Optimizing Airport Building Operations and Maintenance Through Retrocommissioning: A Whole-Systems Approach

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 139

Optimizing Airport Building Operations and Maintenance Through Retrocommissioning: A Whole-Systems Approach

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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FOREWORD

By Joseph D. Navarrete
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ACRP Report 139: Optimizing Airport Building Operation and Maintenance Through Retrocommissioning: A Whole-Systems Approach is a guidebook to help airport industry practitioners incorporate a whole-building systems lifecycle approach to operations and maintenance (O&M) optimization that suits their unique needs. Included with the guidebook is a CD that contains additional appendices and a spreadsheet tool to help practitioners evaluate and select appropriate facility optimization measures based on cost, savings, complexity, visibility, and greenhouse gas savings. Airports looking to facilitate sustainability through enhanced O&M practices will find the guidance and recommended practices extremely valuable and practical.

Airports are increasingly concerned with improving efficiency and reliability as well as reducing costs. Since an airport's O&M budget constitutes a significant portion of its overall budget, many airports have begun exploring ways to optimize O&M and improve overall building system performance through retrocommissioning. Although significant financial and environmental benefits can be realized through O&M optimization and retrocommissioning, the complexity of airport building systems and the lack of a whole-building systems lifecycle approach to decision-making can lead to conflicting priorities and less-than-optimal improvements. Research was needed to help airports understand and apply a whole-building systems lifecycle approach to O&M optimization and retrocommissioning.

The research, led by Sebesta, began with a literature review that addressed O&M best practices for system optimization and energy performance. Next, the team developed a draft primer and process map designed to assist airports in understanding and selecting an appropriate method to pursuing operational improvements. A series of stakeholder focus groups were held to collect feedback on the primer and process map. The team then prepared example case studies. The results of these efforts were used to prepare the guidebook.

The guidebook includes an introduction to retrocommissioning and a discussion of building O&M best practices. It then offers guidance for developing a retrocommissioning plan, addressing the key phases of project scoping, planning, investigation, implementation, and verification. A process map for facility optimization graphically lays out the key steps. The guidebook also provides a glossary and related appendices, including an example retrocommissioning report.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

INTRODUCTION

Optimizing Airport Building Operations and Maintenance Through Retrocommissioning: A Whole-Systems Approach

ACRP Report 139 represents the culmination of ACRP Project 09-04, "Airport Building Operations and Maintenance (O&M) Optimization and Recommissioning: A Whole-Systems Approach." O&M can constitute a significant portion of an airport's overall budget. In the past, many airports may have deferred maintenance tasks to reduce these costs; more recently, however, airports have begun to realize that deferred maintenance often leads to poorly performing buildings that cost more to operate and may even result in significant deterioration of physical assets. Additionally, in this era of sustainability and limited economic and natural resources, airports are now exploring ways to optimize O&M and improve overall building system performance, thereby improving efficiency and reliability as well as reducing costs.

Although significant financial and environmental benefits can be realized through O&M optimization, the complexity of airport building systems and the lack of a whole-building systems lifecycle approach to decision-making can lead to conflicting priorities and less-than-optimal improvements. This report has been created to help airports understand and apply a whole-building systems lifecycle approach to O&M optimization.

Beginning in the early 1990s, it was recognized that, for their successful operation, buildings must first be turned over as fully functioning operations. In implementation, the turnover process reinforced the need for facilities staff training and support documentation. With this in mind, the industry has recognized that application of "commissioning" skills to all phases of a building's lifecycle can add substantial value to building operations.

When a building is **commissioned**, it undergoes a disciplined process of design reviews, construction inspections, and functional testing beginning in the design phase and concluding only at the end of a 1-year occupancy period. This process validates that the facility's performance will meet the airport's objectives and that the facility management and maintenance staff is prepared to operate the building and maintain its systems and equipment.

Recommissioning a building repeats the commissioning process to verify and adjust (as necessary) a building's performance to ensure that the systems and equipment continue to operate in an optimized manner. Recommissioning can be applied effectively at regular intervals to optimize long-term energy profiles, improve reliability, and sustain facility performance.

For a building that was never commissioned, **retrocommissioning** applies commissioning principles to investigating, correcting, and validating existing building performance as required to support the mission carried out in the building. Retrocommissioning often can uncover and resolve problems that occurred during design or construction of the original systems. It also can address problems that have developed as a result of the normal aging of the building's systems and equipment. Retrocommissioning will improve performance and reduce the energy required to support the mission of a building. The process will also enhance the ability of the O&M team to sustain the improvements over time.

For mature airport facilities, a **facility condition assessment (FCA)** will comprehensively document airport assets and their condition. An FCA will quantify the amount of deferred maintenance using a facility condition index and replacement cost index. These are used to establish facilities maintenance and capital budgets, and prioritize projects (Ricondo and Associates 2012). An FCA will include all assets in a facility, including building systems and finishes; however, the FCA generally will not seek to diagnose system performance, as is done for a retrocommissioning effort.

FCAs and energy audits play an important role in facility planning. Retrocommissioning delivers immediate improvements in facility performance, however, and provides O&M staff with the knowledge of recommissioning procedures to incorporate in preventive maintenance activities.

Because this report is focused on optimization of existing buildings, retrocommissioning is a primary focus. Retrocommissioning includes the activities conducted as part of recommissioning, but recommissioning does not include the activities conducted as part of retrocommissioning. Given the frequent changes to airport terminal facilities, retrocommissioning is recommended, as recommissioning may be insufficient to meet current facility requirements. If an airport wishes to implement recommissioning, however, the practices described for retrocommissioning will provide helpful guidance for recommissioning.

The term *commissioning* comes from shipbuilding. A commissioned ship is one deemed ready for service. Before being awarded this title, however, a ship must pass several milestones. Equipment is installed and tested, problems are identified and corrected, and the prospective crew is extensively trained. A commissioned ship is one whose materials, systems, and staff have successfully completed a thorough quality assurance process (Ricondo and Associates 2012).

Once a retrocommissioning effort has been completed, it is strongly suggested that **ongoing commissioning** practices be used to keep the facility in optimal operations. Ongoing commissioning leverages the data collection and analysis capabilities of building control systems to monitor real-time building performance, identify potential issues, and notify the facilities staff to investigate and resolve them. An effective ongoing commissioning process also supports a culture of accountability and reward that provides incentives to sustain superior building performance.

Completed ACRP studies and industry publications were reviewed to provide airports with a comprehensive list of recommendations for optimizing the O&M of terminal facilities. These resources are referenced in Section 1. The recommended practices have been summarized as a Master List in Appendix G, which is provided as a spreadsheet tool on *CRP-CD 169: Spreadsheet Tool and Appendixes to ACRP Report 139*, included with this report. The CD-ROM also contains appendices providing three detailed case studies, a process map, sample scope of work documents, and a sample report with a retrocommissioning plan. The contents of CRP-CD 169 also are available online. To find Appendixes A through G for this report, go to www.trb.org and search for "ACRP Report 139."

ACRP Report 139 is structured as a guidebook for airports that provides: (1) an overview of the benefits of a whole-building systems lifecycle approach to O&M optimization and retrocommissioning, and (2) guidance for preparing a building systems optimization and retrocommissioning plan to suit their unique needs.

SECTION 1

Suggested Practices for Airport Building Operations and Maintenance

This section of the guidebook provides a compilation of suggested practices for consideration in airport terminal O&M. Varying intensity levels of maintenance are reviewed, along with computerized maintenance management programs (CMMS) that electronically support task completion and document management. Energy management practices also are reviewed, including recurring practices for monitoring energy consumption and energy costs as well as engineering studies called energy audits and retrocommissioning. Measurement and verification (M&V) and metering practices are reviewed for monitoring building performance, which leads into ongoing commissioning—using real-time data collection to monitor building performance. Staff training is crucial to effectively communicating these practices to facilities staff. Lastly, suggested practices for building documentation are addressed with regard to staff training and building information models (BIMs).

The complete list of measures is provided in Appendix G, with sources briefly discussed herein.

Maintenance Programs

Maintenance keeps buildings operating. From periodically replacing components to fixing broken parts and removing contaminants, maintenance is a necessary expense to preserve the integrity of a facility. Various approaches to maintenance are used by facilities management (DOE EERE FEMP 2012):

- **Reactive maintenance** can be described as "operating to failure." Nothing is done until a component fails.
  - Reactive maintenance saves costs in that it requires no manpower for maintenance when the equipment is operating properly, but the expense of the emergency maintenance required to fix the equipment upon failure (which may involve overtime labor or expedited part delivery) may outweigh the cost savings.
  - Long-term, shorter equipment life also can be expected from this approach, given that minor corrections that would be made as part of preventive maintenance are not occurring (i.e., tightening belts on a motor, cleaning a cooling coil). Failure of one component can increase the stresses and raise the probability for failure of other components.
  - Reactive maintenance results in
    - Compromised facility conditions and high levels of occupant complaints.
    - Systems operating on the brink of failure, with high risk of unplanned shutdowns.
    - Deferred maintenance that can cause spikes in facility costs due to cascading failures in building systems.
  - As a rule of thumb for facilities, less than 10% of maintenance activities in a maintenance program should use a reactive maintenance approach.

- **Preventive maintenance** includes activities that are performed at regular intervals to keep equipment operating properly. The intervals may be based on calendar days or equipment runtime, and may be adjusted to account for operating conditions.
  - Changing air filters in an air handling unit (AHU) is an example of a preventive maintenance activity that depends on the runtime for the AHU and the cleanliness of the air.
    - Regularly replacing filters in an AHU improves airflow through the filters (saving energy by decreasing pressure drop) and keeps cooling coils clean (saving energy by improving the effective heat transfer of the coil).
    - While the filter is being changed, staff can take the time to observe the AHU and identify any other abnormalities, such as a loose belt or standing condensate water, which could deteriorate equipment and compromise indoor air quality.
  - Preventive maintenance
    - Is estimated to save 12–18% cost savings over reactive maintenance.
    - Reduces unplanned shutdowns for equipment.
    - Prolongs equipment life.
    - Levels maintenance budgets to avoid spending spikes from deferred maintenance.
  - As a rule of thumb for facilities, 25–35% of maintenance activities in a maintenance program should use a preventive maintenance approach.
- **Predictive maintenance** goes a step further to perform maintenance based on actual system performance. Performance is measured using temporary or permanently installed sensors to diagnose the condition of the system and determine real-time maintenance requirements. As a result, the system can be operated beyond a normal preventive maintenance interval, but measurement identifies the need for maintenance prior to failure.
  - Predictive maintenance
    - Reduces system downtime.
    - Virtually eliminates unplanned shutdowns for equipment.
    - Is estimated to save 8–12% cost savings over preventive maintenance.
    - Can initially be expensive to implement compared to preventive maintenance.
  - As a rule of thumb for facilities, 45–55% of maintenance activities in a maintenance program should use a preventive maintenance approach.

