks promising. Already shut off decks seasonally. 3	Great. I propose retrofits in energy audits when applicable. 5	Great. 5	Good 4	OK, 3	OK 3	Good 4	3.8/5 = 77%
Will you continue to investigate?	yes	yes	yes	yes	no	-	yes	5/6-83% yes, 1/6=17% no
Stage of use	Interested	Seeking Funding	Familiarization, Socializing	Interested	Interested	Interested	Interested	5 interested, 2 farther along
What do you need?		Funding	Time to investigate, funding.	Leadership approval, funding	-	-	-	Funding, time, approval
How to fund?	SRM (ERCIP tends to fund micro-grids)	ERCIP, ESPC, UESC	SRM, ESPC, UESC	ERCIP, ESPC, UESC	-	-	-	ESPC/UESC-3 ERCIP/SRM -2

The project met all performance objectives by obtaining acceptable review and constructive feedback from pertinent reviewers throughout the process of scope development, composition of technical description documents, development of the procurement support package, creation of decision and operations support tools, authoring journal articles, giving presentations and training, and conducting outreach to interested parties.

Each presentation, article published, call, email and posting resulted in new interest in the technology and the implementation documents and tools, and new collaborators to review the products. As of the publication of this report:

- Many people asked to be notified when the suite of implementation tools was published.
- The WBDG document suite webpage has had over 450 visitors and ~400 downloads of project related documents, the social media postings had over 9K combined views, and 60 combined positive reactions.
- One attendee at the ESTCP symposium asked if they could have this process applied to other technologies to foster implementation.
- One installation had about a half dozen staff attend a training presentation.
- One USACE PROSPECT course instructor plans to cover the technology and tools in the PROSPECT 327 HVAC Commissioning course. They were provided PowerPoint slides to support this.
- One HVAC Consultant reported that they used the estimator as a preliminary scoping tool and the basis of recommended retrofit of thirteen government multizone units.
- One IMCOM supervisor for eleven installations sent the fact sheet and document suite link to all their installations asking for a preliminary feasibility screening at sites with multizones.
- One NAVFAC supervisor asked for a group webmeeting to review the project with potential implementors, and a quadchart technology summary to post on their technical innovation SharePoint.
- The BCxA presentation provided scoring by 31 participants and received a 4.7/5.0 overall average score.
- A college professor attendee at the BCxA remarked that this is` an excellent technology to apply during retrocommissioning of existing buildings to optimize energy performance.
- GSA asked for a meeting to review the retrofit process
- A utility company efficiency program service provider plans to use the tools.

Numerous enthusiastic reviews were received including the following:

"I just wanted to say how cool this [project] is. I think it is a really good model for how to build resources that provide a practical way for folks to do some good out there. This is so well done. Thanks for all your efforts on it."

"Wow, more than I expected, great job and looking forward to using the tool[s]!"

"Excellent presentation with details of the multizone AHU retrofit, controls strategies, energy and cost savings, and a link to additional resources that anyone can use for future retrofits."

"Great discussion about the potential energy savings. Valuable insight with the experimental data collected!"

"Good data and example retrofit options with valuable savings possibilities."

"This presentation was excellent! I have an application currently where the solutions presented would have been a much more viable interim solution than what the designers have implemented. I look forward to exploring this more on the website. I am looking forward to reviewing this presentation once again when available on demand."

"I have used the Estimator to analyze 13 MZAHUs for a Municipal Transit Authority. I found the [savings estimator] workbook quite easy to use and the documentation well prepared."

"Seems like a great solution for equipment that it's either cost prohibitive to replace and/or the equipment is still in good condition, and it would seem wasteful to rip it out and replace it."

"I was there for your presentation and really enjoyed it. In particular, I thought the kit you folks put together to help others assess the possibility and then implement and commission the improvement is really cool. The industry really needs more of that for sure."

"The air handler control retrofit looks like a promising way to save energy dollars."

"The tools are everything needed to put together and manage a retrofit project."

"These tools are really great! Very helpful for developing energy projects for our multizone systems."

"I propose retrofits in energy audits when applicable."

By all accounts, the assorted feedback on the project was very positive and hopeful regarding implementing the variable volume retrofit, with many stating interest in continuing to explore and several taking action to proceed.

