



FINAL REPORT

Comprehensive Information Transfer Approaches for Advanced Building Controls and Management Projects

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TABLE OF CONTENTS

	Page
ABSTRACT	VII
EXECUTIVE SUMMARY	ES-1
1.0 INTRODUCTION	1
1.1 BACKGROUND	1
1.2 OBJECTIVES	1
2.0 TECHNOLOGY DESCRIPTION	3
2.1 TECHNOLOGY OVERVIEW	3
2.2 TECHNOLOGY DEVELOPMENT	5
2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY	8
3.0 PERFORMANCE OBJECTIVES	9
3.1 SUMMARY OF PERFORMANCE OBJECTIVES	9
3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS	10
4.0 PROJECT DESIGN	13
4.1 PROJECT PHASES	13
4.2 SAMPLING PROTOCOL	14
5.0 PERFORMANCE ASSESSMENT	16
6.0 COST ASSESSMENT	21
6.1 COST MODEL	21
6.2 COST ANALYSIS AND COMPARISON	21
7.0 IMPLEMENTATION ISSUES	23
8.0 REFERENCES	24
APPENDIX A POINTS OF CONTACT	A-1
APPENDIX B A SAMPLE SURVEY QUESTIONNAIRE	B-1
APPENDIX C A SAMPLE SURVEY RESULT SUMMARY	C-5
APPENDIX D TASK 2 TRAINING TOPICS FOR ENERGY MANAGERS	D-1
APPENDIX E TASK 3 TRAINING TOPICS FOR FACILITY ENGINEERS	E-1
APPENDIX F TRAINING DELIVERY MECHANISMS	F-1
APPENDIX G TRAINING MARKETING AND OUTREACH	G-1
APPENDIX H USACE CERL ASHRAE GUIDELINE 36 EVALUATION REPORT ...	H-1

LIST OF FIGURES

	Page
Figure ES-1. Technology Transfer Conceptual Design	ES-2
Figure ES-2. Comprehensive Technology Transfer Approach	ES-4
Figure 1. Technology Transfer Conceptual Design	3
Figure 2. Comprehensive Technology Transfer Approach	3
Figure A-1. A Screenshot of Slipstream LMS	F-1
Figure A-2. A Sample Synchronous Training at DoD Workshops	F-2
Figure A-3. A Sample ESTCP Project Fact Sheet.....	F-3
Figure A-4. Integrate Trainings on USACE RCx University.....	F-4
Figure A-5. Integrate Trainings on Whole Building Design Guide (WDBG)	F-5
Figure A-6. Integrate Short Courses on YouTube.....	F-5
Figure A-7. A Sample Project Webpage	G-1
Figure A-8. ESTCP Project Webpage and Webinar.....	G-2
Figure A-9. Social Media Sample 1	G-3
Figure A-10. Social Media Sample 2	G-4
Figure A-11. Social Media Sample 3	G-5
Figure A-12. Social Media Sample 4	G-6
Figure A-13. Social Media Sample 5	G-6
Figure A-14. Outreach through USACE RCx University	G-7
Figure A-15. Outreach through ESTP Blog	G-7
Figure A-16. Outreach through Industry Newsletter.....	G-8

LIST OF TABLES

	Page
Table ES-1. Training Topics and Delivery Mechanism for DoD Energy Managers	ES-2
Table ES-2. Training Topics and Delivery Mechanism for DoD Facility Engineers	ES-2
Table ES-3. ASHRAE Guideline 36 Review and Training for Stakeholders	ES-2
Table ES-4. ASHRAE Guideline 36 Recommendations	ES-3
Table ES-5. Performance Assessment.....	ES-5
Table ES-6. Cost Model	ES-6
Table 1. Training Topics and Delivery Mechanism for DoD Energy Managers	4
Table 2. Training Topics and Delivery Mechanism for Facility Engineers	4
Table 3. ASHRAE Guideline 36 Review and Recommendations	4
Table 4. Performance Objectives	10
Table 5. Data Collection Protocol	15
Table 6. Performance Assessment Results	17
Table 7. ASHRAE Guideline 36 Recommendation Types and Priorities.....	19
Table 8. ASHRAE Guideline 36 Recommendations Critical Update High Priority List	20
Table 9. Cost Tracking	21
Table 10. Cost Model	22
Table A-1. Point of Contact List.....	A-1
Table A-2. Task 2 Detailed Training Topics for Energy Managers	D-1
Table A-3. Task 3 Detailed Training Topics for Facility Engineers	E-1

ACRONYMS AND ABBREVIATIONS

AFDD	Automated Fault Detection and Diagnostics
AFIT	Air Force Institute of Technology
AMC	Army Materiel Command
ARNG	United States National Guard
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BACnet	Building Automation Control Network
BAS	Building Automation System
BTL	BACnet Testing Laboratories
CCR	Criteria Change Requests
CEC	California Energy Commission
CERL	Construction Engineering Research Laboratory
CUP	Commercial Utilities Program
CMS	Course Management System
DoD	Department of Defense
DPW	Directorate of Public Works
EPMO	Energy Performance and Monitoring Optimization
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EW	Installation Energy and Water
HVAC	Heating, Ventilation, and Air-Conditioning
IMCOM	U.S. Army Installation Management Command
LBNL	Lawrence Berkley National Lab
LMS	Learning Management System
NAVFAC	Naval Command
NIBS	National Institute of Building Sciences
NPS	Naval Post Graduate School
PNNL	Pacific Northwest National Laboratory
PO	Performance Objectives
PPP	Power Projection Platforms
PROSPECT	Proponent-Sponsored Engineer Corps Training Program
RCx	Retro-commissioning
RCxU	Retro-commissioning University
REM	Resource Energy Managers
TT	Technology Transfer

UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE	United States Army Corps of Engineers
USAR	United States Army Reserves
WBDG	Whole Building Design Guide

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ABSTRACT

Advanced building controls and energy management strategies could result in an average of nearly 30% energy savings. There is an industry-wide knowledge gap on how to utilize advanced controls to capitalize on energy savings and to ensure that buildings run at peak performance. Slipstream, in partnership with the U.S. Army Corps of Engineers (USACE), Texas A&M University, and TRC, developed a comprehensive training resource for disseminating building controls basics and advanced building controls concepts to DoD stakeholders.

This technology transfer project was to develop and deliver a comprehensive training resource for disseminating advanced building control concepts and applications to multiple target audiences. Key audiences include DoD installation and acquisition managers, DoD building design and commissioning engineers, facility engineers, and building operators. This training resource will be incorporated into and complement existing DoD training on HVAC system design, control, commissioning, and operation. It will also help promote the awareness and potential future adoption of the ASHRAE Guideline 36 “High-Performance Sequences of Operation for HVAC Systems” within the DoD.

We successfully developed 17 short courses for energy managers and 21 hour-long courses for engineers and facility operators. These courses are now available at Slipstream’s online Learning Management System (LMS), the Whole Building Design Guide (WBDG) website, and YouTube. Our team members also disseminated the training information by presenting at 11 industry workshops and events. In less than six months, these training resources have been accessed by 4,301 participants. On average, these training sessions have a satisfaction rating of 4.25/5 for the short courses and 4.07/5 for the hour-long courses. Lastly, USACE reviewed the ASHRAE Guideline 36 and recommended partial adoption of the guideline in the future version of the Unified Facilities Guide Specifications (UFGS). The cost for developing the short courses is approximately \$3,000 each. The cost of developing the longer courses is estimated at \$12,000 per session. The training resource can be accessed at the following webpage (<https://slipstreaminc.org/estcp>).

The major barrier was not being able to provide in-person training due to the COVID-19 pandemic.

Publications:

Vigliotta, et al., “A New Resource to Understanding Advanced Building Controls”, ACEEE Summer Study, August 2022.

Vigliotta, et al., “Understanding How Building Controls Can Save Energy”, Facilitiesnet.com, February 2022.

EXECUTIVE SUMMARY

INTRODUCTION

A recent PNNL study indicated that building controls and energy management play a prominent role in commercial building energy performance and peak load reduction and could result in an average of 29 percent energy savings. Several past completed ESTCP projects in this technical area demonstrated that both energy savings and short simple payback periods can be achieved. Lessons learned are summarized in the final reports, but more comprehensive training on building control fundamentals and advanced building control concepts are needed to bridge the knowledge gap reported by these principal investigators. The purpose of this technology transfer project was to develop and deliver a comprehensive training resource for disseminating advanced building control concepts and applications to multiple target audiences. This technology transfer effort will be incorporated into and complement existing DoD training on HVAC system design, control, commissioning, and operation. It will also help promote the awareness and potential future adoption of the ASHRAE Guideline 36 “High-Performance Sequences of Operation for HVAC Systems” within the DoD. The training resource can be accessed at the following webpage (<https://slipstreaminc.org/estcp>).

OBJECTIVES

The goal of the project is to produce and deliver a comprehensive training and education resource that is effective for disseminating advanced building control concepts and applications to multiple target audiences across all DoD services. Key audiences include DoD installation and acquisition managers, DoD building design and commissioning engineers, facility engineers, and building operators. The project consisted of the following primary objectives:

- Inform DoD installation and acquisition managers about building control fundamentals, advanced controls concepts, the principles of operations, and the general cost-effectiveness of the most common control strategies.
- Educate and train DoD design and commissioning engineers, facility engineers, and building operators on building control fundamentals and concepts, common advanced control strategies, intelligent building operation and advanced energy performance monitoring, continuous commissioning, and re-tuning.
- Promote the awareness and potential future adoption of the ASHRAE Guideline 36 within DoD and across the industry. This new guideline provides detailed best-in-class control sequences that are supported through ASHRAE-funded research.

TECHNOLOGY OVERVIEW

The comprehensive technology transfer approach addresses the three defined objectives. For each different audience, we tailored our trainings to be most effective for that group. Figure ES-1 shows the conceptual design of the project. Table ES-1 to Table ES-3 summarize the training topics, targeted audiences, and training delivery mechanisms.

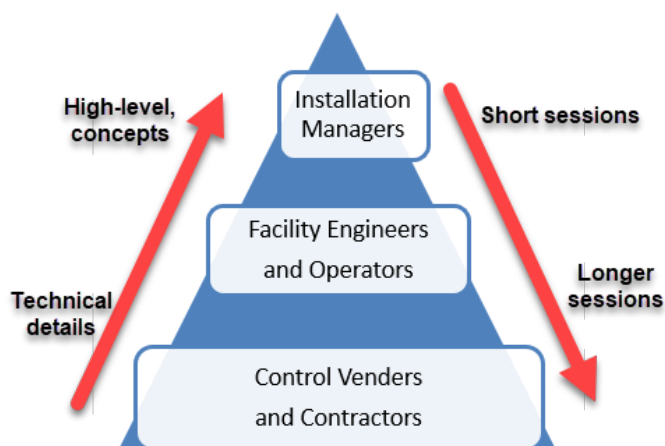


Figure ES-1. Technology Transfer Conceptual Design

Table ES-1. Training Topics and Delivery Mechanism for DoD Energy Managers

Module	Topic	Number of Sessions	Delivery
1	Fundamentals of Building Control Systems	4	Short 15-min webinar series, fact sheets, live technical courses, seminars/workshops at SERDP-ESTCP Symposium and DOE Energy Exchange.
2	Common Advanced Control Strategies	7	
3	Energy Modeling, Intelligent Building Operation and Advanced Energy Performance Monitoring	2	
4	Four ESTCP Demonstration Projects	4	

Table ES-2. Training Topics and Delivery Mechanism for DoD Facility Engineers

Module	Topics	Number of Sessions	Delivery
1	Fundamentals of Building Control Systems	5	Hour-long online courses, live technical courses with Q&A sessions, and virtual training at symposiums, conferences, and workshops.
2	Common Advanced Control Strategies	7	
3	Energy Modeling, Intelligent Building Operation and Advanced Energy Performance Monitoring	3	
4	Four ESTCP Demonstration Projects	4	
5	Existing Building Commissioning	2	

Table ES-3. ASHRAE Guideline 36 Review and Training for Stakeholders

#	Topic	Performer	Delivery
1	Review Guideline 36 sequences for potential future inclusion in UFGS 23 09 13	USACE CERL	Recommendations on if Guideline 36 sequences are appropriate for future UFGS 23 09 13

The four ESTCP Energy and Water demonstration projects in the training include:

- **EW-201408:** Demonstration of Energy Savings in Commercial Buildings for Tiered Trim and Respond Method in Resetting Static Pressure for VAV Systems.
- **EW-201142:** Energy Performance Monitoring and Optimization System for DoD Campuses.
- **EW-201015:** Scalable Deployment of Advanced Building Energy Management Systems.
- **EW-201152:** Controls Retrofit of Multizone HVAC Unit for Energy Efficiency

In the Common Advanced Control Strategies module, ASHRAE Guideline 36 is introduced, and field demonstration preliminary results are summarized based on a demonstration project done in California. USACE CERL also reviewed the ASHRAE Guideline 36. The review resulted in 40 total recommendations that target potential HVAC controls and associated front-end system updates of three Unified Facilities Criteria (UFC) documents and five Unified Facility Guide Specifications (UFGS). CERL recommendation counts by type and priority are summarized in the following Table ES-4.

Table ES-4. ASHRAE Guideline 36 Recommendations

Recommendation Type	Priority			Total
	High	Medium	Low	
Critical Update	11	9	2	22
Additional Research	8	6	4	18
Grand Total	19	15	6	40

The DOE Energy Exchange and DoD ESTCP Symposium were our primary virtual training venues for energy managers because many of them attend these two events. DOE Energy Exchange, DoD ESTCP Symposium, and workshops organized by REM, IMCOM, and USACE on retro-commissioning were incorporated for engineers and facility operator virtual training events. Below is a list of all of the workshops where we presented our training resources.

- 2020 & 2021 DOE Energy Exchange (virtual)
- 2020 & 2021 ESTCP Symposium (virtual)
- 2021 SERDP-ESTCP Webinar Series: Improving Energy Efficiency through Advanced Building Controls (virtual)
- 2021 & 2022 Resource Efficiency Manager (REM) Workshop (virtual)
- 2022 Building Operating Management's National Facilities Management & Technology Conference (in-person)
- 2022 DoD Community of Practice Workshop (virtual)
- 2022 ACEEE Summer Study poster presentation (in-person)
- 2022 Wisconsin Association of Energy Engineers Energy Efficiency Expo (in-person)

Figure ES-2 illustrates our comprehensive technology transfer approach that depicts several education and outreach strategies.

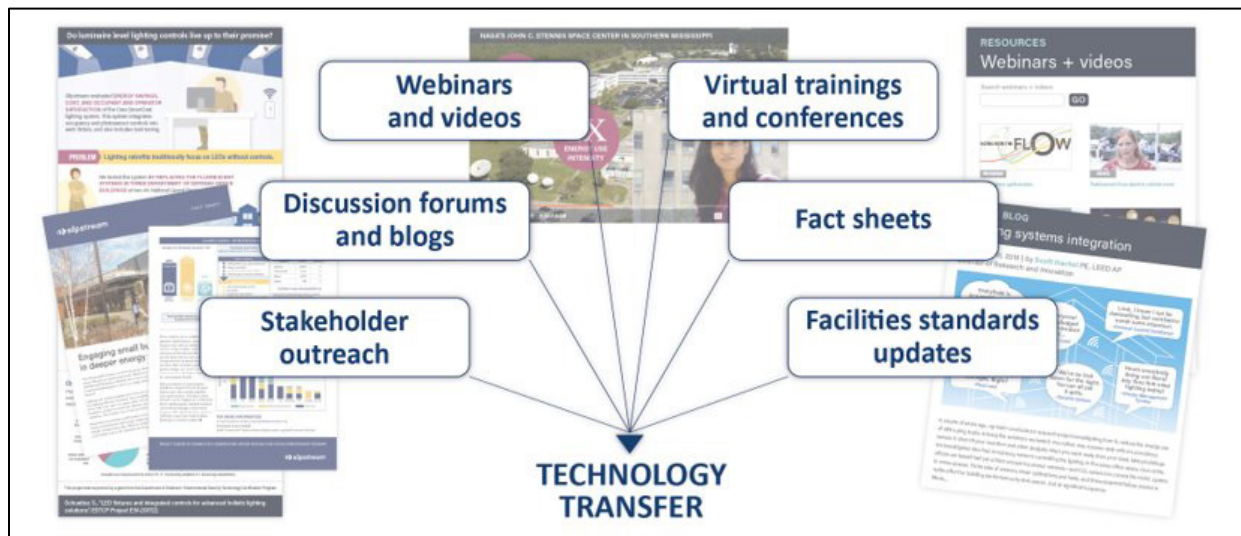


Figure ES-2. Comprehensive Technology Transfer Approach

PERFORMANCE ASSESSMENT

The six quantitative performance objectives and one qualitative performance objective as well as success criteria and results for this project are shown in Table ES-5.

Table ES-5. Performance Assessment

Performance Objective		Success Criteria	Result	Met?
Quantitative Performance Objectives				
#1	Training Participation	Participating in webinars and online courses: 1,020 Participating in-person training: 150	4,301 participants N/A participating in-person due to Covid	Yes
#2	Number of Webinars and Online Courses Per Category (Energy Manager and Engineers/ Facility Operators)	Energy managers: 16 segments of 15-minute webinars/online recordings; Engineers and facility operators: 18 hour-long webinars/online recordings	17 short sessions for energy managers, 21 hour-long sessions for engineers and building operators	Yes
#3	Presentations at Professional Conferences and Symposiums	Presentations at five major conferences and symposiums	11	Yes
#4	Interest in Technology Adoption or Learning More Based on Three Related ESTCP Project Presentations	15% of participants expressed positive for adoption 30% of participants expressed they will explore technology further	We measured if attendees were interested in learning more detail about the topic. For the short courses, 68% responded "yes." For the longer courses, 91% responded "yes."	Yes
#5	Number of Website Visits, Training Video Views, and Course Completions	Website visits: 500; Video views (at least 75% of the content watched for each video): 300; Course completions: 100 (based on exam pass/fail at the end of each online course)	2,640 website views 442 video views 197 course completions	Yes
#6	Incorporate all or part of the ASHRAE Guideline 36 into UFGS	Yes/No	Yes	Yes
Qualitative Performance Objectives				
#7	User Satisfaction from Presentations	3.5 out 5 scale in user satisfaction	4.25 (task 2) 4.07 (task 3)	Yes

COST ASSESSMENT

The cost model and cost assessment results for this project are listed in Table ES-6 below.

Table ES-6. Cost Model

Cost Element	Data Tracked During the Demonstration	Cost
Outreach and planning cost	Hours and rates used to conduct outreach and collect initial user feedback on training topics and in-person training conferences, workshops, and symposiums	\$22,000 total
Training development labor cost	Hours and rates used to develop online and in-person training materials	\$313,000 total. Approximately \$12,000 for each of the hour-long sessions, and \$3,000 for each of the 15-minute short sessions
Training development material cost	Materials costs required to develop online and in-person training materials	\$2,500
Facility operational costs	Facility cost for hosting the online training materials	N/A this is included in our indirect costs for labor.
Software costs	Actual learning management system (LMS) monthly/annual subscription fee and live video streaming costs	\$200 per month for LMS subscription fee.
Online training delivery cost	Hours and rates used in recording online training webinars/videos	This cost is now included in the training development labor cost.
In-person training delivery cost	Actual travel and presentation costs for in-person training sessions	\$1,685 total
Training survey and follow-up cost	Hours and rates used in developing and distributing questionnaires to online and in-person training sessions, as well as collecting responses, following-up, and analyzing the response data	We changed the survey method – now the survey is included in the LMS, so this cost is a part of the training development labor cost.

The cost elements and descriptions of data tracked in the cost model are self-explanatory. On average, developing and delivering each of the 15-minute short sessions cost about \$3,000, and \$12,000 for each of the hour-long technical sessions. Slipstream uses an interactive LMS from Coassemble to host our training content while automating course evaluations, continuing education credits and certificates of attendance. The LMS has a monthly subscription fee of \$200/month.

IMPLEMENTATION ISSUES

The major barrier was not being able to provide in-person training due to the COVID-19 pandemic. Another challenge was the busy schedule and high turnover of our primary target audiences. They often lack the time and resources to attend continuing education trainings. By integrating our trainings with RCxU, along with hosting the content on the Whole Building Design Guide (WBDG), it helped mitigate this challenge. A final challenge was coordinating training material development and delivery, and managing the quality control and review process for team members from different organizations. Our team worked closely with ESTCP to streamline this process.

1.0 INTRODUCTION

1.1 BACKGROUND

The purpose of this project was to develop and deliver a comprehensive training resource for disseminating advanced building control concepts and applications to multiple target audiences. Key audiences include DoD installation and acquisition managers, DoD building design and commissioning engineers, facility engineers, and building operators. This technology transfer effort will be incorporated into and complement existing DoD training on HVAC system design, control, commissioning, and operation. It will also help promote the awareness and potential future adoption of the ASHRAE Guideline 36-2018 “High-Performance Sequences of Operation for HVAC Systems.”

Today’s DoD installation managers are responsible for maintaining the readiness of their installations as “power projection platforms (PPPs).” With a limited budget and resources, they must make difficult resourcing decisions. The design engineers and commissioning engineers need to design and commission high-performance buildings. Facility engineers and building operators should be able to monitor and operate their buildings efficiently to minimize energy use while maintaining occupant comfort.

A recent PNNL study indicated that building controls and energy management play a prominent role in commercial building energy performance and peak load reduction and could result in an average of 29 percent energy savings (Fernandez, et al., 2017). Several past completed ESTCP projects in this technical area (Adetola, et al., 2013) (Adetola, et al., 2014) (Zhou, 2017) have demonstrated both significant energy savings and short simple payback periods can be achieved. These projects demonstrated advanced building controls and energy management projects’ military installation applicability, energy savings, and cost-effectiveness. Lessons learned are summarized in the final reports, but more comprehensive training on building control fundamentals and advanced building control concepts are needed to bridge the knowledge gap reported by these principal investigators.

This project has wide applicability to DoD installation and acquisition managers, design and commissioning engineers, and facility managers and building operators, who are often lacking in building control background and experience. Considering DoD spends \$4 billion per year on energy costs and has nearly 562,000 facilities, it is critical for these audiences to learn basic control concepts and control strategies. The project will increase their knowledge of advanced building control technology and management and enable them to make informed decisions, better specify and commission building control systems, and manage and operate buildings more efficiently.

1.2 OBJECTIVES

The goal of the project is to produce and deliver a comprehensive training and education resource that is effective for disseminating advanced building control concepts and applications to multiple target audiences across all DoD services. Key audiences include DoD installation and acquisition managers, DoD building design and commissioning engineers, facility engineers, and building operators. This information transfer effort will be incorporated into and complement existing DoD training on HVAC system design, control, commissioning, and operation. It will also help promote the awareness and potential future adoption of the ASHRAE Guideline 36-2018 “High-Performance Sequences of Operation for HVAC Systems” within DoD and across the industry.

The first objective was to inform DoD installation and acquisition managers about advanced controls concepts, the principles of operations, and the general cost-effectiveness of the most common control strategies. The economics, applicability, and lessons learned from four past control, monitoring, and commissioning-related ESTCP demonstrations were shared, and the basics of the new ASHRAE Guideline 36 were introduced. The information delivery mechanism for this audience consisted of fact sheets, a 15-minute webinar series, and live technical trainings hosted by DoD stakeholders. We utilized our interactive learning management system (LMS) to host our training content while automating course evaluations, continuing education credits and certificates of attendance when applicable. A LMS is a software application or web-based platform used to plan, implement and assess a specific training initiative through online courses and programs. The second objective was to educate and train DoD design and commissioning engineers, facility engineers, and building operators on advanced control fundamentals and concepts, common advanced control strategies, intelligent building operation and advanced energy performance monitoring, continuous commissioning, and re-tuning. We used four related ESTCP projects as examples. We delivered training through an LMS with a series of hour-long online video courses, with several sessions using live control programming examples, live technical trainings with Q&A sessions, and trainings at various symposiums, conferences, and workshops that these engineers often attend.

The third objective was to promote the awareness and potential future adoption of the ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems within DoD and across the industry. This new guideline provides detailed best-in-class control sequences that are supported through ASHRAE-funded research grants. The goal of ASHRAE Guideline 36 is to take these best-in-class efforts and democratize them through a series of easily adoptable, plug-and-play sequences. The guideline contains many of the advanced control strategies discussed in the training courses to energy managers and facility operators. The training will build a foundation for our target audiences to understand the ASHRAE Guideline 36. However, these best-in-class sequences have not been incorporated in the current versions of the Unified Facilities Criteria (UFC) and Unified Facility Guide Specifications (UFGS). The team reviewed the guideline and made recommendations for potential future inclusion in three UFCs and five UFGS..

USACE is part of the team member organization participating in the development and delivery of the curriculum. Engineers from the Engineer Research and Development Center's (ERDC) Construction Engineering Research Laboratory (CERL) Facilities Division Energy Branch will integrate the project content into its established Retro-commissioning University (RCxU) program, help promote the trainings, inform other military affiliations for training integration and update UFGS 23 09 13 as appropriate.

There is currently no comprehensive training curriculum offered to DoD installation managers that cover advanced building controls and management. By completing these objectives, this project helped fill that gap.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The comprehensive technology transfer approach addresses the three defined objectives. For each different audience, the project team tailored our trainings to be most effective for that group. Figure 1 shows the conceptual design of the project. Figure 2 illustrates our comprehensive technology transfer approach that depicts several education and outreach strategies. Table 1 to Table 3 summarize the training topics, targeted audiences, and planned training delivery mechanisms.

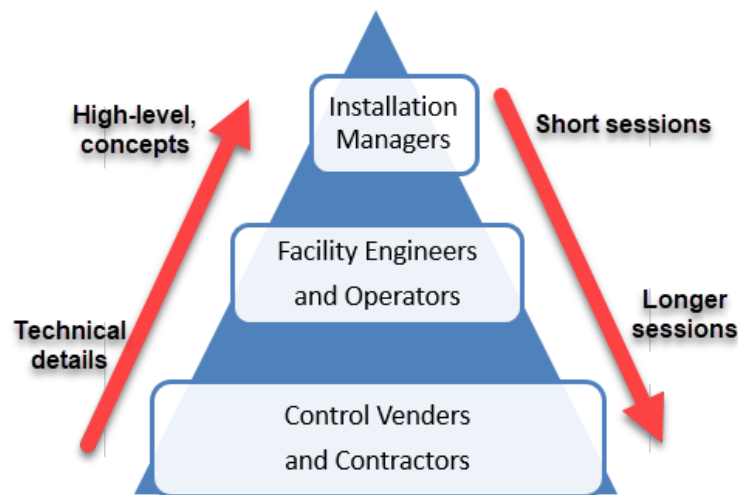


Figure 1. Technology Transfer Conceptual Design



Figure 2. Comprehensive Technology Transfer Approach

Table 1. Training Topics and Delivery Mechanism for DoD Energy Managers

Module	Topic	Speaker/Lecturer	Delivery
1	Fundamentals of Building Control Systems	4 sessions by Slipstream	Short 15-min webinar series (see Appendix D: Task 2 Training Topics for Energy Managers for topics and presenters), fact sheets, seminars/workshops at SERDP-ESTCP Symposium and DOE Energy Exchange.
2	Common Advanced Control Strategies	7 sessions by Slipstream and TRC	
3	Energy Modeling, Intelligent Building Operation and Advanced Energy Performance Monitoring	2 sessions by Texas A&M University	
4	Four ESTCP Demonstration Projects	4 sessions by Slipstream, Texas A&M University, and USACE	

Table 2. Training Topics and Delivery Mechanism for Facility Engineers

Module	Topics	Speaker/Lecturer	Delivery
1	Fundamentals of Building Control Systems	5 sessions by Slipstream	Hour-long online courses (see Appendix E: Task 3 Training Topics for Facility Engineers for topics and presenters), virtual training at symposiums, conferences, and workshops.
2	Common Advanced Control Strategies	7 sessions by Slipstream, QSE/AFIT, and TRC	
3	Energy Modeling, Intelligent Building Operation and Advanced Energy Performance Monitoring	3 sessions by Texas A&M and QSE/AFIT	
4	Four ESTCP Demonstration Projects	4 sessions by Slipstream, Texas A&M University, and USACE	
5	Existing Building Commissioning	2 sessions by PNNL and Texas A&M University	

Table 3. ASHRAE Guideline 36 Review and Recommendations

#	Topic	Speaker/Lecturer	Delivery
1	Review Guideline 36 sequences for potential future inclusion in UFGS 23 09 13	USACE CERL	Recommendations on if Guideline 36 sequences are appropriate for future UFGS 23 09 13 Refer to Appendix H: USACE CERL ASHRAE Guideline 36 Evaluation Report.

The four ESTCP Energy and Water demonstration projects in the training include:

EW-201408: Demonstration of Energy Savings in Commercial Buildings for Tiered Trim and Respond Method in Resetting Static Pressure for VAV Systems. This is a customized advanced controls solution on existing building automation systems (BAS) to reduce air handling unit or rooftop top unit fan energy. Demonstration results showed that compared with a typical VAV system with traditional fixed supply air static pressure control, the total fan energy savings for the five demonstration sites ranged from 14.4 percent to 34.8 percent with the simple payback years of 1.7, 4.9, 5, 11.8, and 14.9, respectively.

EW-201142: Energy Performance Monitoring and Optimization System for DoD Campuses. This demonstration applied an Energy Performance and Monitoring Optimization (EPMO) system prototype to existing building management systems to improve the energy efficiency of both heating and cooling. The EPMO system integrates optimal control algorithms with system performance monitoring, diagnostic tools, and visualization tools. The EPMO system exceeded the energy consumption reduction target of 20 percent and improved occupant thermal comfort by reducing the number of instances outside of the temperature comfort band by 75 percent. The simple payback period is 3.5 years, and the savings-to-investment ratio is 2.

EW-201015: Scalable Deployment of Advanced Building Energy Management Systems. This project demonstrates a building energy management system that employs advanced methods of whole-building performance monitoring combined with statistical learning methods and data analysis to enable the identification of both gradual and discrete performance erosion and faults. Demonstration results showed facility engineers with actionable energy fault information to identify and correct poor system performance achieved 10 percent building energy savings. Identifying alternative energy system operation strategies that improve building energy performance saved an additional 10 percent.

In addition, the California Energy Commission (CEC) sponsored field demonstrations of ASHRAE Guideline 36 energy savings, cost-effectiveness, and replicability. This new guideline provides detailed best-in-class control sequences that have been developed through ASHRAE-funded research. The goal of ASHRAE Guideline 36 is to take these best-in-class efforts and democratize them through a series of easily adoptable, plug-and-play sequences. The introduction of ASHRAE Guideline 36 and the field demonstration results are part of the sessions in the “Common Advanced Control Strategies” module in this training.

Finally, USACE CERL reviewed the ASHRAE Guideline 36-2018 sequences and make recommendations for potential future inclusion in three UFCs and five UFGSs. The transfer of various aspects of guideline into the UFCs and UFGSs is a very important part of this project as it will help future DoD facilities to improve energy efficiency and operation and maintenance. The recommendations are summarized in Section 5 performance assessment, and the detailed report is attached as Appendix H: USACE CERL ASHRAE Guideline 36 Evaluation Report.

2.2 TECHNOLOGY DEVELOPMENT

The key project objective was to disseminate the comprehensive training program for basic and advanced building controls concepts and applications to multiple target audiences. Before developing the curriculum, our team of academia and industry subject matter experts first reached out to our targeted audiences to gather qualitative and quantitative information and data to better understand the knowledge gaps, skills, competencies, education needs, and major barriers to advanced controls and energy management. Our team connected with several additional DoD services and stakeholders such as:

- Energy & Utilities Branch, Public Works Division, U.S Army HQ (IMCOM)
- US National Guard (ARNG)
- U.S. Army Reserves (USAR)

- Resource Energy Managers (REM)
- Naval Command (NAVFAC)
- Air Force Institute of Technology (AFIT)
- Naval Post Graduate School (NPS)
- Marine Corps

Based on several one-on-one phone interviews with key stakeholders and surveys across multiple military branches, our team members identified a few topics that were not in the originally planned curriculum, but our target audiences wanted to learn. Basics of HVAC systems, BAS cybersecurity, and building monitoring through trend analysis were the three new topics added to our curriculum development. We also consulted with the USACE and a building controls instructor from the Air Force Institute of Technology (AFIT) to ensure the training materials were relevant to DoD installations. A finalized two-pronged training curriculum — one for energy managers and another for engineers and building operators — are listed in Appendix D: Task 2 Training Topics for Energy Managers and Appendix E: Task 3 Training Topics for Facility Engineers, respectively.

The primary training mechanism was developing online education modules through Slipstream’s interactive LMS so attendees could track their performance and customize topics that are most relevant to them through a self-paced option. The training curriculum consists of different “modules,” each with several training sessions in the same training topic area. Within each session, an online video recording is available along with a downloadable PDF file for the presentation. Quiz/exam questions are available to either reinforce participants’ learning (for the short sessions) or test if participants can pass 80% of the threshold to obtain a professional development hour (PDH) certificate for the session (for the hour-long sessions). Automatically generated PDH certificates will be stored in the LMS in downloadable PDF format.