Industry guidelines suggest that maintenance budgets be funded at an annual rate of 2–4% of current replacement value (APPA 2013). When a maintenance task is required but not completed, it is *deferred maintenance*. Studies show that every dollar of deferred maintenance requires four dollars in future capital (a 4:1 ratio).

Establishing an effective maintenance program is fundamental to optimizing facility operations. A maintenance program will identify all equipment and components with specific maintenance activity instructions following the maintenance approaches outlined above. This task can quickly generate a large database that requires archiving of completed activities and updating for future maintenance activities. Many software solutions are available, called computerized maintenance management systems (CMMSs).

Computerized Maintenance Management Systems

A CMMS will help manage the logistics for a maintenance program (see Figure 1). Common CMMS functions include:

- Work order procedures, frequency and assigned staff
- Archived records for completed work orders
- Tracking for unscheduled maintenance activities
- Capital and labor cost tracking by equipment or component

Figure 1. Sample CMMS dashboard from packaged software.

- Parts and materials inventory with automated reordering
- Portable interface devices (i.e., tablets) to facilitate remote access in the field (DOE EERE FEMP 2012)

A CMMS can efficiently manage maintenance program activities to ensure the program is followed and scheduled activities are not inadvertently missed. Training through the CMMS vendor will support staff in using the technical capabilities of the system. To encourage proper documentation, management should consistently review and verify that documentation in the CMMS is complete and up-to-date. Accurate documentation helps to ensure that the maintenance program is being followed to optimize facility operations.

Energy Management

At an organizational level, energy management refers to the responsibilities of tracking and trending energy use on a daily, monthly, and annual basis. Energy management goals are to:

- Provide a comfortable and productive indoor environment in facilities by controlling the HVAC and lighting systems.
- Operate HVAC and lighting systems to optimize energy performance while maintaining a comfortable and productive indoor environment (i.e., demand-side management).
- Control energy costs by reviewing and negotiating power purchase agreements and procuring supplemental power as necessary (i.e., supply-side management).

- Lead the identification, evaluation, and implementation of energy conservation measures (ECMs) to improve building systems and reduce energy use.
- Acquire outside funding to support the implementation of ECMs.
- Establish an M&V program to track energy savings from previously implemented ECMs.
- Manage utility bills, review them for accuracy, approve payments, and track utility costs on a daily, monthly, and annual basis.

Establishing an effective energy management program will reduce operating costs by identifying opportunities for improving energy efficiency and reducing energy costs. Depending on the total square footage of facilities, complexity of systems, and potential energy savings, an organization may wish to hire a dedicated staff person as a professional energy manager or assign the energy management responsibilities to a technically qualified staff person. Using an in-house staff person (such as a facility manager, property manager or building operator) usually is appropriate only for smaller (less than 300,000 sq. ft.) facilities (PECI 1999).

As a roadmap, the energy manager can develop the energy management program through:

- **Benchmarking utility consumption.** Benchmarking establishes a baseline performance level against which improvements can be measured. This can also help to identify specific areas of operation, specific facilities, which are consuming higher amounts of energy that may benefit the most from focused improvement efforts. In addition to all energy sources, water and sewer can be included in benchmarking, as documentation and analysis will have synergies with the energy data.
- **Conducting an energy audit.** The energy audit will identify a range of opportunities for improving a facility's energy performance. Recommendations will be provided, including an assessment of relative savings and cost to implement. Projects can be reviewed and prioritized for budgeting and implementation.
- **Retrocommissioning.** Retrocommissioning involves investigating, correcting, and validating existing building performance as required to support the facility mission. Retrocommissioning seeks to uncover and resolve problems that occurred during design or construction of the original systems. It can also address problems that developed as a result of the normal aging of the building's systems and equipment. Retrocommissioning will improve performance and reduce the energy required to support the mission of a building. The process will also enhance the ability of the O&M team to sustain the improvements over time. Retrocommissioning can be implemented by itself, or as a recommendation from an energy audit (SEE Action 2013).

Energy Audits

Energy audits can be seen as a starting point to provide building operators with the information they need to make better short-term and long-term energy management decisions (SEE Action 2013). Across the country, municipalities and organizations have adopted policies to conduct periodic energy audits. For example, Local Law 87 (LL87) in New York City requires energy audits and retrocommissioning for buildings. The City of Austin, Texas, Energy Conservation Audit and Disclosure Ordinance requires energy audits for buildings. In California, San Francisco Environment Code Chapter 20 requires that buildings get an energy audit every 5 years.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has published guidance for energy audits in *Procedures for Commercial Building Energy Audits.* The energy audit:

- Analyzes facility energy consumption.
- Investigates system design, equipment condition and operations strategy.

- Recommends ECMs to reduce energy consumption at the facility, which range from low-cost, quick fixes to measures classified as capital investments.
- Delivers a report summarizing the engineer's findings and recommendations.

Three levels of effort are defined by ASHRAE. The three levels are briefly described as:

- Level 1—Walk-Through Analysis.
  - The engineer conducting the audit performs a site visit at the building to identify possible ECMs and review historical energy consumption. Limited calculations are required for this level of effort.
- Level 2—Energy Survey Analysis.
  - Savings and cost analyses are required for all identified energy efficiency measures that are deemed practical by the engineer and facility maintenance staff. Building systems and energy consumption are analyzed to estimate an annual end-use energy breakdown, showing how much energy each building system consumes. The energy breakdown supports the engineer in estimating the potential energy savings for each recommendation.
- Level 3—Detailed Analysis of Capital Intensive Measures.
  - Detailed calculations are performed, which may include additional data collection from the building using portable data loggers or trending from the building automation system. A Level 3 energy audit requires more detailed calculations, so the increased cost of such a study means this type of audit is intended for major capital investments in the facility, such as a central plant upgrade or modifications to the building envelope (e.g., reskinning a building).

Appendix A provides an example of a Level 1 energy audit from Colorado Springs Airport. The traditional hands-off structure of the energy audit delivers a report with recommendations that rely on the maintenance staff to implement and incorporate into a capital plan, whereas the hands-on nature of retrocommissioning delivers immediate improvements to the facility through quick fixes in controls sequencing and scheduling, system balancing, and minor repairs.

Retrocommissioning

Retrocommissioning moves beyond the energy audit, reviewing a building's operations to ensure that all systems are working as required to meet current facility requirements (SEE Action 2013). The retrocommissioning process consists of four stages. Table 1 describes the tasks and activities within each stage, and the associated outcomes and deliverables.

Once a building's performance has been established by either a commissioning or retro-commissioning effort, building systems and equipment begin to degrade in the normal aging process. Published studies suggest that building performance will deteriorate at a rate of 4% to 8% per year (Toole and Claridge 2011).

When a recommissioning process is integrated into the regular rhythm of preventive maintenance, it can stimulate a high-performance culture within the facilities staff rather than a culture of "just keep it running." Recommissioning can become a practice of regularly revisiting the system performance using the checklists and test procedures used during the original building commissioning effort. In this manner, recommissioning becomes part of a fundamental business-as-usual process. The federal government has established a practice of recommissioning their facilities every 4 years as part of their commitment to reducing the energy used by all federal agencies by 30% (Interagency Sustainability Working Group 2008).

The retrocommissioning effort will generate a list of recommendations to improve the performance of the facility. These recommendations are also commonly referred to as opportunities or

Table 1. General process work flow for retrocommissioning.

Stage		Tasks/Activities	Outcomes/Deliverables
1	**Planning**	• Select project and define scope • Set project objectives • Select commissioning team • Interview facilities staff & occupants • Evaluate current facility requirements • Conduct initial site walk-through and set up initial trend logs • Review historical utility data • Review facility documentation • Develop retrocommissioning plan	• Contract/Scope of Work document • Energy performance benchmarking • Current Facility Requirements document • Retrocommissioning Plan (see Appendix F on CRP-CD 169 for sample)
2	**Investigation**	• Conduct detailed site investigation • Assess systems and equipment, including Test & Balance System Read Out • Perform diagnostic monitoring and trending • Perform functional testing • Complete simple repairs (quick fixes) and adjustments • Develop list of findings • Prioritize and select moderate-cost to high-cost improvements	• Retrocommissioning report (see Appendix F on CRP-CD 169 for sample) • Diagnostic and test results • Master list of deficiencies and ECMs • Prioritized ECMs and improvements for implementation • Costs and savings for identified ECMs • Recommended long-term capital improvements
3	**Implementation**	• Develop implementation plan for selected improvements • Implement selected improvements • Verify results • Develop final report • Develop operational documentation, as required • Provide training • Implement persistence strategies • Track performance	• Completed repairs and improvements • Commissioning Report – Improvement Tasks • As-built documentation • Revised or upgraded building or system documentation • Building Operation Plan • Training materials
4	**Verification and Monitoring**	• Implement preventive maintenance procedures to verify operating status for implemented measures • Set up trending in building automation system for future diagnostic capabilities	• Updated energy performance benchmarking • Additional recommendations for performance improvements, as applicable

as ECMs. Table 2 provides a typical list of ECMs that are evaluated for relevance and opportunity by the personnel completing the retrocommissioning investigation. This list has been organized by building system to highlight the whole-building approach to system optimization.

Additional examples are provided in the case studies for Logan International Airport's Central Plant retrocommissioning (Appendix C) and for Colorado Springs Airport's energy audit (Appendix A). The spreadsheet tool (Appendix G) also provides an extensive list of recommendations compiled for ACRP Project 09-04.

Beyond energy performance improvements, other common non-energy related outcomes of retrocommissioning include:

- Extension of equipment life
- Improved indoor air quality
- Reduced operations costs

Table 2. Common energy conservation measures.