4.0 COST ASSESSMENT

The cost assessment of this technology transfer project is a review of the cost benefit of conducting this work. The objective of this project is to further the adoption of the multizone variable volume retrofit technology that was previously demonstrated in an earlier ESTCP project. The cost of the current project is given with a cost breakout by task. A discussion of the value added by the technology transfer effort is provided along with observations on the relative cost.

4.1 COST ESTIMATE

This technology transfer project cost $310K. The estimate for the project labor and costs broken out by tasks is given in

Task		Labor Hours	Cost	% Cost
Product Development	Scope Development	25	$ 3,200	1%
	Technical Description Documents (Posters, Technical Note, Fact Sheet, Pitch Briefing)	175	$ 30,000	10%
	Decision Support: Field Scoping Guide	115	$ 18,000	6%
	Decision Support: Estimator	250	$ 40,000	13%
	Procurement Support (Design Guide, Contacting Templates)	180	$ 26,000	8%
	Operations Support (Commissioning Guide)	80	$ 14,000	5%
	QC of Product Suite	120	$ 20,000	6%
Outreach	Presentations & Training (7)	240	$ 40,000	13%
	Articles (4)	170	$ 28,500	9%
	Contacting Users, Posting	280	$ 45,000	15%
	Report Prep	85	$ 13,300	4%
Mgt	Project Management	180	$ 32,000	10%
	Total	1900	$ 310,000	100%

Table 6.

It is estimated that the project team spent about half, 49%, of the project funds on developing the documents and tools previously described. Development tasks included interviewing potential users to adjust the scope of the project to their needs; composing, checking, and improving products; acquiring and incorporating reviewer feedback; and a quality control review of the implementation support suite. Team members visited two demonstration sites to view how the original demonstrations are operating and to interview stakeholders on the operation. There were limited expenses for travel and printing.

The outreach process of this project is estimated to have cost about 41% of the funding and included presenting to technical conferences, writing technical articles, producing on-line training, reaching out to interested parties, providing potential users with implementation insights, and coordinating the posting of documents for public use. The project management is estimated to have cost about 10% of the funding.

Table 6:Task Labor and Cost Breakdown Estimate

Task		Labor Hours	Cost	% Cost
Product Development	Scope Development	25	$ 3,200	1%
	Technical Description Documents (Posters, Technical Note, Fact Sheet, Pitch Briefing)	175	$ 30,000	10%
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Mgt	Project Management	180	$ 32,000	10%
	Total	1900	$ 310,000	100%

4.2 COST ANALYSIS AND COMPARISON

The previous project conducted a technology demonstration test of five systems and produced a detailed technical report that showed significant technical merit of the retrofit but with mixed economic returns. The previous project also initiated many technical transfer efforts. It began development of technical transfer documents but did not vet them with potential users. It began identification of interested parties but was not able to offer implementation support. For context of the relative cost observation below, the technology development and field demonstration project cost $1,564K.

The current technology transfer work picks up where the last project left off. The demonstration project output was refined and augmented. The improved and expanded implementation support tools were vetted with industry experts and potential users. Multifaceted outreach to prospective implementers was conducted.

This technology transfer effort provides many benefits for the DoD and for installing contractors. A major value added by the technology transfer project is development of estimates of the typical economic impact of the retrofit which are very favorable. This is an insight not sought by the field demonstration effort. The technology transfer effort also established the means for applying the experimentally derived savings of the field demonstration to the specific circumstance of potential users. Further, its standard approach and tools for implementation provides cost savings to the installation and its contractors in the process of applying the technology and increases the likelihood of quality retrofit execution and successful operation. The outreach was very well received, and many people are taking action to implement the retrofit with investigations, feasibility screenings, proposals, and search for funding. These are implementation actions that took place because of the dedicated technology transfer of this project beyond what the demonstration project was able to accomplish.

To assess the relative cost of the technology transfer, two ratios are calculated, the technology transfer cost relative to the initial demonstration efforts, and the technology transfer cost relative to the annual energy savings.