At the beginning of the curriculum development, team members discussed the software tool options for curriculum development and online course video recording. Microsoft PowerPoint was the consensus for course material development. Among video and webinar recording software Zoom, GoTo webinar, Snagit, and the PowerPoint slide show function in Microsoft PowerPoint, the team chose to use the PowerPoint slide show function to record online course videos, mainly due to its ease of record and ease later edit the recordings slide-by-slide. Recommendations on how to record high-quality presentation videos were distributed to all presenters of these training sessions.

During the curriculum development process, presenters first drafted their presentations and uploaded them to a shared online project folder for other team members to provide comments and feedback. Then they revised and finalized the content based on the comments received and recorded their videos independently and uploaded them to the shared online project folder. The videos are embedded in the PowerPoint presentation files. The video editor from the Slipstream team then extracted the video files from the PowerPoint slides and edited them in video and audio editing software for better overall quality and smoothness. The edited videos and presentation slides were then sent to the ESTCP reviewer for comments and feedback. A second round of video and presentation slide editings were done to incorporate the reviewer’s comments and feedback. The final versions were then uploaded to the Slipstream LMS.

After the presentation slides and videos were finalized, each presenter wrote a course description and 10 questions and answers for each of their training sessions. These documents were used in the LMS to describe the course content and for the PDH exams.

Slipstream uses the interactive LMS from Coassemble to host our training content. The LMS can be accessed at the following webpage (<https://slipstreaminc.org/estcp>). The key feature of Coassemble is the ability to provide a self-paced training option so attendees can track their own progress. Our LMS also tracks learning competencies through quizzes and evaluations. Continuing education credits and certificates of attendance are automated and generated for attendees. Other training delivery mechanisms include posting the 15-minute short sessions on [YouTube](#), migrating the hour-long sessions to the [WDBG](#) website, synchronous presentations at DoD training workshops and conferences, creating fact sheets for the four ESTCP demonstration projects, integrating trainings on USACE RCx University courses, and miscellaneous outreach and marketing effort to raise awareness of the training resource. The following highlights a combination of training delivery mechanisms that were executed.

- Online video and training modules through Slipstream's LMS
- Synchronous presentations at DoD training workshops and conferences
- ESTCP building controls demonstration fact sheets
- Integrate trainings on USACE RCx University
- Integrate trainings on the Whole Building Design Guide
- Integrate short courses on Slipstream's YouTube channel

Sample screenshots or images for each of the training delivery mechanisms can be accessed in Appendix F: Training Delivery Mechanisms.

We worked with several partners and stakeholders to promote the training resource. The following features a combination of marketing strategies that were executed to raise awareness of the training resource.

- Slipstream project webpage
- ESTCP webinar
- Slipstream social media
- ESTCP social media
- WBDG social media
- USACE RCxU stakeholder outreach
- DoD stakeholder outreach
- Presentations at industry events
- Articles in industry publications

Images for each of the outreach and marketing strategies can be accessed in Appendix G: Training Marketing and Outreach.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Delivering a multifaceted training approach that targets multiple DoD audiences and stakeholders was a distinct advantage of this project. Our approach targeted different audiences (managers vs. engineers/operators) with different training methods and levels of detail. Customized to each unique DoD audience, this technology transfer significantly lowered the learning barriers surrounding the latest advanced building controls and control sequences. The LMS provided a two-way, long-term sustainable training platform beyond the project period. The review of Guideline 36 sequences for future inclusion in UFGS 23 09 13 had a direct impact on future DoD building design and commissioning.

Our curriculum consists of an extensive suite of offerings including online training modules, targeted regional webinars, web portals and blogs, in-person training and workshops, technology fact sheets, and a review of the new advanced control sequence guidelines. By aligning our team with USACE and other DoD education partners such as the WBDG, we will have sustaining impacts and be more cost-effective as these training platforms are already established and recognized by DoD target audiences.

An additional advantage of the project is combining four advanced controls and management-related ESTCP projects as industry-leading examples rather than focusing on one project. The webinars are offered at no cost and are also archived and available on-demand so viewers can watch at any time. To remove registration barriers our Task 2 trainings have also been uploaded to Slipstream's [YouTube](#) channel. We also integrated our training resource on USACE's RCx University and the WBDG platform (<https://wbdg.org/continuing-education/dod-courses/estcp>) to increase exposure to target audiences.

3.0 PERFORMANCE OBJECTIVES

Our approach targeted different audiences (managers vs. engineers/operators) with different training methods and levels of detail. After the training, we hope participants will be able to:

- Improve their understanding of building automation system basics
- Increase their awareness of common advanced control strategies
- Increase their awareness of energy modeling, intelligent building operation and advanced energy performance monitoring
- Increase their awareness and adoption of the static pressure reset retrofit (EW-201408), energy performance and monitoring optimization (EW-201142), advanced building energy management system (EW-201015), and controls retrofit of multizone HVAC unit for energy efficiency (EW-201152)
- Inform themselves and their managers and engineering staff on the new ASHRAE Guideline 36 “High-Performance Sequences of Operation for HVAC Systems.”
- increase the awareness of facility staff on using BAS for re-tuning and continuous commissioning
- influence the currency and usability of the applicable Unified Facilities Guide Specifications (UFGS)

Our main project performance objectives are evaluated based on the following:

1. Training participation
2. Number of webinars and online courses
3. Presentations at professional conferences and symposiums
4. The intent for technology adoption after presentations
5. Number of website visits and video “clicks” or “views”
6. Incorporate ASHRAE Guideline 36 into UFGS
7. User satisfaction from webinars, online courses, and presentations

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

The summary of the six quantitative performance objectives and one qualitative performance objective and the success criteria are shown in Table 4.

Table 4. Performance Objectives

Performance Objective		Success Criteria
#1	Training Participation	Participating in webinars and online courses: 1,020 Participating in person training: 150
#2	Number of Webinars and Online Courses Per Category (Energy Manager and Engineers/ Facility Operators)	Energy managers: 16 segments of 15-minute webinars/online recordings; Engineers and facility operators: 18 hour-long webinars/online recordings
#3	Presentations at Professional Conferences and Symposiums	Presentations at five major conferences and symposiums
#4	Interest in Technology Adoption or Learning More Based on Three Related ESTCP Project Presentations	15% of participants expressed positive for adoption 30% of participants expressed they will explore technology further
#5	Number of Website Visits, Training Video Views, and Course Completions	Website visits: 500; Video views (at least 75% of the content watched for each video): 300; Course completions: 100 (based on exam pass/fail at the end of each online course)
#6	Incorporate all or part of the ASHRAE Guideline 36 into UFGS	Yes/No
Qualitative Performance Objectives		
#7	User Satisfaction from Presentations	3.5 out 5 scale in user satisfaction

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

PO#1: Training Participation

- Name and Definition: Track the total number of participants that attended the in-person and online trainings.
- Metric: Number of total attendees.
- Data: Collect data through in-person and online training registrations.
- Success Criteria: We expect 30 attendees per online course for a total of 1,020 attendees for the 34 online sessions, and 30 attendees per in-person training for a total of 150 attendees at five major conferences and symposiums.

PO#2 Number of Webinars and Online Courses

- Name and Definition: Track the total number of webinars and online courses.
- Metric: Number of webinars and online courses
- Data: We will track the total number of webinars and online courses organized.
- Success Criteria: Execute the required number of webinars and online courses. For task #2 DoD manager training, a total of 16 segments of 15-minute webinars/online recordings. For task #3 DoD engineer and facility operator training, a total of 18 one-hour long webinars/online recordings;

PO#3 Presentations at Professional Conferences and Symposiums

- Name and Definition: Track the number of professional conferences and symposiums where the team will present seminar or workshop sessions to DoD stakeholders.
- Metric: The number of professional conferences and symposiums.
- Data: Requested and presented conferences and symposiums
- Success Criteria: Team presentations at five major conferences and symposiums.

PO#4 Interest in Technology Adoption or Learning More After Presentations

- Name and Definition: Track the intent for technology adoption and learn more after the three advanced controls and management-related ESTCP project presentations.
- Metric: Calculate the percentage of participants that will adopt the technology and calculate the percentage of participants that will explore technology further.
- Data: We will calculate the data through a survey after each presentation.
- Success Criteria: Primary goal is for 15% of participants to express positive for adoption. A secondary goal is for 30% of participants to express they will explore technology further.

PO#5 Number of Website Visits and Training Video “Views”

- Name and Definition: Track the total number of website visits and “views” of training videos.
- Metric: Total amount of website visits and “views” of training videos.
- Data: We will track the total number of website visits and “views” of training videos in our online training platform.
- Success Criteria: Based on our number of attendees per online course we expect to reach a total of 500 website visits and 300 “views” of our training videos.

PO#6 Incorporate ASHRAE Guideline 36 into UFGS

- Name and Definition: The team will review the ASHRAE Guideline 36 sequences for potential future inclusion in UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS) 23 09 13 Instrumentation and Control Devices for HVAC – Controls Sequences of Operation.
- Metric: Yes or no metric based on accomplishing this task.
- Success Criteria: We will demonstrate success if the USACE review result shows that ASHRAE Guideline 36 is appropriate to be included in future UFGS) 23 09 13.

PO#7 User Satisfaction from Presentations

- Name and Definition: Track the overall user satisfaction from our trainings and presentations.

- Purpose: At the end of each training, we will conduct paper-based and web-based surveys to obtain audience feedback on the training session effectiveness. Survey data will be analyzed and incorporated into the final report.
- Metric: We will include questions asking participants to rate the effectiveness, quality and user satisfaction on a scale from 1 to 5.
- Data: We will calculate the data through a survey tool.
- Success Criteria: For each training, the participant rating average will be used to compare with the success criteria of 3.5 out of 5.

4.0 PROJECT DESIGN

Fundamental Problem

There is a huge gap in the building controls and management knowledge base for many DoD installation and acquisition managers, design and commissioning engineers, facility engineers, and building operators. A comprehensive and systematic approach to technology transfer in this technical subject area will enable them to make sound energy efficiency project decisions, or better design, specify, commission, and operate buildings with a building control system to save facility operation and energy cost.

Our new comprehensive and systematic approach to technology transfer in specific energy and water technology area (rather than a specific technology) will help the DoD gauge the effectiveness of this information transfer approach and possibly adopt it to other energy and water technology areas in the future.

Demonstration Question

- Is the training session well participated by targeted audiences? (Training Participation)
- How many webinars and online courses are organized for the technology area? (Number of Webinars and Online Courses)
- How many in-person training sessions are organized and implemented for the technology area? (Presentations at Professional Conferences and Symposiums)
- How effective are these training sessions? (Interest in Technology Adoption or Learning More After Presentations)
- Can the project have a direct impact on DoD facility design? (Incorporate ASHRAE Guideline 36 into UFGS)
- How satisfied are the audiences with the training organized? (User Satisfaction from Presentations)

4.1 PROJECT PHASES

Our comprehensive and systematic approach follows the sequential and logical project design process to address the performance objectives. The project had four main phases: 1) outreach, 2) training development and training delivery and tracking, 3) ASHRAE Guideline 36 review, and 4) project evaluation.

- Task 1 Outreach: conducted outreach and training planning to connect with key DoD training managers and evaluate the interests of our targeted audience in our planned training. The key stakeholders were identified in partnership with USACE. A questionnaire was developed in Microsoft Word format as well as the online format (through SurveyMonkey) and used in collecting target audience feedback. Through the online survey we received responses from a total of 30 stakeholders. In addition to the survey, we set up phone meetings with 12 stakeholders to get anecdotal feedback on our training plan.

The questionnaire included questions on the topics/subtopics of interest and the conferences, symposiums, and workshops DoD managers and engineers often go to for in-person training. Based on the feedback, we adjusted and finalized our training plan, which includes key project performance objectives. Traditional communication methods (phone, email, and virtual meetings) were used to reach out to these DoD training managers as well as some of our target audiences. See Appendix B: A Sample Survey Questionnaire and Appendix C: A Sample Survey Result Summary.

- Task 2 and 3 Training development and delivery: training material development and delivery for DoD energy managers is Task 2. Task 3 is for DoD energy engineers and facility operators. To increase the effectiveness of the comprehensive information transfer approach, short 15-minute online videos and fact sheets were used primarily for energy managers for online training. Longer (approximately one hour in length), more in-depth and technical online training courses were developed for engineers and facility operators.

For training delivery and tracking, besides the online training through Slipstream LMS, various other training delivery mechanisms are used. Our team members presented our training resource at the following in-person or virtual events.

- 2020 & 2021 DOE Energy Exchange (virtual)
 - 2020 & 2021 ESTCP Symposium (virtual)
 - 2021 SERDP-ESTCP Webinar Series: Improving Energy Efficiency through Advanced Building Controls (virtual)
 - 2021 & 2022 Resource Efficiency Manager (REM) Workshop (virtual)
 - 2022 Building Operating Management’s National Facilities Management & Technology Conference (in-person)
 - 2022 DoD Community of Practice (virtual)
 - 2022 ACEEE Summer Study poster presentation (in-person)
 - 2022 Wisconsin Association of Energy Engineers Energy Efficiency Expo (in-person)
- Task 4 is the ASHRAE Guideline 36 review by USACE. This task is designed for this information transfer project to have a direct impact on the future DoD facility design and specification related to building controls.
 - Task 5 Project evaluation is mainly to answer the demonstration questions related to the project performance objectives. The task period overlaps the project delivery periods from Task 2 to Task 4. Online surveys were developed, and responses were tracked through Slipstream LMS for each online training session to assess user satisfaction and intent for technology adoption. Other relevant data such as the number of webinar participants or online course “views” are collected and analyzed and compared with the “Success Criteria” for each performance objective.

4.2 SAMPLING PROTOCOL

The data collection sampling protocol for this project is listed in Table 5.

Table 5. Data Collection Protocol

Phase	Outreach	Training Development	Training Delivery
Data Collector(s)	Slipstream	Slipstream	Slipstream
Data Recording	Monthly time and costs tracking through Slipstream internal accounting system. Audience training topic and delivery method feedback through SurveyMonkey.	Monthly time and costs tracking through Slipstream internal accounting system, as well as subcontractor reporting.	Monthly time and costs through Slipstream internal accounting system, as well as subcontractor reporting. Survey responses through SurveyMonkey. The number of online training “clicks” or “views” through the new training website/platform.
Data Description	Hours and costs spent on outreach. SurveyMonkey response results in the outreach questionnaire.	Hours and costs spent on developing training materials and building the online training platform.	Hours and costs spent on training development. Participant responses to the questionnaire designed for each training session. The number of people participated in the training session. The total number of website visits and “views.”
Data Storage and Backup	All data will be downloaded, saved and stored in Slipstream’s internal data storage and sharing system, which uses Microsoft SharePoint with full backup capability and is maintained by Slipstream’s IT department.		
Data Collection Diagram	Refer to Appendix C for an example of survey result summary		
Non-standard Data	Not applicable		
Survey Questionnaires	Refer to Appendix B for an example of survey questionnaires		

5.0 PERFORMANCE ASSESSMENT

- Performance Objective Analysis Overview: The rationale for our information transfer project is using a “comprehensive” approach to make a broader impact in one technology area, compared to a “focused” approach on one specific technology or product. We combined both online training and in-person training at conferences, symposiums, and workshops that most DoD energy managers, engineers, and facility operators often attend, to minimize the cost for our target audience to receive training. Our key performance matrix of “overall training participation,” “number of training sessions,” and “user satisfaction” are all used to assess the broad impact of our project. Another characteristic of our project is we try to target different audiences with different training formats. The additional performance matrix of “intent for technology adoption,” “ASHRAE Guideline 36 review and consideration for UFGS,” and “user satisfaction” are all used to assess the information transfer effectiveness.
- Statistical Methodologies: Basic statistical analysis (minimum, maximum, mean, median, standard deviation, and statistical significance using a standard 95% confidence level) may be used to analyze our survey results for our training participation and effectiveness.
- Graphical Methodologies: We will use the appropriate chart and graphic types available in the Microsoft Excel spreadsheet tool to analyze other data types collected.
- Modeling and Simulation: Not applicable to this project.
- Sensitivity Analysis: There is no plan to conduct sensitivity analysis for this project.
- Anecdotal Perspectives: In the outreach phase, we talked with selected target audiences (energy managers, engineers, and facility personnel) and HVAC controls trainers through phone interviews to get direct feedback on our planned training topics and effective delivery methods. We also received anecdotal feedback from our electronic survey that was also distributed to various DoD stakeholders. During online training delivery, our web-based training platform provided ways of communication (such as through forums or blogs) to collect audience feedback and anecdotal perspectives on the effectiveness of the training content and willingness to adopt the technology. During real-time webinars and in-person training sessions, the lecturer also had Q&A sessions to direct communication with audiences.
- Industry Standards: we are not aware of any industry standard of performance assessment for the information transfer demonstration project.
- Internal Validity: We worked with the internal web platform development/implementation team to make sure specific web “clicks,” video view counts, and course completion data are collected correctly. For SurveyMonkey response data collected, we will rely on SurveyMonkey’s data collection system, but use their filter functionality to remove data from invalid periods.
- External Validity: Our findings will not be limited to a single technology or military installation. If successful, our approach should be replicable to other ESTCP technology areas and impact all DoD installations at U.S. Army, Air Force, Navy, and other services listed throughout the demonstration plan.

The results associated with each performance objective are outlined in Table 6 and explained in detail subsequently. The performance data were collected within the six months from February 2022 to July 2022 after our training resources were officially available to the public in February 2022.

Table 6. Performance Assessment Results

Performance Objective		Success Criteria	Result	Met?
Quantitative Performance Objectives				
#1	Training Participation	Participating in webinars and online courses: 1,020 Participating in-person training: 150	4,301 participants N/A participating in person due to Covid	Yes
#2	Number of Webinars and Online Courses Per Category (Energy Manager and Engineers/ Facility Operators)	Energy managers: 16 segments of 15-minute webinars/online recordings; Engineers and facility operators: 18 hour-long webinars/online recordings	17 short sessions for energy managers, 21 hour-long sessions for engineers and building operators	Yes
#3	Presentations at Professional Conferences and Symposiums	Presentations at five major conferences and symposiums	11	Yes
#4	Interest in Technology Adoption or Learning More Based on Three Related ESTCP Project Presentations	15% of participants expressed positive for adoption 30% of participants expressed they will explore technology further	We measured if attendees were interested in learning more detail about the topic. For the short courses, 68% responded “yes.” For the longer courses, 91% responded “yes.”	Yes
#5	Number of Website Visits, Training Video Views, and Course Completions	Website visits: 500; Video views (at least 75% of the content watched for each video): 300; Course completions: 100 (based on exam pass/fail at the end of each online course)	2,640 website visits 442 video views 197 course completions	Yes
#6	Incorporate all or part of the ASHRAE Guideline 36 into UFGS	Yes/No	Yes	Yes
Qualitative Performance Objectives				
#7	User Satisfaction from Presentations	3.5 out 5 scale in user satisfaction	4.25 (task 2) 4.07 (task 3)	Yes

Training participation

The success criteria were whether 1,020 stakeholders participated in webinars and online courses. We achieved this threshold by training a total of 4,301 participants. Note that we did not deliver in-person trainings due to Covid. We did, however, present several virtual trainings and had hundreds of attendees over the course of these workshops.

Number of webinars and online courses per category

The success criteria were to develop at least 16 segments of short 15-minute webinars and online recordings for energy managers and at least 18 hour-long webinars and online recordings for engineers and facility operators. We achieved this threshold by developing 17 short sessions for energy managers and 21 hour-long sessions for engineers and building operators.

Number of presentations at professional conferences and symposiums

The success criteria were to present our project at a minimum of five major conferences and symposiums. We achieved this threshold by presenting at a total of X conferences and symposiums. Below is a list of the conferences and symposiums where we presented our project. This also included several DoD stakeholder workshops to generate awareness about the project.

- 2020 & 2021 DOE Energy Exchange (virtual)
- 2020 & 2021 ESTCP Symposium (virtual)
- 2021 SERDP-ESTCP Webinar Series: Improving Energy Efficiency through Advanced Building Controls (virtual)
- 2021 & 2022 Resource Efficiency Manager (REM) Workshop (virtual)
- 2022 Building Operating Management's National Facilities Management & Technology Conference (in-person)
- 2022 DoD Community of Practice (virtual)
- 2022 ACEEE Summer Study poster presentation (in-person)
- 2022 Wisconsin Association of Energy Engineers Energy Efficiency Expo (in-person)

Interest in technology adoption

The success criteria were to identify the level of interest in technology adoption or willingness to learn more about the technology through completion of a survey. After participants complete courses through our LMS they have the option to complete a short survey so we can track effectiveness and learning competencies. This threshold was achieved as on average, the training sessions received a satisfaction rating of 4.25/5 for the short courses and 4.07/5 for the hour-long courses.

Number of website visits, training views, and course completions

The success criteria were to track the number of website visits, training video views, and course completions. We achieved the web traffic threshold by measuring 2,650 website visits between Jan 1, 2022 - July 14, 2022. The number of training views and course completions threshold was partially achieved as many of the participants watched the videos from various sources such as YouTube where we are unable to calculate these metrics. In addition, the videos have just recently appeared on WBDG, so it is too soon to measure the number of views and course completions on the WBDG platform (<https://wbdg.org/continuing-education/dod-courses/estcp>). Further, many of our videos will be integrated in the USACE RCxU training catalog where this metric is not measured.

ASHRAE Guideline 36 review

The training courses build a foundation for DoD energy managers and facility operators to understand building control basics as well as key advanced control strategies. These advanced control strategies are major components in ASHRAE Guideline 36 that help standardize and streamline industry building control design and implementation and cost-effective, deeper energy savings, but they have not been incorporated into the DoD design standards. USACE CERL partnered with the industry and Tri-Service criteria management and developed a list of prioritized recommendations for DoD HVAC controls criteria updates based on the review of ASHRAE Guideline 36-2018. This review is part of this project to promote advanced building controls concepts, and the training courses for DoD energy managers and building operators helped undersatdning the control sequences in the guideline. Moreover, this effort is in direct support of National Defense Strategy goals and the related USACE Campaign Plan objective to maintain and advance DoD critical enabling technologies. CERL evaluated the initial 2018 edition over the past year using the DoD operating environment, system design, and field engineering perspectives. The 100-page Guideline (Appendix E) contains requirements for HVAC system set points, sequences, alarms, and advanced diagnostics capabilities called AFDD (Automated Fault Detection and Diagnostics). Some of the content can be considered best practice for DoD to consider adopting into its design criteria or construction specifications. Other Guideline requirements represent best-in-class approaches to HVAC controls that require additional research for future consideration at DoD installations. Review of the Guideline resulted in 40 total recommendations that target potential HVAC controls and associated front-end system updates of three Unified Facilities Criteria (UFC) documents and five Unified Facility Guide Specifications (UFGS). CERL recommendation counts by type and priority are summarized in Table 7.

Table 7. ASHRAE Guideline 36 Recommendation Types and Priorities

Recommendation Type	Priority			Total
	High	Medium	Low	
Critical Update	11	9	2	22
Additional Research	8	6	4	18
Grand Total	19	15	6	40

CERL will continue to engage with industry and Tri-Service criteria management on the next steps. As part of the submission of this report to ESTCP, CERL is submitting all high-priority criteria update recommendations summarized in Table 2 as Criteria Change Requests (CCR) for their associated UFC and UFGS documents housed on the Whole Building Design Guide (wbdg.org). Where additional research is recommended, CERL will pursue additional funding to demonstrate or coordinate as needed to determine criteria update needs. Additional feedback is planned with the USACE controls systems Community of Practice, Tri-Service Coordinating Panel, and ASHRAE Guideline 36 Project Committee.

The 11 high-priority critical updates recommended by CERL are listed in Table 8. For a detailed report including recommendations on updates or additional research, please refer to Appendix H: USACE CERL ASHRAE Guideline 36 Evaluation Report.

Table 8. ASHRAE Guideline 36 Recommendations Critical Update High Priority List

Rec. #	Category	Description
1	Ventilation Zone Setpoints	Non CO2-based DCV Sequences
2	Central System Sequences	Adopt a Multi-Stage Approach to Coil Freeze Protection
3	General Sequence Methodologies	Align DSP Set Point Reset Criteria
4	General Sequence Methodologies	Use of Zone Group Schedules
5	General Sequence Methodologies	Establish Configuration Defaults for Hardwired VFD Command and Networked Min Speed
6	General Sequence Methodologies	Create VFD Interface Points Schedule Template
7	Terminal Unit Sequences	Zone-level Demand-limiting Sequences and Set points
8	Alarms	Expanded Alarm Conditions
9	Alarms	Better Alarm Local Display Options
10	Alarms	Alarm-Specific Testing Requirements
11	AFDD	Address AHU Sensor Gaps

User satisfaction from presentations

The success criteria were to measure user satisfaction from presentations through completion of the survey. After participants complete courses through our LMS they have the option to complete a short survey so we can track effectiveness and learning competencies. This threshold was achieved as on average, the training sessions received a satisfaction rating of 4.25/5 for the short courses and 4.07/5 for the hour-long courses.

6.0 COST ASSESSMENT

6.1 COST MODEL

The cost model tracking for our comprehensive technology transfer approach is listed in Table 9 below.

Table 9. Cost Tracking

Cost Element	Data Tracked During the Demonstration
Outreach and planning cost	Hours and rates used to conduct outreach and collect initial user feedback on training topics and in-person training conferences, workshops, and symposiums
Training development labor cost	Hours and rates used to develop online and in-person training materials
Training development material cost	Materials costs required to develop online and in-person training materials
Facility operational costs	Facility cost for hosting the online training materials
Software costs	Actual learning management system (LMS) monthly/annual subscription fee and live video streaming costs
Online training delivery cost	Hours and rates used in recording online training webinars/videos
In-person training delivery cost	Actual travel and presentation costs for in-person training sessions
Training survey and follow-up cost	Hours and rates used in developing and distributing questionnaires to online and in-person training sessions, as well as collecting responses, following-up, and analyzing the response data

The cost elements and descriptions of data tracked in the cost model are self-explanatory. We will use the data collected to calculate the Cost Effectiveness of both online training and in-person training in terms of cost per presentation, cost per attendee, and average user feedback. If past ESTCP technology transfer projects' performance metrics are available, we can also compare our “comprehensive approach” to the information transfer approaches in those projects, which mostly focused on a single technology or single past ESTCP project.

6.2 COST ANALYSIS AND COMPARISON

The cost analysis results for this project are listed in the cost model table below.

Table 10. Cost Model

Cost Element	Data Tracked During the Demonstration	Cost
Outreach and planning cost	Hours and rates used to conduct outreach and collect initial user feedback on training topics and in-person training conferences, workshops, and symposiums	\$22,000 total
Training development labor cost	Hours and rates used to develop online and in-person training materials	\$313,000 total. Approximately \$12k for each of the hour-long sessions, and \$3k for each of the 15-minute short sessions
Training development material cost	Materials costs required to develop online and in-person training materials	\$2,500
Facility operational costs	Facility cost for hosting the online training materials	N/A this is included in our indirect costs for labor.
Software costs	Actual learning management system (LMS) monthly/annual subscription fee and live video streaming costs	\$200 per month for the LMS subscription fee.
Online training delivery cost	Hours and rates used in recording online training webinars/videos	This cost is now included in the training development labor cost.
In-person training delivery cost	Actual travel and presentation costs for in-person training sessions	\$1,685 total
Training survey and follow-up cost	Hours and rates used in developing and distributing questionnaires to online and in-person training sessions, as well as collecting responses, following-up, and analyzing the response data	We changed the survey method – now the survey is included in the LMS, so this cost is a part of the training development labor cost.

On average, developing and delivering each of the 15-minute short sessions cost about \$3,000, and \$12,000 for each of the hour-long technical sessions. Training delivery and survey tracking were through the online learning management system, which has a monthly subscription fee of \$200/month. Since this is the first comprehensive technology transfer project in the ESTCP energy and water program, we did not find similar past technology transfer project cost information for comparison.

7.0 IMPLEMENTATION ISSUES

The major barrier was not being able to provide in-person training due to the COVID-19 pandemic. Another challenge was the busy schedule and high turnover of our primary target audiences. They often lack the time and resources to attend continuing education trainings. By integrating our trainings with RCxU, along with hosting the content on the WBDG, it helped mitigate this challenge. A final challenge was managing the quality control and review process of developing several new trainings that needed to get approval by ESTCP. Due to the technical nature of the trainings, there was a long approval process for some of the materials. Our team worked closely with ESTCP to streamline this process.

8.0 REFERENCES

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- Zhou, X. (2017). *Demonstration of Energy Savings in Commercial Buildings for Tiered Trim and Respond Method in Resetting Static Pressure for VAV Systems*. Iowa Energy Center. ESTCP. Retrieved from <https://serdp-estcp.org/content/download/42187/402238/file/EW-201408%20Final%20Report.pdf>

APPENDIX A POINTS OF CONTACT

Table A-1. Point of Contact List

Point of Contact	Organization	Phone & E-mail	Role in Project
David Vigliotta	Slipstream	608-210-7143, dvigliotta@slipstreaminc.org	PI
Xiaohui Zhou	Slipstream	608-210-6989 jzhou@slipstreaminc.org	Technical Director and Lead Educator
Julie Bird	Slipstream	608-210-7125 jbird@slipstreaminc.org	Finance and Accounting
Ben Bartling	Slipstream	608-210-7173 BBartling@slipstreaminc.org	Educator
Kevin Frost	Slipstream	608-210-6823 kfrost@slipstreaminc.org	Technical Project Manager
Cherie Williams	Slipstream	608-210-6967 cwilliams@slipstreaminc.org	Art Director
Lonna Berg	Slipstream	608-210-7157 LBerg@slipstreaminc.org	Project Manager
Andrea Cherney	Slipstream	608-210-7126 acherney@slipstreaminc.org	Digital Media Director
Zheng O'Neill	Texas A&M	979-845-4931 ZONeill@tamu.edu	Educator
David Claridge	Texas A&M	979-845-1280 dclaridge@tamu.edu	Guest Speaker
Brian Clark	USACE	217-373-3338, Brian.C.Clark@usace.army.mil	Educator
Chris Battisti	USACE	217-373-3345 Christopher.M.Battisti@usace.army.mil	Educator
Miles Ryan	Questions & Solutions Engineering	612-817-5272 Miles.Ryan@qseng.com	Educator
Gwelen Paliaga	TRC	510-224-4496, GPaliaga@trccompanies.com	Educator
Rupam Singla	TRC	510-469-0810 RSingla@trccompanies.com	Educator
William Elliott	Spectrum Solutions, Inc.	540-372-0212 belliott.ctr@spectrumsi.com	Outreach
Srinivas Katipamula	PNNL	509-372-4281, Srinivas.Katipamula@pnnl.gov	Guest Speaker
Ron Underhill	PNNL	Ronald.Underhill@pnnl.gov	Guest Speaker

APPENDIX B A SAMPLE SURVEY QUESTIONNAIRE

→ slipstream

DoD Advanced Building Controls and Management Training Topic Questionnaire

DoD ESTCP EW19-5055 Project (Slipstream, USACE, Texas A&M, TRC Engineers)

The questionnaire is intended to gauge the interests of DoD energy and facility managers, engineers, as well as facility operators to learn specific topics/subtopics related to Advanced Building Controls and Management. Your feedback is very important to our team in designing and delivering our training. We have a total of 20 questions and it should take less than 5 minutes to complete.

- * 1. How interested are you in **Building Automation System (BAS) basics and architecture** subtopic in the BAS Fundamentals topic area?

not interested at all slightly interested moderately interested very interested extremely interested

★ ★ ★ ★ ★

- * 2. How interested are you in **Sensors, actuators, and controllers** subtopic in the BAS Fundamentals topic area?

not interested at all slightly interested moderately interested very interested extremely interested

★ ★ ★ ★ ★

- * 3. How interested are you in **HVAC controls and common communication protocols** subtopic in the BAS Fundamentals topic area?

not interested at all slightly interested moderately interested very interested extremely interested

★ ★ ★ ★ ★

- * 4. How interested are you in **Data analysis techniques using BAS trends** subtopic in the BAS Fundamentals topic area?

not interested at all slightly interested moderately interested very interested extremely interested

★ ★ ★ ★ ★

- * 5. How interested are you in **Cybersecurity of facility-related control systems** subtopic in the BAS Fundamentals topic area?

not interested at all slightly interested moderately interested very interested extremely interested

★ ★ ★ ★ ★

- * 6. How interested are you in **Optimal scheduling** subtopic in the Common Advanced Control Strategies topic area?

not interested at all slightly interested moderately interested very interested extremely interested

★ ★ ★ ★ ★

* 7. How interested are you in **AHU supply air static pressure and temperature resets** subtopic in the Common Advanced Control Strategies topic area?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 8. How interested are you in **Air-side economizer control** subtopic in the Common Advanced Control Strategies topic area?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 9. How interested are you in **Demand-controlled ventilation** subtopic in the Common Advanced Control Strategies topic area?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 10. How interested are you in **Multi-zone and dual duct controls optimization** subtopic in the Common Advanced Control Strategies topic area?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 11. How interested are you in **Energy Modeling 101** subtopic in the Energy Modeling and Intelligent Building Operations topic area?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 12. How interested are you in **Intelligent building operations** subtopic in the Energy Modeling and Intelligent Building Operations topic area?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 13. How interested are you in **ASHRAE guideline 36 High-Performance Sequences of Operation for HVAC Systems and field demonstration results?**

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 14. How interested are you in the **Re-tuning** subtopic?

not interested at all	slightly interested	moderately interested	very interested	extremely interested
				

* 15. How interested are you in the **Continuous Commissioning** subtopic?

not interested at all slightly interested moderately interested very interested extremely interested

☐ ☐ ☐ ☐ ☐

16. What **other advanced building controls related topic(s)** you would like to learn (optional)?

* 17. Which national or regional conference, symposium, or workshop you often go to for training (multiple choice)?