System Category	Measures
Building Envelope	• Seal windows and doors • Install weatherstripping • Correct building envelope leaks • Install insulation in roof systems
Controls	• Replace/repair/calibrate sensors • Replace/repair/calibrate actuators • Tune/upgrade controls and control strategies • Reduce system/equipment runtimes • Restore systems to automatic operation • Reduce equipment cycling • Automate/optimize heating and cooling plants • Optimize cooling tower control • Add or optimize optimal start • Apply reset strategies to chilled water, hot water, and supply air temperatures
Mechanical (HVAC)	• Reduce air leakage • Reduce fan static pressure by cleaning coils • Reduce valve leakage • Eliminate simultaneous heating and cooling • Add or optimize water-side economizer • Add or optimize air-side economizer • Add or optimize supply air temperature reset • Adjust circulation air flow rates • Adjust ventilation air flow rates • Adjust space pressure control • Add or optimize duct static pressure control • Add or optimize demand control ventilation • Add or optimize zone setup/setback • Adjust pump flow rates • Trim pump impellers
Electrical (Lighting)	• Reduce lighting schedules/runtimes • Apply or adjust occupancy and daylight sensors • Apply plug load controls

- Upgraded system operational reliability
- Improved comfort and productivity
- More knowledgeable building staff
- Increased net operating income and tenant retention
- Exposure of maintenance staff to different approaches for troubleshooting problems and improved staff understanding of equipment and control strategies
- Early detection of equipment issues

Measurement and Verification (M&V) and Advanced Metering

M&V for a building includes a program to evaluate building energy use by using a combination of hardware (i.e., building sensors, meters, submeters) and software (i.e., the building automation system [BAS] and the energy management and control system [EMCS]). The goal is to better understand how energy is used within the building by strategically placing several meters around the building, rather than simply having one utility meter that captures only whole-building energy use.

10 Optimizing Airport Building Operations and Maintenance Through Retrocommissioning: A Whole-Systems Approach

An M&V program can also be used to track energy and cost savings realized from implementing specific ECMs. Upon completion of the ECM, an M&V program would be developed specifically for the scope of the project. M&V varies depending on scope, systems involved, and complexity of the variables determining energy use. Often, it can be accomplished by installing submeters at the point of use for the new equipment (e.g., at the electrical panel board for a circuit with new lighting). This submeter continuously logs the energy used by the new system, which is also dependent on actual operating hours, and records this information in the BAS or EMCS; or, data loggers will store the information, which can be periodically downloaded onto a computer for review. After a period of time, typically 1 year, actual energy use is compared to the energy used by the former system to calculate the realized savings. Tracking these savings ensures that ECMs are actually reducing campus energy use and operating costs and also assists in identifying, evaluating, and requesting funding for more ECMs.

Advanced metering is the integration of electronic communication into metering technology to facilitate one-way or two-way communication between utility and customer equipment. With advanced metering, an automatic system for metering energy use provides for continuous, real-time communication between the energy provider (i.e., the utility) and the consumer (i.e., the airport).

At a basic level, advanced metering allows for automated meter reading from a remote location. Through an electronic system, metering data is compiled for individual buildings. When used in combination with other programs, the utility can provide innovative rate structures to vary the cost of energy based on demand, power factor, and time-of-day use. Advanced metering benefits the utility and the consumer, since utilities seek to generate energy at a steady and predictable rate and consumers seek to reduce their costs related to energy use.

Advanced meters can be installed consistently at each building to provide whole-building energy data for airport-owned buildings, or advanced meters can be strategically installed at high energy use locations to better monitor consumption and identify further opportunities to reduce costs (e.g., through changes to operational schedules and sequencing or through equipment maintenance and upgrades).

Strategic installation of meters should also be coordinated with the submetering plan, to better manage energy use in areas with excessive usage. The data can be valuable to building occupants (e.g., concessionaires and operational groups functioning in airport facilities) as well, because providing direct feedback can help occupants understand their impact on building energy use. Occupants are incentivized to continue conservation practices when they can see the results of their actions.

Recent studies by major universities and industry suggest the typical savings potential of installing an advanced metering system could be as high as 5% to 20% of a facility's current utility budget (DOE EERE FEMP 2006 and ACEEE 2010). The technique does not produce a true cost/payback because the metered data do not produce savings directly; rather, the actions from the decisions made and use of the data will drive the savings.

Ongoing Commissioning

Once a building's performance has been reestablished by a retrocommissioning project, the ability of systems to meet current facility requirements can begin to deteriorate almost immediately. Ongoing commissioning leverages the data collection and analysis capabilities of building control systems to monitor real-time building performance, identify potential issues, and notify the operations team to investigate and resolve them. Implementation of data acquisition and exception report tools requires that software tools be integrated into the building control and energy metering systems.

Ongoing commissioning is an area of rapidly evolving software solutions. Section 4 of this guidebook discusses the principles behind ongoing commissioning that should be considered in implementation.

Staff Training

A staff training and development program will assist maintenance staff in optimizing airport facility operations. A building operator training program expands knowledge and cross-trains participants in important skill areas, maximizing the operator's versatility within the agency and allowing operations staff to take on more responsibility. Airports can save money through training by developing the skills of their own staff and avoiding the need to hire outside contractors. The program can also enhance careers and often improves job retention.

As with building operator training, training for the facilities building control system will have compounding impacts. Training in building controls allows for the development of internal knowledge and flexibility at a low cost to make day-to-day systems upgrades, as well as the ability to recognize and solve issues promptly and effectively, reducing the reliance on third-party controls contractors.

These educational investments and system upgrades typically have a high return on investment, given that the controls program is already in the building and being used at a basic level. With the completion of this training, operators will become more comfortable working with the system and have the capability to monitor and control building systems at a new level.

In addition to the controls training, system modifications also require a level of administrative access to manipulate a code that may need to be purchased from the controls manufacturer. Many of the measures described in this report can be implemented by in-house staff at low cost or no cost with the training and sufficient access. Returns on the training investment are expected to begin within less than 1 year, as the training gives in-house staff the ability to effectively implement more upgrades and fixes on a regular basis as they are discovered.

Documenting the training information provides trained staff with reference material and supports training for new staff. Saving files electronically in a logical folder structure is a good start. The next step is to build a BIM to collect all the information (including building plans, system narratives and control strategies, and maintenance manuals) into one database.

Building Information Models (BIMs)

BIMs continue to be developed as a standard practice in the building industry. Creating a BIM has been defined as "the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes" (buildingSMART alliance 2007). Various BIM software solutions are available, and sample screenshots are shown in Figure 2 and Figure 3.

In operations, a BIM provides a means for:

- **Record modeling,** or depicting an accurate representation of the physical conditions, environment, and assets of a facility.
- **Building maintenance scheduling,** or proactively and appropriately allocating maintenance staff in coordination with the CMMS.
- **Building system analysis,** or measuring how a building's performance compares to the specified design.

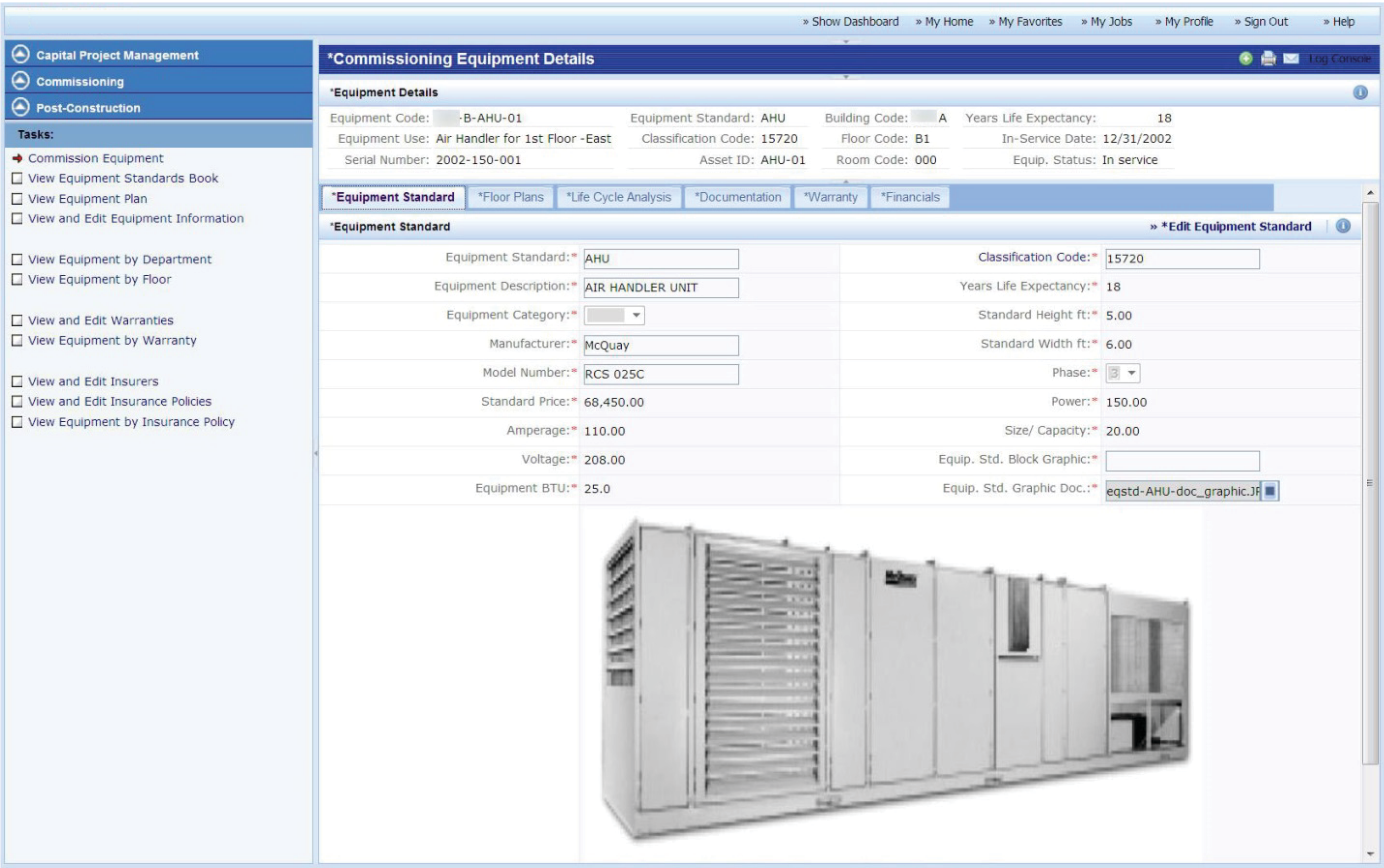

Figure 2. Sample AHU equipment detail.

- **Asset management,** or storing operations, maintenance owner user manuals, and equipment specifications for faster access (Penn State 2013).
- **Space management and tracking,** which involves distributing, managing, and tracking appropriate spaces and related resources within a facility.
- **Disaster planning,** which for airports will include improving documentation for irregular operations (IROPS) and providing emergency responders with critical building information in the form of a model and information system.

As new projects are contracted and delivered, airports can most effectively use BIM if a standard is developed and communicated to designers and contractors. This BIM standard establishes goals and objectives for model development, and provides guidelines for implementation.