The technology transfer effort costs 20% of the cost of the field demonstration ($310K/$1,564K=20% or 0.2 times the cost of the demonstration). To put this percentage into perspective, a related metric of comparison provided by the US Department of Commerce, Economic Development Administration (EDA) is that "commercialization costs between 10 and 100 times the cost of development and demonstration of a new technology" (EDA 2003, U.S. Department of Commerce, EDA. 2003. *Technology Transfer and Commercialization: Their Role in Economic Development*.) Here commercialization refers to the movement of an idea from the laboratory to the commercial market and creating value with it. This project did not require manufacture of equipment since the equipment is off the shelf. This fact reduces both the demonstration cost and the commercialization cost. This project has circumstances that reduce commercialization costs. It does not require management of intellectual property rights as its design has been published without qualification and is in the public domain. It does not attempt to put in place service providers. However, significant commercialization has been accomplished as significant financial value is added for both the implementer and the installer and risk is reduced for both by the decreased cost of project development resulting from thoroughly considered methods. In comparison to typical commercialization costs, the technology transfer cost is minimal.

The annual cost savings potential for the DoD due to the decreased energy use of the variable volume retrofit was estimated at $15,000K/yr agency-wide by the previous field demonstration project. The current technology transfer effort costs a fraction (2%) of one year of this potential savings that is expected to accrue as a benefit each year for the anticipated life of the retrofits ($310K/$15,000K =2%). Again, this minimal investment provides substantial benefit.

Based on the comparison of the cost of this technology transfer project to both typical commercialization costs and the quantitative and qualitative benefits accrued, the investment to support retrofit implementation is very reasonable and impactful. This effort positions the DoD for significant facility efficiency success.

5.0 IMPLEMENTATION ISSUES

The project team had its share of implementation issues, but they were all resolved satisfactorily.

The COVID pandemic, with its resulting travel restrictions and unoccupied buildings with remote workforce, changed the nature of the planned interactions with people and equipment. Instead of being a field intensive effort, with significant time in mechanical rooms, the team adapted to primarily virtual meetings, photos and videos of equipment, and heavy reliance on former field experience of the team members. This reduced the incidental discoveries that occur while viewing equipment in action in the context of its full system, as well as the fortuitous brainstorming that occurs with person-to-person interactions. It also limited the opportunity to mentor more junior staff in field operation. The pandemic also pulled team staff away in the early months to support the USACE response with recommendations on Alternate Care Sites. During the second year of the pandemic the team was able to visit the local demonstration site, converse with the equipment operators, and test the performance of equipment, but the overall extent of travel was less than the multiple sites that had been anticipated. The pandemic also resulted in cancellation of the team's first scheduled presentation at Energy Exchange, and a switch to a virtual presentation at the following year's conference. An adaptive, innovative team spirit met these challenges with resolve and succeeded in producing quality products.

The many collaborators required accommodations to their schedules, and this stretched out the project timelines. The benefits of multiple perspective were well worth the time.

After multiple attempts to use the demonstration data to model a typical multizone system, the project team realized that the former demonstration team was not asking the same questions as the current implementation team. The demonstration team calculated the energy and cost impact of the technology alone. It did not attempt to capture a typical annual multizone energy use by building type. Further, the demonstration was conducted at sites that were readily available and cooperative, not the most typical, average sites. Extrapolation of field data was required to apply the experimental results to other potential sites for implementation. The resulting length of time to develop a rigorous estimator was far longer than anticipated but resulted in a very adaptive estimating platform.

The *ASHRAE Journal* article peer review process was quite thorough and required significant time to address the many questions and recommendations of the multiple reviewers including a patent review of similar technologies. The end product, after a year and a half of effort, was a detailed and comprehensive review of the original technology and the technology transfer effort. The extended length, feature article will remain accessible and searchable through this established and esteemed organization for years to come.

The final suite of implementation support documents consisted of 47 documents produced and refined over the course of two and a half years. The on-going, often parallel review from internal team members, outside collaborators, and feedback from people who saw the multiple presentations and articles, led to considerable evolution of thought regarding the best way to describe and represent the work, and challenges with versioning control of these inter-related documents. Careful, meticulous review of documents with cataloging of issues, impacted documents and resolution status led to an integrated, harmonized suite of resources.