- ☐ SERDP/ESTCP Symposium
- ☐ DOE Energy Exchange
- ☐ DoD Maintenance Symposium
- ☐ Training held at U.S. Army IMCOM training center
- ☐ Building commissioning annual conference
- ☐ Other (please specify)

* 18. Which job title best describes you? (Please choose only one.)

- ☐ Energy manager or facility manager
- ☐ Engineer
- ☐ Facility operator (uses or repairs building automation systems)
- ☐ Other (please specify):

19. Which DoD agency do you belong to? (Please choose only one, optional.)

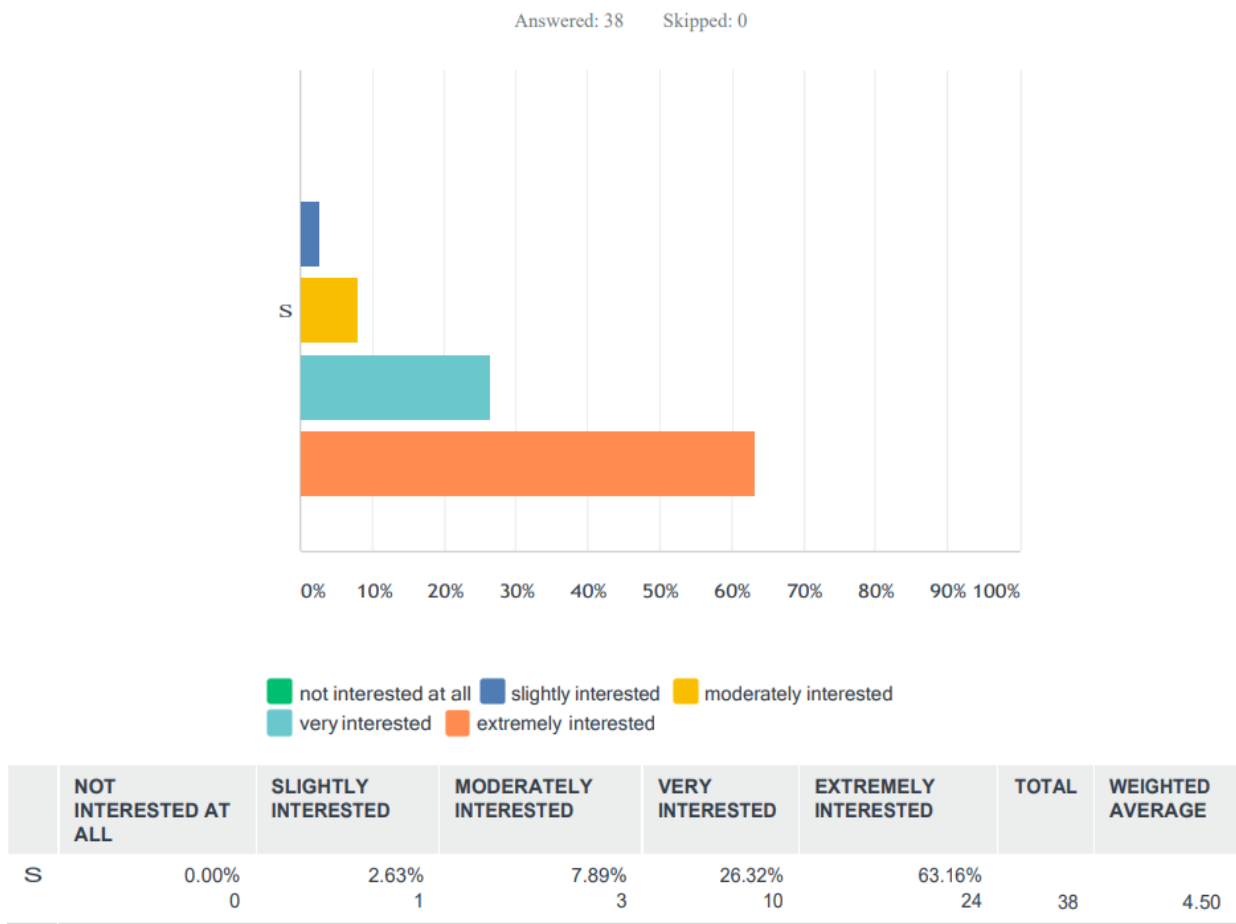
- ☐ U.S. Army
- ☐ U.S. Navy
- ☐ U.S. Air Force
- ☐ Other (please specify):

20. Please fill your contact information (optional.)

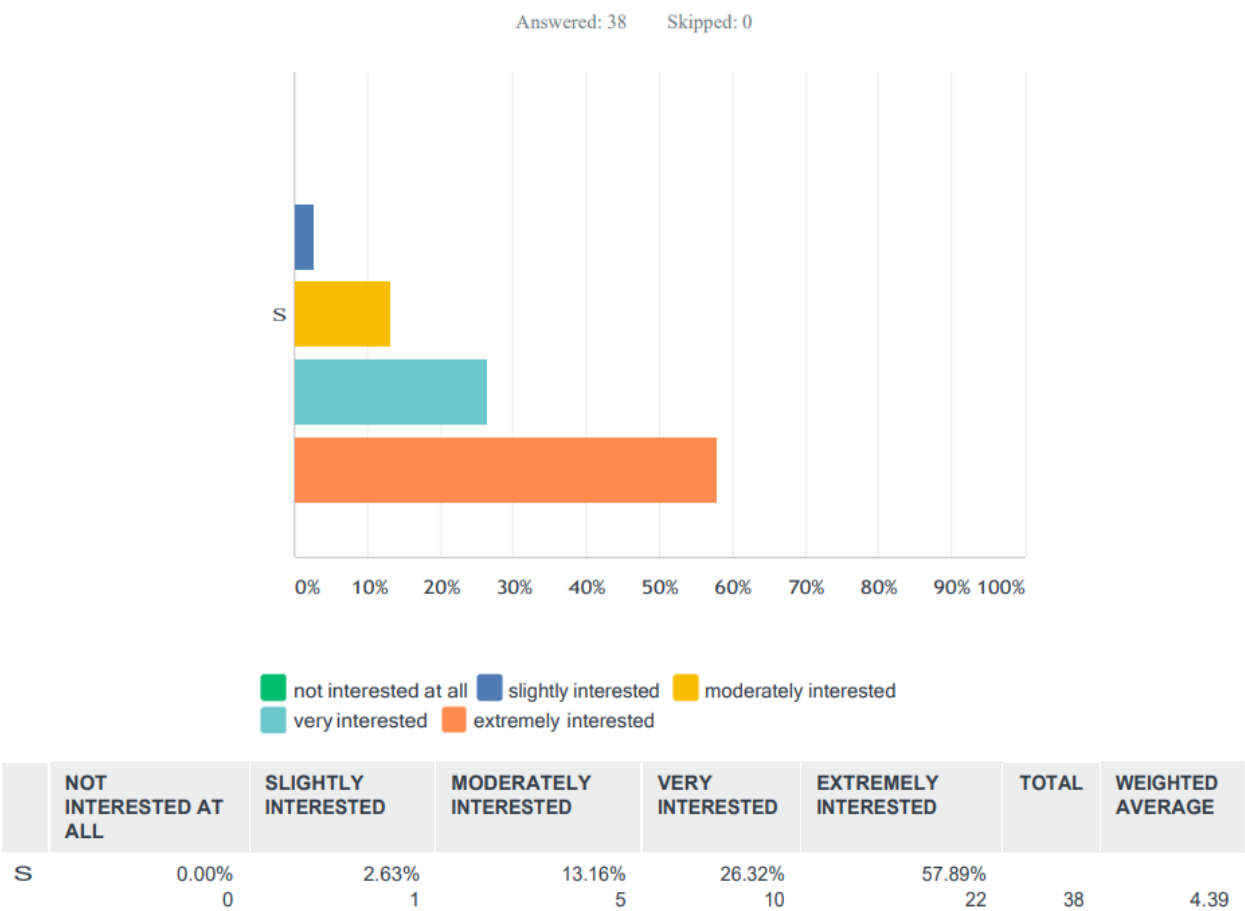
Name	
Company	
Title	
Email Address	

APPENDIX C A SAMPLE SURVEY RESULT SUMMARY

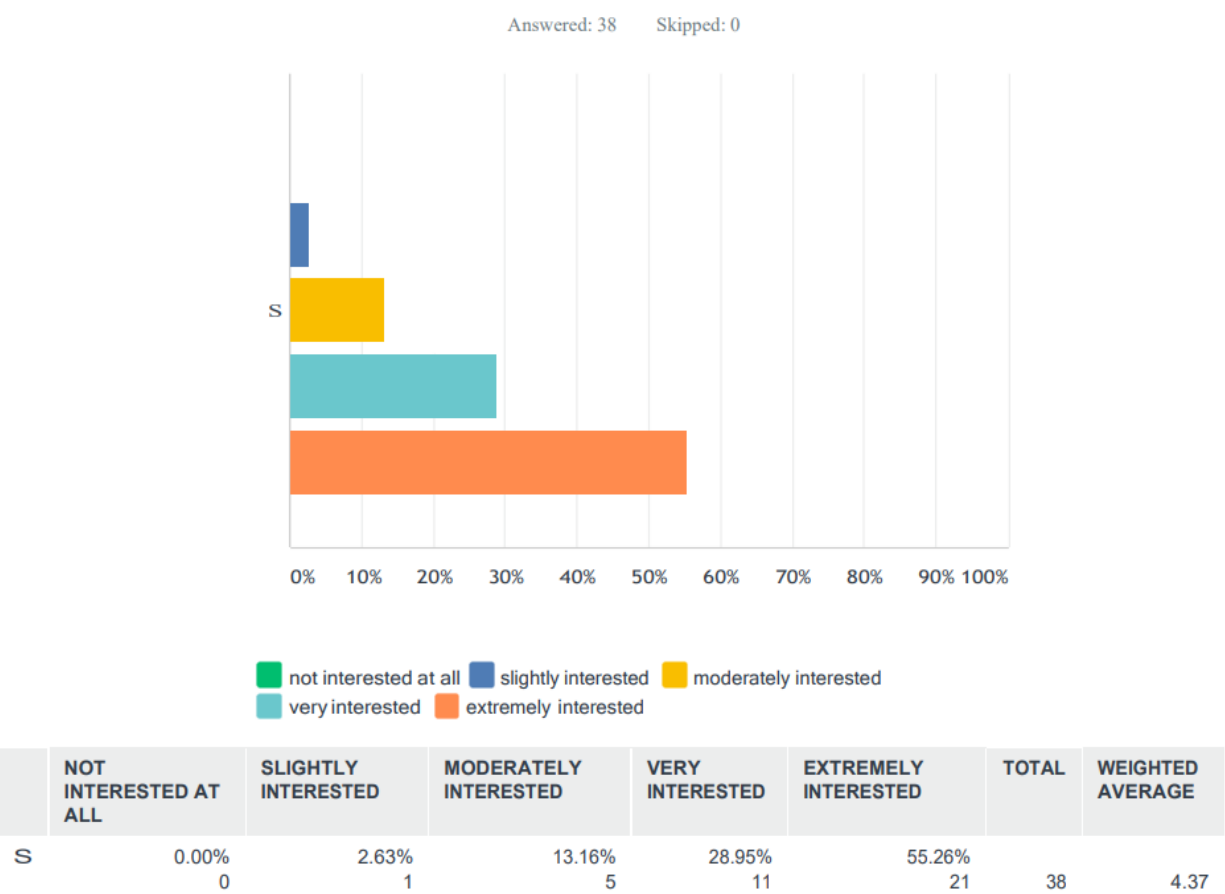
Q1 How interested are you in Building Automation System (BAS) basics and architecture subtopic in the BAS Fundamentals topic area?



Q2 How interested are you in Sensors, actuators, and controllers subtopic in the BAS Fundamentals topic area?

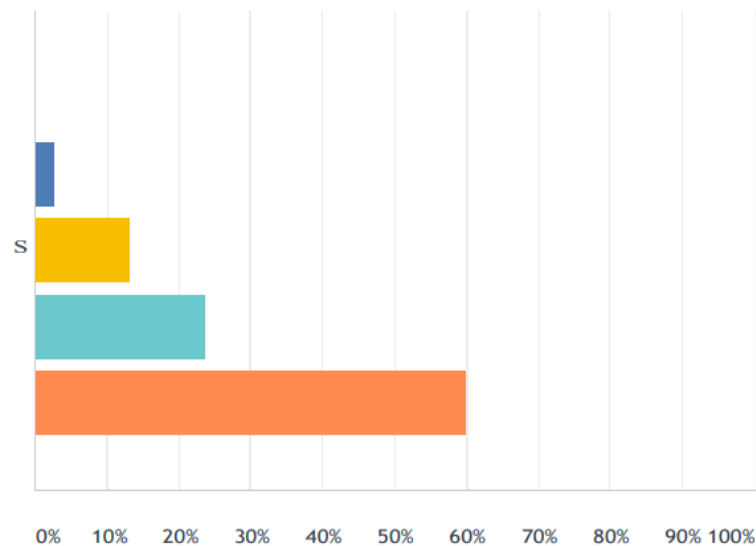


Q3 How interested are you in HVAC controls and common communication protocols subtopic in the BAS Fundamentals topic area?



Q4 How interested are you in Data analysis techniques using BAS trends subtopic in the BAS Fundamentals topic area?

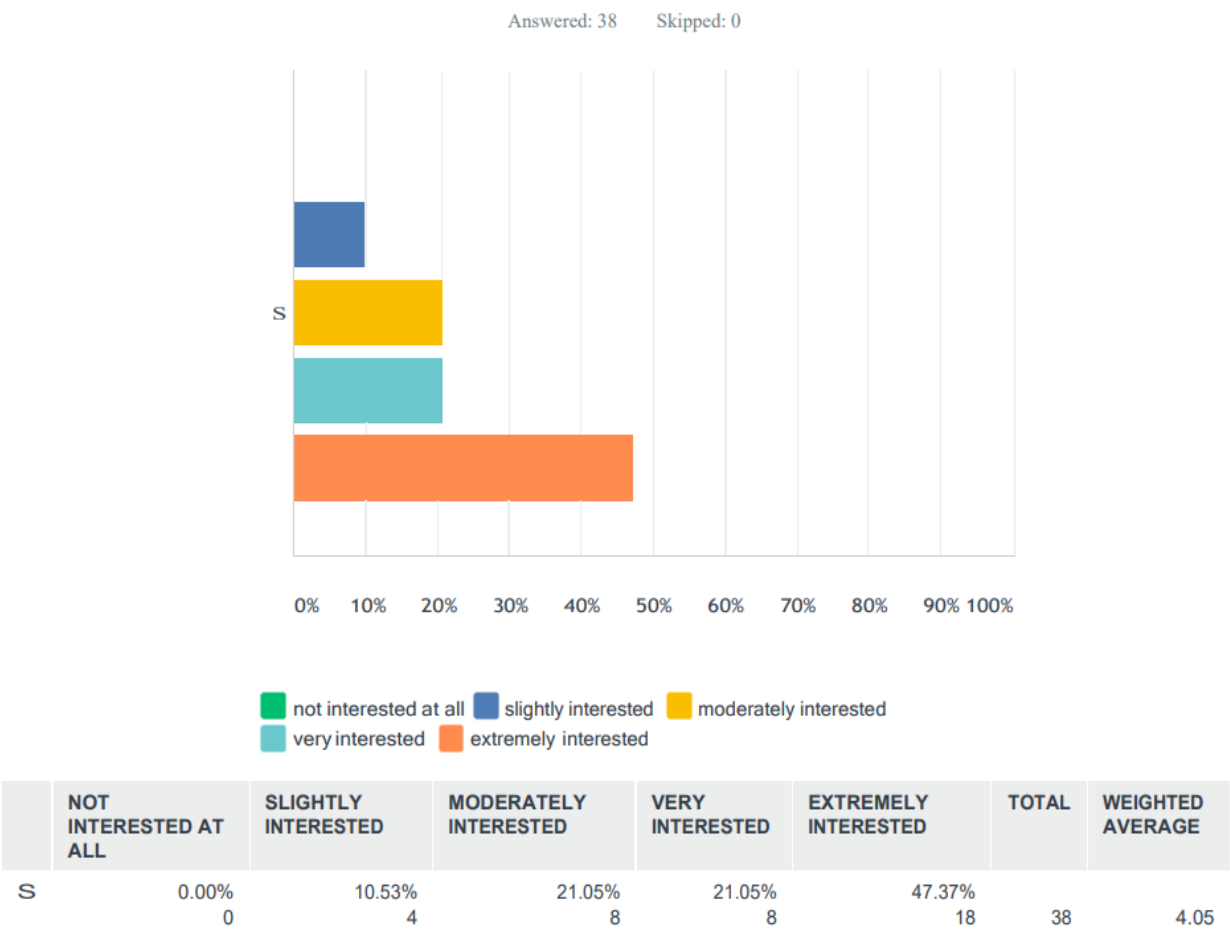
Answered: 38 Skipped: 0



not interested at all slightly interested moderately interested
very interested extremely interested

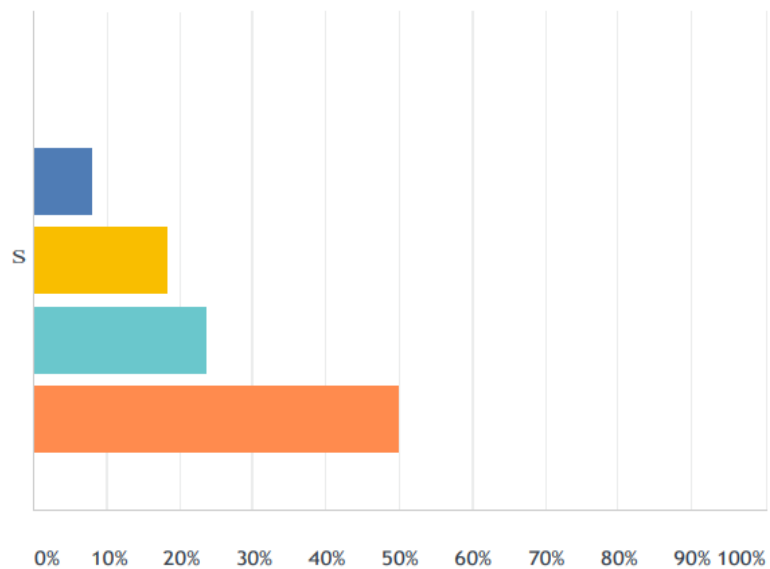
	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	0.00% 0	2.63% 1	13.16% 5	23.68% 9	60.53% 23	38	4.42

Q5 How interested are you in Cybersecurity of facility-related control systems subtopic in the BAS Fundamentals topic area?



Q6 How interested are you in Optimal scheduling subtopic in the Common Advanced Control Strategies topic area?

Answered: 38 Skipped: 0

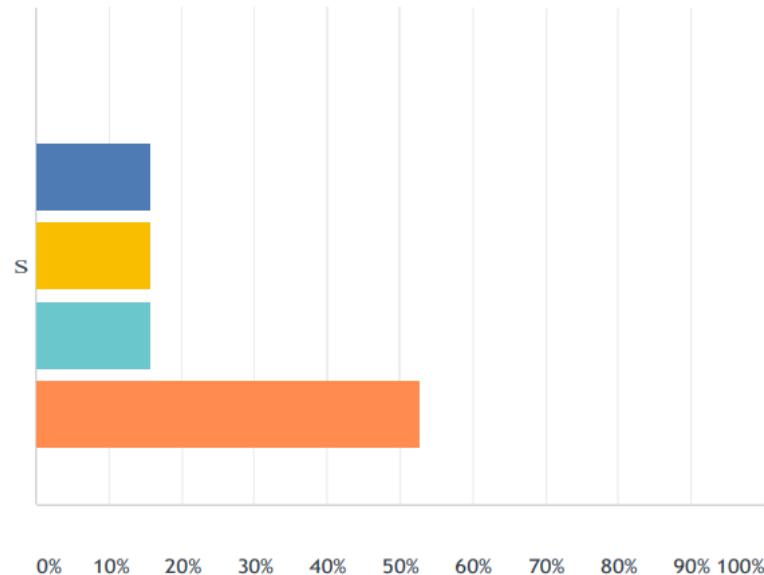


not interested at all slightly interested moderately interested
very interested extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	0.00%	7.89%	18.42%	23.68%	50.00%	38	4.16
	0	3	7	9	19		

Q7 How interested are you in AHU supply air static pressure and temperature resets subtopic in the Common Advanced Control Strategies topic area?

Answered: 38 Skipped: 0

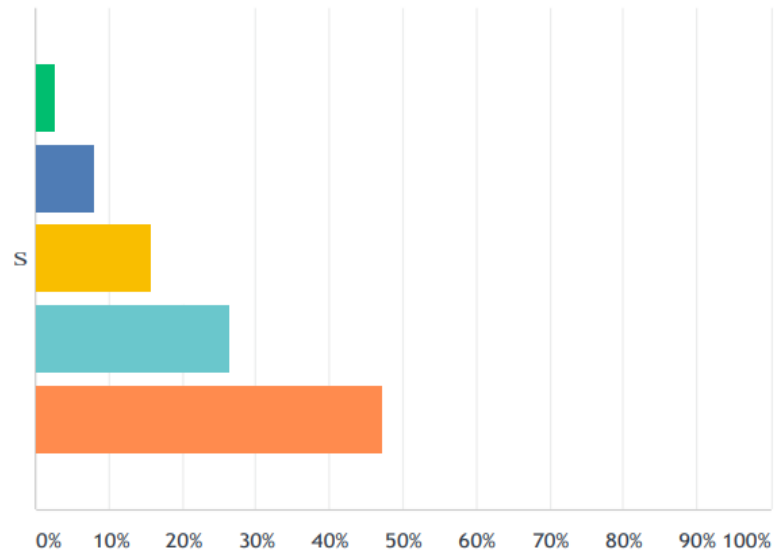


■ not interested at all
 ■ slightly interested
 ■ moderately interested
 ■ very interested
 ■ extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	0.00%	15.79%	15.79%	15.79%	52.63%	38	4.05
	0	6	6	6	20		

Q8 How interested are you in Air-side economizer control subtopic in the Common Advanced Control Strategies topic area?

Answered: 38 Skipped: 0

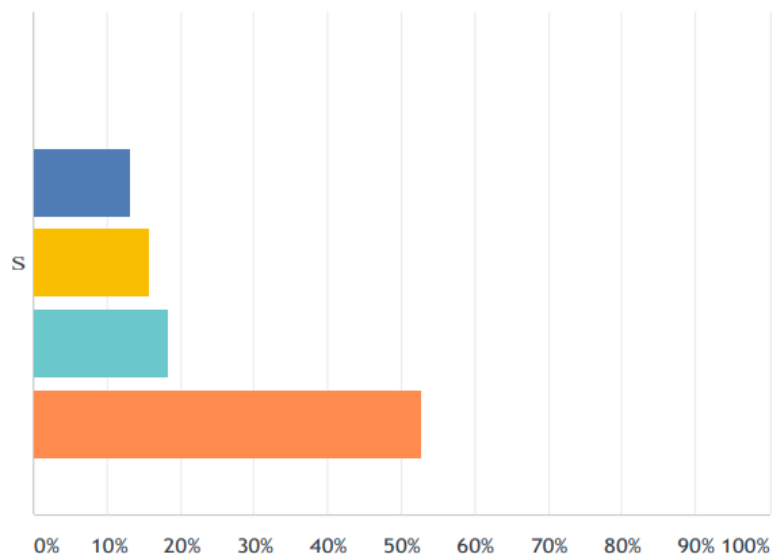


not interested at all slightly interested moderately interested
very interested extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	2.63% 1	7.89% 3	15.79% 6	26.32% 10	47.37% 18	38	4.08

Q9 How interested are you in Demand-controlled ventilation subtopic in the Common Advanced Control Strategies topic area?

Answered: 38 Skipped: 0

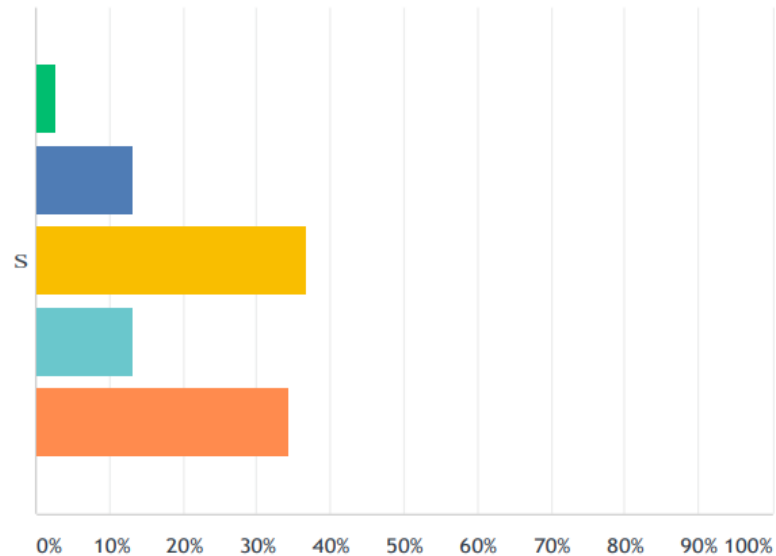


■ not interested at all
 ■ slightly interested
 ■ moderately interested
 ■ very interested
 ■ extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	0.00% 0	13.16% 5	15.79% 6	18.42% 7	52.63% 20	38	4.11

Q10 How interested are you in Multi-zone and dual duct controls optimization subtopic in the Common Advanced Control Strategies topic area?

Answered: 38 Skipped: 0

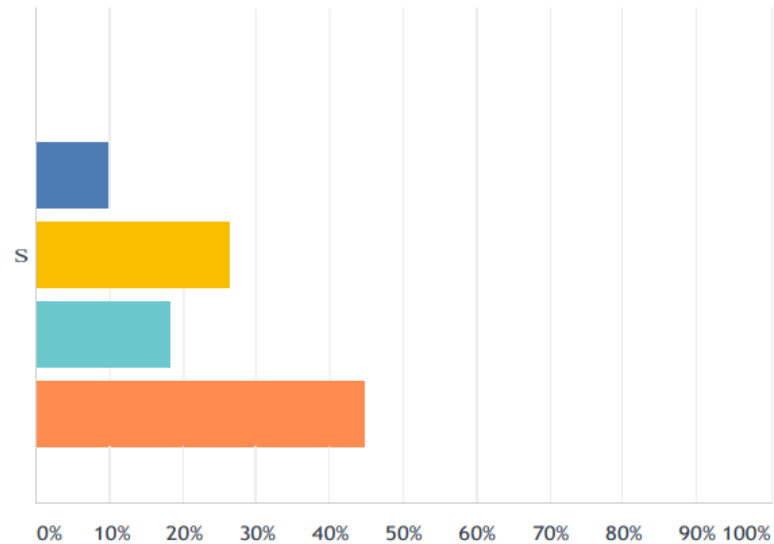


not interested at all slightly interested moderately interested
very interested extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	2.63% 1	13.16% 5	36.84% 14	13.16% 5	34.21% 13	38	3.63

Q11 How interested are you in Energy Modeling 101 subtopic in the Energy Modeling and Intelligent Building Operations topic area?

Answered: 38 Skipped: 0

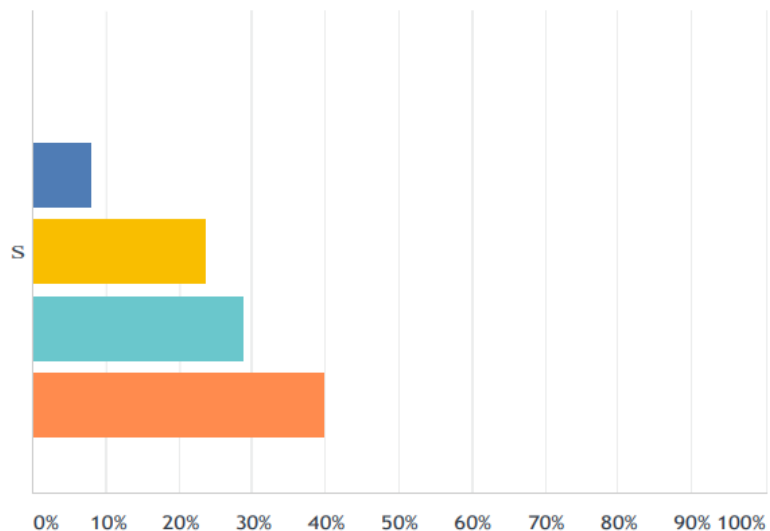


■ not interested at all
 ■ slightly interested
 ■ moderately interested
 ■ very interested
 ■ extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	0.00%	10.53%	26.32%	18.42%	44.74%	38	3.97
	0	4	10	7	17		

Q12 How interested are you in Intelligent building operations subtopic in the Energy Modeling and Intelligent Building Operations topic area?