Long-term, an airport's BIM can grow to include information about each of the main subjects covered in this section:

- Maintenance programs, including CMMS
- Energy management and energy audits
- Controls scheduling, sequencing, and calibration
- M&V
- Procedures for ongoing commissioning and for retrocommissioning
- Training materials

Although assembling this information can seem like a daunting task, organizations should begin by including the highest priority fields from their BIM standard, and require the deliverable as part of all new capital projects.

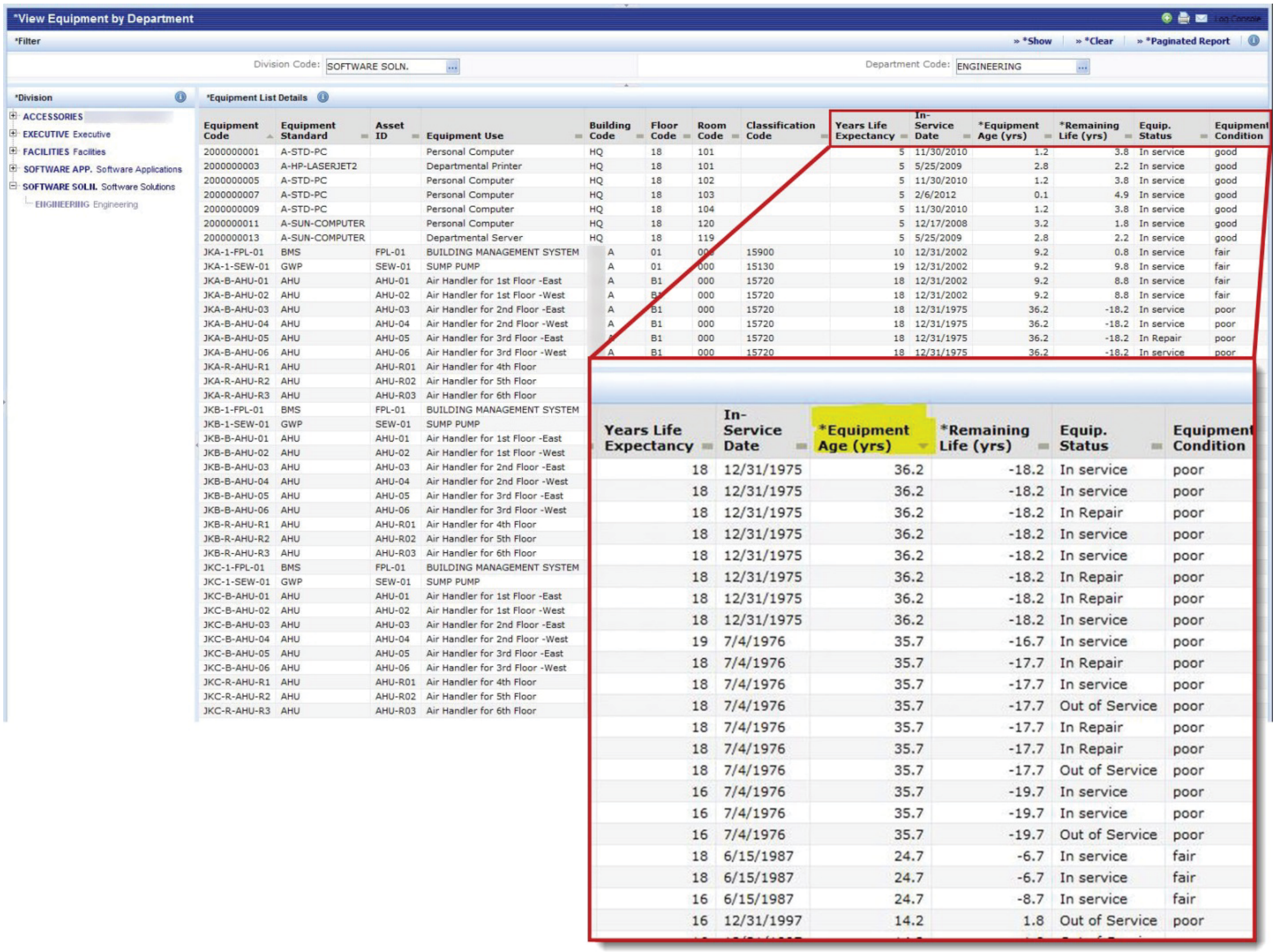

Figure 3. Asset inventory sample; inset shows equipment sorted by age.

Referenced Sources

ACRP Research Results Digest 2: Model for Improving Energy Use in U.S. Airport Facilities summarizes key findings from ACRP Project 11-02, Task 1, of the same name. Recommendations from this publication focus primarily on energy reduction. Additional ACRP reports reviewed as part of this research project include:

- *ACRP Synthesis 21: Airport Energy Efficiency and Cost Reduction* specifically focuses on identifying low-cost strategies and short payback.
- *ACRP Report 92: Guidebook to Creating a Collaborative Environment Between Airport Operations and Maintenance* provides guidance for creating a collaborative environment between airport O&M staffs. Chapter 6 in *ACRP Report 92* devotes a section to collaboration between an airport's engineering department and the O&M departments.
- *ACRP Synthesis 20: Airport Terminal Facility Activation Techniques* and *ACRP Report 42: Sustainable Airport Construction Practices* discusses practices that directly relate to terminal buildings and the systems required in airport operations.
- *ACRP Synthesis 20: Airport Terminal Facility Activation Techniques* addresses the phase of a new building project during which commissioning activities would include final testing and training.

- *ACRP Report 42: Sustainable Airport Construction Practices* specifically focuses on best practices for construction related to sustainability, with specific references to the Leadership in Energy and Environmental Design (LEED) rating system.

The Sustainable Aviation Guidance Alliance (SAGA) website has compiled examples of specific actions that can be implemented to advance sustainability, which include optimizing facility operations. Within this resource, areas of focus directly applicable to existing terminal facilities include water efficiency, energy efficiency, indoor environmental quality, and facility operations.

In 1999, Portland Energy Conservation, Inc. (PECI) published an O&M best practices series (*Fifteen O&M Best Practices for Energy-Efficient Buildings)* intended to build the available literature for "operations" best practices. Suggestions pulled from this publication emphasize system documentation and personnel training.

In August 2010, the U.S. Department of Energy released the third version of *Operations & Maintenance Best Practices: A Guide to Achieving Operational Efficiency*. Suggestions pulled from this guide include identifying measurable indicators for assessing and tracking performance over time.

In 2009, Seattle-Tacoma International Airport published an Environmental Strategy Plan that lists goals in seven categories: air quality and climate change; energy use and conservation; buildings and infrastructure; materials use and recycling; water resources and wildlife; noise; and education and integration. Each category included measures that are applicable to facility optimization.

In 2007, an assessment conducted by the Salt Lake City Department of Airports (SLCDA) resulted in a report titled Making the Business Connection to Airport Sustainability. The report describes several strategies that have been captured as suggestions for best practices in *ACRP Report 139*.

Non-airport specific references reviewed as part of ACRP Project 09-04 include:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). Guideline 0-2005, *The Commissioning Process*, 2005.
- ASHRAE 1651-RP. Development of Maximum Technically Achievable Energy Targets for Commercial Buildings, Draft Final Measure List, 2013.
- National Environmental Balancing Bureau (NEBB). *Procedural Standards for Retrocommissioning of Existing Buildings.* First Edition, March 2009.
- National Institute of Building Sciences. Whole-Building Design Guide (WBDG)—available online; see information at http://www.wbdg.org/.
- California Commissioning Guide, available online at http://www.cacx.org/resources/documents/CA_Commissioning_Guide_Existing.pdf.
- Oregon Department of Energy. *Retrocommissioning Handbook for Facility Managers* (2001), prepared by Oak Ridge National Laboratory and PECI.
- U.S. Department of Energy. *A Practical Guide for Commissioning Existing Buildings* (1999), prepared by Oak Ridge National Laboratory and Portland Energy Conservation, Inc. (PECI).
- U.S. Environmental Protection Agency and U.S. Department of Energy. *Operations and Maintenance Assessments: A Best Practice for Energy-Efficient Building Operation* (1999), prepared by Oak Ridge National Laboratory and PECI.
- U.S. Department of Energy, Rebuild America Program. *Building Commissioning: The Key to Quality Assurance* (1998), prepared by PECI.

SECTION 2

Getting Started with Retrocommissioning

How to Determine the Need for Retrocommissioning

Ideally, a recommissioning plan is established as part of a new building's original commissioning process or an existing building's retrocommissioning process. Recommissioning should be seen as part of the facilities O&M program. If recommissioning is not a normal practice, the decision to retrocommission may be triggered by a change in building use, the onset of operational issues, or the need to reduce facility operations costs. Such instigating factors may include:

- Performance failures discovered following initial construction and turnover
- Normal equipment and system deterioration that is not addressed by the normal O&M strategies
- Systematic problems in building operation, such as simultaneous heating and cooling
- Indoor air quality complaints
- High or increasing energy consumption profiles
- Malfunctioning equipment or sensors, such as inoperable dampers
- Control optimization issues, such as sub-optimal chilled water-supply temps
- Excessive equipment repair and replacement costs
- Traveler comfort complaints
- Employee complaints or high employee absenteeism
- Tenant requests during contract negotiations
- Frequent tenant turnover
- Operations team personnel turnover

The Value Proposition for Retrocommissioning

The value proposition for retrocommissioning and recommissioning stands on three key principles:

- **Performance.** Retrocommissioning yields performance improvements that enhance a facility's ability to support its intended mission in a safe, reliable, and cost-effective manner. Such benefits include reduced energy consumption, improved indoor air quality, and greater reliability of systems and equipment.
- **Economics.** Increased efficiency typically accompanies performance improvement in buildings with regard to energy and operations. Although increased energy efficiency is realized in lower utility bills, operational efficiency is seen in reduced system and equipment failures and fewer emergency maintenance calls. A 2004 study on commissioning published by Lawrence Berkeley National Laboratory analyzed the results from 224 buildings across 21 states, representing 30.4 million square feet, 73% of which were existing buildings that underwent retrocommissioning. The study concluded that for existing buildings, the median savings was 15% of energy

costs with a payback of 0.7 years (Mills et al. 2004). Besides the energy cost savings, prolonged equipment life will reduce whole-building lifecycle costs.
- **Compliance and safety.** Retrocommissioning and recommissioning help to ensure that systems and equipment operation remain in compliance with performance, safety, and other regulatory codes or standards.