The interested parties that were identified in the demonstration project have changed. The identification of current people in the energy manager roles at specific installations was time consuming and required multiple avenues of approach. Methods included reaching out to all business contacts, obtaining Army energy manager lists from AWERS, web searches of organizations and installations for contact information, and connecting with many people on LinkedIn in the Navy and Air Force to find someone with the needed personnel information.

6.0 CONCLUSION

This technology transfer effort is a significant step toward reaping the benefits of a field proven technology in the DoD. The work made the field demonstrated technology accessible to potential implementers that have limited time, budget, or detailed knowledge of controls. The developed full-spectrum implementation tools support a potential user through entire process of evaluating, implementing, and using the technology. The application of the experimentally determined energy improvement on typical buildings showed expected paybacks of 3-5 yrs. The multi-faceted outreach efforts have been well received by DoD, industry, and academia. Many people have received and reviewed the documents and tools, and several are taking action. Some have used or plan to use the Savings Estimator. Others have initiated feasibility review or are in the process of socializing the retrofit or seeking funding. The MZ-VV technology is a cost-effective interim solution to accrue savings and meet energy reductions goals. The overall process of product implementation support that off loads the end user as much as possible can be a model for promoting other promising technologies.

7.0 PUBLICATIONS

Westervelt, E., Battisti, C., Morton, B., and D. Schwenk, Feb 2021. *Multizone Air Handler Controls Retrofit for Energy Efficiency,* ASHRAE Transactions – 2021 Virtual Conference, Vol 127, Part 1, VC-21-C009.

Westervelt, E., and C. Battisti, Mar 2021. *Upgrades for HVAC Systems.* The Military Engineer, Pgs. 50-51. https://samenews.org/tme-march-april-2021/

Bush, J., Westervelt, E, Clark, B., Schwenk, D., Battisti, C., Morton, B., and H. FitzHenry, June 2022. *Multizone to Variable Volume HVAC Controls Retrofit – Design and Implementation Suite*. Whole Building Design Guide, https://www.wbdg.org/ffc/army-coe/design-guides.

This 47-document suite includes:

01- Multizone to Variable Volume Overview Fact Sheet
02- Multizone to Variable Volume Technical Note
03- Multizone to Variable Volume Savings Estimator
04- Multizone to Variable Volume Pitch Briefing
05- Multizone to Variable Volume Scoping Guide
06- Multizone to Variable Volume Design Guide with Performance Work Statement, Specifications Book, and Sequences of Operation
07- Multizone to Variable Volume Points Schedules
08.1- Multizone to Variable Volume Bypass Unit Controls Drawings
08.2- Multizone to Variable Volume Conventional Unit Controls Drawings
08.3- Multizone to Variable Volume Neutral Deck Unit Controls Drawings
09- Multizone to Variable Volume Commissioning Guide
10.1- Multizone to Variable Volume Bypass Unit AutoCAD Drawings (12 files)
10.2- Multizone to Variable Volume Conventional Unit AutoCAD Drawings (12 files)
10.3- Multizone to Variable Volume Neutral Deck Unit AutoCAD Drawings (12 files)

Westervelt, E., Bush, J., and D. Schwenk, September 2022. *Exploring a Multizone to Variable Volume HVAC Controls Retrofit*. ASHRAE Journal, Vol. 64, No. 9 pgs. 32-47.

Westervelt, E. and J. Bush, Mar 2023. *Making The Most of Inefficient HVAC Systems*. The Military Engineer. https://www.same.org/tme-the-military-engineer/

8.0 REFERENCES

Schwenk, D. (2017). *Converting Constant Volume, Multizone Air Handling Systems to Energy Efficient Variable Air Volume Multizone Systems*. Retrieved from https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201152

APPENDIX A: POINTS OF CONTACT

Table 7: Points of Contact

Point of Contact	Organization	Phone & E-mail	Role in Project
Eileen Westervelt	ERDC-CERL	(217) 373-6756, Eileen.T.Westervelt@usace.army.mil	Principal Investigator
Joseph Bush	ERDC-CERL	(217) 373-4433 Joseph.Bush@usace.army.mil	Co-Principal Investigator
Chris Battisti	ERDC-CERL	(217) 373-3345, Christopher.M.Battisti@usace.army.mil	Co- Principal Investigator