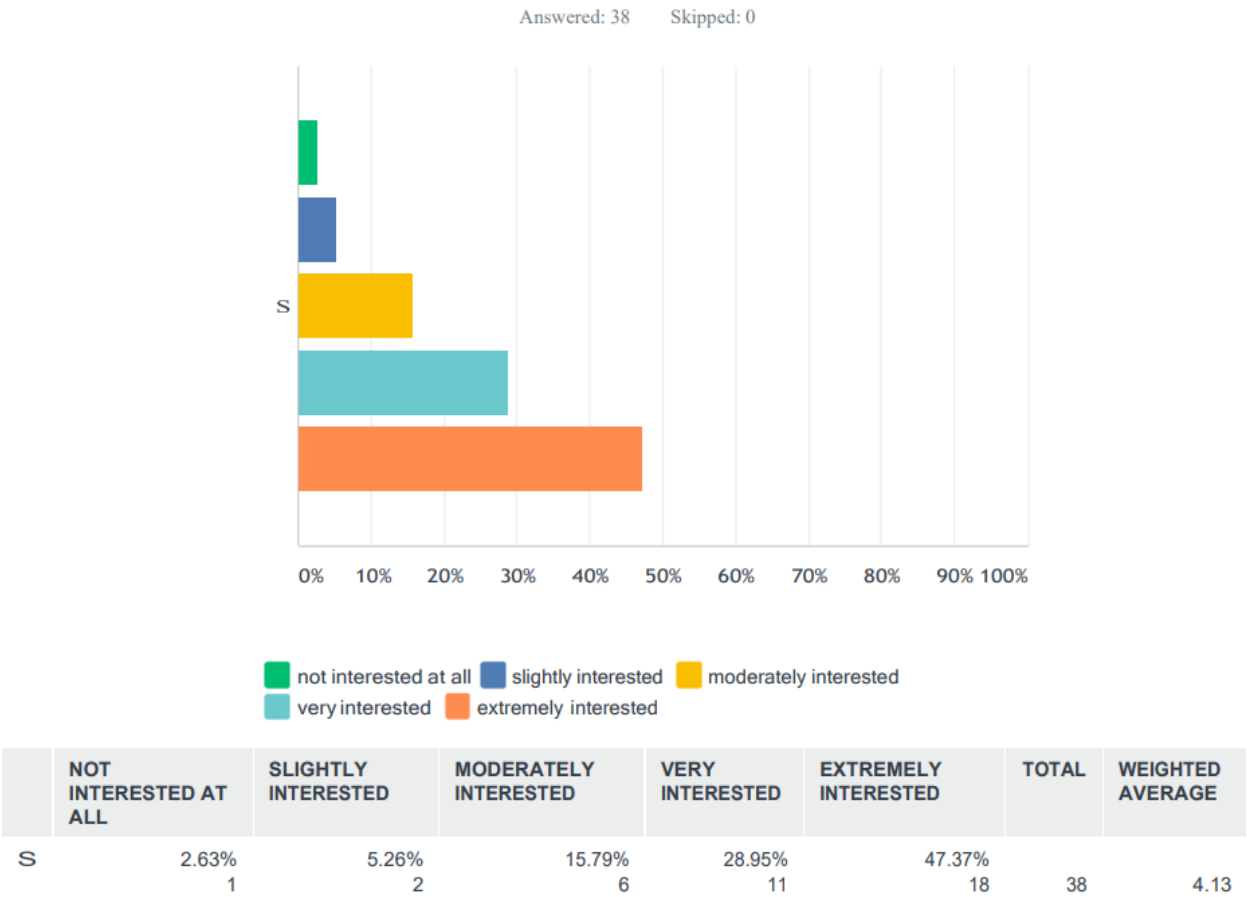
Answered: 38 Skipped: 0



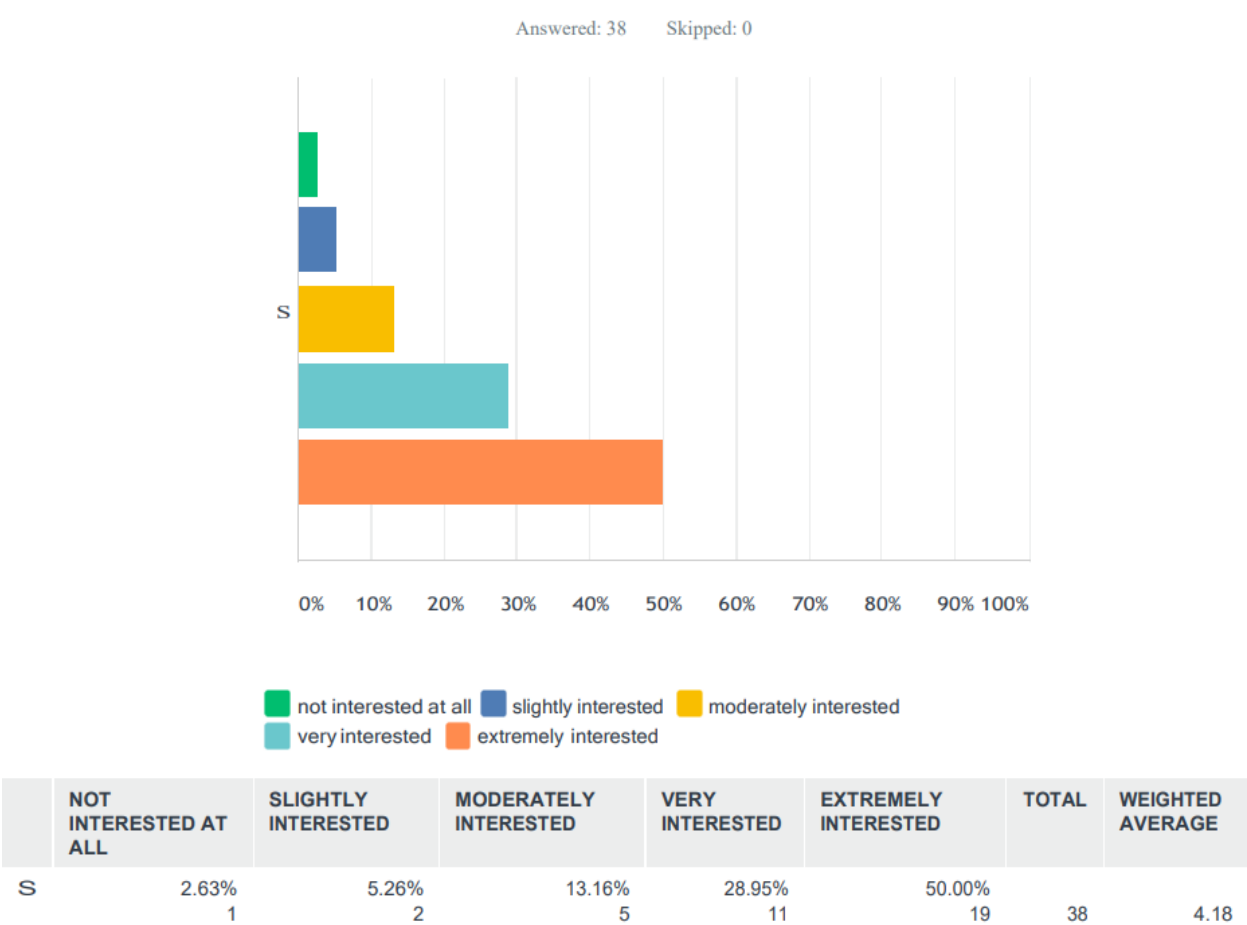
■ not interested at all
 ■ slightly interested
 ■ moderately interested
 ■ very interested
 ■ extremely interested

	NOT INTERESTED AT ALL	SLIGHTLY INTERESTED	MODERATELY INTERESTED	VERY INTERESTED	EXTREMELY INTERESTED	TOTAL	WEIGHTED AVERAGE
S	0.00%	7.89%	23.68%	28.95%	39.47%	38	4.00
	0	3	9	11	15		

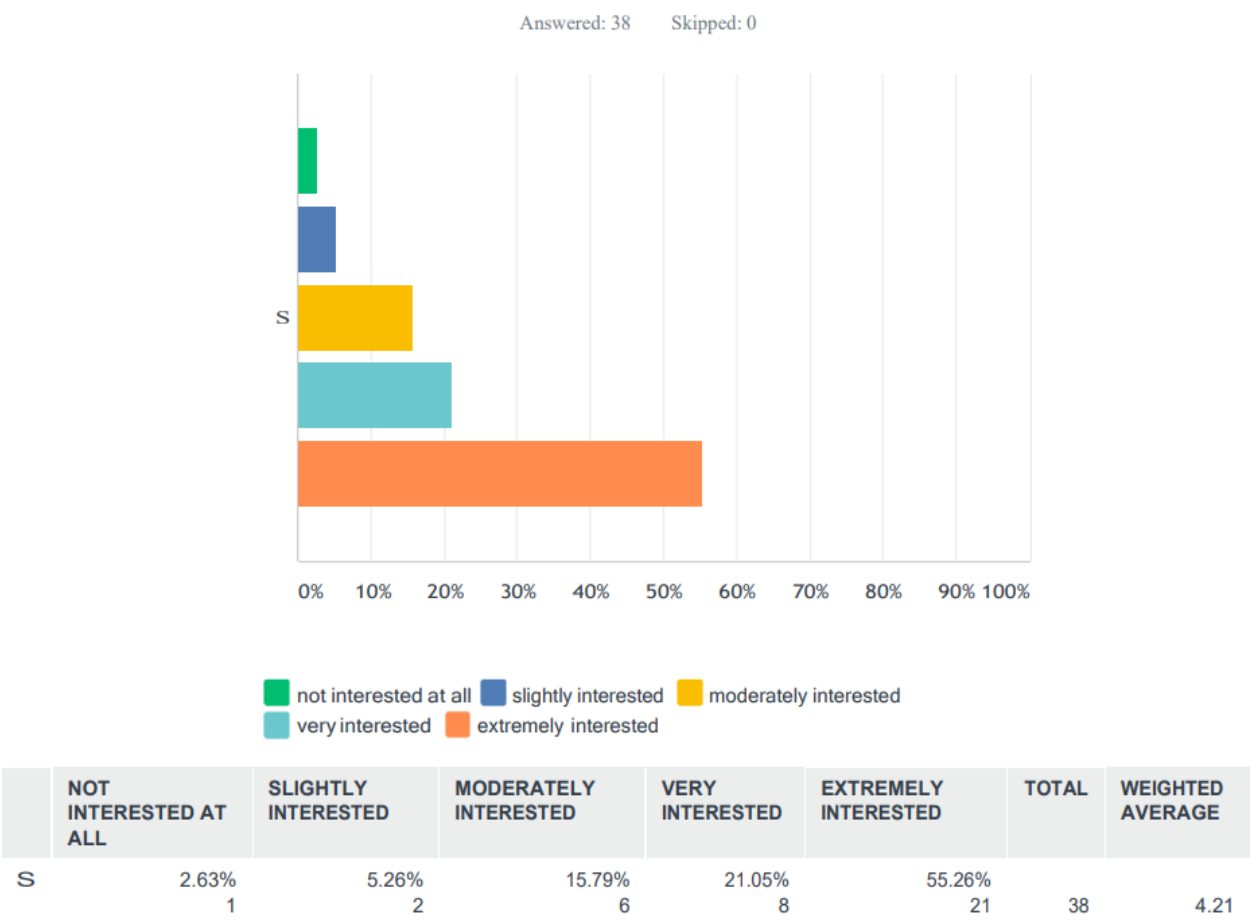
Q13 How interested are you in ASHRAE guideline 36 High-Performance Sequences of Operation for HVAC Systems and field demonstration results?



Q14 How interested are you in the Re-tuning subtopic?



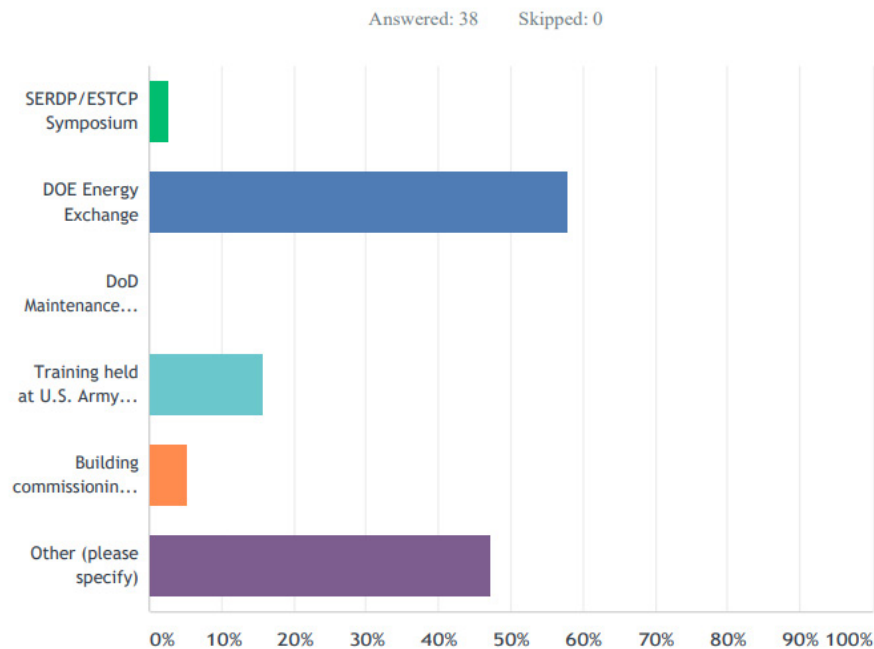
Q15 How interested are you in the Continuous Commissioning subtopic?



Q16 What other advanced building controls related topic(s) you would like to learn (optional)?

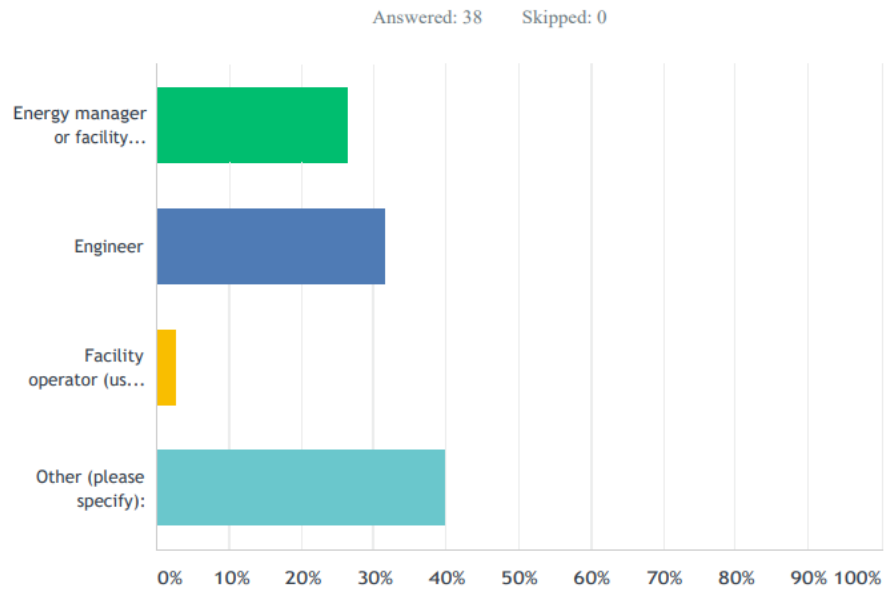
Answered: 18 Skipped: 20

Q17 Which national or regional conference, symposium, or workshop you often go to for training (multiple choice)?



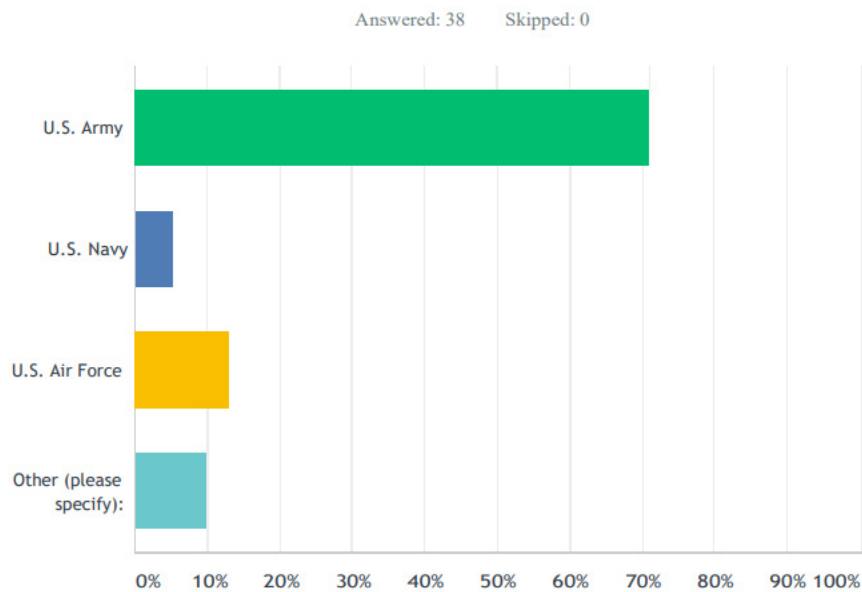
ANSWER CHOICES	RESPONSES	
SERDP/ESTCP Symposium	2.63%	1
DOE Energy Exchange	57.89%	22
DoD Maintenance Symposium	0.00%	0
Training held at U.S. Army IMCOM training center	15.79%	6
Building commissioning annual conference	5.26%	2
Other (please specify)	47.37%	18
Total Respondents: 38		

Q18 Which job title best describes you? (Please choose only one.)



ANSWER CHOICES	RESPONSES	
Energy manager or facility manager	26.32%	10
Engineer	31.58%	12
Facility operator (uses or repairs building automation systems)	2.63%	1
Other (please specify):	39.47%	15
TOTA		38

Q19 Which DoD agency do you belong to? (Please choose only one, optional.)



ANSWER CHOICES	RESPONSES	
U.S. Army	71.05%	27
U.S. Navy	5.26%	2
U.S. Air Force	13.16%	5
Other (please specify):	10.53%	4
TOTAL		38

Q20 Please fill your contact information (optional.)

Answered: 30 Skipped: 8

ANSWER CHOICES	RESPONSES	
Name	100.00%	30
Company	96.67%	29
Address	0.00%	0
Address 2	0.00%	0
City/Town	0.00%	0
State/Province	0.00%	0
ZIP/Postal Code	0.00%	0
Title	93.33%	28
Email Address	100.00%	30

APPENDIX D TASK 2 TRAINING TOPICS FOR ENERGY MANAGERS

Table A-2. Task 2 Detailed Training Topics for Energy Managers

Module 1: Fundamentals of Building Control Systems	
Introduction to Building Automation System Architecture	Xiaohui Zhou, Slipstream
BACnet, LonWorks, and Niagara Framework	Xiaohui Zhou, Slipstream
Basics of HVAC Controls - Components	Kevin Frost, Slipstream
Basics of HVAC Controls - Control Loops	Kevin Frost, Slipstream
Module 2: Advanced Control Strategies	
Energy Savings of Advanced Controls	Xiaohui Zhou, Slipstream
Introduction to Optimal Scheduling	Xiaohui Zhou, Slipstream
Introduction to AHU Supply Air Temperature and Pressure Resets	Xiaohui Zhou, Slipstream
Introduction to Economizers	Kevin Frost, Slipstream
Introduction to Demand-Controlled Ventilation	Kevin Frost, Slipstream
ASHRAE Guideline 36: Overview, Benefits, and Field Demonstration	Gwelen Paliaga, TRC
ASHRAE Guideline 36: What It Covers	Xiaohui Zhou, Slipstream
Module 3: Energy Modeling, Intelligent Building Operation, and Advanced Energy Performance	
Building Energy Modeling 101	Zheng O'Neill, Texas A&M
Smart Building Operations through Optimal Control and Energy Performance Monitoring	Zheng O'Neill, Texas A&M
Module 4: ESTCP Technology Demonstration Projects	
EW-201408 Demonstration of Tiered Trim and Response Method	Xiaohui Zhou, Slipstream
EW-201142 Energy Performance Monitoring and Optimization System for DoD Campus	Zheng O'Neill, Texas A&M
EW-201015 Scalable Deployment of Advanced Building Energy Management Systems	Zheng O'Neill, Texas A&M
EW-201152 Multi-Zone Unit Control	Brian Clark, USACE

APPENDIX E TASK 3 TRAINING TOPICS FOR FACILITY ENGINEERS

Table A-3. Task 3 Detailed Training Topics for Facility Engineers

Module 1: Fundamentals of Building Control Systems	
Basic HVAC Equipment and Systems	Kevin Frost, Slipstream
Basic HVAC Controls	Kevin Frost and Ben Bartling, Slipstream
Building Control System Design	Xiaohui Zhou, Slipstream
Building Control Project Implementation	Ben Bartling, Slipstream
Utility Monitoring and Control System Front End and Integration	Xiaohui Zhou, Slipstream
Module 2: Common Advanced Control Strategies	
Introduction to Optimal Scheduling	Xiaohui Zhou and Kevin Frost, Slipstream
Introduction to AHI Supply Air Pressure and Temperature Resets	Xiaohui Zhou and Kevin Frost, Slipstream, Miles Ryan
Introduction to Economizer	Xiaohui Zhou and Kevin Frost, Slipstream, Miles Ryan, Questions and Solutions Engineering
Introduction to Demand-Controlled Ventilation	Xiaohui Zhou and Kevin Frost, Slipstream
Cost-Benefit Analysis	Miles Ryan, Questions and Solutions Engineering
ASHRAE Guideline 36: Field Demonstration	Gwelen Paliaga, TRC
Introduction to ASHRAE Guideline 36	Xiaohui Zhou, Slipstream
Module 3: Energy Modeling, Intelligent Building Operation, and Advanced Energy Performance	
Building Energy Modeling 101	Zheng O'Neill, Texas A&M
Smart Building Operations through Optimal Control and Energy Performance Monitoring	Zheng O'Neill, Texas A&M
Building Monitoring, Data Analysis, and Troubleshooting	Miles Ryan, Questions and Solutions Engineering
Module 4: ESTCP Technology Demonstration Projects	
Demonstration of Tiered Trim and Respond Method	Xiaohui Zhou, Slipstream
Energy Performance Monitoring and Optimization System for DoD Campuses	Zheng O'Neill, Texas A&M
Scalable Deployment of Advanced Building Energy Management Systems	Zheng O'Neill, Texas A&M
Multizone To Variable Volume Control Retrofit	Chris Battisti, USACE
Module 5: Existing Building Commissioning	
Overview of Building Re-tuning: Using Analytics to Improve Building Operations	Srinivas Katipamula and Ron Underhill, PNNL
Building Operation and Continuous Commissioning	David Claridge, Texas A&M

APPENDIX F TRAINING DELIVERY MECHANISMS

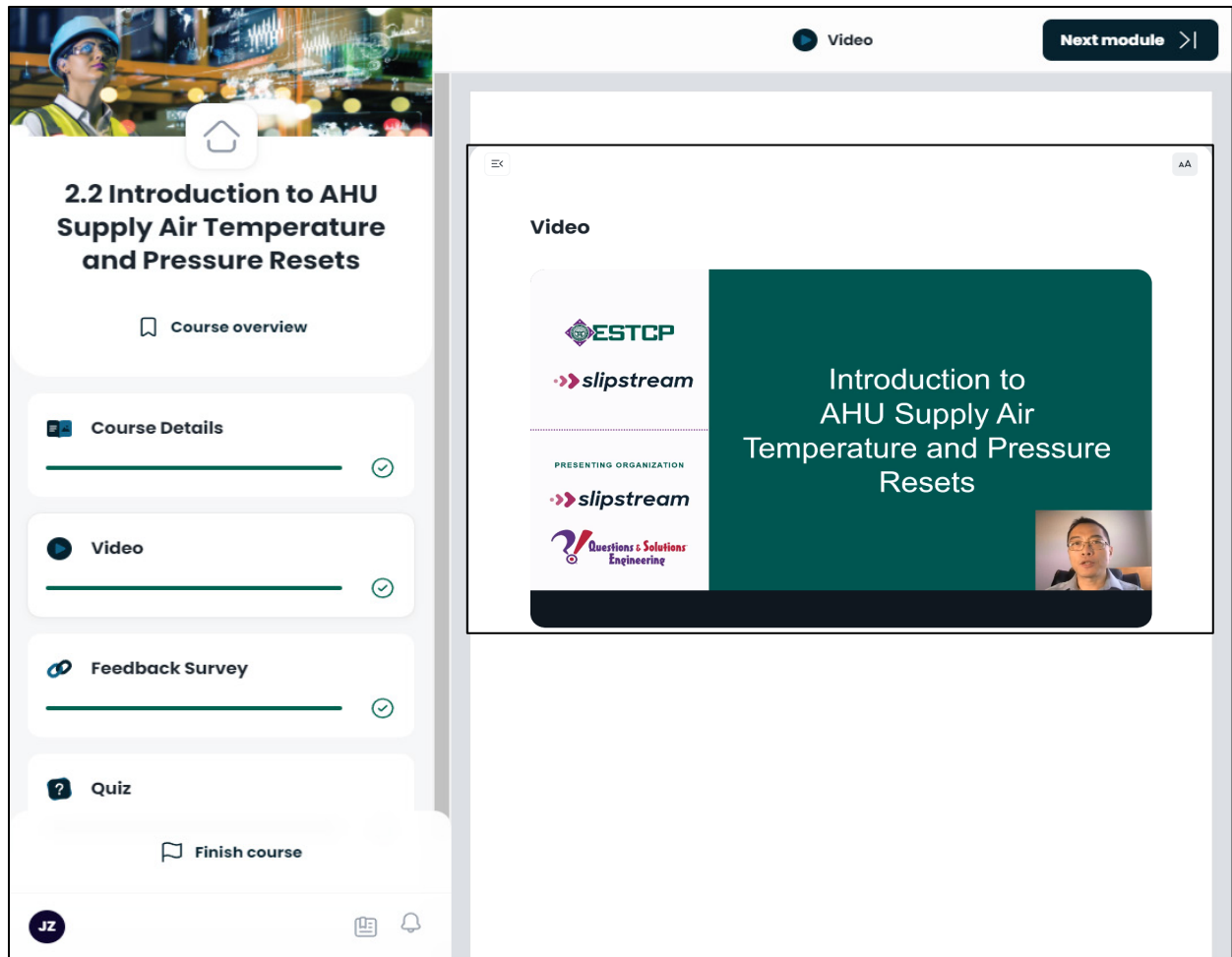


Figure A-1. A Screenshot of Slipstream LMS

USACE Resource Efficiency Manager Program Workshop Agenda

April 27 - 29, 2021
1200 – 1430 Central Time
WebEx

April 27, 2021

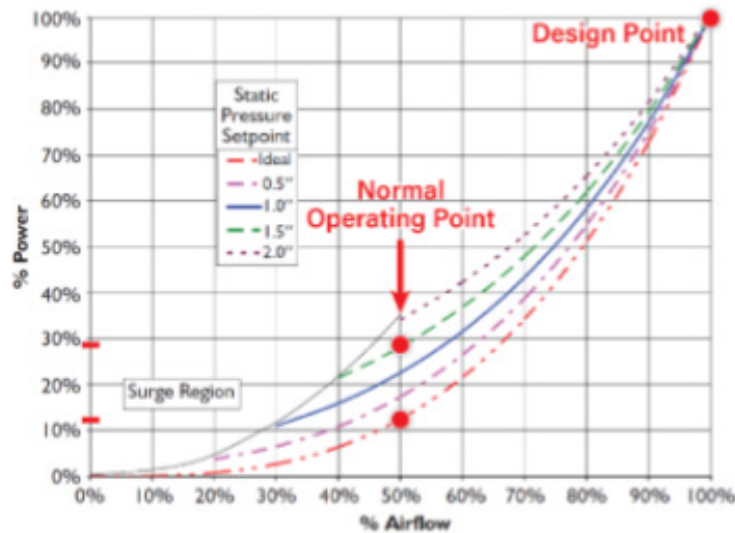
11:50 - 12:00 WebEx Sign-in
12:00 - 12:05 Welcome – John Trudell, REM Program
12:05 - 12:25 USACE Energy Overview – Chip Marin, HNC Programs and Business Director
12:25 - 12:35 REM Program Overview – John Trudell, REM Program
12:35 - 12:45 Monthly Reports – Teresa Whalen/Melissa Johnson, REM Program
12:45 - 13:00 Safety Update – Kyle Shireman, HNC Safety Office
13:00 - 14:00 Remote Audits Overview, Guidance, Resources, and Examples/Case Studies– DOE FEMP
14:00 - 14:15 Q&A and Closing Remarks

April 28 2021

11:50 - 12:00 WebEx Sign-in
12:00 - 12:05 Welcome – John Trudell, REM Program
12:05 - 12:30 50001 Ready and Energy Act 2020 – DOE-FEMP
12:30 - 13:00 50001 Ready and Garrison Implementation – USACE REM
13:00 - 13:30 ESTCP Energy Manager/Facility Manager Online Training – David Vigliotta - Slipstream
13:30 - 14:00 FEMP Resources – DOE FEMP
14:00 - 14:15 Q&A and Closing Remarks

Figure A-2. A Sample Synchronous Training at DoD Workshops

Resetting AHU/RTU Static Pressure Using Tiered Trim and Respond Method



SAVES 14% TO 35% AHU/RTU FAN ENERGY COMPARED TO TRADITIONAL FIXED STATIC PRESSURE CONTROL

Between 2014–2016, the demonstration was conducted at five Iowa Army National Guard facilities. Control retrofits were implemented on four different brands of building control systems.

Tiered Trim and Respond

- A version of the Trim and Respond method
- Reset Air Handling Unit (AHU) or Rooftop Unit (RTU) supply air static pressure using Tiered Trim and Respond (TTR) method based on Variable-Air-Volume (VAV) terminal unit damper positions
- In partial-load conditions, lower static pressure can result in significant fan energy savings while maintaining airflow

Advantages Over Fixed Pressure Control Method

- Save significant AHU and RTU supply and return fan energy
- Reasonable simple payback
- No impact on occupant comfort

Best Suited For

- Control retrofit at existing buildings with VAV system and direct digital

Figure A-3. A Sample ESTCP Project Fact Sheet

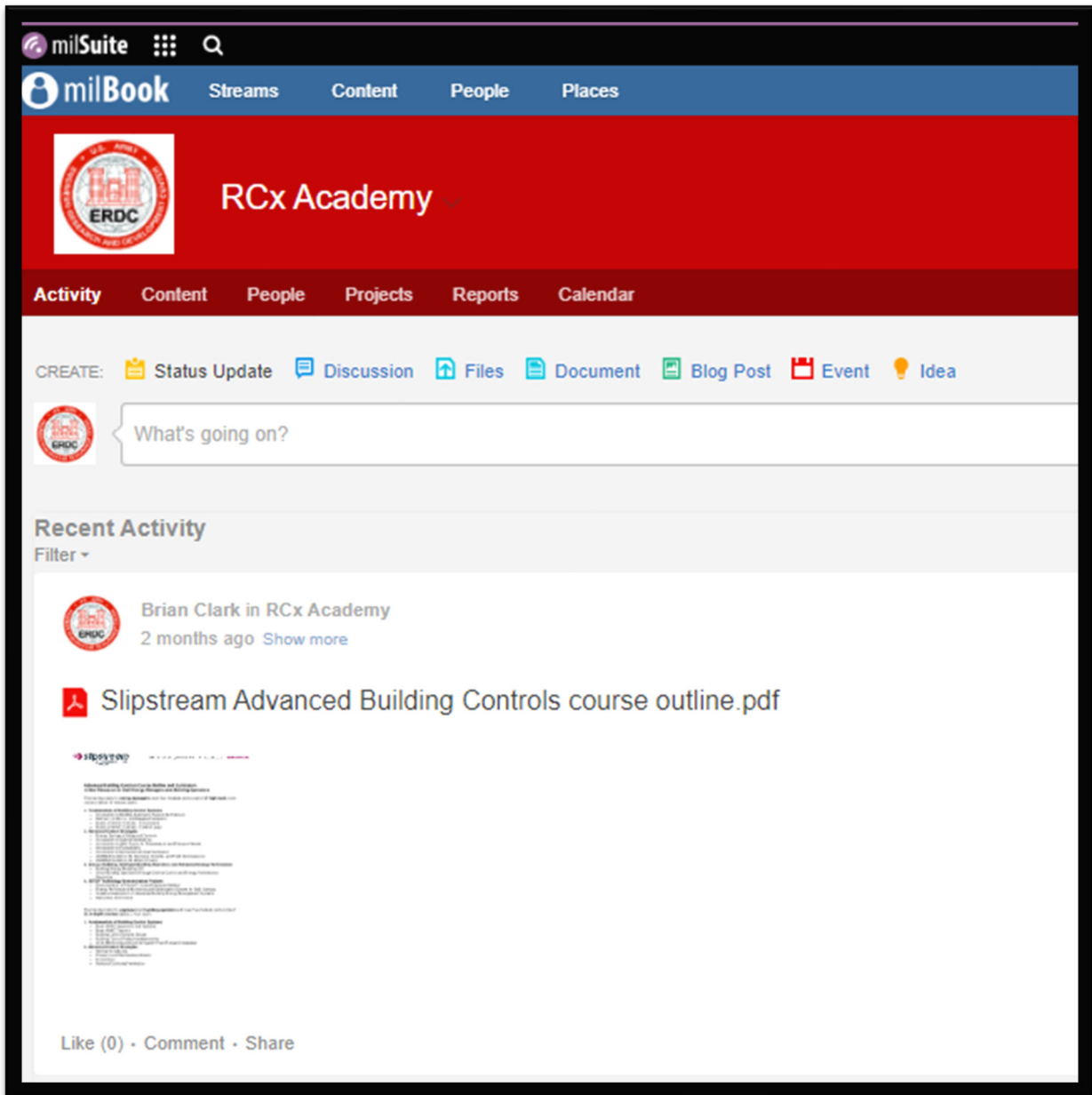


Figure A-4. Integrate Trainings on USACE RCx University


WBDG Whole Building Design Guide

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[DESIGN RECOMMENDATIONS](#)
[PROJECT MANAGEMENT - O & M](#)
[FEDERAL FACILITY CRITERIA](#)
[CONTINUING EDUCATION](#)
[ADDITIONAL RESOURCES](#)

[CONTINUING EDUCATION](#) / [DOD COURSES](#) / [ADVANCED BUILDING CONTROLS](#)

Advanced Building Controls

Did you know that advanced building controls and energy management strategies could result in an average of nearly **30% energy savings**? Unfortunately, there is an industry-wide knowledge gap that addresses how to utilize advanced controls to capitalize on energy savings and ensure buildings run at peak performance.

Funded by a grant from the Department of Defense (DoD) [Environmental Security Technology Certification Program \(ESTCP\)](#), Slipstream developed this comprehensive training series to bridge that gap with 21 in-depth, hour-long sessions. Topics cover fundamentals of building controls, advanced control strategies including the ASHRAE Guideline 36 high-performance sequences of operations for HVAC systems, building energy modeling and intelligent building operations, and retro-commissioning and re-tuning.

Although the trainings address specific DoD criteria, these sessions are intended for all energy managers, building operators, and facility engineers who may lack background or experience in advanced controls. Each course is presented by an industry expert through an on-demand, self-paced learning environment.

Education Type: Live Online

Duration: 21 Hours (Combined)

Level: Intermediate

Prerequisites: None

Professional Development Hours: 21 PDH (Combined)

Sponsored by:



Partner:



Figure A-5. Integrate Trainings on Whole Building Design Guide (WBDG)

<https://wbdg.org/continuing-education/dod-courses/estcp>


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Advanced Building Controls

17 videos • 426 views • Last updated on Mar 14, 2022

Did you know that advanced building controls and energy management strategies could result in an average of nearly 30% energy savings? This video series focuses on how to use advanced controls to capitalize on energy savings and ensure buildings run at peak performance.