For airports, the potential value of retrocommissioning and recommissioning is amplified by the fact that airport facilities are complex and operate for extended hours, every day of the week. Airports are critical to the transportation system in the United States, which emphasizes the need for high reliability in building systems. Furthermore, at an airport the mechanical and electrical systems extend well beyond the typical commercial building envelope, and they are applied to support the unique mission of the airport. For example, mechanical HVAC systems provide cooling and heating to aircraft that are parked at gates, and electrical systems are used to provide ground power to the same aircraft. The operation of all building systems should be considered to optimize whole-building lifecycle costs. With so many systems in play, the potential for energy and operational savings identified through retrocommissioning and recommissioning is correspondingly large.

How to Plan for Retrocommissioning

Planning for retrocommissioning begins with project definition and goal setting. Goals for retrocommissioning should consider performance improvements, operating cost reduction, regulatory compliance, or improvements in facility reliability. Goals for the retrocommissioning process may be specific and quantifiable or may simply state the overall objectives outlined above, along with targets for quantifiable improvements (e.g., energy reduction goals or O&M cost management goals).

Identifying appropriate buildings and building systems also is important. Although nearly all buildings can benefit from retrocommissioning, application of limited funding requires that airports prioritize candidate buildings. Given that the process is intended to reduce the lifecycle cost for facilities and improve long-term performance, the following considerations can be used to prioritize buildings for inclusion in the process:

- Buildings that experience the highest rate of critical failures or represent the greatest risk to operations from building deterioration or system failures.
- Buildings with the highest overall energy consumption or the highest energy intensity. (Also consider total energy cost per gross square foot.)
- Buildings with the highest number of occupant complaints or buildings that are known to operate poorly.
- Buildings in which automatic control of systems has been defeated over time to address operational or occupant concerns.

From an energy perspective, the acceptable simple payback period can provide some guidance in selecting buildings for retrocommissioning. Industry studies suggest that retrocommissioning provides an average 15% energy savings with a 3-year simple payback. The consensus in the industry is that this "average" applies very reliably to any moderately complex building.

With that information in mind, using an average overall cost of retrocommissioning, Table 3 provides some guidance in estimating the financial return from an investment in retrocommissioning.

When identifying systems to be included in a retrocommissioning process, given that the process is intended to be a holistic review of buildings, it is best to include all major systems in

Table 3. Budgeting guidance for executing an energy efficiency project that meets simple payback criteria.

Energy Cost ($/sq. ft.)	Anticipated Energy Savings ($/sq. ft.)	Acceptable Simple Payback (Years)	Total Acceptable Investment ($/sq. ft.)
$1.50	$0.225	3	$0.68
		5	$1.13
		7	$1.58
$2.00	$0.30	3	$0.90
		5	$1.50
		7	$2.10
$2.50	$0.375	3	$1.13
		5	$1.88
		7	$2.63

the process—mechanical, electrical, and envelope. If funding is limited, the selection of systems should be driven by the criteria noted above with a focus on including those systems that most directly impact the overall objectives of the program.

The Cost of Retrocommissioning

The cost of any effort to improve building operations through commissioning processes is entirely dependent on the scope of work established for the recommissioning or retrocommissioning effort. Before recommissioning, many airports need to first retrocommission their facilities. In this way, airport operations can establish an effective operational baseline that both meets the mission of the airport facilities and provides the optimum energy profile required to support the mission. This report will focus on the cost of retrocommissioning. Based on these costs, it is possible to predict the cost of follow-on recommissioning efforts.

Limited but useful cost data are currently available in the literature for retrocommissioning. The largest sample data analysis for retrocommissioning costs has been reported in studies from Lawrence Berkley National Laboratories (LBNL), such as *Building Commissioning, A Golden Opportunity for Reducing Energy Costs and Greenhouse Gases*, published in July 2009 (Mills 2009). This study considered a total of 186 million square feet of building space. In reviewing the cost data reported, the cost for retrocommissioning ranges from $0.026 to $1.01 per square foot. The data pose a dilemma, however: the work provided by the lowest-cost effort and that provided by the highest-cost effort cannot reasonably be considered comparable.

Analysis of retrocommissioning costs is further complicated by confusion about terminology. The term *retrocommissioning* has been applied to everything from energy studies that entail building sampling and energy modeling to intensive investigation and correction of building components and systems. For the purposes of *ACRP Report 139*, cost analysis focuses on retrocommissioning that is designed to address operational stability and reliability issues as well as energy optimization. This process may also identify capital improvements required to achieve a sufficient level of building system performance.

The sample cost analysis provided in the following paragraphs provides guidance—based on the available literature (e.g., the LBNL study), on the authors' experience providing retrocommissioning services, and on the anecdotal experience of industry peers—for addressing the cost of an intensive effort to identify and correct operational deficiencies that result in poor environmental control, poor occupant satisfaction, and higher energy costs. This discussion focuses on retrocommissioning programs whose objective, most simply stated, is to *leave the building operating more effectively than when the effort began.*

With these criteria in mind, the following information can be gleaned: The overall cost of retrocommissioning averages $0.82 per square foot, including implementation. This average cost is based on a variety of facilities that range from simple offices, hotels, and elementary schools, to more complicated facilities such as hospitals and government complexes.

Based on experience in the marketplace, retrocommissioning costs for any given building can be reasonably broken down by phases in the process. (A brief explanation of retrocommissioning project phases appears with this discussion; a more detailed examination is provided in Section 3.)

The literature on this subject usually breaks the retrocommissioning process into three base phases: planning, investigation, and implementation. A fourth optional phase, monitoring and verification (M&V), also may be used. Typically, requests for proposals used by government agencies will also break the process into these phases. Based on these phases, some cost guidance can be provided (see Table 4).

Table 4. Budgeting guidance for retrocommissioning, by phase.

Phase	Description	Cost Range ($/gross sq. ft.)
Planning	Planning includes review of available documentation; preliminary site inspection; condition assessment of existing equipment and systems; baseline energy and performance analyses; preliminary evaluation of energy conservation opportunities; and investigation phase planning.	$0.15 to $0.35
Investigation	Detailed investigation of components and system, including control system testing, testing and balancing (TAB) survey and calibration, sensor and actuator calibration, implementation of "no cost" corrective measures, identification of both low-cost and medium-cost corrective actions and capital project opportunities for energy and performance enhancements, staff training, and retrocommissioning reporting.	Professional fees $0.40 to $0.65 Quick-fix allowance (Note 1) $0.15 to $0.25
Implementation	Implementation of low-cost and medium-cost corrective actions and commissioning of the implemented strategies; enhanced staff training; validation of capital projects not included in implementation phase.	Professional fees $0.12 to $0.20 Corrective action cost allowance $0.15 to $0.50
Total professional fees Recommended allowance for corrective work		$0.67 to $1.20 $0.15 to $0.50 (Note 2)
Optional: Monitoring and Verification Phase	Post-occupancy monitoring of implemented corrective actions; energy baseline verification and reporting; staff training reinforcement.	$0.10 to $0.25 per sq. ft. (Note 3)

Note 1: A quick-fix budget allowance should be included in a retrocommissioning budget to provide funds to correct component and systems deficiencies that prevent the retrocommissioning team from testing and evaluating systems. The allowance can be managed by the airport directly or by a qualified retrocommissioning provider based on airport approvals for expenditures.

Note 2: Implementation costs are a function of the findings from the investigation phase and the budget available for implementation of recommendations.
Generally, retrocommissioning has been found to deliver 15% energy savings annually with an average overall payback of 3.0 years. Thus, based on a "typical building" consuming approximately $2.00 per square foot energy cost, the allowable budget for this work would be approximately $0.90 per square foot (15% x $2.00/sq. ft. annually x 3 years = $0.90/sq. ft.). This analysis can be applied to a specific building by updating actual energy cost per square foot.

Note 3: Alternatively, the Federal Energy Management Program's M&V Guidelines Version 3.0 recommends a budget for M&V as 1–10% of the projected annual cost savings from the implemented measures. (Source: FEMP. [2008]. M&V Guidelines: Measurement & Verification for Federal Energy Projects, Version 3.0. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Federal Energy Management Program. Available at http://www1.eere.energy.gov/femp/pdfs/mv_guidelines.pdf.)

Frequency of Recommissioning

The frequency of recommissioning will vary from system-to-system, building-to-building, airport-to-airport, and will depend on several factors, including:

- How critical is proper system performance to the airport or to the mission of the facility?
- How will the improper performance of a system affect the performance of other systems?
- How frequently are parts of the building renovated?
- How frequently does space usage change?
- What are the energy and operational cost impacts of improperly performing systems?
- How does system performance affect tenant satisfaction with the facility?

For example, emergency generators are critical and tested monthly at most facilities, though used infrequently. Central plant, HVAC, and electrical systems will require monthly, quarterly, or annual testing frequency, depending on the criticality of the areas served, the age and condition of the equipment, and the diagnostic information available during normal operations.

For airports, building systems are important to the airport operations. Airport facilities are functional spaces, providing the medium for airlines to serve travelers. Interruptions in facility operations that affect the airline's ability to meet traveler expectations will have financial impacts and user satisfaction issues. Energy costs for airport facilities also are significant. Achieving small improvements in energy efficiency can have a significant financial return.

SECTION 3

Guidance for Developing a Retrocommissioning Plan

The execution of a retrocommissioning effort in an airport facility starts with the evaluation of current facility requirements. Next, building systems need to be assessed to determine if their performance sufficiently supports current facility requirements. Underperforming buildings and systems are identified and selected for a disciplined and thorough "operational tune up." If optimizing building system performance is not sufficient to meet current facility requirements, capital improvements will be identified to improve system performance to appropriate levels. Baseline and optimized performance metrics for building systems will be tracked and reported during the retrocommissioning process.

The recommissioning process follows a similar but abbreviated documentation effort that leverages documentation from the retrocommissioning process to review system performance on an established frequency, recognize and address changes in facility requirements, and reinforce staff training.

It is imperative to recognize that the greatest value of any retrocommissioning or recommissioning effort is gained from the full participation of the airport operations team. Some airports may elect to execute the work with internal resources, others with the help of qualified retrocommissioning providers. Although a third-party contractor may do much of the work, airport staff from maintenance and administration need to be engaged during all phases of retrocommissioning to ensure alignment with airport goals.

Objectives

The retrocommissioning effort provides recommendations to improve the operational efficiency and effectiveness of airport facilities. Industry experience has proved that, regardless of the primary driver (operational cost savings, regulatory compliance, or performance improvements), the process results in reduced operating costs and improved occupant comfort, satisfaction, and productivity. The following primary objectives are often stated for a retrocommissioning program. In every case, evaluation of these and other objectives is a critical first step in developing the retrocommissioning program and scope of work.