- 1 **Intro to Building Automation System Architecture** Slipstream 11:27
- 2 **Advanced Building Control Protocols and Frameworks** Slipstream 11:42
- 3 **Basics of HVAC Controls - Components** Slipstream 18:21
- 4 **Basics of HVAC Controls - Control Loops and Sequences** Slipstream 19:03
- 5 **Low-Effort Measures That Save Energy** Slipstream 10:28

Figure A-6. Integrate Short Courses on YouTube

<https://www.youtube.com/playlist?list=PL-mtgGdh8bvg023icBCcGPcD-SeYe6RW4>

APPENDIX G TRAINING MARKETING AND OUTREACH

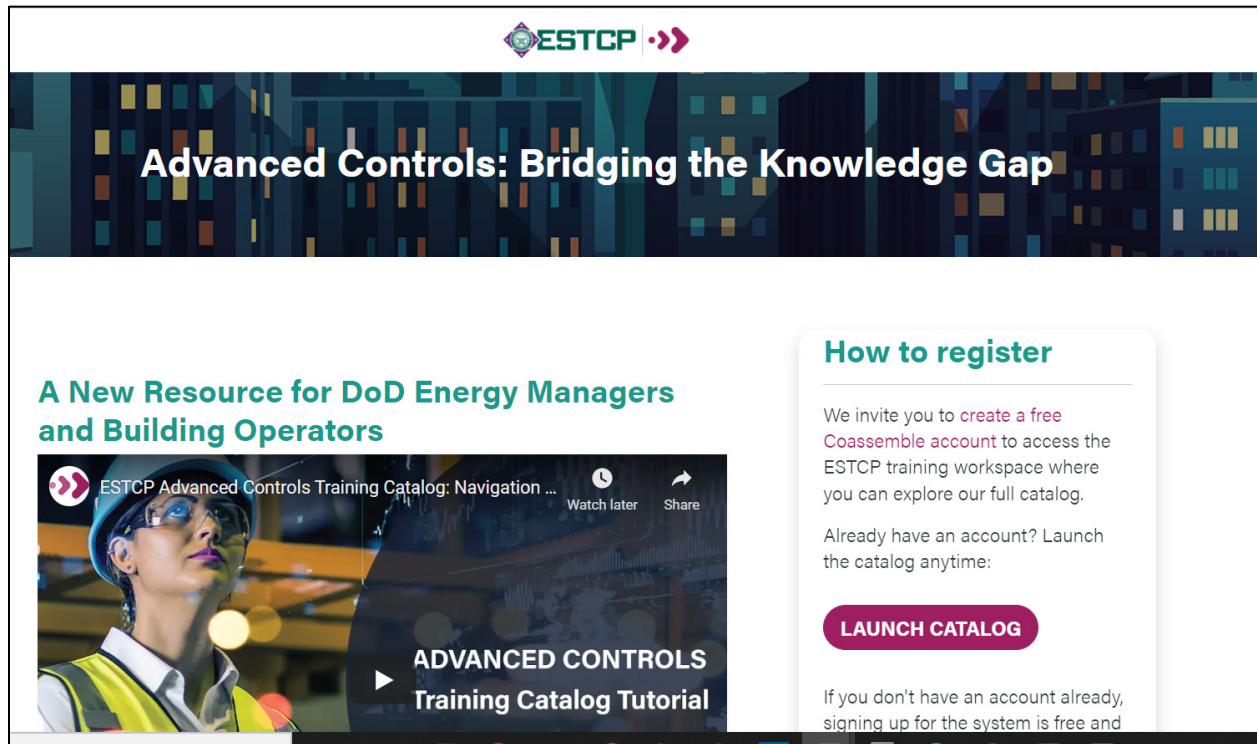


Figure A-7. A Sample Project Webpage

<https://slipstreaminc.org/estcp>



1/14/2021

Improving Energy Efficiency through Advanced Building Controls

This SERDP and ESTCP webinar focused on an ESTCP-funded project aimed at disseminating knowledge of advanced controls and energy management strategies for improving building efficiency. Specifically, investigators discussed a comprehensive training and education platform for DoD energy managers, engineers and building operators that enables them to make informed decisions, better specify and commission building control systems, manage and operate buildings more efficiently, and implement the new industry guidelines.

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[Home](#) / [Tools & Training](#)

Presented January 14, 2021- [Presentation Slides](#)



Figure A-8. ESTCP Project Webpage and Webinar

<https://www.serdp-estcp.org/toolsandtraining/details/33f0297a-9af9-4ea6-af9f-9ba8a4451358/improving-energy-efficiency-through-advanced-building-controls>

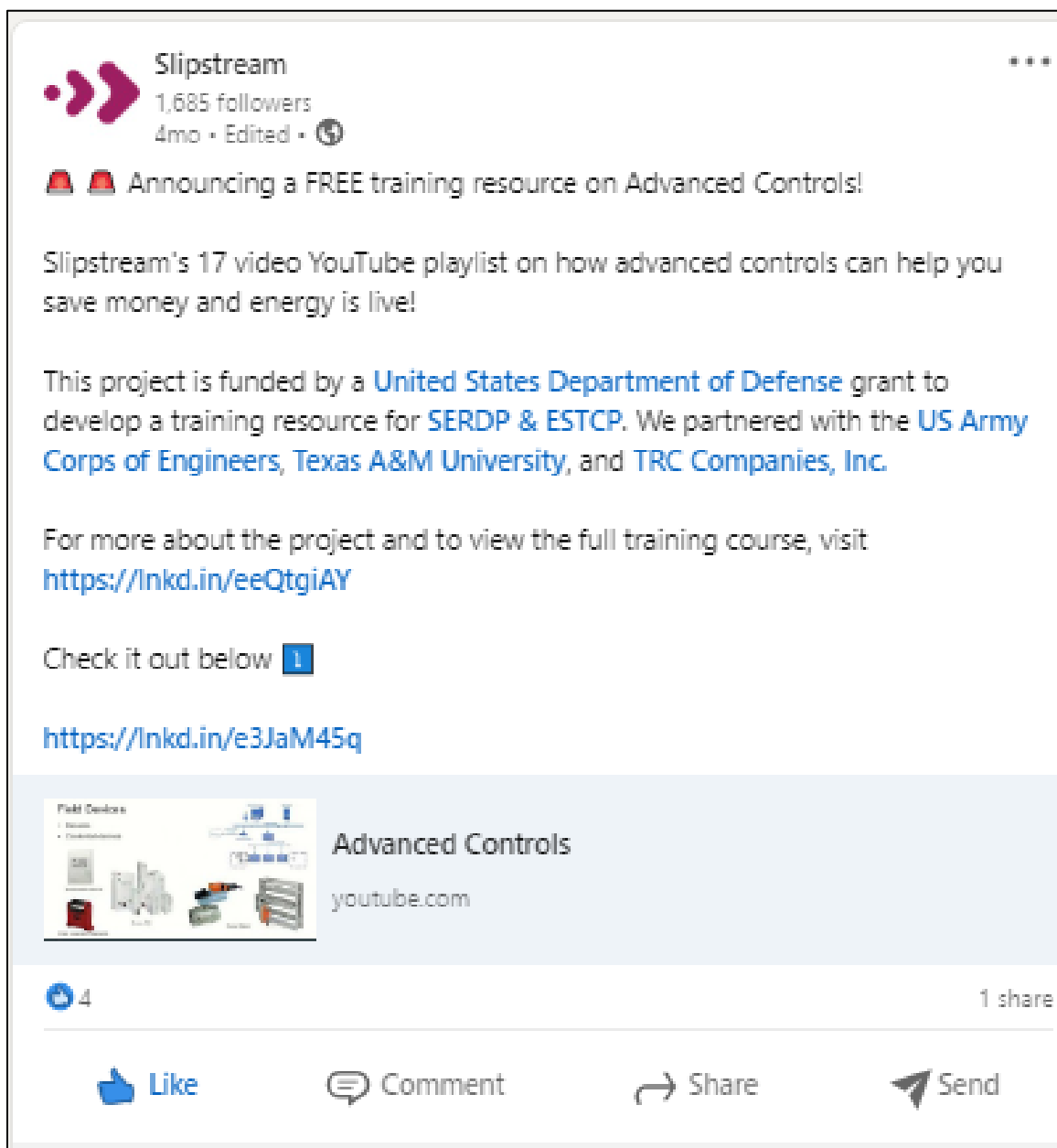


Figure A-9. Social Media Sample 1

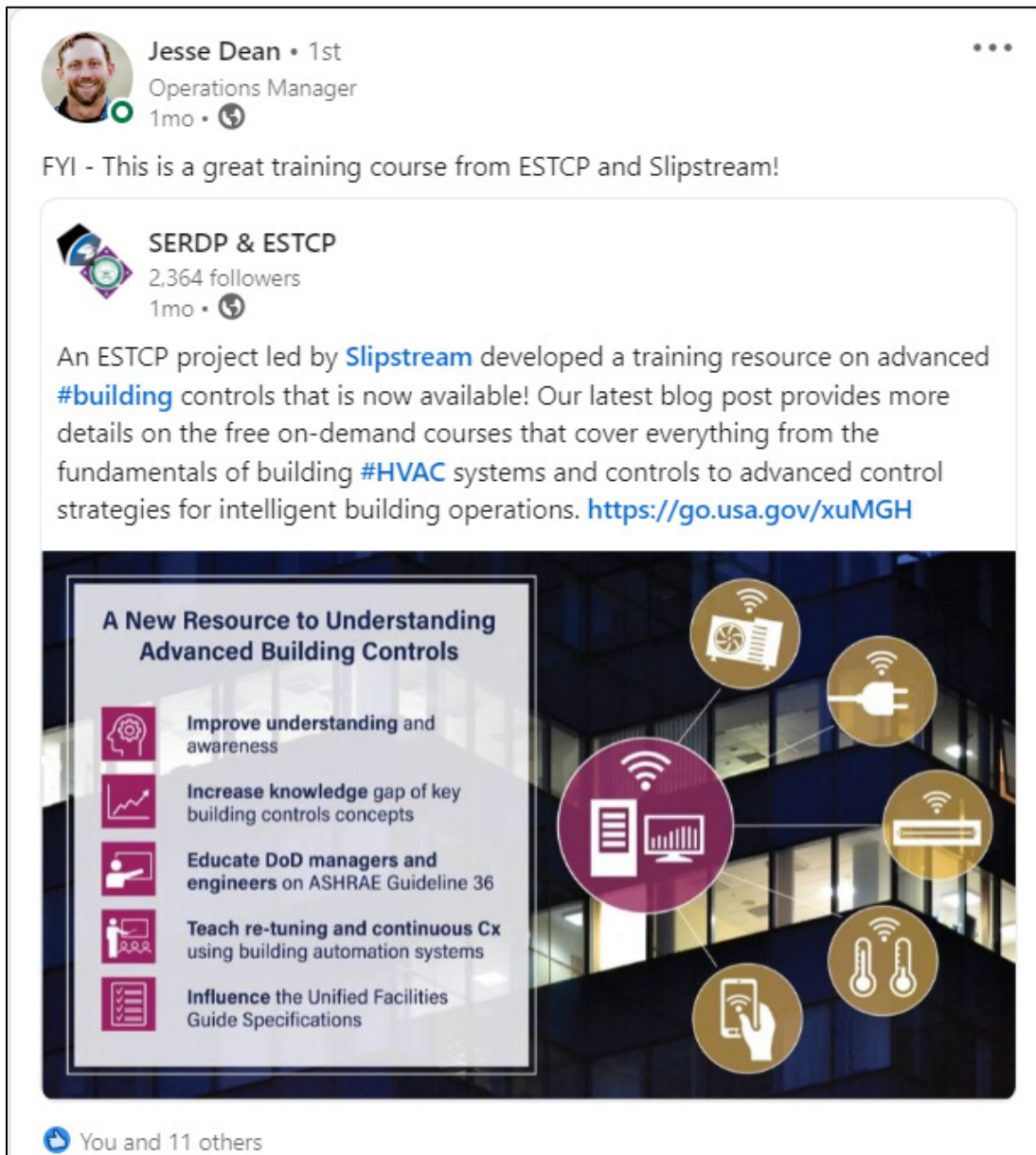


Figure A-10. Social Media Sample 2



Figure A-11. Social Media Sample 3



Figure A-12. Social Media Sample 4

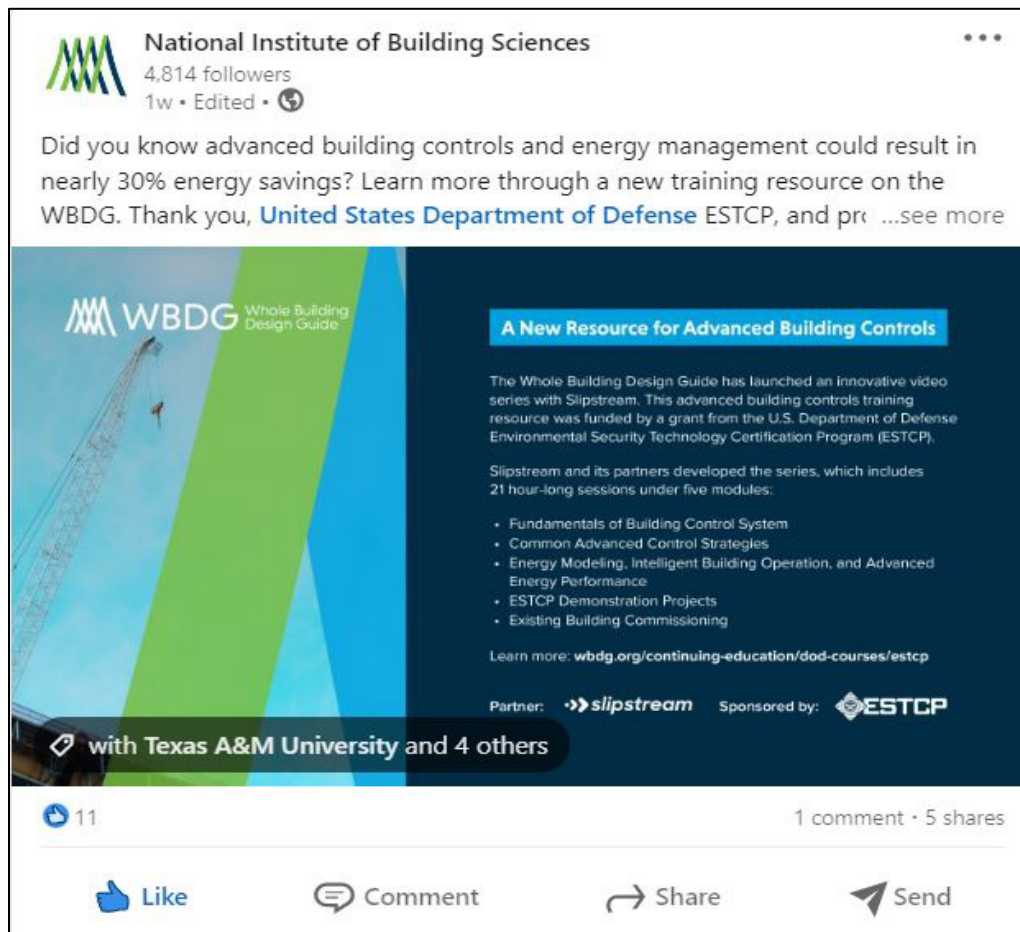


Figure A-13. Social Media Sample 5

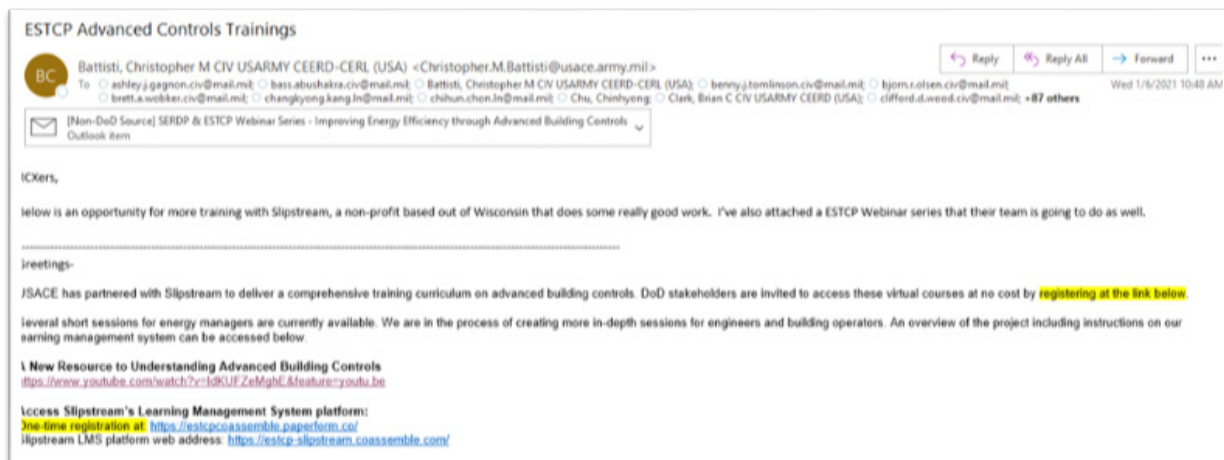


Figure A-14. Outreach through USACE RCx University



Figure A-15. Outreach through ESTP Blog

<https://www.serdp-estcp.org/News-and-Events/Blog/ESTCP-Training-Resource-for-DoD-Energy-Managers-and-Building-Operators>

APPENDIX H USACE CERL ASHRAE GUIDELINE 36 EVALUATION REPORT



**US Army Corps
of Engineers®**
Engineer Research and
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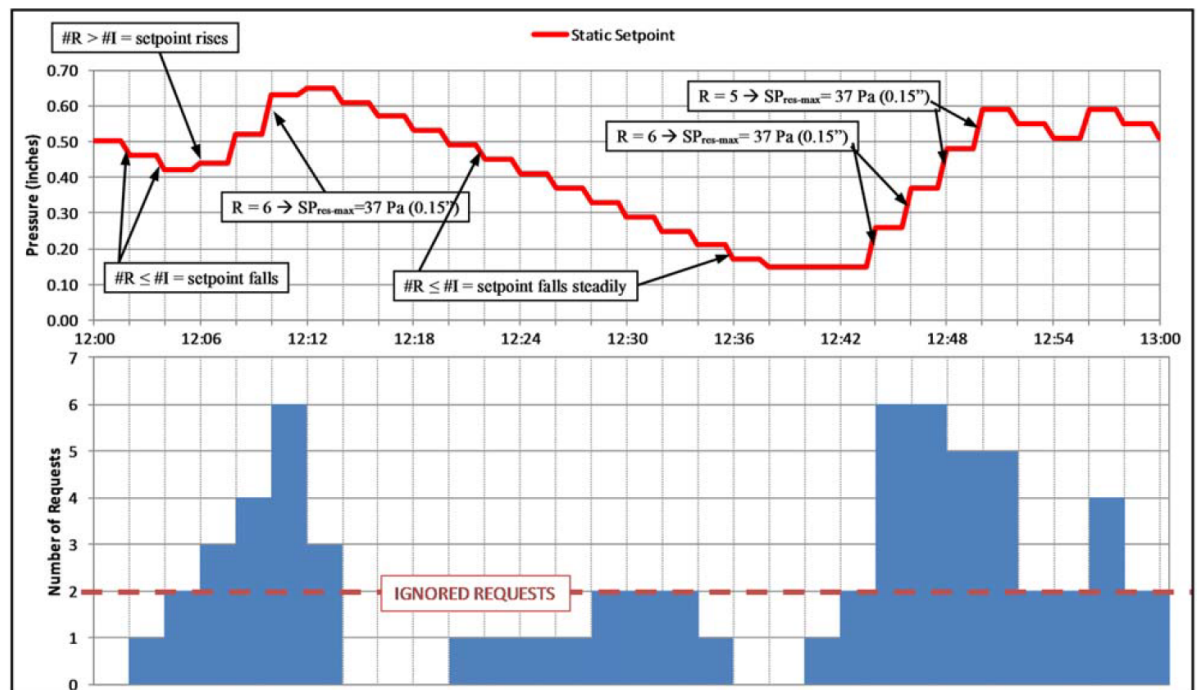
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for a safer, better world

Technical Review of ASHRAE Guideline 36-2018 - High-Performance Sequences of Operation for HVAC Systems

Recommendations for DoD Tri-Service Criteria Adoption

SEP 2022

Brian Clark and Chris Battisti



Source: ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems Informative Figure 5.1.14.4

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Technical Review of ASHRAE Guideline 36-2018 - High-Performance Sequences of Operation for HVAC Systems

Recommendations for DoD Tri-Service Criteria Adoption

Brian Clark and Chris Battisti

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Prepared for Slipstream, Inc and Environmental Security Technology Certification Program (ESTCP)
<https://slipstreaminc.org>

Under Environmental Security Technology Certification Program (ESTCP) Project EW19-5055
<https://www.serdp-estcp.org/>

Executive Summary

The US Corps of Engineers Construction Engineering Research Laboratory (USACE CERL) has developed a list of prioritized recommendations for DoD HVAC controls criteria updates based on review of a related industry guideline recently published by ASHRAE. This review has been in support of Environmental Security Technology Certification Program (ESTCP) Project EW19-5055 to promote advanced building controls concepts. Moreover, this effort is in direct support of National Defense Strategy goals and the related USACE Campaign Plan objective to maintain and advance DoD critical enabling technologies.

CERL evaluated the initial 2018 edition ASHRAE Guideline 36 High-Performance Sequence of Operations for HVAC Systems over the past year using DoD operating environment, system design, and field engineering perspectives. The 100-page Guideline contains requirements for HVAC system set points, sequences, alarms, and advanced diagnostics capabilities called AFDD. Some of the content can be considered best practice for DoD to consider adopting into its design criteria or construction specifications. Other Guideline requirements represent best-in-class approaches to HVAC controls that require additional research for future consideration at DoD installations. Review of the Guideline as resulted in 40 total recommendations that target potential HVAC controls and associated front-end system updates of three Unified Facilities Criteria (UFC) documents and five Unified Facility Guide Specifications (UFGS). CERL recommendation counts by type and priority are summarized in Table 1:

Table 1 Summary Counts of CERL Recommendations by Type and Priority Based on Review

Recommendation Type	Priority			Total
	High	Medium	Low	
Criteria Update	11	9	2	22
Additional Research	8	6	4	18
Grand Total	19	15	6	40

CERL will continue to engage with industry and Tri-Service criteria management on next steps. As part of submission of this report to ESTCP, CERL is submitting all high priority criteria update recommendations summarized in Table 2 as Criteria Change Requests (CCR) for their associated UFC and UFGS documents housed on the Whole Building Design

Guide (wbdg.org). Where additional research is recommended, CERL will pursue additional funding to demonstrate or coordinate as needed to determine criteria update needs. Additional feedback is planned with the USACE controls systems Community of Practice, Tri-Service Coordinating Panel, and ASHRAE Guideline 36 Project Committee.

Table 2 High Priority Recommended Criteria Updates Based on GL36 Content

Rec #	Category	Description	Report Chapter
1	Ventilation Zone Set points	Non CO2-based DCV Sequences	Ch 2
2	Central System Sequences	Adopt a Multi-Stage Approach to Coil Freeze Protection	Ch 3
3	General Sequence Methodologies	Align DSP Set Point Reset Criteria	Ch 3
4	General Sequence Methodologies	Use of Zone Group Schedules	Ch 3
5	General Sequence Methodologies	Establish Configuration Defaults for Hardwired VFD Command and Networked Min Speed	Ch 3
6	General Sequence Methodologies	Create VFD Interface Points Schedule Template	Ch 3
7	Terminal Unit Sequences	Zone-level Demand-limiting Sequences and Set points	Ch 3
8	Alarms	Expanded Alarm Conditions	Ch 4
9	Alarms	Better Alarm Local Display Options	Ch 4
10	Alarms	Alarm-Specific Testing Requirements	Ch 4
11	AFDD	Address AHU Sensor Gaps	Ch 5

Contents

Executive Summary	9
1 Introduction	13
1.1 Project Overview	13
1.2 ASHRAE Guideline 36-2018 Overview	13
1.3 UFC and UFGS HVAC Controls Content Overview	13
1.4 Technical Approach to Review and Recommendations	15
2 HVAC Set Points.....	18
2.1 Summary of Design GL36 Set Points.....	18
2.1.1 Set Point Documentation Requirement.....	19
2.1.2 Review of Space Temperature Design Set Point Requirements.....	20
2.1.3 Review of Outdoor Air Ventilation Set Point Requirements.....	20
2.1.4 Review of Terminal Unit Airflow Design Set Point Requirements.....	21
2.1.5 Review of Supply Air Temperature Design Set Point Requirements.....	21
2.1.6 Review of Air-Side Economizer Design Set Point Requirements.....	22
2.1.7 Review of Dual Duct Dual Fan Supply Air Temp Design Set Point Requirements.....	22
2.2 Summary of Field-Determined GL36 Set Points	22
2.3 DoD Criteria Set Point Recommendations	23
3 HVAC Sequences of Operation.....	25
3.1 General GL36 Approaches to HVAC Sequences of Operation	25
3.1.1 Dependent Methodologies for HVAC Sequences of Operation.....	25
3.1.2 Independent Best Practices for HVAC Sequences of Operation	35
3.2 Terminal Unit Sequences of Operation	42
3.3 Central Air-Side System Sequences of Operation	44
3.4 DoD HVAC Sequence Recommendations	47
4 HVAC Alarms	50
4.1 Summary of GL36 HVAC Alarm Requirements	50
4.1.1 Alarm Scope.....	50
4.1.2 Alarm Level Criteria	52
4.1.3 Hierarchical Alarm Suppression	54
4.1.4 Discussion of DoD Criteria Approaches to HVAC Alarms.....	56
4.1.5 DoD Criteria Alarm Recommendations.....	58
5 Automated Fault Detection & Diagnostics (AFDD)	62
5.1.1 GL36 AFDD Components.....	62
5.1.2 GL36 AFDD Conditions	64
5.1.3 DoD AFDD Criteria Recommendations.....	65
6 Conclusion.....	68

Preface

The Building Energy Systems Team is comprised of engineers, scientists, and specialists in the area of HVAC controls, building systems optimization, and cybersecurity working at the Construction Engineering Research Laboratory's (CERL) Energy Branch. CERL is one of seven Engineer Research Development Center (ERDC) laboratories within the US Corps of Engineers (USACE). ERDC's mission is to help solve our Nation's most challenging problems in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, Department of Defense, civilian agencies, and our Nation's public good.

This effort is part of Energy and Water project EW-19-5055 sponsored by DoD's Environmental Security Technology Certification Program (ESTCP). The key objective of this overall project is to effectively develop and deliver a comprehensive training and education package for disseminating advanced building controls concepts and applications to multiple target audiences. As a related effort and the focus of this report, the project will also help promote the awareness and potential future adoption of the newly-published American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 36 "High-Performance Sequences of Operation for HVAC Systems."

1 Introduction

1.1 Project Overview

This goal of this effort is to perform a technical a review of ASHRAE Guideline 36-2018 to determine if content would be appropriate for adoption into HVAC controls DoD criteria. While the effort will not result in immediate integration into DoD criteria, recommendations from the final project will be coordinated with the DoD facilities community and packaged into Criteria Change Requests (CCRs) for future consideration by Service-level Discipline Working Groups (DWGs).

1.2 ASHRAE Guideline 36-2018 Overview

ASHRAE Guideline 36 High-Performance Sequences of Operation for HVAC Systems is a 100-page guideline released 4JUN18 with 5 minor addendums and under continuous maintenance by Standing Guideline Project Committee (SGPC) 36. Scope is largely constrained to set points, sequences, and Automated Fault Detection & Diagnostics (AFDD) associated with common air-side central and terminal systems. For the purposes of this report, ASHRAE Guideline 36 High-Performance Sequences of Operation for HVAC Systems will be shorthand as “GL36” or “the GL”.

In September of 2021 ASHRAE released a new version of GL36, adding new systems and fixing some “bugs” in the GL. For the purposes of this report, the 2018 version of the GL was reviewed.

1.3 UFC and UFGS HVAC Controls Content Overview

Various designer and contractor requirements are detailed in HVAC, HVAC Controls, and Utility Monitoring & Control System (UMCS) specifications and criteria. There are managed by mechanical and controls DoD DWGs, with varying level of approval process depending on the document. The documents are housed on the Whole Building Design Guide (WBDG), which is managed by the National Institute of Building Sciences (NIBS).

Unified Facilities Criteria (UFC) constitute the DoD Building Code, and compliance with this Code is mandatory for all DoD construction, regardless of executing agency or funding type. For the Army, the Engineer Senior Executive Panel (ESEP) member and signature authority for UFC is the Chief of Engineering and Construction of the Army Corps of Engineers.

Deviation from the code requires an exemption or waiver request approved by the ESEP member as defined in MIL STD 3007. There are several design and construction criteria documents used by DoD that intersect with GL36 content. Targeted criteria for this effort are:

- UFC 3-410-01 Heating, Ventilating, Air Conditioning Systems
- UFC 3-410-02 Direct Digital Control for HVAC and Other Building Control Systems
- UFC 3-470-01 Utility Monitoring and Control System (UMCS) Front-End and Integration.

Unified Facilities Guide Specifications (UFGS) provides construction requirements in support of UFC criteria. Per DoDD 4270.5 UFGS shall be used to the greatest extent possible in the DoD, but are not referenced directly in UFCs. Note that in the case of HVAC controls, the UFCs **directly require** the use of the related UFGS, and that use of UFGS 25 10 10 is also required by 10 USC 2867. Target specs for this effort are:

- UFGS 23 09 00 Instrumentation and Control for HVAC
- UFGS 23 09 13 Instrumentation and Control Devices for HVAC
- UFGS 23 09 93 Sequences of Operation for HVAC Control
- UFGS 25 10 10 Utility Monitoring and Control System (UMCS) Front-End and Integration

Throughout this document, UFC or UFGS documents may be abbreviated by their division numbers and related approaches may be short-handed as “DoD approaches”.

One of the most important pieces of DoD controls criteria that will be referenced throughout the document is the Points Schedule. The Points Schedule drawing is a system and project-specific table of point-level details that includes interface requirements. For every DoD project, a controls designer is required per UFC 3-410-02 to complete fields that include whether HOA is required, where point configuration occurs, whether a point is viewable or overridable from the front-end (web) display, or

whether a point is viewable or overridable from a local display panel, if a trend is required, and what alarm conditions/priority/routing (if any) are required. Note: is it generally recommended for DoD projects to configure some parameters such as PID values as settings internal to the controller due to the potential for disruption or damage, however any Points Schedule entry *could* be specified to match GL36 requirements.

1.4 Technical Approach to Review and Recommendations

Reviewers have knowledge and experience in field engineering and the controls industry, while also understanding the unique DoD operating environment. The GL36 review was approached from that perspective, knowing how operations and maintenance is funded in the DoD greatly affects the sustained operations of mechanical systems and control strategies. The reviewer's recommendations are based on how sustainable the control strategy is in the DoD in terms of complexity and reliability, and is not a criticism of the GL and its value to the HVAC industry. The focus will be on prioritized criteria adoption, not prohibition of the GL, to allow installations and projects to choose to adopt additional GL36 content as desired.

The DoD is a unique facility owner whose primary mission is warfighting and not operating and maintaining buildings. Funding is limited for sustainability, replacement, and modernization after the building has been turned over to the DoD. In the minds of the reviewer, there is a higher priority to using existing data in a more effective way, rather than add more instrumentation and hardware. With that in mind there was specific intent to evaluate GL36 from a systems design standpoint that emphasizes certain factors including:

- **Reliability:** ability to perform a specific function and may be given as design reliability or operational reliability
- **Availability:** ability to keep a functioning state in the given environment
- **Maintainability:** effective and safe maintenance of the system in the least amount of time, cost, and other resources (including servicing, inspection and check, repair and/or modification)
- **Operability:** ability to keep the system in a functioning condition based on operational requirements
- **Safety:** ability not to harm people, the environment, or any assets during a whole life cycle

The review was separated into chapters focused on the major areas of GL36 content: set points, sequences of operation, alarms, and AFDD. These chapters attempt to first categorize and summarize GL36 content. Following these summaries, a discussion of correlating DoD requirements is presented. Finally, recommendations are provided as either criteria adoption to be submitted as CCRs or additional research required to further validate, coordinate, or develop concepts from the GL. A priority is assigned with each recommendation based on the above factors as well as the following assumptions concerning the DoD operating environment:

- **DoD Facilities Scale:** Given that DoD owns and operates several billion square feet of building space, there is no one-size-fits-all approach to DoD facilities criteria. Criteria emphasis is on tools, deliverables, and standards that can be tailored to meet project-specific needs.
- **DoD Mission:** DoD essentially manages their installations like small or large cities. And while there are many support facilities that operate similar to corollaries in commercial, academic, or industrial sectors, the overall mission is unique. Critical and supporting facilities serve as a power projection platform from which DoD will conduct its military operations worldwide. This places emphasis on the reliability review factors.
- **DoD Resource Shortfalls:** As previously stated, DoD has limited funding for the sustainment of its facilities systems. DoD installations are further challenged to maintain their facilities with staff turnover, training gaps, and multi-vendor control systems. This places further emphasis on controls system reliability and simplicity.
- **DoD Energy Goals:** Despite these shortfalls, DoD has ambitious goals for improved energy resilience with decreased energy usage, costs, and carbon footprints. Balancing these new objectives with existing resource shortfalls requires a strategic approach to technology adoption.
- **DoD Criteria Adoption and Implementation Processes:** Recommendations from this report reflect the challenges in integrating new criteria into DoD processes. The goal is to align recommendations with ongoing controls criteria updates and prioritize based in part of anticipated adoption or implementation.

-
- **DoD Installation Support Programs:** Once a control system is installed and operating in DoD, there are a number of efforts that may regularly or periodically interact with it. In the Army alone, there are multiple energy auditing programs, resilience assessment teams, local and/or central Resource Efficiency Managers, 3rd party financing initiatives, in-house and/or local controls service contractors, and other controls retrofit or renovation contracts. A “set-it and forget-it” controls approach is not likely to work at DoD installations.

Once the review is complete, the objective is for CERL technical report publication and a submission of recommended CCRs through WBDG content management channels. These criteria adoption recommendations and additional research proposed will be presented to DoD DWGs and the Coordinating Panel to help inform the recommended changes to DoD S&C. Recommendations will also be communicated to the DoD building design and operations community through various government venues, such as USACE Communities of Practice meetings.

For the purposes of this report, several sections from GL36 have been omitted from review. These includes areas where there is close alignment with established DoD controls design approaches or areas of non-applicability. The following GL36-2018 content was not reviewed:

- **Hardwired Points:** DoD controls design requires use of Points Schedules to define requirements for hardwired points as well other interface, configuration, protocol-specific needs. Given the depth of DoD Points Schedule requirements and conventions, Section 4 List of Hardwired Points was not reviewed.
- **California Title 24 Requirements:** DoD ventilation criteria mandates use of ASHRAE Standard 62.1 for outside air calculations. Thus, CA Title 24 alternatives to ASHRAE 62.1 Ventilation Rate Procedure were presented in the GL were not considered in this report.
- **Informative Appendices:** Appendix A contains Control Diagrams for systems presented in the GL and Appendix B contains Acronyms used in the GL. Given DoD established conventions for Schematic drawings defined in UFC 3-410-02 and related acronyms lists, these sections were not evaluated.

2 HVAC Set Points

HVAC set points tell the control system what to control to, such as temperature and pressure set points. It is a key part in how a control sequence functions, and the GL goes into detail to define the set points and their determination by two different methods:

- **Design:** determined by the designers during the design phase of the project based on building, system, and customer requirements. Most set points are designer determined.
- **Field-Determined:** determined during system testing, adjusting, and balancing.

This chapter covers the set points as defined in the GL and compares to the DoD criteria whether the set point is a conflict, gap, or in alignment.

Summary of Design GL36 Set Points

Table 3 summarizes the set points in GL36, and how they align with current DoD criteria. This summary helps identify the potential changes that could be recommended to DoD if there is room for improvement. For the purposes of this chapter, any reference to the UFGS is referring to UFGS 23 09 93 – Sequences of Operation for HVAC control. If another UFGS is referenced, it will describe which one.

The DoD is not required to follow CA Title 24, and will not be included in this chapter.

Table 3 ASHRAE GL36 Set Points Summary

Set Point Type	ASHRAE Set Point Name	ASHRAE Set Point Defaults	DoD Criteria Alignment
Space Temperature	VAV Zones Space Temp Set Point	Occ: 70°F heat, 75°F cool; Unocc: 60°F heat, 90°F cool	Conflict: UFC 3-410-01 3-5.3
	Mech/Elec Room Space Temp Set Point	65°F heat / 85°F cool	
	Computer Room Space Temp Set Point	65°F heat / 75°F cool	
Ventilation	Breathing Zone Outdoor Air Flow: Area Component	Per ASHRAE Standard 62.1-2016: $V_{ba-A} = A_z \cdot R_a$	Gap: UFGS 23 09 93
	Breathing Zone Outdoor Air Flow: People Component	Per ASHRAE Standard 62.1-2016: $V_{ba-P} = P_z \cdot R_p$	
	Zone Air Distribution Effectiveness: Heating	Per ASHRAE Standard 62.1-2016: Table 6.2.2.2 ($E_zH = 0.5$ to 1.0)	

	Zone Air Distribution Effectiveness: Cooling	Per ASHRAE Standard 62.1-2016: Table 6.2.2.2 (EzC = 0.5 to 1.2)	Conflict: UFC 3-410-01 4-2.4.1
	Uncorrected Design Outdoor Air Rate: DesVou	Per ASHRAE Standard 62.1-2016: $Vou = D * \sum (Pz * Rp) + \sum (Az * Ra)$	
	Design Total Outdoor Air Rate: DesVot	Per ASHRAE Standard 62.1-2016: $Vot = Vou / Ev$	
	CO ₂ Set Point	Calculated (Section 3.1.1.3) or Table 3.1.1.3	
Terminal Unit Airflow	Zone Maximum Cooling Airflow Set Point : V cool-max	-	Gap: UFC 3-410-01 Points Schedules
	Zone Minimum Airflow Set Point: Vmin		
	Zone Maximum Heating Airflow Set Point: Vheat-max		
	Zone Maximum DAT Above Heating Set Point: MaxΔT		
	Heating Minimum Airflow Set Point: Vheat-min		
	Parallel Fan Maximum Heating Airflow Set Point: Pfan-htgmax		
	Series Fan Maximum Heating Airflow Set Point: Sfan-htgmax		
Supply Air Temp	Lowest Cooling Supply Air Temperature Set Point: Min_ClgSAT	no lower than the design coil leaving air temperature	Gap: UFC 3-410-01 Points Schedules
	Cooling Supply Air Temperature Set Point: Max_ClgSAT	typically 65°F in mild/dry climates; ≤ 60°F in humid climates	
	Lower Value Of The OAT Reset Range: OAT_Min	Typical values are OAT_Min = 60°F or 55°F and OAT_Max = 70°F or 65°F (lower range may improve net energy performance where economizer/reheat/chiller enables are not impacted)	
	Higher Value Of The OAT Reset Range: OAT_Max		
Econo-mizer	Econo High Limit Set Point	Per ASHRAE Standard 90.1-2015: By climate zone for Fixed dry bulb or Differential dry bulb options	Gap: UFC 3-410-01
Dual Duct Dual Fan Supply Air Temp	Highest Heating Supply Air Temperature: Max_HtgSAT	Typically design heating and cooling set points (no higher than 20°F above space temperature)	Gap: UFC 3-410-02, Points Schedules, and UFGS 23 09 93
	Lowest Cooling Supply Air Temperature Set Point: Cool_SAT	typically the design coil leaving air temperature	
	Highest Heating Supply Air Temperature: Heat_SAT	typically the design coil leaving air temperature, no more than 20°F above the active heating set point	
	Maximum Supply Air Dew-Point Temperature: MaxDPT	typical value is 62°F in humid climates with higher set point (e.g. 75°F) in mild and dry climates for maximum efficiency	

2.1.1 Set Point Documentation Requirement

The GL recommends documenting the set points in the equipment schedules for each zone, including terminal boxes and any AHU equipment. This allows for clear communication to the contractor on what is expected

for set points. This differs from the DoD requirements, UFC 3-410-02 requires the use of a points schedule for every control project to document set points.

2.1.2 Review of Space Temperature Design Set Point Requirements

UFC 3-410-02, the criteria for HVAC systems, has indoor design condition requirements for zones related to what is outlined in GL36 is as follows:

- Comfort Conditioning:
 - Cooling Occupied - 78.0 °F DB, 57.9 °F DP, 50% RH
 - Cooling Unoccupied - no requirement
 - Heating Occupied – 68 °F DB
 - Heating Unoccupied – 55 °F DB
- Heating for Freeze Protection:
 - 55 °F DB

The GL default set point requirements are closer to what is typically seen in the industry. Many installations do not operate their buildings at the UFC standards and are more in line with the GL defaults, which may lead to undersized equipment for conditioning internal loads.

2.1.3 Review of Outdoor Air Ventilation Set Point Requirements

DoD criteria requires the use of ASHRAE Standard 62.1-2016, which is in line with the GL. However, GL36 allows the use of CO₂ sensors for demand-controlled ventilation. The use of CO₂ sensors is prohibited due to maintainability issues with calibration/recalibration, unless it is approved by the Authority Having Jurisdiction (AHJ) for use on a project. Until CO₂ sensor calibration issues are resolved, this prohibition is unlikely to change.

ASHRAE 62.1 does allow ventilation to be reduced to zero when the space is in occupied-standby mode in certain zones, which uses occupancy sensors to determine if the zone is in occupied standby. To reduce ventilation

requirements while meeting ASHRAE 62.1, occupancy sensor based DCV should be evaluated per the standard.

2.1.4 Review of Terminal Unit Airflow Design Set Point Requirements

DoD criteria does not give much guidance on terminal unit airflow set point requirements beyond requiring an airflow rate of each VAV box as a DDC point. Calculating the airflow requirements does not go beyond requiring minimum ventilation and minimum primary airflow rates must attain a minimum velocity pressures of 0.03-inch w.g. The Navy individually requires the use of at least four air changes per hour in accordance with ASHRAE 55.

GL 36 requires several different terminal unit set points depending on the terminal unit layout to define any operating mode (min/max flow, and discharge air temperature), compared to DoD HVAC criteria does not require documentation of these set points in the design but does require the use of pressure independent terminal units. DDC criteria does require sequencing of terminal units, but does not get into what must be included in that sequence.

The UFGS describes the need for a VAV box supply air flow (VAV-SA-F) and set point (VAV-SA-F-SP) but does not describe beyond that. Based on the UFGS, the documentation of terminal unit airflow design set points on the is not a part of the standard template beyond VAV-SA-F. There is room for a more detailed baseline design represented in the UFGS and/or that documents required terminal unit set points to meet ASHRAE 62.1.

2.1.5 Review of Supply Air Temperature Design Set Point Requirements

The GL requires various set points based on cooling min/max temperature versus the OAT min/max to set up a reset schedule:

- Minimum cooling temperature set point at the maximum OAT reset temperature
- Maximum cooling temperature set point at the minimum OAT reset temperature

Similar to terminal unit set points, DoD does not provide any details on reset schedules regarding cooling and OAT. The UFGS provides recommendations on using OAT for enabling sequences, and has a reset schedule for the hot deck for a multizone unit. The Trim and Respond (T&R) set point approach in GL36 is discussed in detail in later chapters of this report.

2.1.6 Review of Air-Side Economizer Design Set Point Requirements

Army and Air Force Criteria prohibits the use of air-side economizers where practicable (UFC 3-410-02, 3-7.3) due to their high failure rate, opting to use water economizers. The Army and Air Force also strictly prohibits the use in climate zones 1, 2, 3a, and 4a. The Navy allows for air-side economizers unless water-side economizers are more life cycle cost effective.

There is no guidance in criteria on how to determine an air-side economizer high limit set point, leaving it up to designers to decide what control type (enthalpy versus dry bulb).

2.1.7 Review of Dual Duct Dual Fan Supply Air Temp Design Set Point Requirements

Similar to other set points described in the GL, criteria does not cover specific set points for dual duct dual fan systems. The UFGS has cold-deck and hot-deck supply air temperature control points, which is in line with the GL. However, there is no point for the maximum heating SAT.

2.2 Summary of Field-Determined GL36 Set Points

There are several set points described in the GL that requires the TAB contractor to determine in the field. This review is control-based only, and does not do a deep review of field-determined set points. A list of field-determined information ASHRAE GL36 requires from TAB contractor is as follows:

- Minimum (S, Ret, Rel), MinSpeed
- DesMinDP
- RFDSPmin
- RFDSPmax
- S-R-DIFF
- MaxHeatSpeed

-
- MaxCoolSpeed
 - MinOA
 - DesOA
 - MinRelief
 - MaxRelief

2.3 DoD Criteria Set Point Recommendations

The following bullets summarize the list of set point-related recommendation from this report. For each recommendation, additional criteria may be impacted, further justification will be provided in Criteria Change Requests using content from this report, and priorities are assigned based on the technical approach from Chapter 1. Note that the recommendation to develop non CO₂-based DCV sequences is repeated in later sections on general sequence methodologies presented in GL3.

- **Non CO-based DCV Sequences:** As a high priority, add UFC 3-410-01 designer requirement to evaluate use of occupancy sensors or other non-CO₂-based DCV in limited zone types including lecture classroom, auditoriums, and office spaces. Demand Control Ventilation (DCV) using CO₂ sensors is prohibited in the UFC. Criteria is required for DCV using occupancy sensor in Intermittent Occupancy Facilities and other applications.
- **Align Zone Temp Set points with Industry Approaches:** As a medium priority, provide additional guidance in UFC 3-410-01 on different zone types, and include cooling unoccupied requirements. Bring zone set points more in line with industry, operation practices, and the GL. Currently, criteria only covers limited zone types for set points, and is not as “restrictive” as the GL and how most buildings operate.

Where more information, validation, or coordination is required to consider criteria adoption, the following HVAC sequence of operation additional research is recommended. Note that the recommendation to develop non CO₂-based DCV and improved sequences is repeated in later sections on general sequence methodologies presented in GL36:

- **Research CO₂ Sensor Use in DCV:** As a high priority, conduct a study on the CO₂ sensor market to assess any improvements in

accuracy and calibration requirements. Also study design techniques for more guidance if the AHJ allows use of CO₂ sensors. Prohibition of CO₂ sensors limits energy savings requirements through requiring full ventilation even if a zone does not need it.

- **Economizer High Limit Set Points:** As a medium priority, establish criteria for fixed dry bulb economizer high limit set points at DoD installations using local weather data. Current use of ASHRAE Standard 90.1 approaches could result in error-prone humidity sensors and climate zone approximations that limit economizer effectiveness.
- **TAB Spec Coordination for Field-Determined Set Points:** As a low priority, coordinate on benefits of adding field-determined set points to TAB specifications in through the USACE commissioning center of excellence. Field-determined set points are not defined in criteria or in TAB specifications.
- **Additional Terminal Unit Flow Set Points:** As a low priority, update Points Schedule to include GL36-based optional terminal unit airflow points for designer selection, including heating airflow setpoint, cooling airflow setpoint, people-based minimum outside air setting, effective outside air setpoint, and others.

3 HVAC Sequences of Operation

Roughly 75% of GL36-2018 content (by page count) is located in *Chapter 5 Sequences of Operation*. This chapter covers many generic, system-specific, alarm-related, user interface, and AFDD requirements that represent the majority of gaps or conflicts in corresponding DoD criteria. This section will focus on general GL36-2018 approaches to HVAC sequences of operation and system-specific GL36-2018 sequences requirements.

3.1 General GL36 Approaches to HVAC Sequences of Operation

There are many general approaches to HVAC control throughout GL36. This review will categorize and evaluate this general approach prior to considering system-specific sequences of operation. General approaches from the GL appear to fall into two main types:

1. **Dependent Methodologies:** major GL approaches that are required to establish HVAC controls data streams, relational hierarchies, or other functionality described elsewhere in the GL (i.e., alarm functionality and/or AFDD).
2. **Independent Best Practices:** general approaches to HVAC sequences of operation from industry or academia that could be adopted independent from other GL36 criteria.

Given challenges to the DoD operating environment described in Section 1 of this report, this evaluation may apply a preference for *independent best practices* and an additional degree of scrutiny towards *dependent methodologies*.

3.1.1 Dependent Methodologies for HVAC Sequences of Operation

There are several dependent methodologies presented in Chapter 5 of GL36 that serve as major building blocks to GL functionality. For this purposes of evaluating content for recommended adoption into DoD criteria, this report will focus on: the “request” building block, advanced hierarchical equipment relationships, Trim & Respond logic, demand-based ventilation adjustments, and expansive operator interface requirements.

3.1.1.1 Many Uses of the “Request” Building Block

Many areas of the GL rely on tracking and transmission of demand-side “requests” for a variety of upstream system enables, set point reset adjustments, alarming, and operator interface capabilities. Zone-level damper position is often cited in the GL as the basis for many air-side system requests, however damper command, valve position, or temperature deviation from set point could also convey request information. Here is a summary with examples of how GL36 applies its request concept:

1. **Enables** – requests are used as part of system enable sequences based on downstream requests registered:

“If the HW valve position is greater than 95%, send 1 request [to the heating hot water plant] until the HW valve position is less than 10%.”
(5.6.8.4.a)

2. **System-level Reset Adjustments** – requests are used to modify trim or response set point reset rates within a given system in tiered request sequences given time interval settings, alarm suppression configurations, and zone-level importance factors:

“If the zone temperature exceeds the zone’s cooling set point by 3°C (5°F) for 2 minutes and after suppression period due to set point change, send 3 requests [to the SAT set point reset sequence].”
(5.5.9.1.a)

3. **Plant-level Reset Adjustments** – requests are used to modify trim or response set point reset rates at the hot or chilled water plant level in tiered request sequences:

“If the DAT is 17°C (30°F) less than set point for 5 minutes, send 3 requests [to the hot-water reset sequence].” (5.6.8.3.a)

4. **Request-Accumulation** – downstream zone or subsystem requests are accumulated for a resettable running tally of valid requests based on hierarchical system relationships, status, and operating mode:

“Provided SystemOK is TRUE for the zone/system, every x minutes (default 5 minutes), add x divided by 60 times the current number of requests.” (5.1.14.2.a.2) and *“[Provide software switch points to] reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).”* (5.6.7.g)

-
5. **Alarming** – these accumulated requests are used to help BCS operators identify rogue zones through tiered alarm notifications based on importance multiplier factors and system runtime thresholds.

“A Level 4 alarm is generated if the zone Importance-Multiplier is greater than zero, the zone/system Cumulative% Request Hours exceeds 70%, and the total number of zone/system run hours exceeds 40.” (5.1.14.2.a.6)

6. **Equipment Protection** – GL36 uses a staged response to coil freeze protection sequences with decreasing levels of air-side supply air temperature prompting more aggressive action starting with added requests to the hot water system serving the coil.

“If the supply air temperature drops below 4.4°C (40°F) for 5 minutes, send two (or more, as required to ensure that heating plant is active) heating hot-water plant requests, override the outdoor air damper to the minimum position, and modulate the heating coil to maintain a supply air temperature of at least 6°C (42°F).” (5.16.12.1)

The request concept is not new in HVAC control, however the various uses in GL36 represent an expanded application from DoD approaches to HVAC sequences of operation. It is generally recommended that DoD approaches to system enables and set point resets continue to use the request concept in the form of demand-based information at the zone or sub-system level. The DoD operating environment, however, mandates a cautious approach to use of request data to drive various BCS functionality. Recommendations for DoD criteria should prioritize demand-based sequences in single-zone applications, specify fail-safe values and notification approaches for out-of-range data or communication drop scenarios, and ensure network resource testing is conducted in larger HVAC systems.

3.1.1.2 *Advanced Hierarchical Equipment Relationships*

Another recurring element of GL36 is the requirement to establish hierarchical relationships between related pieces of HVAC equipment. The review identified three areas where hierarchical equipment relationships appear:

1. **Zone-level Set point Selections Based on Hardwired Device Status** – set point will be determined by zone group schedules

with the following prioritized restrictions to be applied in the prioritized fashion (5.3.2.10):

- *always maintain minimum cooling/heating set point offset of 1F*
- *provide absolute limits on set point adjustments*
- *adjust set points based on window switch status*
- *apply further adjustments for demand limit events*

2. AHU Mode Selections based on Box Mode Status – for AHUs serving multiple zone groups, the AHU mode will be determined by the following hierarchy (5.15.1):

- *if any zone is in occupied mode, AHU will be in occupied mode*
- *else if any zone is in cooldown mode, AHU will be in cooldown mode*
- *else if any zone is in setup mode, AHU will be in setup mode*
- *else if any zone is in warm-up mode, AHU will be in warm-up mode*
- *else if any zone is in setback mode, AHU will be in setback mode*
- *else if any zone is in freeze protection setback mode, AHU will be in freeze protection mode*
- *else AHU will be in unoccupied mode*

3. Alarm Suppression based on Hierarchical Equipment Relationships – to facilitate suppression of connected faults, “source”, “load”, or “system” designations will be assigned to every piece of HVAC based on upstream, downstream, and parallel equipment configurations (5.1.19), for example:

- *Multiple cooling towers are a “system” and also a “source” to chillers*
- *Multiple chillers are a “system”, “load” to the cooling towers, and “source” to chilled water pumps*
- *Multiple chilled water pumps are a “system”, “load” to the chillers, and “source” to AHUs*
- *Each AHU is a “load” to the ChW pumps and a “source” to VAV boxes*
- *Each VAV box is a “load” to its AHU and a “source” to its zone space*
- *Each zone space is a “load” to its associated VAV box*

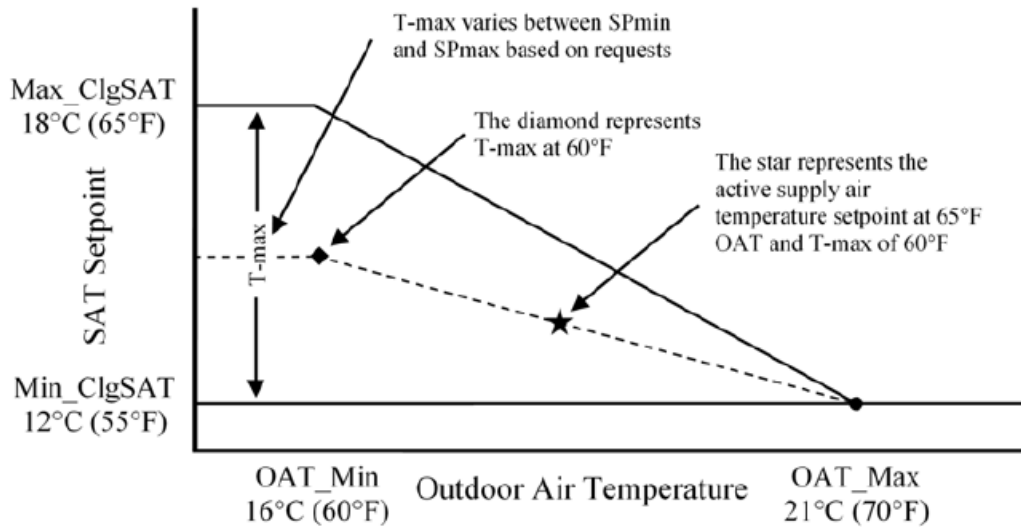
Each of these areas represents potential criteria improvement for DoD facilities. Proper zone-level set point selection, appropriate determination of AHU mode, and limitation of unhelpful BCS alarms are all valuable goals and widely applicable to DoD HVAC. The DoD has limited temperature control module (thermostat) constraints and AHU mode selection is performed through more binary sequences. To prioritize DoD criteria update efforts, we should consider value, difficulty, and longevity associated with implementing these different GL36 requirements. Space temperature set

point selection approaches from GL36 would create a relatively simple solution to current DoD gaps that should persist for the life of terminal unit controller and thermostat equipment. Similarly, AHU mode selection content from GL36 provides a simple, valuable, and persistent methodology that justifies a higher priority recommendation for DoD criteria adoption. Equipment “source”, “load”, and “system” designations, however, represent a more significant deviation from DoD criteria approaches and implementation challenge that will be discussed in later chapters. Given the value of these designations in avoiding nuisance alarms and broader applicability in conveying overall system configurations to operational data models, DoD research into metadata and other related methodologies is recommended.

3.1.1.3 Trim & Respond (T&R) Logic

GL36 establishes a Trim and Response approach to air-side HVAC sequences to actively reset set points based on load conditions. The fundamental driver for GL36 T&R logic is load-side “requests” transmitted to upstream systems when meaningful set point deviations are registered. The accumulation of these requests triggers a calculated response rate towards the maximum (design) set point, otherwise a separately configured trim rate is applied until a minimum set point is reached. The GL36 T&R sequence contains a number of designer-specified variables for time delays, initial set points, respond rate maximums, and load-side Importance-Multipliers. The GL indicates use of this T&R reset strategy for duct static pressure and supply air temperature set points, however for SAT the T&R set point reset is combined with a concurrently calculated OAT-based set point reset as shown in Figure 1.

Figure 1 GL36 Supply Air Temperature Reset using OAT and Zone-Demand T&R Logic



Source: ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems Informative Figure 5.16.2.2

The GL contains both parallels to and deviations from current DoD approaches to set point control for air-side HVAC systems. Template controls drawings on WBDG for VAV AHU systems show a similar approach for duct static pressure (DSP) set point reset in that starved terminal unit damper positions are registered as zone-level requests that ultimately drive a trim or respond rate. This rate, however, is a fixed and single value (e.g., 0.01 inches w.c./min) that is not modified based on request quantity or importance. The DoD approach triggers this fixed set point offset whenever the most open damper is above a configured high limit (e.g. 90% open) or the most closed damper is below a configured low limit (e.g. 50% open). Larger gaps exist with the DoD approach to VAV AHU SAT control which is currently static with no reference to set point reset methodology.

The DoD approach to DSP set point reset does not represent a significant deviation from the GL approach. Higher priority consideration should be given to updating UFGS 23 09 93 to reflect the current DSP set point reset approach and adding SAT set point reset sequences using T&R methods. For best implementation and maintainability of HVAC sequences, it is recommended to establish SAT set point reset control based on the predominant load driver of either outside air OR zone cooling requests, but not both. For additional set points where a single HVAC parameter is controlled based on multiple downstream demand points, T&R logic is recommended. PI loop or simple floating control may be used for single zone system resets. For all reset strategies, additional settings are required in DoD Point Schedules. Zone-level importance multipliers are non-critical

to the sequence and therefore should be optional; Trim/response amounts and related set point min/max settings should be documented and available for view or override as desired per DoD project. Some GL36 T&R set points can likely be combined or ignored (e.g., trim/response values can include time step information). Further study may be required to field evaluate the effectiveness and implementation success of GL36 vs current DoD approaches to DSP set point reset.

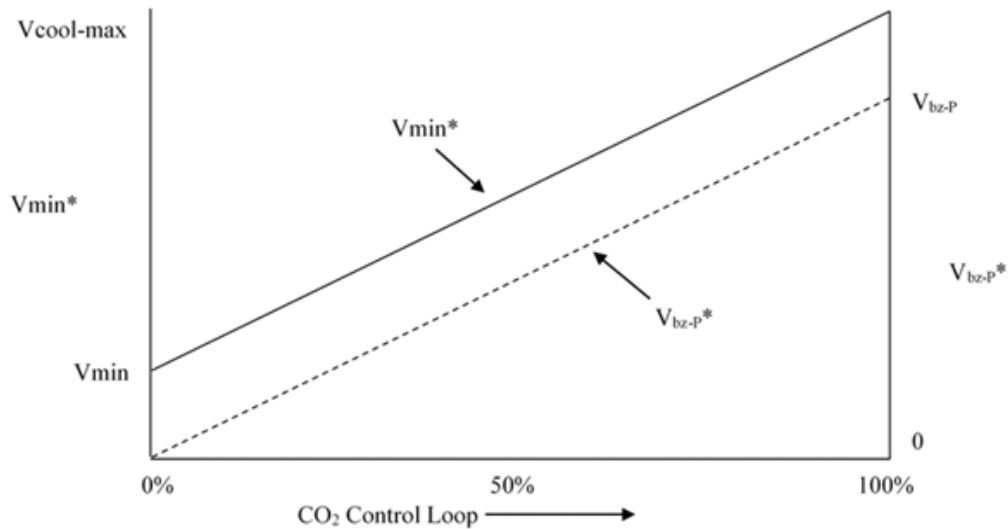
3.1.1.4 Demand-based Ventilation Adjustments

GL36 also addresses the need for control systems to adjust ventilation requirements based on real-time demand conditions at the zone-level. Relevant requirements focus on controller-based ASHRAE 62.1 Ventilation Rate Procedure (VRP) calculations to dynamically adjust the zone and AHU-level outdoor airflows. Additional requirements cover mitigation techniques for terminal unit box minimum flow capabilities and dual inlet ventilation needs. A summary of dynamic adjustment requirements include:

- Linearly reset each zone-level population component (V_{bz-P}) VRP calculations from design values down to zero based on CO₂ inputs (5.2.1.3)
- Update zone air distribution effectiveness (E_z) to heating or cooling settings (E_{zH} or E_{zC}) based on whether DAT is greater or less than ZN-T (5.2.1.3)
- If window switches are present and indicate open window status, reduce zone-level outdoor airflow to zero (5.2.1.3)
- If occupancy sensors are present and indicate unoccupied status, reduce zone-level outdoor airflow either to zero or to area-based minimum only depending on whether standby mode is in use (5.2.1.3)
- At the AHU-level, continuously recalculate uncorrected outdoor air rates (V_{ou}), maximum zone outdoor air fractions (Z_{pz}), and system ventilation efficiencies (E_v) based on real-time zone-level flow requirements and status (5.16.3.1)
- Validate/update actual minimum airflow capabilities at each VAV box through measurements with visual, pressure signal fidelity, and/or manufacturer amplification factor data (5.1.16.)
- Where zone airflow must be controlled below VAV capabilities, use time-averaged ventilation techniques to oscillate between open and closed periods to maintain an average minimum zone-level airflow (5.2.2)

- For various configurations of dual duct boxes, select whether minimum outside air is provided from hot vs cold duct inlets based on most recent heating and cooling loop signals (5.11 through 5.14)

Figure 2 Example CO₂-based Demand-Controlled Ventilation Sequencing from GL36



Source: ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems Informative Figure 5.2.1.3-1

The current DoD approach to ventilation is overall significantly simplified relative to GL36 requirements for dynamic ventilation adjustments. UFC 3-410-01 supports a static VRP design using the latest edition of ASHRAE 62.1 and prohibits use of CO₂ sensors in demand-controlled ventilation sequences. There are a number of reasons to consider expanding DoD approaches to DCV, including:

1. Many facility type categories such as instructional, administrative, fitness, and dining include large meeting spaces that have been observed to go unused or underused relative to design for much of the building schedule
2. Widespread adoption of remote meeting platforms following the COVID-19 pandemic has further reduced the usage of many DoD building space
3. Overventilation and excessive reheat of building spaces can result unnecessary cooling, fan, and heating energy that conflicts with DoD resilience, energy/cost savings, and carbon reduction goals
4. Field conditions suggest that CO₂-based DCV is being implemented during or after construction randomly across DoD despite UFC prohibitions; improved DCV criteria may better ensure appropriate approaches

Additional research is needed to sufficiently replace the UFC prohibition on CO₂-based DCV, however there are simpler criteria changes to consider addressing overventilation in DoD facilities. Recommendations include default occupancy or user-override based DCV for all single-zone HVAC systems, window switch logic /options for terminal unit Points Schedules, and alternative flow settings for VAV AHU zone schedules.

3.1.1.1 **Expansive Operator Interface Requirements**

Although GL36 indicates that defining the operator interface falls outside the scope of the GL, it nevertheless specifies a number of controls interface requirements to review, including:

- Point overrides - *“Values for all points, including real (hardware) points used in control sequences shall be capable of being overridden by the user with appropriate access level”* (5.1.11)
- Thermostat overrides: *“When thermostat override buttons are depressed, the call for occupied mode operation shall be sent to the zone group control for 60 minutes”* (5.3.3)
- Demand-limit thermostat – *“The active [cooling or heating] set points for all zones shall be increased when a demand limit is imposed on the associated zone group. The operator shall have the ability to exempt individual zones from this adjustment through the normal BAS user interface”* (eg, 5.3.2.6, 5.3.2.7)
- Testing/commissioning overrides: *“Provide software switches that interlock to a system-level point to*
 - a. force zone airflow set point to zero,*
 - b. force zone airflow set point to V_{cool-max},*
 - c. force zone airflow set point to V_{min},*
 - d. force damper full closed/open, and*
 - e. reset request-hours accumulator point to zero”* (5.5.8)
- HOA Hand Status in Lead/Lag Rotations – *“If a device is ON-in-hand (e.g., via an HOA switch or local control of VFD), the device shall be set to the lead device”* (5.1.15.2.b)
- Maintenance mode – *“Operators shall have the ability to put any device (e.g., AHU) in/out of maintenance mode. All alarms associated with a device in maintenance mode will be suppressed.”* (5.1.12.2)
- User-adjustable points: *“All set points, timers, deadbands, PID gains, etc. listed in sequences shall be adjustable by the user with appropriate access level whether indicated as adjustable in sequences or not. Software points shall be used for these variables. Fixed scalar numbers shall not be embedded in programs except for physical constants and conversion factors”* (5.1.10)

-
- Rogue zone displays/resets: *“The Request-Hours Accumulator and System Run-Hours Total are reset to zero as follows:*
 - i. *Reset automatically for an individual zone/system when the System Run-Hours Total exceeds 400 hours.*
 - ii. *Reset manually by a global operator command. This command will simultaneously reset the Request-Hours point for all zones served by the system.” (5.1.14.2.5)*
 - Other operator adjustments, eg: “The mass factor [of each zone, for warm-up or cooldown mode] shall be manually adjusted or self-tuned by the BAS” (5.4.6.2))

DoD approaches to operator interfaces are less prescriptive and focus on mechanisms for specifying user requirements rather than standardizing interface requirements themselves. Chief among these mechanisms is the Points Schedule drawing.

As a robust but flexible mechanism for specifying user and other point-level requirements, the Points Schedules provide DoD a standard approach to incorporating project-specific needs. Where individual projects desire GL36 user interface functionality, Points Schedule templates can be manipulated to accommodate. Thus, changes to DoD criteria are not required. A few important exceptions where criteria changes may be warranted include:

1. DoD criteria does not contain “Maintenance Mode” options. Additional content is recommended for UFGS 25 10 10 to allow designer specification of maintenance mode override timeframes, suspension of related status alarms, and automatic adjustment to lead/lag equipment selection sequences.
2. DoD criteria does not contain “Commissioning Mode” options. Additional content is recommended for and UFGS 25 10 10 to allow designer specification of system and zone group-level set point adjustments for air and related hydronic flow set points. This could be accomplished as extension of Maintenance Mode to trigger similar timeframe, alarm, and equipment selection responses.
3. DoD has yet to incorporate ASHRAE Standard 90.1 requirements for identifying and adjusting rogue zone conditions in DSP set point reset sequences. Additional research is recommended to establish controls criteria requirements to align with ASHRAE Standard 90.1 and consider related GL36 rogue zone display/override functionality.