- Document current facility requirements.
- Identify and resolve building system operation, control, and maintenance problems.
- Ensure that building systems are operating in accordance with applicable local, state, and federal performance requirements.
- Reduce or eliminate occupant complaints and increase occupant satisfaction.
- Optimize control systems through calibration of sensors, review metered data and trend logs, and perform functional equipment testing.

- Improve building performance by saving energy and reducing O&M costs.
- Improve indoor environmental comfort and quality.
- Document system operation.
- Identify O&M personnel training needs.
- Improve operator knowledge and expertise through effective training programs integrated into the retrocommissioning process.
- Extend equipment lifecycles by correcting minor deficiencies and encouraging effective preventive maintenance activities.

Managing the Retrocommissioning Effort

Successful retrocommissioning projects are driven by a clear, stepwise approach to the process, by collaboration between the retrocommissioning provider and the airport, and by thorough testing and results evaluation and demonstration. This technical approach is best demonstrated by the project execution matrix depicted in Table 5. The matrix is a stepwise approach to system inspection, evaluation and repair/upgrade activities.

The process depends firstly on identifying those areas of a selected building where either the largest energy consumers reside or where the most significant challenges exist to managing energy efficiency or complying with regulatory requirements. Collaboration with the O&M team begins immediately, through engaging them in the process, understanding their needs and their expertise, and embarking on a process of mutual discovery and training.

During the process of information gathering, the team should also be assessing the potential for system improvements. The spreadsheet tool (Appendix G) provides a master list of recommendations, which is an extensive list of practices to improve system performance. The team will need to identify whether (and which of) the practices listed have valid applications in the facility under investigation.

The initial phases of the retrocommissioning effort may include repair of minor deficiencies that would otherwise inhibit a thorough test of systems and components. These repairs often include belt replacements; sheave repair; sensor, actuator, or controller repair or replacement; reconnection of linkages; coil cleaning; and filter replacements. Repairs can be implemented by the operations team or by the retrocommissioning provider as part of the quick-fix budget allowance.

Once the team has a clear understanding of the site and the systems—and once the systems are prepared for testing—the retrocommissioning team should conduct exhaustive tests of the major system components and the controlling software. To the extent reasonable, it is suggested that the operations team again be engaged in the process of control system demonstration and testing, to (1) leverage their knowledge of the systems and spaces, to (2) exchange insights into the systems and the consequences of the operational strategies in place, and (3) provide a training opportunity for the operations personnel.

As minor repairs are identified and approved, implementation can occur through a combination of operations personnel and personnel from the retrocommissioning provider or local approved service contractors. As repairs or upgrades are completed, each upgraded system will be thoroughly commissioned to ensure that tasks are completed successfully and that the improvements in systems operations—whether energy or performance related—are achieved.

Finally, as the process enters the final phases of work, it is suggested that the retrocommissioning team develop systems training and deliver the training to the operations team. Formal training sessions provide operators with the information and insights necessary not only to

Table 5. Project plan (project execution matrix).

Project Scoping		
Task	**Description**	**Deliverable**
Identify Scope of Project	Discuss the following questions during a scoping meeting: • What issues need to be resolved? Examples include occupant comfort complaints, building pressurization issues, chronic equipment alarms and failures. • How is this area currently being used? • Will this use remain consistent for the foreseeable future?	• List of desired outcomes • Building plans
Assess Feasibility and Boundaries for the Project	Define an appropriate boundary for the project. Consider: • Tenant lease boundaries • Construction vintage (year of construction) • Utility feeds • AHU zoning and building controls	• Building plans • Equipment schedule • Metered energy data • List of points from controls system
Finalize Project Scope of Work	Provide succinct description of project objectives, which may include: • Identify low-cost and no-cost recommendations to improve whole-building performance. • Emphasize energy savings opportunities. • Reduce occupant complaints. • Extend equipment lifecycle and reduce lifecycle costs. • Identify recommendations for capital planning. • Document current and proposed system operations for optimized performance. • Implement quick fixes to realize immediate facility improvements and verify that expected results were achieved.	• If executed with a third-party retrocommissioning provider, this will form the basis for the scope in the request for proposals (RFP). NOTE: Reference sample scopes of work are included in Appendix E. • If executed with internal staff, this will outline the tasks to draft a budget proposal for approval.
Requests for Proposals and Budgeting	If executed with a third-party retrocommissioning provider, consider issuing a request for qualifications to prequalify contractors, as procurement procedures allow. If executed with internal staff, communicate the need for sufficient resources to complete the effort within a reasonable timeframe.	• Review proposed cost for the retrocommissioning effort against potential savings. • Highlight other benefits: o Extend equipment life o Improve comfort • Submit for approval.
Kick-Off Meeting	A kick-off meeting should be held with building personnel and the project team to confirm project scope, discuss approach and facilitate delivery of building documentation included in the document and design review task.	• Minutes of scoping meeting • Functional performance test plan • Project schedule
Document and Design Review	Complete a thorough review of the available documents to determine what equipment and systems are currently in place and to ascertain the intended methods of operation. Documents will include drawings and other contract documents that reflect the original and subsequent building construction efforts, TAB reports, O&M manuals, Operating and preventive maintenance (PM) historical data and other information available from the operators or facility managers. In addition to existing building documentation, complete a review of applicable codes and standards that apply to each building. This analysis will be incorporated into the current facility requirements (CFR) document (see Document Current Facility Requirements in this table).	• Site by site, system by system report of design and drawing errors • Documents to be provided by airport

Table 5. (Continued).

Phase 1: Planning Phase		
Task	**Description**	**Deliverable**
Operations Record Review	Review operations records to establish building baseline performance. Records to include: • 3 years' data of all utility bills and costs • 3 years' PM schedules • 3 years' maintenance work order trouble calls • FCAs, space plans, current capital 5-year plans, existing energy assessment	• Utility review report • Operations records to be provided by airport
Facility Preliminary Inspection	Complete a preliminary inspection in connection with the onsite kick-off meeting to understand the facility operational needs, CFR, and system configurations to support the development of the investigation phase retrocommissioning plan.	• Field report
Management and Maintenance Staff Interview	Interview each site's facility manager, energy manager, and the key site maintenance personnel to clarify the retrocommissioning process and to discover any special protocols for the facility, including: • Security issues and access requirements; understand the history of the systems and any special challenges or persistent operating or maintenance issues. • Understand the capital programs in place and preferences of the local teams that might bear on the project.	• Interview report
Document Current Facility Requirements	Develop a CFR document that outlines facility operating requirements, schedules and other critical parameters that are required to support each building's mission.	• CFR
Retrocommissioning Plan	Develop a retrocommissioning plan that details the project execution strategies and proposed project schedule. The plan will include the final technical approach to the implementation phase and a final proposed project schedule. As part of the detailed execution plan, it should include but not necessarily be limited to the following elements: • Site survey and condition assessment strategy • Functional performance testing plan • Functional performance test procedures • Diagnostic monitoring plan, including data capture with both independent data loggers and BAS trending and validation.	• Retrocommissioning plan • Project schedule

Phase 2: Investigation Phase		
Task	**Description**	**Deliverable**
Occupant Interviews	Interview occupants in each area of the site and each space use (i.e., airline staff, food service, baggage handlers) to determine any current operational issues. Develop and distribute occupant surveys in collaboration with the O&M team to measure occupant satisfaction for baseline purposes. Interviews should include follow up discussions with facility maintenance personnel as appropriate.	• Interview report • Corrective actions tracking spreadsheet • Update CFR as needed
Systems Condition Assessment	Survey all systems in the area to document current system condition. Identify basic repairs or upgrades that are necessary to allow for the existing equipment to function properly and report such repairs on the retrocommissioning issues log (e.g., coil cleaning, filter replacements, belt maintenance, and sensor/actuator repairs that are apparent from visual inspections).	• Field survey observation forms and photographs • Corrective actions tracking spreadsheet

(continued on next page)

Table 5. (Continued).

Phase 2: Investigation Phase (continued)		
Task	**Description**	**Deliverable**
Site Diagnostic Monitoring	During the site investigation, launch data loggers throughout the facilities to record existing operating parameters including temperature, humidity, pressure, timed events, and CO_2 Levels in appropriate locations. Initiate data trending on the existing building direct digital control (DDC) systems. Document operational data collection procedures in the diagnostic monitoring plan. This plan provides the basis for evaluating ongoing system performance as well as impacts of simple repairs and corrective actions.	• Performance analysis and baseline report • Diagnostic monitoring plan
Systems Test Procedures and Plan Development	Develop systems test procedures and plans for the systems identified in the project scope and submit for review and approval as required. Test plans typically focus on confirming that the system performance is meeting the performance requirements of the occupants set forth in the CFR.	• Systems testing plan
Detailed System Investigation and Testing	Execute systems testing in accordance with the approved systems testing plan to evaluate the building systems performance and provide the results and analyses in a system testing report. In addition, any anomalies or issues identified in prior work tasks should be considered for further evaluation during system testing to determine root causes and possible solutions. The testing process should include the verification and calibration of all sensors, verification of system sequences of operations, and validation of successful mechanical function and performance.	• Observation forms • Retrocommissioning forms, check sheets • Corrective actions tracking spreadsheet
Test and Balance	The team should evaluate the current state of the systems air and water balance, and perform test and balancing as required to establish current system performance and appropriate rebalancing requirements. Balancing should address air inlets and outlets, terminal units, AHUs, outside air intakes, exhaust fans, building pressurization, hydronic flows at coils, pumps, chillers, cooling towers, and boilers.	• TAB report • Retrocommissioning forms, check sheets • Corrective actions tracking spreadsheet
Identify Opportunities to Optimize System Performance	"Quick fixes" (minor repairs and field repairs requiring little or no cost to implement) are identified during the course of the investigation. Such repairs should be implemented in collaboration with the maintenance staff. Recommendations that require significant system downtime or equipment replacement should be noted for inclusion in the final report as measures for further consideration, or capital improvements.	• Record findings in the issues log for inclusion in final report
Document System Operations and Modifications	Provide documentation of the critical environmental control and energy-consuming systems and make appropriate adjustments in operating strategies, setpoints and schedules to improve facility performance and reduce energy consumption. Systems documentation should include schematic flow diagrams, system sequences of operations, setpoints, measured operating parameters, and tuning evaluation reports.	• Systems documentation, control system sequences of operation
Final Retrocommissioning Investigation Report	Develop a final retrocommissioning report to document all retrocommissioning efforts and provide specific recommendations for corrective actions, including a description of the recommendations, implementation cost estimates, a brief description of performance impacts, and projected energy savings from each action where appropriate.	• Final retrocommissioning report

Phase 3: Implementation		
Task	**Description**	**Deliverable**
Develop an Implementation Plan	• Draft a plan that outlines the opportunities that are going to be implemented, how they will be implemented, the project schedule and the budget. Review the plan with the stakeholders and collect feedback. Based on approval by all pertinent parties, proceed to plan execution.	• Implementation phase plan

Table 5. (Continued).