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4. GL36 references different user roles, however no DoD drawings or other criteria exists to specify different view, override, or other interface customization specific to different installation roles. Additional research is recommended to update criteria with options to specify interface role assignments with installation defaults.
 5. Due to designer time constraints and technical complexity, Points Schedules are not always sufficiently completed. Additional research is recommended to automate the construction of Points Schedule to include a wizard-style approach to generating interface requirements.

3.1.2 Independent Best Practices for HVAC Sequences of Operation

3.1.2.1 Performance-Based nature of sequence content:

GL36 Section 5.1.1 states “sequences are intended to be performance based. Implementations that provide the same functional result using different underlying detailed logic will be acceptable.”

This approach is generally in line with DoD HVAC controls criteria (UFC 3-410-02 and UFGS 23 09 00) that support designer flexibility in modifying HVAC controls sequences, Points Schedules, and secondary deliverables. DoD criteria similarly emphasizes Performance Verification Testing (PVTs) rather than direct validation of sequence programming and configuration.

3.1.2.2 General Control Loop Requirements:

The GL contains several control loop tuning requirements, including anti-windup (5.1.2), neutral loop output values upon enable (5.1.3), limitations on use of the integral and derivative tuning parameters (5.1.8), and user-adjustable “ramp” defaults on loop outputs (5.1.9).

In contrast, corresponding DoD criteria consists of one paragraph on Controller Tuning in UFGS 23 09 00 (3.4) that focuses on high gain tuning conditions, settling criteria, and documentation of final PID settings. The UFGS also prescribes tuning in a manner consistent with ASHRAE Fundamentals Handbook and manufacturer instructions/requirements. Ideally control loop stability issues would be identified and corrected through DoD specification required endurance trends and other Performance Verification Testing. Given the scale and pace of DoD construction, campus-level O&M, and UMCS staffing, these GL best practices may provide enhanced protection against control loop issues that could otherwise persist unnoticed. Care should be taken, however, to ensure that delicate control

loop parameters are documented in Points Schedules and accessible to controls technicians but not directly adjustable by UMCS operators via graphics screens.

3.1.2.3 *Outdoor Temperature Sensor Locations:*

The GL addresses a number of scenarios related to outdoor air sensor temperature location:

- For multiple outdoor temp sensors, the GL states: “use the valid sensor that most accurately represents the outdoor air conditions at the equipment being controlled” (5.1.5)
- On validity of sensor data at outdoor air intakes, the GL indicates: “considered valid only when the supply fan is proven ON and the unit is in occupied mode or any other mode with the economizer enabled” (5.1.5.1)
- When used in global sequences (like optimum start or plant lockout), the GL directs an averaging of valid sensor readings with a discard of highest and lowest values where four or more exist (5.1.5.2)

Additional controls programming would be required to establish sensor validity, average sensor readings in global sequences, and discard high/low values. This additional programming complexity represents added cost and risk for error in initial programming, network connectivity, and future controls maintenance.

There is, however, a gap in DoD criteria that does not address how or when to defer to single or multiple outdoor air temperature sensor signals. The Execution section of UFGS 23 09 13 (3.1.7.4) only contains requirements for protected North-side installation of outdoor air temperature sensors with no related UFC design criteria. To best address gaps between the GL and DoD criteria, the following is recommended for consideration:

- Augment the North-side OAT sensor installation requirement in UFGS 23 09 13 for hydronic plant use only and require use of this sensor for building-level global sequences.
- Supplement UFGS 23 09 13 language to indicate that central air-side system OAT sensors must be installed and shielded at their OAT louvers with one sensor per system (no reliance on the network for OAT-related control of the unit).
- Increase the accuracy requirements for OAT sensors in UFGS 23 09 13 from +/- 1°F or 2°F to +/- 0.5°F to match duct temperature accuracy standards and better ensure effective air-side economizer high and low-limit lockouts.
- Add designer selection/notes in UFGS 23 09 13 (and potentially Point Schedule templates) for optional use of single base-wide OAT sensor for installation-level or building-

level global sequences; include a caution about reliance on the installation network and need for preventative recurring calibration checks for this single sensor.

3.1.2.4 Zone Group Assignments

GL36 establishes a number of HVAC zone-level designations within controls systems. One foundational concept in the GL for zone-level controls is the assignment of zone groups. Zones must be grouped on controls design drawings into collections of one or more zones served by the same air-side system with common schedules, shared set points, and capable of being overridden or tested together. An example of Zone Group assignments is shown below in Figure 3.

Figure 3 Zone Group Design Drawing Example from GL36 3.1.3

Zone Group Name	AH Tag	Terminal Unit Tags	Default Schedule
First-floor assembly	AH-1	VAV-1-1 through 11	WD: 6 am to 8pm WE: 8 am to 10pm HOL: OFF
Second-floor office	AH-1	VAV-2-1 through 15	WD: 7 am to 7 pm SAT: 9 am to 2 pm SUN: OFF HOL: OFF
IDF rooms	AH-1	VAV-1-12, VAV-2-16	ALL: 12 am to 12 am
First-floor lobby	AH-2		WD: 6 am to 8 pm WE: 8 am to 10 pm HOL: OFF

Source: ASHRAE Guideline 36 - 2018 High-Performance Sequences of Operation for HVAC Systems Informative Table 3.1.3

The GL proceeds to build off the zone group concept to establish zone group operating mode hierarchies. While an individual zone state may be in either *heating*, *cooling*, or *deadband*, zone groups will share one of the following operating modes: *occupied*, *cooldown*, *setup*, *warm-up*, *setback*, *freeze protection setback*, or *unoccupied*. Unless an individual zone *occupied-standby* mode is configured and triggered, zone group operating mode will determine temperature set points and ventilation requirements.

There are deviations and similarities with DoD approaches to zone groups, states, and operating modes. There are no designer prompts or resources for establishing zone groups. Air-side system template drawings, however, show UFC-required Sequencing Diagrams that represent changes in airflow and other VAV box commands by operating mode. While this approach to operating modes is similar to GL36, DoD Sequencing Diagrams

and Points Schedules contain far less quantity of default modes and related temperature set points. DoD approaches establish operating modes at the AHU-level and do not contain *setup or setback* functionality. Additionally, GL36 zone states are captured on DoD Points Schedules as a *unit status* that is either *heating* or *cooling*, but not in *deadband*.

Although the zone group approach serves as a GL36 building block, there is standalone value for consideration as independent best practices. The benefits of adoption zone group assignment approaches and related requirements are both energy and operational in nature. Energy savings potential exists from reduced ventilation, reheat, and cooling; operational benefits stem from more global capabilities in adjusting zone-level temperature, flow, or schedule configurations. Recommendations fall roughly under two categories:

- **Zone Group Design Schedules:** as a higher priority to address gaps in DoD criteria, a change in how air-side schedules are configured is recommended. This can be accomplished as an adoption of the GL36 approach where zone group schedules drive AHU-level operating modes or by simply appending existing Occupancy Schedules drawings with zone group assignment info. An updated description of the Occupancy Schedule table in UFC 3-410-02 section 5-10 is also required to promote zone-level scheduling.
- **Operating Mode/State Expansions:** as a lower priority to improve DoD criteria, additional content for zone/AHU-level operating modes and state is recommended. Consider further, defining operating mode at the zone-level, including *deadband* as a unit status value, and provide descriptions for setup/setback modes for optional designer use.

3.1.2.5 VFD Speed Ranges, Configuration, and Settings:

The GL contains three distinct requirements regarding VFD fan speed to consider:

1. **VFD Speed Command Range:** The GL indicates that the analog output command from an HVAC controller to the VFD will have a range configured to ensure 0% command results in 0 Hz (and not a VFD-configured minimum speed) and 100% command results in

maximum speed (which in some cases may be below or above 60 Hz):

“The speed AO sent to VFDs shall be configured such that 0% speed corresponds to 0 Hz, and 100% speed corresponds to maximum speed configured in the VFD” (5.1.13.1)

2. **Minimum VFD Speed Determination:** While the GL implies the controls designer should determine VFD maximum speed range, it is explicit in Section 3.2 that the TAB process should produce a minimum VFD speed setting in supply, return, and relief fans (through the lowest AO value that results in fan (or pump) movement):

“Minimum speed set points for all VFD-driven equipment shall be determined in accordance with the testing, adjusting, and balancing (TAB) specifications” (3.2.1.2)

3. **Minimum VFD Speed Configuration:** The GL includes a note indicating the preference for minimum VFD speed settings to reside in HVAC controllers and bound/written to networked VFDs in order to avoid conflicting minimum speed values, however a network vs hardwired options are still given:

“For each piece of equipment, the minimum speed shall be stored in a single software point... in the case of a hard-wired VFD interface, the minimum speed shall be the lowest speed command sent to the drive by the BAS.” (5.1.13.2)

There are a number of gaps and conflicts in DoD approaches to related VFD controls design, balancing, and operation:

- UFGS 23 05 93 Testing, Adjusting, and Balancing for HVAC does not give requirements on how the TAB must be completed for equipment such as fan or pump VFDs, other than it must be done as part of the construction process. No criteria is given for determining minimum VFD speed setting.
- UFC 3-410-01 requires systems to be balanced to achieve design flows with variable speed drives between 55 and 60 Hz only. Drive sheave replacement and discharge throttling are also indicated for

use in achieving system balance, despite the presence of variable speed drive equipment.

- HVAC controls criteria does not include requirements or designer notes on when or how to configure minimum speed settings, only that networked VFDs would need to meet UFGS 23 09 23.01 or UFGS 23 09 23.02 requirements.
- Points Schedule templates do not include a network interface for VFD devices (as they do for chiller or boiler interfaces).
- Existing Points Schedule systems with fan or pump equipment all use set 0-100% speed ranges and either do not include minimum speed settings (Chilled Water Plant) or contain a designer default of [25%]
- DoD criteria language ranges from Variable Frequency Drive (UFC 3-410-02) to “Adjustable Speed Drives” (UFGS 26 29 23) to “Variable Speed Drives” (UFC 3-410-01).

Set point recommendations cover coordination required with TAB criteria design groups that would apply to minimum fan speed determination. To address additional gaps and conflicts associated with HVAC controls design with VFD devices, the following DoD criteria action is recommended:

- **VFD Interface Criteria:** as a higher priority, provide designer notes in UFC 3-410-02, UFGS 23 09 93, and/or UFGS 23 09 23.01/02 to recommend specification of VFD network interface to transmit minimum speed settings (eg, as an LonMark nci or writeable BACnet object) and receive key VFD diagnostics/performance data while connecting analog speed commands through a more robust hardwired configuration.
- **Points Schedule Improvements:** as a higher priority, create a new system tab in the UFGS 23 09 00 Points Schedule template for “VFD Interface” that includes a minimum speed setting and optional diagnostics or performance points such as HOA status, kW value, and alarm description. Decrease minimum fan and pump speed defaults on all systems from [25%] to [10%] (or <10%> if TAB criteria coordination results in a new requirement for minimum fan speed determination). Include default alarms for HOA status (eg, when HOA not in auto for > 72 hours) and VFD alarm description strings.

-
- **HVAC and TAB Coordination:** as a medium priority, additional research and coordination is recommended with HVAC and TAB criteria government leads to address gaps in VFD TAB procedures, inefficiencies in redundant discharge valve balancing, and inconsistencies in VFD terminology.

3.1.2.6 *Equipment Staging & Rotation:*

The GL indicates sequences for automatic equipment staging and rotation will be provided at a later date, however several related requirements are presented in Section 5.1.15. These requirements dictate how equipment staging or rotation will be affected by alarm, HOA override, or manual software override. For example, fault conditions or switched OFF equipment will generate a level 2 alarm the equipment will be moved to the last-stage position unless another device goes into alarm. If a device is ON in-hand, however, this equipment will be set to the lead device and a level 4 alarm will be generated.

Like the initial release of GL36, DoD criteria does not contain sequences for equipment staging or lead/lag rotations, only a reference to an IMC requirement for the use of lead/lag controls as part of UFC 3-410-01. DoD resilience/environmental goals, black-start testing, and O&M staffing challenges suggest that some language should be developed for these type of equipment selection sequences.

There are two relevant recommendations to consider:

- **Performance-based Lead/Lag Rotation Requirements:** as a short-term performance based solution, add content to UFGS 23 09 93 System Mode section 3.1.1 to indicate that all similarly sized/operated lead/lag pump, boiler, and chiller configurations will rotate on a configurable run-hours basis (rather than scheduling) and with selection logic that ensures overridden equipment remains as lead status and failed/alarmed equipment is deferred to lag status.
- **Plant Equipment Staging and Lead/Lag Sequences:** as a longer-term and more prescriptive solution, develop necessary narrative, CLD, and interface requirements to provide equipment lead/lag and optimized plant staging sequences. Additional research is required to develop this criteria with an emphasis on use of plant load information to allow for demand-based plant staging.

Consider adoption of later GL36 equipment staging and rotation content as part of this criteria development.

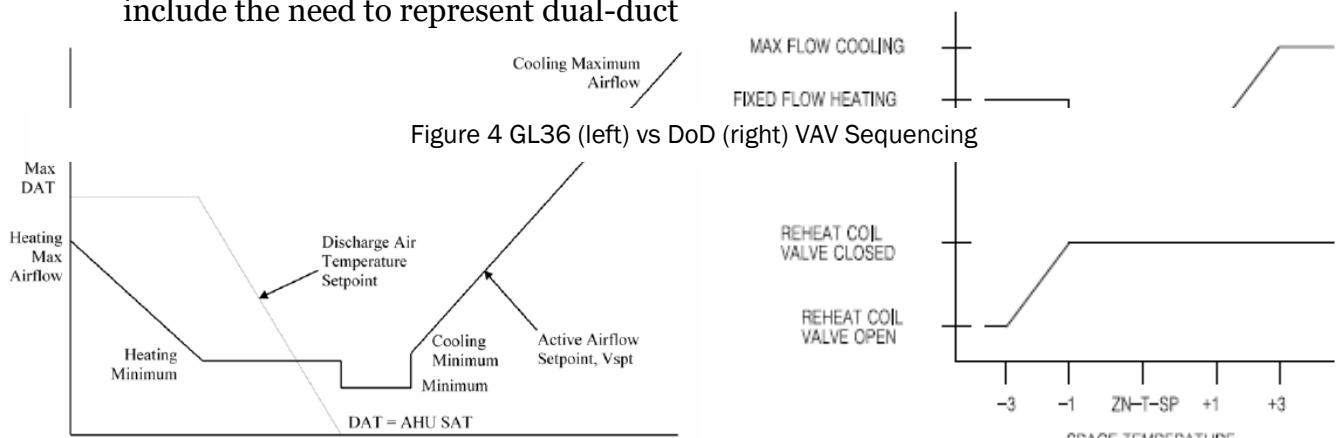
3.2 Terminal Unit Sequences of Operation

GL contains additional sequence of operation requirements specific to different terminal unit configurations. These requirements are housed predominantly in Section 5.2 Generic Ventilation Zones, Section 5.3 Generic Thermal Zones, and equipment-specific Sections 5.5 through 5.14. The scope of these systems largely aligns with DoD system targeted as shown in the below Table 4 with exceptions as shown in UFGS 23 09 93 contains additional terminal units systems such as fan coil units and perimeter radiators.

Table 4 Air-side Terminal Unit Systems: GL36 and DoD

Terminal Unit System	GL36 Section	UFGS 23 09 93
VAV Terminal Unit – Cooling Only	5.5	3.3.1
VAV Terminal Unit with Reheat	5.6	3.3.2
Parallel Fan-Powered Terminal Unit	5.7 - 5.8	3.3
Series Fan-Powered Terminal Unit	5.9 - 5.10	
Dual-Duct VAV Terminal Unit	5.11 - 5.14	-

VAV terminal units represent the predominant air-side terminal unit system type being installed in industry and DoD installations. Since GL36 and DoD criteria both address these systems, it can be a lower priority to consider reconciling current gaps shown in UFGS 23 03 93. These gaps include the need to represent dual-duct



Source: ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems Informative Figure 5.6.4

terminal units and breakout series vs fan-powered terminal unit sequences.

The actual sequences for these terminal units similarly align with some exceptions. As shown in the above Figure 4 Sequencing Diagrams, GL36 aligns with DoD's overall heating, cooling, and deadband changeover schemes for airflow and temperature control (note: GL36 Sequencing Diagram does capture its demand-based ventilation requirements but does show alignment with DoD approaches in that separate heating vs ventilation minimums are applied). Zone-level operating mode, temperature set point selection, and demand-controlled ventilation review has been conducted in earlier sections of this report. Additional GL36 terminal unit sequence content includes:

- **Demand-Limiting:** GL36 establishes demand-limiting event requirements with incremental adjustments based on demand-limit event types, levels, and zone group exemptions (e.g., “*At demand-limit Level 3, decrease set point by 2°C (4°F)*”)
- **Variable Speed Terminal Unit Fans:** GL36 requires fan-powered boxes to vary airflow based on zone state. By comparison, template DoD Points Schedules available on WBDG do not contain fan command or status entries, however Sequencing Diagram templates and sequence narratives indicate terminal unit fan operation is binary.
- **Damper/Valve Position Info:** GL36 Section 5.1.18 expands allowable methods of determining the value of a zone damper or valve position for the purposes of T&R sequences. In addition to analog output value to the actuator, position feedback and floating actuator timers are supported.

Higher priority recommendations for zone system changes to DoD criteria are contained in the General Approaches section of this report. Lower priority recommendations are as follows:

- **Address Dual Duct and Fan-Powered System Gaps:** Update UFGS 23 09 23 and Points Schedules to include sequences on dual duct terminal units, missing fan-powered point information, breakout of and options for variable speed box fan operation.

- **Demand-Limiting Options:** To support resilience goals, cost savings demand charge reduction, and O&M flexibility, develop optional designer criteria for demand-limiting sequencing. Current criteria requires demand-limiting capability at the front-end but does not include zone-level requirements, points, or designer templates. Criteria needs include alternate heating/cooling set point information in Zone Group Schedules and automated sequences or interface features to trigger a demand-limiting event (for implementation simplicity, use single event types with a one-level approach)

3.3 Central Air-Side System Sequences of Operation

GL contains additional sequence of operation requirements specific to different central air-side system configurations. These requirements are housed throughout the GL, with system-specific requirements housed in Sections 5.16 through 5.18. The scope of these systems has less alignment with DoD system targeted as shown in the below Table 5 with exceptions as shown in UFGS 23 09 93 contains additional packaged units, multi-zone systems, and various options for fan or coil bypass configurations.

Table 5 Central Air-side Systems: GL36 and DoD

Central System	GL36 Section	UFGS 23 09 93
Multiple-Zone VAV Air-Handling Unit	5.16	3.2.9
Dual-Fan Dual-Duct Heating VAV Air-Handling Unit	5.17 (5.16 for single duct)	3.2.7
Single-Zone VAV Air-Handling Unit	5.18	3.2.3 - 3.2.6
All-Air Small Package Unitary System	-	3.2.1
Heating and Ventilating Unit (or Unit Ventilator)	-	3.2.2
Multizone (with Return Fan and Hot Deck Bypass options)	-	3.2.7 - 3.2.8

The actual sequences for these central systems similarly align with some exceptions. There are similar groups of control loops for supply air temperature, supply air temperature, minimum airflow, economizer damper, and return or relief fan control processes. GL36 differences in central air-side system sequences are largely due to an expansion in the degree that zone-level information provides near real-time update to AHU set points.

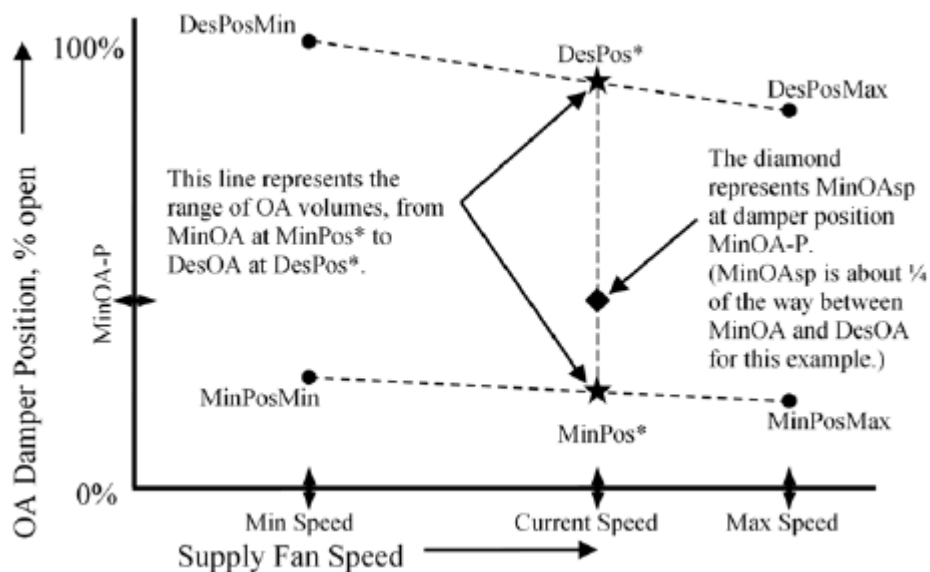
This can be seen in approaches where flow, temperature, and pressure targets are reset based on either multiple process variables, controller-based code calculations, operating mode, or zone-specific importance factors.

Economizer high limit set point, T&R sequences, request accumulations, demand-controlled ventilation, and determination of AHU modes are covered in earlier sections of this report. Additional GL36 central air-side system sequence content includes:

- **Perimeter Zone Groups:** the GL contains requirements for AHU supply fan start/stop based on the mode priority from its zone groups. There is an exception, however, for setback and warm-up mode. In these modes, the AHU shall run when perimeter zones contain VAV boxes. This configuration-specific requirement would necessitate special designer guidance to potentially modify AHU mode hierarchies presented in Section 5.15.1 based on whether VAV boxes of segregated ventilation is installed.
- **Software Totalization of VAV Box Airflow:** the GL provides an option for summing airflow at the zone-level for dynamic ventilation rate calculations or diagnostics purposes. This is presented as an alternative to use of a supply-side Air Flow Monitoring Stations (AFMS).
- **Relief Fan Sequences:** Like UFGS 23 09 93, the GL presents variations in equipment configuration within a given air-side system. Of note, GL36 presents sequences for relief fan within a VAV AHU system as well as the use of direct building pressure in either return or relief fan control loops. It is also noted that designers must specify relief fan groups that control common air volumes for equipment enabling purposes.
- **Coil Freeze Protection Sequences:** rather than a binary freeze-stat failure condition, GL36 provides several stages of coil freeze protection (example omits the tiered hot water plant request and alarm level configurations):
 1. 1st stage: If SAT < 40F for 5 min, disable economizer and raise SAT to > 42F until SAT > 45 for 5 min

2. 2nd stage: If SAT < 38F for 5 min, go to 0% OA for 1 hour and reenter 1st stage of freeze protection
 3. 3rd stage: If SAT < 38F for 15 min or SAT < 34F for 5 min or freeze-stat trips, disable AHU (fans and dampers), open ChW valve to 100%, and start the ChW pump system
- **Outdoor Air Damper Control without AFMS:** GL36 describes an AFMS-less option for outdoor air flow controls in single zone systems. Given that fan performance in single zone VAV systems is a function of fan speed only, the GL describes a linear interpolation method using damper position with reset outdoor air flow across fan speeds as shown in Figure 5 below.

Figure 5 GL36 Option for Outdoor Air Control Using Damper Position for Single Zone AHU



Source: ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC Systems Informative Figure 5.18.6.2

Of this GL36 content, designer notes for perimeter zone group assignments could be implemented as part of earlier recommendations for defining operating modes at a zone-level. There are a number of additional recommendations to consider associated with these central air-side system sequence requirements from GL36. These prioritize needed O&M improvements to coil freeze protection that should limit trips and further protect against coil damage with additional recommendations to address sequence gaps and opportunities for increased designer flexibility in system selection:

-
- **Coil Freeze Protection Sequences:** As a higher priority, update coil freeze protection DoD criteria. Currently, UFGS 23 09 23 and template drawings use a latching (hardware or software) reset on freeze-stat status as single stage binary coil protection. Adopt a tiered approach similar to GL36 that first disables economizer control loops and increases SAT, then eliminates outside air requirements, following by locking out the AHU and forcing ChW through the coil. Provide associated points and alarms for this sequence. For simplicity, use a single low limit temperature and an even time interval progression between stages.
 - **Expanded Relief/Return Fan Sequences:** As a medium priority, update UFGS 23 09 23 and Points Schedules to include sequences and points associated with relief fan configurations and use of building pressure in return or relief fan control. There is currently a gap in DoD criteria for any relief/exhaust fan sequences or points. Additional criteria for use of building pressure for relief and return fan control where appropriate would provide designer flexibility and better coverage of HVAC industry methods.
 - **Options for AHU Operation without AFMS:** As a low priority, update UFGS 23 09 23 and Points Schedules to include sequences and points associated with alternatives to use of AFMS. In AHUs with no return fan, provide an option for a VAV box airflow totalization software point for diagnostic or future controller-based VRP calculations. In single zone AHUs, provide optional criteria, related setting points, and designer notes on required TAB procedures associated with use of outdoor dampers without an AFMS. In all AHUs, provide a designer option for use of an economizer rather than a separate minimum outside air damper for ventilation flow control.

3.4 DoD HVAC Sequence Recommendations

Given the expansive set of HVAC sequence of operations topics in GL36, recommendations for DoD criteria adoption have been including within each topic's discussion. The below Table 6 DoD Criteria Recommendations for HVAC Sequences of Operation summarize the list of HVAC Sequence of Operation recommendation from this report. For each recommendation, additional criteria may be impacted, further justification will be provided in Criteria Change Requests using content from this report,

and priorities are assigned based on the technical approach from Chapter 1.

Table 6 DoD Criteria Recommendations for HVAC Sequences of Operation

Rec #	Category	Description	Primary Criteria Targeted	Priority
1	Central System Sequences	Adopt a Multi-Stage Approach to Coil Freeze Protection	UFGS 23 09 93 and template drawings	High
2	General Sequence Methodologies	Align DSP Set Point Reset Criteria	UFGS 23 09 93	High
3	General Sequence Methodologies	Non CO2-based DCV Sequences	UFGS 23 09 93	High
4	General Sequence Methodologies	Use of Zone Group Schedules	UFC 3-410-02	High
5	General Sequence Methodologies	Establish Configuration Defaults for Hardwired VFD Command and Networked Min Speed	UFC 3-410-02	High
6	General Sequence Methodologies	Create VFD Interface Points Schedule Template	Points Schedule	High
7	Terminal Unit Sequences	Zone-level Demand-limiting Sequences and Set points	UFGS 23 09 93 and Occupancy Tables	High
8	Central System Sequences	Demand-based Single Zone System Operation	UFGS 23 09 93	Medium
9	Central System Sequences	Add Building Pressure Return/Relief Fan Control Sequences	UFGS 23 09 93 and Points Schedules	Medium
10	General Sequence Methodologies	Test Mode for Equipment Group Overrides	UFGS 25 10 10	Medium
11	General Sequence Methodologies	Require Lead/Lag Rotation Based on Runhours and Overrides	UFGS 23 09 93	Medium
12	Points Schedule	Global Zone Temp Set points with Demand-Limiting	Points Schedule	Medium
13	Terminal Unit Sequences	Add Missing Content on Dual Duct and Fan-Powered Terminal Unit Control	UFGS 23 09 93 and Points Schedules	Medium

14	Central System Sequences	Add AHU Configuration Options without MinOA or Supply Air AFMS	UFGS 23 09 93 and Points Schedules	Low
15	General Sequence Methodologies	Expand Operating Mode Options to Include Setup, Setback, and Deadband Modes	Points Schedules	Low

Where more information, validation, or coordination is required to consider criteria adoption, additional research is recommended. The following additional research recommendations from this chapter are summarized in the below Table 7.

Table 7 Additional Research Recommended for HVAC Sequences of Operation

Rec #	Category	Description	Primary Criteria Targeted	Priority
1	General Sequence Methodologies	Establish Controls Interface Needs for Rogue Zones	UFC 3-470-01	High
2	General Sequence Methodologies	Expand Setpoint Reset Sequences to Supply Air and Hydronic Systems	UFC 3-470-01, UFGS 23 09 93	High
3	General Sequence Methodologies	Research CO2 Sensor Use in DCV	UFC 3-410-01	High
4	General Sequence Methodologies	Development and Implementation of a DoD Controls Design Wizard Tool	UFC-3-410-02	High
5	General Sequence Methodologies	Develop Criteria for Equipment Lead/Lag and Demand-Based Plant Staging	UFGS 23 09 00	High
6	General Sequence Methodologies	Establish Defaults for Installations M&C User Roles	UFGS 25 10 10	Medium
7	General Sequence Methodologies	TAB Spec Coordination for Field-Determined Set points	UFC 3-410-01, UFGS 23 05 93, UFGS 26 29 23	Medium
8	General Sequence Methodologies	Tech Note on Procedures for Measuring NFGS Network/Memory	UFGS 23 09 23.01 and 02	Low

4 HVAC Alarms

In DoD, alarms currently as a primary building interface for various facilities management staff. Where base-wide HVAC control systems are in place and configured to send alerts past installation networks, cell phone texts and email notifications provide critical information to controls operators and O&M technicians about their equipment. Standalone buildings, while offering less comprehensive and real-time data, nevertheless may contain operator consoles that can similarly supply this critical info.

There is, however, a delicate balance in communication controls designers must consider. Too little information can create a time-consuming puzzle for O&M staff to solve. Too much information or info sent to the wrong people becomes nuisance and noise. Both problems are exacerbated by control infrastructure or network failure; both problems result in a lack of confidence in and use of control systems to repair, diagnose, or avoid issues in our building systems.

GL36 contains a spectrum of content on HVAC alarms. The range of GL requirements includes simple best practices that highlight current gaps in DoD approaches as well as sophisticated advancements in alarm suppression that require additional research fully consider. The goal of this chapter is to help prioritize criteria adoption of HVAC alarm approaches that best fit the DoD operate environment to better strike the balance of information needed to engage our facilities staff.

4.1 Summary of GL36 HVAC Alarm Requirements

GL36's alarm requirements span the majority of the guideline. To facilitate a review of the alarm functionality required in GL36, the following categories of alarm requirements can be considered:

4.1.1 Alarm Scope

The HVAC systems and properties targeted by GL36's alarm requirements are not exotic. The typical central and air-side systems presented in GL36 are continuously evaluated for set point deviations in temperature and pressure or failures in equipment status. The following content summaries should help establish the scope of what GL36 aims to accomplishment with alarms:

-
- **Alarm Message Content:** GL36 section 5.1.12 begins with recommendations on what type of information alarms should display to operators. These include a message timestamp, alarm timestamp, alarm level, alarm description, equipment tags, upstream HVAC sources of the equipment, and alarm acknowledgement requirements.
 - **AFDD Alarms:** There is an additional GL36 recommendation for alarm message content to include possible causes of the alarm. In GL36, alarms are the mechanisms to convey the special detection and diagnostics recommendations resulting from AFDD routines configured. AFDD is discussed in detail later in this report.
 - **Alarm Sorting:** One additional workflow-related GL36 recommendation for alarm interfaces is to provide the capability for controls operators to sort alarms by timestamp, level, and current status.
 - **Command Deviation Alarms:** Most GL36 alarms can be defined as set point deviation or equipment status fail alarms. These are more conventional HVAC alarm types and can be categorized as follows:
 - **Zone Temp:** alarm if above or below set point for a given time range
 - **Zone Airflow:** alarm if below some percent of set point for some time
 - **Building Pressure:** alarm if above or below predefined limits
 - **Fan Status:** alarm if status does not match start/stop command in 15s
 - **Low Discharge:** alarm if RH DAT is below set point by a certain amount and a given time period with the hot water plant proven on
 - **O&M Diagnostics Alarms:** GL36 contains additional alarms that promote improved O&M diagnostics. These are not AFDD alarms since they do not apply the same rigorous AFDD routine criteria and calculations. Rather these O&M Diagnostics alarms use similar comparative or basic math methods as conventional alarms to provide more detailed information on O&M action needed. These can be summarized as:

-
- **Freeze Protection:** alarm if AHU fan is shut down from 3rd stage freeze protection sequence
 - **Leaking Zone Damper:** alarm if damper is 0%, AHU fan is on, zone airflow is above some percent of set point for a given amount of time
 - **Leaking Zone Valve:** alarm if valve is 0% for a given time period, AHU fan is on, and RH DAT is above AHU SAT by a set amount
 - **Filter DPs:** alarm if pressure drop exceeds filter manuf limit for a given flow (filter manuf DP limit at design x (% of design flow)^{1.4})
 - **Airflow Sensor Calibration:** alarm if AHU fan has been off for some time period and sensor reads above some percent of design flow
 - **CO2 Sensor Calibration:** alarm if below 300ppm or if above 600ppm after 2 hours if occupied status
 - **T&R Reset Tracking:** alarm if zone with importance factor greater than 0 has cumulative request hours above 70% for more than 40 hrs
 - **Hand/rotation:** alarm if a device HOA switch or VFD is in ON or OFF position (and adjust lead/lag sequence accordingly)
 - **High Runtime:** low-level alarm when fans exceed preset runtimes

4.1.2 Alarm Level Criteria

For each alarm condition in GL36, one of four alarm levels is specified. These levels are used to isolate alarm priorities and assign various alarm suppression conditions. The four GL36 alarm levels with examples are:

- **Level 1:** Life-safety message

(no specific Level 1 alarms are specified in GL36)

- **Level 2:** Critical equipment message

“If the lead device has a fault condition or has been manually switched OFF, a Level 2 alarm shall be generated and the device shall be set to the last-stage position in the staging order until the alarm is reset by an operator” (5.1.15.2)

- **Level 3:** Urgent message

“If the fan serving the zone has been OFF for 10 minutes, and airflow sensor reading is above 10% of the cooling maximum airflow set point, generate a Level 3 alarm” (5.5.7.2)

- **Level 4:** Normal message

“If the valve position is 0% for 15 minutes, DAT is above AHU SAT by 3°C (5°F), and the fan serving the zone is proven ON, generate a Level 4 alarm” (5.6.6.5)

These levels are referenced in a number of ways throughout the GL to require building alarm configurations specific to alarm priority:

- **Tiered Alarm Conditions:** GL36 alarms often include tiered conditions, meaning that different sets of out-of-range values may exist for the same alarm condition. Assignment of these ranges is accomplished with alarm levels. Examples include:
 - **Zone Temp Alarms:** *“If the zone is 2°C (3°F) above cooling set point for 10 minutes, generate Level 3 alarm”; “If the zone is 3°C (5°F) above cooling set point for 10 minutes, generate Level 2 alarm” (5.3.6.1)*
 - **Fan Status Alarms:** *“Commanded ON, status OFF: Level 2”; “Commanded OFF, status ON: Level 4” (5.18.12.2)*
 - **Freeze Protection:** *“If the supply air temperature drops below 3°C (38°F) for 5 minutes...set a Level 3 alarm noting that minimum ventilation was interrupted”; “Upon signal from the freeze-stat (if installed), or if supply air temperature drops below 3°C (38°F) for 15 minutes or below 1°C (34°F) for 5 minutes...set a Level 2 alarm indicated the unit is shutdown by freeze protection” (5.18.11)*
- **Alarm Trigger Exceptions:** GL36 goes to great lengths to attempt to avoid nuisance alarms. This is largely specified as various suppression conditions that delay the triggering of alarm conditions. Alarm trigger exceptions in GL36 are as follows:
 - **Maintenance Mode Alarm Suppression:** Operators shall be able to place any device in or out of maintenance mode; all device alarms except Level 1 (life safety) shall be suppressed and a daily Level 3 alarm is issued as a reminder
 - **Time-based Alarm Suppression:** to avoid set point deviation alarms or requests that would occur immediately following a change in set point, calculated or default time-based suppression values are required (eg, 10 min/Δ°F NTE 120 mins)
 - **Alarm Entry Delays:** all alarms require adjustable time delays such that the alarm condition must be met for a level-specific amount of time

- **Alarm Post-exit Suppression:** to avoid premature reoccurrence, an alarm may have an adjustable post-exit suppression period to be met prior to retriggering
- **Alarm Return-to-normal Conditions:** Similarly, the GL specifies certain conditions for exiting an alarm state. Once an alarm has been triggered, both of the following conditions must be met for the alarm to no longer be active:
 - **Alarm Exit Hysteresis:** alarms require adjustable time-based and value-based (for analog alarms) hysteresis to return-to-normal such that a certain amount of time and a certain percent of the limit condition has been met (eg for a zone temp trigger above 80F with 1m/5% exist hysteresis, temp must be below 76F for 1 minute before alarm can exit)
 - **Latching:** if an alarm has been configured as latching type, an acknowledgment from a controls operator is required before a return-to-normal

GL36 provides defaults for all level-specific alarm suppression functionality. These defaults are summarized in below Table 8:

Table 8 GL36 Alarm-related Defaults

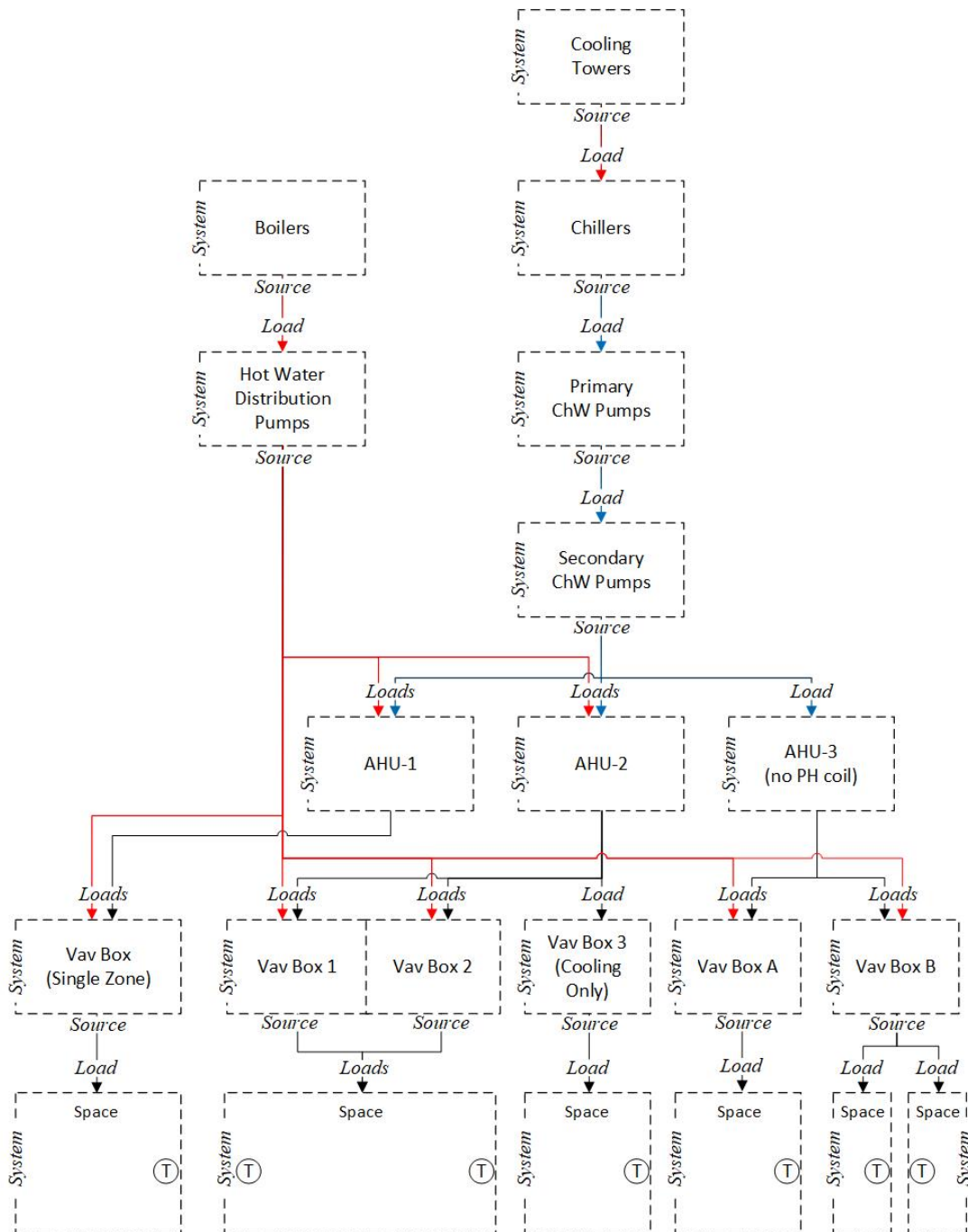
Alarm Level	Trigger Exceptions				Return-to-normal	
	Maintenance Mode Suppression	Time-Based Suppression	Entry Delay	Post-Exit Suppression	Exit Hysteresis	Latching Type
1	Never	Thermal zone temp alarms: 10 minutes per °F of set point delta (120 min max) Thermal zone temp heating or cooling requests: 9 minutes per °F of set point delta (30 min max)	1 second	0 minutes	Time Hysteresis: 5 seconds	Latching
2	Yes		10 seconds	5 minutes		Latching
3	Yes		1 minute	24 hours	Analog Percent-of-limit Hysteresis: 0%	Non-Latching
4	Yes		5 minutes	7 days		Non-Latching

4.1.3 Hierarchical Alarm Suppression

There is an additional set of criteria presented in GL36 to inhibit nuisance alarms known as hierarchical alarm suppression. This feature

requires the control system to track relationships between pieces of HVAC equipment such that an alarm of upstream system (or “source”) would suppress more minor alarms related to downstream equipment (or “loads”). “Systems” share a common load and tagged with a “SystemOK” true or false status to drive hierarchical suppression. This feature was introduced in Section 3.1.1.2 of this report and can be seen below in Figure 6 example using common HVAC equipment:

Figure 6 Example GL36 Source, Load, and System Hierarchies for a Typical HVAC Systems



Hierarchical suppression is intended to cascade through various level load and sources configurations. Level 1 through level 3 alarms configured to interact with this suppression hierarchy will result in a SystemOK of false that will prevent alarms for all downstream loads. Level 1 alarms and equipment status fail alarms shall never be suppressed by this hierarchical logic. SystemOK shall remain true when the system is proven on, achieving its respective set point(s) for at least 5 minutes, and the system is able/available to serve its load as defined by the design engineer or later configured by controls operators. This hierarchical suppression logic differs from alarm entry/exit suppression in it is alarm *notifications* that are suppression rather than the alarms themselves (alarms may still be logged by front-end software).

4.1.4 Discussion of DoD Criteria Approaches to HVAC Alarms

The DoD Criteria approach to HVAC alarms is significantly more basic than GL36 alarm requirements and focuses on a few key area. The emphasis on project-specific input and standard deliverables on interface systems:

- **Points Schedule Alarm Fields:** Points Schedule drawing requirements are defined in UFC 3-410-01 and UFC 3-470-01. These requirements are refenced across HVAC controls and front-end specifications and provide a fundamental tool to document points required, naming or other conventions, protocol-specific configuration info, and operator interface needs. Alarm needs that can be defined for every point's alarms are alarm condition, alarm priority, and M&C routing information. A number of default alarms are provided in Points Schedule templates, including:
 - *Supply fan proof failed*
 - *MINOA-F is less than 80% of MINOA-F-SP*
 - *BLDG-T is less than BLDG-T-LL*
 - *ZN-T is more than 37 Deg F above or below ZN-T-SP*
 - *HWS-T more than 41 Deg F above or below HWS-T-SP*
- **Alarm Priority:** UFGS 25 10 10 Section 2.4.10.13 requires that at least two alarm priorities levels are supported by software. These are defined as Critical (latching) and Informational (non-latching).

For each alarm defined for a given point in the Points Schedule, an alarm level is entered in the Alarm Priority field.

- **Alarm Routing:** UFC 3-470-01 requires additional tables from the design engineer defining where alarm information will go. These are the Alarm Contact Schedule and Alarm Routing Group Schedule. The former defines alarm recipient information including email and text details. The latter defines the action prompted by specific alarms by establishing how alarms from the Points Schedule will be email, texted, pop-up on screen, or locally print.
- **Alarm Data:** UFGS 25 10 10 defines what alarm information must be displayed for recipients or stored in front-end systems. Information includes:
 - *Identification info for building, system or subsystem, and device name*
 - *Timestamp and alarm priority*
 - *High or low alarm info including limits; Out-of-range or bad data indication*
 - *Current point value/status including units and alarm acknowledgement status*
 - *A unique and editable message with a field of at least 60 characters*
- **Alarm Acknowledgement:** Another UFGS 25 10 10 requirements in section 2.4.10.13 indicate that front-end Monitoring and Control (M&C) software must display and store alarm data. Display requirements at controls operator workstations include capability acknowledging multiple alarms with a single command with no automatic suppression between alarms. Stored alarms (both open and acknowledged) must be sortable, searchable, and printable.
- **M&C Software Permission Levels:** UFGS 25 10 10 section 2.4.10.8 also contains requirements for front-end M&C software capabilities that impact alarm features. M&C is required to support a minimum number of distinct users (100 default) and a minimum number of user permission levels (4 default). Default permission level 2 can acknowledge alarms; default permission level 3 can setup alarms.

4.1.5 DoD Criteria Alarm Recommendations

GL36 and DoD requirements for alarms contain many similar approaches. Alarm levels are defined, some default alarm conditions are provided, and alarm message content is established. If desired, GL36 alarm conditions could supplement or replace DoD Points Schedule defaults. DoD alarm Points Schedules could also be used to align with GL36 alarm levels by defining two critical and two informational priorities. And UFGS 25 10 10 alarm data content very closely overlaps with GL36 alarm message recommendations.

However many fundamental differences exist between how GL36 and DoD approach alarm functionality. DoD Points Schedule templates feature relatively few basic default alarms with some latching requirements, whereas GL36 has a much higher number of alarms with tiered conditions, more diagnostic targets, various entry or exit suppression, and aggressive latching for even zone-level alarms. DoD exceeds GL36 in establishing how and where to send alarms through Routing Group and Alarm Recipient standard deliverable tables, however GL36 exceeds DoD criteria by defining multiple alarm levels per alarm condition. Perhaps the greatest deviation is in the use of hierarchical alarm suppression by GL36 that have no corollary in DoD criteria.

In recommending changes to DoD criteria to potentially enhance alarm features and usage, an outright adoption of GL36 alarm requirements is not appropriate. Given the scale of DoD construction and controls projects, the DoD approach of providing tools or deliverables such as the Points Schedule best allow project-specific tailoring or alarm needs by designers and installation staff. There remains, however, a number of improvement opportunities in DoD criteria that borrow from GL36 alarm approaches, including:

- **Expanded Alarm Conditions:** As a high priority, provide additional default alarm conditions to better cover out-of-range sensor conditions and common equipment diagnostics issues. Current alarm defaults in DoD Points Schedule focus on set point deviation or start/stop vs status fails. UFGS 25 10 10 specifies out-of-range or bad data alarm types, however these are not represented in Points Schedule defaults. To improve the current Points Schedule zone temp alarms, for example, DoD criteria could include default GL36-type alarms to perform the following:

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- **Initial Zone Temp Alarm:** Generate low priority alarm if ZN-T is above or below set point by 5°F for 30 minutes
 - **Urgent Zone Temp Alarm:** Text urgent alarm to O&M building technician if ZN-T is above or below set point by 8°F for 2 hours
 - **Bad Data Alarm:** Notify O&M building technician and senior technician if ZN-T reads above 100°F or below 30°F to replace sensor or terminal unit controller
 - **Zone Temp Source Alarm – Valve Stuck Open:** Text informational alarm to O&M building technician and Energy Manager if VAV box DAT is above SAT by 5°F or more with HW valve command at 0% and SF/HWS are proven on
 - **Zone Temp Source Alarm – Valve Stuck Closed:** Text urgent alarm to O&M building tech if VAV box DAT is not above SAT by at least 5°F with HW valve command above 0% and SF/HWS are proven on

Note that this degree of alarm specification may require reference to outside Points Schedule fields.

- **Better Alarm Local Display Options:** As a high priority, modify the current UFGS 25 10 10 requirement for locally printing alarms to include an designer option to instead require a local display panel for alarm viewing and acknowledgement. While use of printers to transmit alarm data can generally be considered antiquated, there may be DoD sites concerned with IT infrastructure that will opt for this approach. A superior and more modern method, however, should be to include as a designer option the display and possibly acknowledgement of alarms at the building or system level.
- **Alarm-Specific Testing Requirements:** As a high priority, develop content for UFGS 25 10 10 to require and validate test procedures for alarm functionality. This Guide Spec currently includes general front-end Performance Verification Testing (PVT) requirements and Quality Control (QC) checklists for the contractor to complete and submit as a contract deliverable. Given the operational importance of functioning alarms, recommendation is for explicit testing requirements to ensure at least representative validation of alarm conditions, suppression, and especially routing. QC checklists should contain an entry for alarm routing verification.

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- **Key Alarm Suppression:** As a medium priority, consider adopting simple but key alarm suppression concepts from GL36. Hierarchical and time-based suppression represent significant implementation challenges compared to other entry or exit alarm exceptions in the GL. Entry delay would perhaps offer the most valuable improvement to avoid command deviation alarms at start-up or set point change. Alarm exit delays and maintenance mode alarm suppression for plant-level control overrides or HOA hand mode should also be considered. Latching is already supported through alarm priority designations.

GL36 contains a wealth of alarm methodology that cannot be sufficiently addressed in this report without considerable additional research. This additional research recommended is as follows:

- **DoD Defaults for M&C Routing Group:** As a higher priority, develop default alarm routing groups that align with typical facilities management roles at DoD installations. The Points Schedule deliverable and Alarm Recipient/Routing tables provide the necessary framework for DoD projects to indicate where and how alarms should be routed. Field experience suggests, however, that these deliverables are underutilized or unused entirely. This results in “flat” alarm structures that provide no nuance in urgency or recipient and a widespread alarm neglect at many DoD installations. Given the common structure of DoD Public Works and related staff, default routing groups could be selected for the following types of control system roles: O&M Building Technician, Senior O&M Technician, Controls Technician, Controls Operator, Energy Manager, O&M Chief, IT Staff, Building Manager, and Security. While not every installation has roles in place or routing needs, there is value in providing defaults to select. These defaults can also drive other UFGS 25 10 10 requirements for user permission levels and help form the basis for custom controls graphics navigation and summary views by user type.
- **DoD Alarm Library:** As a medium priority, consider development of an alarm library to tailor and/or reference in DoD Points Schedules. There is likely not sufficient space in the already overcrowded Points Schedule template drawing for adding tiered

alarms, bad data alarms, or multiple routing groups. If this functionality is to be supported by DoD criteria, consider a separate table of alarms for designers and installation staff to select from. These can be categorized by alarm type, point type, system, etc and could serve as an interface selection alarm module for the wizard-style approach to DoD controls design recommended elsewhere in this report.

- **Semantic Metadata Demonstrations:** As a medium priority, continue research into industry developments with semantic metadata tagging of control system points as means to potentially support hierarchical alarm suppression and other installation of the future concepts. Metadata approaches to data management may provide the most readable available path for implementing the system, load, and source relationships required in GL36. Controls manufacturers show varied adoption of tagging dictionaries for commercially available libraries such as Haystack or Brick Schema. DoD research into semantic metadata DoD standards is ongoing and if/when transferred to DoD criteria will better prepare DoD projects for this type of advanced alarm functionality.
- **Air Filter Optimization Research:** As a lower priority, conduct research into approaches for replacing air-side filter systems that optimize purchase/labor costs for recurring filter replacements with energy costs for filter loading over its lifecycle. Despite the DoD standard for installing AHU filter switches as part of criteria implementation, filter replacements at DoD installations are conducted almost entirely based on schedules (eg, 3 months for pre-filters, 6 months for final filters). Research or demonstration is required to consider GL36 calculated approaches to pressure drop limits, to estimate cost savings for on-demand filter replacement procedures, and most importantly to help standardize the in-house or contracted work flow integration required.

5 Automated Fault Detection & Diagnostics (AFDD)

GL36 defines Automated Fault Detection & Diagnostics (AFDD) as a sophisticated system for detecting and diagnosing air-handler faults using specific sensors and data. The size of buildings, complexity of HVAC systems, and limited availability or capability of facilities staff renders AFDD an attractive capability to supplement more standard control system interfaces. Given that DoD owns billions of facility square feet globally, AFDD approaches holds great potential to enhance the never-ending process of finding and fixing the many and often hidden problems in our buildings.

The GL provides a structure for AFDD design or scoping, however the focus is limited to specific air-side systems and less than effectively 20 fault conditions. These systems are multiple zone VAV AHUs, single zone VAV AHUs, and the far less common dual-fan dual-duct VAV AHUs. This section will discuss the components of AFDD for these systems as prescribed in GL36 and make recommendations on DoD could approach prudent but meaningful adoption of these advanced uses of control system data.

5.1.1 GL36 AFDD Components

Although the output of GL36 AFDD is transmitted through conventional alarm routing, the components to make AFDD logic work represent new functionality within a typical HVAC control system. These components can be broken up as follows:

- **Operating States:** in order to enable and drive specific AFDD routines, the operating state (OS) of an AHU is determined. This OS is distinct from any mode or status for zone and AHUs defined elsewhere in the GL. For a VAV AHU, OS is defined and by valve commands and outdoor air damper position as follows:

Table 9 Operating States for a VAV AHU

Operating State	Heating Valve Position	Cooling Valve Position	Outdoor Air Damper Position
#1: Heating	> 0	= 0	= min
#2: Free cooling, modulating OA	= 0	= 0	min < x < 100%
#3: Mechanical + economizer cooling	= 0	> 0	= 100%
#4: Mechanical cooling, minimum OA	= 0	> 0	= min
#5: Unknown or dehumidification	No other OS applies		

- **Sensor Data:** GL36 AFDD routines require specific sensor data and reasonable accuracy to function. There are 16 control points listed as necessary for each AHU with AFDD. None of these points are exotic to a standard control system implementation, however there are a few things to note:
 - **Mixed Air Temperature (MAT):** the GL specifically calls out an averaging MAT sensor as essential for effective AFDD. This is due to temperature stratification expected in an AHU mixed air plenum. Economizer as well as downstream coil fault detection may be ineffective without this averaging sensor infrastructure.
 - **Outside Air Temperature (OAT):** there is also a note recommending OAT sensor placement at the AHU for accurate incoming air representation. Additional GL36 OAT sensor requirements are discussed in the General HVAC Sequences section of this report.
 - **Heating-Coil Leaving Temperature (HCLT):** AHU preheat coil control should include a HCLT sensor, however it is possible to implement control using cooling coil leaving air temp or supply air temp. This approach would render HW coil AFDD ineffective.
- **Rolling Averages:** For all analog sensor data required by AFDD (all AHU temps and DSP), rolling averages are calculated. These 9 sets of rolling averages are calculated with operator-adjustable sampling times and averaging windows defaulted at 1-minute and 5-minutes, respectively.
- **Internal Variables:** The last component required for GL36 AFDD to function are a set of internal variables. These variables collectively represent the various assumptions, temperature deltas, error thresholds, and delay criteria needed largely to avoid excessive false positives in AFDD. These internal variables are listed in the table below with GL36 defaults that are intended to further limit AFDD nuisance alarms.

Table 10 GL36 AFDD Internal Variables List and Defaults

Variable Type	Variable Name	Description	Default Value
Temp Delta	Δ TSF	Temperature rise across supply fan	1°C (2°F)
	Δ Tmin	Minimum difference between OAT and RAT to evaluate economizer error conditions	6°C (10°F)
Sensor Error	ϵ SAT	Temperature error threshold for SAT sensor	1°C (2°F)
	ϵ RAT	Temperature error threshold for RAT sensor	1°C (2°F)

	εMAT	Temperature error threshold for MAT sensor	3°C (5°F)
	εOAT	Temperature error threshold for OAT sensor	1°C (2°F) if local; 3°C (5°F) if global
	εF	Airflow error threshold	30%
	εVFDSPD	VFD speed error threshold	5%
	εDSP	DSP error threshold	Varies
	εCCET	CCET sensor error; equal to εSAT or dedicated sensor error	
	εCCLT	CCLT sensor error; equal to εSAT or dedicated sensor error	
	εHCET	Heating-coil entering temperature sensor error; equal to εMAT or dedicated sensor error	
	εHCLT	Heating-coil leaving temperature sensor error; equal to εSAT or dedicated sensor error	
OS Tracking	ΔOSmax	Maximum number of changes in OS during the previous 60 minutes (moving window)	7
AFDD Delays	ModeDelay	Time in minutes to suspend fault condition evaluation after a change in mode	30
	AlarmDelay	Time in minutes to that a fault condition must persist before triggering an alarm	30
	TestMode Delay	Time in minutes that test mode is enabled	120

5.1.2 GL36 AFDD Conditions

Potential GL36 Fault Conditions (FCs) are assessed continuously based on AHU Operating States (OS) and using the control points, calculated rolling averages, and configured internal variable components described in the previous section of this report. Accounting for redundant FCs across AHU system types in GL36, there are effectively 20 FCs defined in the GL.

As an example, FC#5 continuously evaluates for an inappropriately low supply air temperature whenever the AHU is in a heating OS. The routine is essentially comparing SAT to MAT in rolling average windows and accounting for sensors error thresholds and fan heat assumptions. This example equation is shown below in Figure 7.

Figure 7 Example Fault Condition (FC#5): SAT too low during “Heating” (OS#1)

Internal Variables

$$SAT_{avg} + \epsilon_{SAT} \leq MAT_{avg} - \epsilon_{MAT} + \Delta T_{SF}$$

5-minute rolling averages

εSAT: temp error threshold (default 2F)

εMAT: temp error threshold (default 5F)

ΔTSF: temp rise across the fan (default 2F)

A number of possible sources are listed in GL36 for each FC. The GL indicates that FC will be reported to controls operators as a level 3 alarm to

that includes this diagnostics information. As an example, the possible diagnosis list for FC#5 (SAT too high while in heating OS) is as follows:

- SAT sensor error
- MAT sensor error
- Cooling-coil valve stuck closed or actuator failure
- Fouled or undersized cooling coil
- CHW temperature too high or CHW unavailable
- DX cooling unavailable
- Gas or electric heat stuck ON
- Heating-coil valve leaking or stuck open

The GL gives AFDD suspension and suppression criteria, including a cessation of AFDD evaluations when the AHU is not operating, FCs are not applicable to the current OS, and configured delays for alarm triggers and mode changes have lapsed. An AFDD test mode feature is also required to set these delays to 0 minutes for a configurable test period to evaluate AFDD functionality.

5.1.3 DoD AFDD Criteria Recommendations

There is no DoD criteria to support GL36 AFDD or any related methodologies for history-based, qualitative, or quantities fault detection. There are clear benefits to enhanced use of control system data and more action-oriented operational insights in our O&M alarms. More urgent, however, are gaps, outdated content, and missing guidance on HVAC sequences and operator interfaces. Rather than pursue the substantial effort of adoption AFDD functionality into DoD criteria outright, the following recommendations focus on key AFDD building blocks that provide standalone value:

- **Sensor Infrastructure Gaps:** As a high priority, address controls infrastructure gaps concerning two AHU sensor configurations. First, add content to UFGS 23 09 13 and UFC 3-410-01 to require use of MAT averaging sensors in all AHUs greater than 1,000 CFM to match DoD Controls Schematic drawing templates for AHU systems. There currently no explicit requirement to use MAT averaging sensors, only sensor accuracy and install requirements where they are used. Second, require use of a separate hot water coil discharge air temperature sensor for control where multiple AHU coils are specified. While these changes provide improved sensor infra-

structure for future AFDD implementation, the primary and immediate value to DoD is in improved control and monitoring of these systems.

- **OS Software Points:** As a medium priority, update Points Schedules for all AHU types to include a software point representing the Operating State (OS). This would be distinct from existing unit status or mode points and would aid in the evaluation, trending, and analysis of HVAC systems with or without AFDD. In effect, the point removes the burden from controls operators to *infer* an AHU Operating State based on a number of valve, status, temperature, and damper parameters. Provide GL36 OS values #1 through 5 as the default Points Schedule range and criteria in UFC 3-410-01 and UFGS 23 09 93 for OS determination. Note: GL36 assumed an integrated economizer configuration for AHUs.

Most of the AFDD content in GL36 will require demonstration to best determine the cost savings, operational benefits, and implementation needs in the DoD operating environment. There are two additional research recommendations associated with the AFDD section of GL36:

- **AFDD Demonstrations:** As a medium priority, continue DoD and Service-specific evaluations of AFDD at military installations. Ongoing projects such as ESTCP EW19-5167 are evaluating commercial off-the-shelf fault detection and diagnostics packages with the technical objective of determining associated DoD implementation needs. Construction criteria controls leads and subject matter experts should compile results of related DoD demonstration efforts into vendor-agnostic AFDD adoption recommendations to criteria leadership.
- **Diagnostics Messaging:** As a lower priority and before (or as an alternative to) AFDD criteria adoption in DoD, current approaches to O&M alarms may benefit from more diagnostics information. As part of additional research recommendation from the previous chapter of this report on alarms, consider adding a requirement on “Possible Diagnosis” to the message body of alarm notifications. While this approach is no substitute to time-averaged and configured AFDD, there are certain common alarms in HVAC systems that have corresponding common fixes. For instance, an alarm for out-of-range zone temp can include discharge air and VAV reheat

valve information with notes on next steps to check valve actuator, test valve signal or controls command, and clean strainer.

6 Conclusion

ASHRAE's GL36 contains a wealth of controls concepts for improving HVAC system operation. The breadth of air-side systems and depth of detail closely aligns with the technical areas covered by related DoD criteria. The GL's initial focus has been on 3 central air-side system types and effectively 5 configurations of terminal units. There is, however, a substantial amount of generic controls methodologies presented in the GL that can be made generally applicable beyond this limited system scope. Furthermore, GL36 has value to the controls industry as a resource not just for HVAC sequences of operation but also for determining system set points, advanced alarm requirements, and prescriptive AFDD approaches.

The objective of this report's review of GL36 was to isolate content into a prioritized list of recommendation to DoD for rapid criteria adoption and additional research. The review team at CERL considered a number of factors during review, however the primary lens with which content was reviewed was that of the DoD operating environment. From this perspective, the GL represents both an opportunity and a challenge to DoD facilities construction and operation. Rather than adopt or reject the GL outright, the overall recommendation of this report is to pursue a set of updates to DoD criteria that are based on severable and high value GL36 content.

Review of GL36 has resulted in 40 total recommendations of varying priority. Of these, there are 11 high priority criteria adoption recommendations presented in Table 11 and 8 high priority items for additional research presented in

Rec #	Category	Description	Report Chapter
1	Ventilation Zone Set points	Non CO2-based DCV Sequences	Ch 2
2	Central System Sequences	Adopt a Multi-Stage Approach to Coil Freeze Protection	Ch 3
3	General Sequence Methodologies	Align DSP Set Point Reset Criteria	Ch 3
4	General Sequence Methodologies	Use of Zone Group Schedules	Ch 3
5	General Sequence Methodologies	Establish Configuration Defaults for Hardwired VFD Command and Networked Min Speed	Ch 3

6	General Sequence Methodologies	Create VFD Interface Points Schedule Template	Ch 3
7	Terminal Unit Sequences	Zone-level Demand-limiting Sequences and Set points	Ch 3
8	Alarms	Expanded Alarm Conditions	Ch 4
9	Alarms	Better Alarm Local Display Options	Ch 4
10	Alarms	Alarm-Specific Testing Requirements	Ch 4
11	AFDD	Address AHU Sensor Gaps	Ch 5

Table 12 below. This content was selected to best help DoD address controls criteria gaps, expand existing controls approaches, and improve controls operator interfaces. Following submission of this report, the CERL review team will submit priority recommendations as Criteria Change Requests, propose addition research through existing criteria update programs, and coordinate with the DoD criteria community and leadership accordingly.

The review of GL36 concluded that DoD is not a good candidate to fully adopt criteria at this time for industry advancements in dynamic ventilation set points, hierarchical alarm suppression, and AFDD as described. The GL, however, has helped highlight a number of gaps and improvements in key areas of HVAC system control and interface. DoD has criteria update needs for standardized set point reset, demand-control modes of operation, some degree of alarm suppression, averaging sensor requirements, modern interface guidance, rapid controls design tools, and others. The recommendations of this report are expected to improve controls system operation using GL36 *best practices* while preparing DoD for future adoption of smart building capabilities including GL36's *best-in-class* requirements.

Table 11 High Priority Recommendations for DoD Criteria Adoption Based on GL36 Content

Rec #	Category	Description	Report Chapter
1	Ventilation Zone Set points	Non CO2-based DCV Sequences	Ch 2
2	Central System Sequences	Adopt a Multi-Stage Approach to Coil Freeze Protection	Ch 3
3	General Sequence Methodologies	Align DSP Set Point Reset Criteria	Ch 3
4	General Sequence Methodologies	Use of Zone Group Schedules	Ch 3
5	General Sequence Methodologies	Establish Configuration Defaults for Hardwired VFD Command and Networked Min Speed	Ch 3

6	General Sequence Methodologies	Create VFD Interface Points Schedule Template	Ch 3
7	Terminal Unit Sequences	Zone-level Demand-limiting Sequences and Set points	Ch 3
8	Alarms	Expanded Alarm Conditions	Ch 4
9	Alarms	Better Alarm Local Display Options	Ch 4
10	Alarms	Alarm-Specific Testing Requirements	Ch 4
11	AFDD	Address AHU Sensor Gaps	Ch 5

Table 12 High Priority Recommendations for Additional Research Based on GL36 Content

Rec #	Category	Description	Report Chapter
1	Ventilation	Research CO2 Sensor Use in DCV	Ch 2
2	Terminal Unit Set Points	Explore Terminal Unit Flow Set point Design Approaches	Ch 2
3	General Sequence Methodologies	Establish Controls Interface Needs for Rogue Zones	Ch 3
4	General Sequence Methodologies	Expand Setpoint Reset Sequences to Supply Air and Hy-dronic Systems	Ch 3
5	General Sequence Methodologies	Development and Implementation of a DoD Controls Design Wizard Tool	Ch 3
6	General Sequence Methodologies	Develop Criteria for Equipment Lead/Lag and Demand-Based Plant Staging	Ch 3
7	Alarms	DoD Defaults for M&C Routing Group	Ch 4