Phase 3: Implementation (continued)		
Task	**Description**	**Deliverable**
Execute Low-Cost and Approved Capital Cost Work Items	• Utilizing the resources of the retrocommissioning provider, the operations team and selected contractors, execute the corrective actions and, if appropriate, capital cost improvements approved at the conclusion of the investigation phase of the project.	• Updated the master issue tracking log
Commission all Implementation Tasks	• Provide inspection and testing of all implemented task items to validate that the implemented items meet the intent of the project and to configure the final systems to deliver the performance intended by the project.	• Master issue tracking log • Completed functional and integrated test procedures
Develop a Systems Manual	• Draft a manual that describes the installed equipment, baseline operations and the O&M practices necessary to keep the building operating properly. • Provide recommissioning forms for use by the O&M staff.	• Systems manual • Recommissioning manual • Suggested O&M best practices
Provide Building Staff Training	• Provide training to ensure that energy savings and operational goals are met. Additional operator training may be appropriate to improve the level of knowledge of building equipment and systems for O&M staff and management.	• Training plan • Training documentation
Implementation Phase Final Reporting	• Develop final reporting that outlines the activities completed during implementation, including an updated CFR. • Collect and turn over O&M and warranty information (if applicable).	• Implementation final report • Updated CFR • O&M and warranty documents
Lessons Learned Meeting	• Facilitate a meeting to review the work performed and the process by which it was executed.	• Meeting agenda • Meeting minutes

keep the system functioning properly but also to extend their knowledge and understanding of how to deal with unforeseen conditions that may arise. Training sessions should cover not only system operational strategy training but also troubleshooting and issue resolution to assist the operators in understanding the power of the installed building control systems, of independent data loggers, and of the baseline data that is delivered as a part of the final commissioning report.

Table 5 provides both a detailed view of the retrocommissioning process and an effective tool for the airport project management team to understand and track the progress of their efforts. The plan provided in the table draws substantially from the NEBB's *Procedural Standard for Retro-commissioning of Existing Building Systems* (National Environmental Balancing Bureau 2009).

SECTION 4

Ongoing Commissioning

Ongoing commissioning (Figure 4) leverages the data collection and analysis capabilities of building control systems to monitor real-time building performance, identify potential issues, and notify the operations team to investigate and resolve them. Ongoing commissioning in the industry may also be called *monitoring based commissioning.*

The intent of ongoing commissioning is to fully integrate the commissioning philosophy into the business-as-usual O&M process. The objective is to continuously monitor and optimize total building performance. Once a facility's operation has been optimized, the building must maintain this "optimized performance" to sustain the benefits of the retrocommissioning or recommissioning process.

To sustain the benefits of the retrocommissioning process, the operations team can employ both administrative and technology solutions that encourage a culture of ongoing commissioning. The description of an ongoing commissioning process provided in this section of *ACRP Report 139* can serve as a basis for a cost-effective process that supports the existing staff with technology, information, and technical support. Further, an effective ongoing commissioning process will support a culture of accountability and reward that provides incentives to sustain superior building performance.

Objective

The objective of an ongoing commissioning process is to provide support and accountability for the operations team for maintaining effective facility operations while optimizing energy consumption. The process is intended to address the traditional issues that impede effective O&M of energy-consuming systems. The process should achieve, as a minimum, the following objectives:

- Provide technical solutions (i.e., software data acquisition, analysis, and exception reporting tools) that provide visibility of system performance deficiencies in a user-friendly manner. Examples of system performance deficiencies include deviations from setpoint standards, occupancy schedule standards, and well-established performance criteria such as discharge air temperature setpoints, outdoor air volumes, chilled water temperatures, and energy consumption profiles.
- Provide for periodic reviews with third-party support of system operations to create space in the operations team schedule to analyze system performance. Reviews should provide the opportunity to review and establish best practices and reinforce staff training.
- Provide a mechanism to execute corrective actions to repair or upgrade system components that fail or deteriorate to the point of compromising system performance as part of the periodic review process. Establish a repair and renovation budget that allows for "quick-fix" execution no less than annually to address persistent component deterioration issues.

Rationale

Once a building's performance has been reestablished by a retrocommissioning project, the ability of systems to meet CFRs can deteriorate almost immediately. Deterioration may be caused by:

- Failure of system components (e.g., coil fouling, sensor calibration drift, sensor failure, or actuator failure).
- Not following through on the O&M process to reinforce the best practices developed during the retrocommissioning process (e.g., implementing system overrides in response to complaints, or taking temporary corrective actions that are never reversed).
- Changes in space environmental control requirements (e.g., conversion of gate areas to dense retail space or installation of computer rooms with server equipment loads).

If an effective ongoing commissioning program is in place (described as "Monitoring Based Continuous Operation" in Figure 5), the facility will continue to operate in an optimized condition. Moreover, although ongoing commissioning requires a first-time setup (which can be included in the scope of a recommissioning or retrocommissioning project), ongoing program costs are minimal.

Deterioration in system performance can be exacerbated if sufficient funds or contracting processes are not available to correct component failures that normally occur in any building. Finally, the cultural attitudes that make efficient resource allocation a value in each facility should be periodically reinforced so that the effective practices established during the retrocommissioning process are not overwhelmed or undone by "comfort complaints" and "special circumstances" that lead to compromising these good practices. When special circumstances arise that require a change, the goal should be to (1) resume normal procedures according to the O&M process as soon as possible and/or (2) address permanent changes by making additional changes to maintain optimized performance.

To this end, an ongoing commissioning process should incorporate the following values:

- Provide the tools to efficiently identify system deficiencies and guide resolution of those deficiencies in an expeditious manner.

Figure 4. Ongoing commissioning.

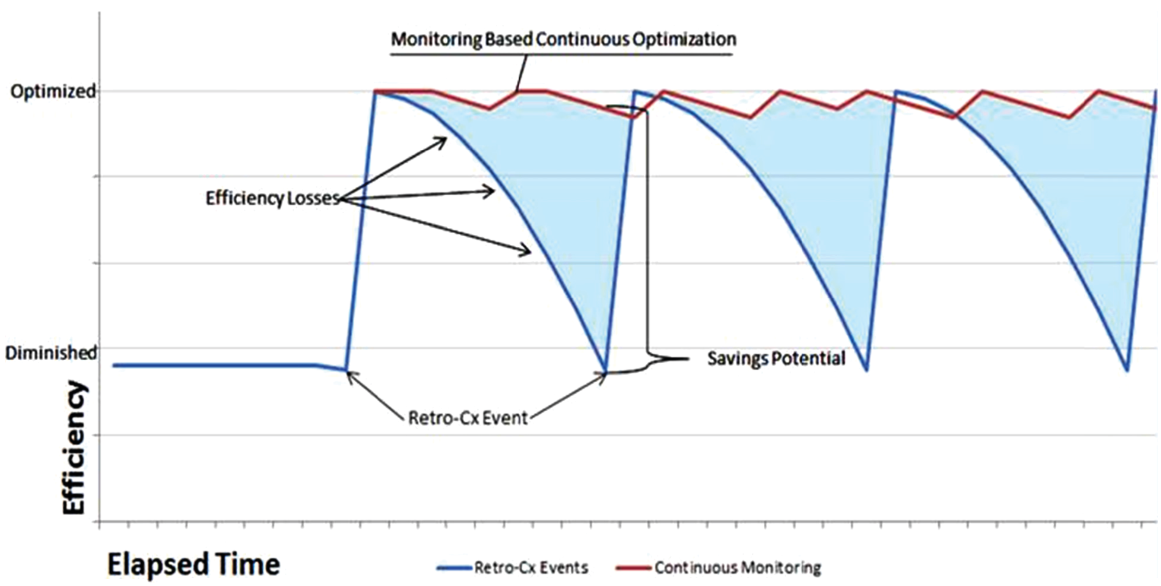

Figure 5. Maintaining optimum efficiency with ongoing commissioning.

- Provide expert support for the operations team to resolve identified deficiencies in a cost-effective fashion. This support must recognize the challenge of sustaining operations on a daily basis while at the same time executing repair/upgrade tasks necessary to sustain system operations.
- Provide funding and a time-efficient way to contract for materials and services that are necessary to implement a variety of small and potentially disassociated tasks required to sustain building systems.

Process

Four steps can be taken to address the objectives outlined above. These steps should be designed to make the best practices "business as usual" for each operations team. Thus, the ongoing commissioning process will have the potential to become an entirely internal process within the system.

Step 1. Implement the use of data acquisition and analysis software that can provide an effective exception reporting tool for the operations and ongoing commissioning team. This software should allow an O&M team to review the entirety of a large campus system by examining only those components that are operating outside the boundaries of "acceptable systems operating parameters."

Step 2. Develop and deploy a set of operating rules within the data acquisition and analysis software to address the most critical operating parameters that affect system performance and energy consumption. These rules need to be developed for the facility to address operating strategies, system types, and predicted energy profiles. By using the software and configuration tools, exception reports can be generated at will. Exceptions should be limited to a manageable volume, however, so that O&M teams are not overwhelmed with deficiencies. Finally, deficiencies should be prioritized to distinguish between the most critical failures and those failures that can be addressed over longer intervals.

Step 3. Using qualified third-party resources, either internal or external, provide periodic site-visit reviews of both the exception reports and overall system operations "checkups." The checkups should be designed to provide (1) technical support for analyzing exception reports and trended performance data and (2) additional training to reinforce effective team practices. Periodic checkups can include annual reviews of FCAs to support the capital budgeting process at the airport.

Step 4. In conjunction with the periodic visits, provide a "quick-fix" budget to allow the third-party technical support team to contract for and implement corrections in a process similar to that used for retrocommissioning. The ability to identify and correct deficiencies is at the heart of sustaining O&M team support and in changing the O&M paradigm to one that expects systems to operate at high levels of performance. The periodic visits are critical to providing both accountability and positive feedback for superior results.

Technology Tools

Implementation of data acquisition and exception report tools requires that software tools be integrated into the building control and energy metering systems. Integration typically requires either Internet web-based access or the installation of multiple servers onsite to access the direct digital control (DDC) local area network and log data to a proprietary database.

The data acquisition and reporting tools should have the following characteristics:

- The data acquisition system should allow for periodic data transfer to the operating database to allow the operator to schedule data downloads and manage DDC system network traffic.

- The data reporting software should provide the ability to generate standard reports on preset frequencies. It should also provide easily customizable reports to allow for interrogation of the DDC system as appropriate for investigating identified system deficiencies.
- The data acquisition system should incorporate energy monitoring and reporting to ensure that the tool and its information can be configured into a comprehensive energy and performance management system.

Periodic Site Visits

As part of the ongoing commissioning process, the airport may either develop an in-house team or contract for third-party support to visit facilities periodically (e.g., quarterly) to accomplish the following objectives:

- Review the exception reports with the O&M team to verify that the information provided by the reports is clearly understood.
- Reinforce training with regard to (1) reading and understanding the information provided by the tool and (2) determining the appropriate response to that information.
- Review any corrective action items created by the O&M team based on the exception reports reviewed by that team. Confirm that corrective actions are being created and acted on by the O&M team.
- Develop additional corrective action items based on a detailed review of the operating systems on the campus. Create alternative execution strategies for each item or group of items to facilitate component and systems repairs necessary to sustain performance.
- Based on agreements with the airport's O&M team, facilitate execution of significant corrective actions by onsite personnel or service contractors. Validate proper completion of each item.
- Review with site personnel each service contract's records and performance to validate that active service contracts are being fully executed and delivering value to the site.
- Reinforce training and recommend additional third-party training for O&M personnel to supplement their technical skills as necessary to sustain performance of the installed systems.

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Glossary

Baselining means the process of identifying the condition of the building, including energy use, at the outset of an energy analysis and/or performance evaluation.

Benchmarking (a building's energy performance) means the process of measuring how efficiently a building uses energy relative to the same building over time, other similar buildings, or modeled simulations of a building built to code or to some desired standard.

Building automation system (BAS) means a computer-based system that monitors and controls a building's mechanical and electrical equipment, such as HVAC, lighting, power, fire, and security systems.

Building information models (BIMs) relate to the generation and management of digital representations of a facility. BIMs contain "object-intelligent information," including physical and functional characteristics of building systems, components, and furnishings. When managed as complete sources of facility information, BIMs are shared-knowledge resources that support decision-making for a facility.

Commissioning refers to a systematic process of assuring by verification and documentation, from the design phase to a minimum of 1 year after construction, that all facility systems perform interactively in accordance with the design documentation and intent, and in accordance with the owner's operational needs, including preparation of operation personnel.

Controls refers to the equipment, appliances, and sensors that control a building's mechanical and electrical equipment and provide feedback to the BAS on the state of the building conditions, operations, occupancy, and scheduling.

Current facility requirements (CFRs) means the building owner's current operational needs and requirements for a building, including temperature and humidity setpoints, operating hours, filtration, and any integrated requirements such as building automation, warranty review, and service contract review.

Deferred maintenance means any maintenance task that is not performed when scheduled or needed, but rather is put off or delayed for a future period. (Based on a definition from the Federal Accounting Standards Advisory Board, FASAB)

Energy audit means a systematic process of identifying and developing modifications of and improvements to the base building systems that meets or exceeds the *Procedures for Commercial Building Energy Audits* published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE).

Preventive maintenance (PM) is work performed by various trade personnel based on scheduled inspections and testing, and includes minor element replacements. PM involves a series of maintenance requirements that provide a basis for planning, scheduling, and executing scheduled maintenance for improving equipment life, avoiding any unplanned maintenance activity, and minimizing equipment breakdowns.

Reactive maintenance is work performed in situations requiring immediate attention because of a failure in or around the facility that would not only cause significant damage to the facility, facility systems, and/or equipment, but also create an imminent threat to people in an/or around the facility. Such emergencies can create an unmanageable situation or unsafe conditions, and involve issues that need to be fixed immediately.

Recommissioning means to return to a facility, after it has been initially commissioned and operated for a period of time, to repeat the systematic commissioning process of assuring by verification and documentation that all facility systems perform interactively in accordance with the design documentation and intent, and in accordance with the owner's operational needs, including preparation of operation personnel.

Retrocommissioning (may be abbreviated Rcx) means a systematic process for optimizing existing building systems through the identification and correction of deficiencies in such systems, including but not limited to repairs of defects; cleaning; adjustments of valves, sensors, controls, or programmed settings; and changes in operational practices.

APPENDICES

Appendices A, B, and C are printed with *ACRP Report 139.* Appendices D, E, F, and G are provided on *CRP-CD 169: Spreadsheet Tool and Appendixes to ACRP Report 139*, which is enclosed with the printed report. Online readers may download the contents of *CRP-CD 169* from the report's web page at www.trb.org. This introduction provides brief descriptions of all the appendices and lists the filename(s) to which Appendices D-G correspond on the CD-ROM.

Appendix	Subject
A	Colorado Springs Case Study: How to Leverage a Utility Conservation Program
B	Minneapolis-Saint Paul Case Study: Open Architecture and Adaptive Operations
C	Boston Case Study: Central Plant Retrocommissioning at Logan International Airport
	Subject and Filename on CRP-CD 169
D	Airport Facility Optimization Process Map (December 2014)
	Filename: AppD_RCx Process Map.pptx
E	Sample Retrocommissioning Scope of Work (Option 1 and Option 2)
	Filename: AppE_RCx Scope of Work.pdf
F	Sample Retrocommissioning Report with Plan
	Filename: AppF_RCx Report with Plan.pdf
G	Master List of Measures (Spreadsheet Tool)
	Filename: AppG_RCx Spreadsheet Tool.xlsx

Introduction to the Case Studies

The research conducted for *ACRP Report 139* included interviews with airports to evaluate various solutions to O&M challenges. The three case studies, presented with *ACRP Report 139* as Appendices A, B, and C, represent a sampling of strategies pursued at airports nationwide, including utility energy audits, intelligent monitoring and control systems, and retrocommissioning.

Each airport addressed challenges that amounted to variations on the same theme: improving operational efficiency with limited staff time, expertise, and financial resources. Regardless of the strategy selected, three basic elements clearly are critical to success in improving operations:

- **Get the right people at the table.** These include facility operators, managers, and financial decision-makers. In addition to being at the table, airport staff must be willing to openly discuss how their facilities operate and be amenable to considering a variety of solutions. Having the right people at the table will enhance probability and timeliness of implementation success.

- **Engage a third party.** Involvement of a third party immediately grows the expertise of the team, brings a neutral outside perspective to problem-solving, and aids in long-term planning for the organization.
- **Commit to implementation.** Improving and optimizing O&M is an ongoing effort, and the process will evolve over time. Commitment to implementation by all parties and patience to see the implementation through will yield the best results and likely uncover additional opportunities.

When choosing a strategy, each organization must evaluate its operational strengths and limitations, including budget, political willingness, availability of staff, and internal knowledge base.

Leveraging a Utility Conservation Program

Appendix A provides an example of a Level 1 energy audit from Colorado Springs Airport. The traditional hands-off structure of the energy audit yields recommendations that rely on the maintenance staff to implement and incorporate them into a capital plan.

Using Open Architecture and Adaptive Operations

Appendix B explores the justification, challenges and opportunities that surrounded Minneapolis-Saint Paul International Airport's decision to adopt an open architecture platform. Lessons learned from this experience can be valuable for other airport facilities teams seeking to increase systems performance with new or existing resources.

Central Plant Retrocommissioning

Appendix C details a retrocommissioning investigation at Boston's Logan International Airport. The goal of this investigation was to identify low-cost and no-cost changes that would improve plant operations and performance, and reduce energy consumption and greenhouse gas emissions.

Sample Documents and Tools

Airport Facility Optimization Process

Appendix D presents the airport facility optimization process in a series of flowcharts, depicting both the overall process and details within each major step in the process.

Sample Retrocommissioning Scope of Work

Appendix E provides sample retrocommissioning scope of work documentation that illustrates two approaches: Option 1 describes task order objectives for retrocommissioning services during the investigation phase; Option 2 provides sample checklists and a documentation framework for contract administration, including data needed for the scope of work, a statement of work, and sample documents, exhibits, and attachments defining procedures for contract solicitations.

Airport Facility Optimization Process

Appendix F provides a complete sample retrocommissioning report with plan based on a focused engineering review and analysis of buildings at the 148th Air National Guard facility in

Duluth, MN. The report documents the following elements of the retrocommissioning effort: review and analysis of building information provided by the owner; interview of operations and maintenance staff; site observations obtained during a walk-through of the facility; evaluation of trending data; definition of the current and intended operations of the facility; recommendations; cost and payback estimates for the recommended measures; and implementation of selected measures.

Master List of Measures (Spreadsheet Tool)

Appendix G presents a master list of recommendations/measures that can be used to rank choices for airport facility optimization during a retrocommissioning effort. The spreadsheet tool includes an introduction to the ranking tool, simple and advanced versions of a master list of recommendations, and an airport facility optimization summary that groups each retrocommissioning opportunity by category.

APPENDIX A
Colorado Springs Case Study

How to Leverage a Utility Conservation Program

Implementing Energy Efficiency Improvement Projects at Colorado Springs Airport
Transportation Research Board, ACRP Project 09-04

Table of Contents

Case Study

Introduction

All types of organizations are pursuing means to improve the sustainability of their operations. For small hub airports, improving the energy efficiency of terminal facilities can have a big impact in their operations budgets and promote sustainability. Aircraft and ground operations make up a majority of greenhouse gas (GHG) emissions from an airport, but airport administration has little influence over airline operations. However, energy and water use in terminal buildings represent a significant portion of airport-controlled GHG emissions. 10-15% reductions in energy consumption can often be achieved through no-cost and low-cost changes to the existing building systems. Lighting upgrades and retrofits can also reduce energy consumption and improve aesthetics, while offering an attractive financial payback.

In 2012, Colorado Springs Airport's Environmental Specialist proposed an energy audit to support sustainability initiatives at the airport. The audit was arranged through the Colorado Springs Utilities Enhanced Service Engineering, which provides a courtesy energy audit to identify potential projects for further investigation.

Energy audits can range greatly in scope and level of detail. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines different levels for energy audits in, *Procedures for Commercial Building Energy Audits,* most recently published in 2012, the second edition. The three levels of effort are briefly described as:

- Level 1 – Walkthrough Analysis.
  - The engineer conducting the audit performs a site visit at the building to identify possible energy conservation measures and review historical energy consumption. However, no calculations are required for this level of effort.
- Level 2 – Energy Survey Analysis.
  - Savings and cost analysis are required for all identified energy efficiency measures that are deemed practical by the engineer and facility staff. Building systems and energy consumption is analyzed to estimate an annual end-use energy breakdown, showing how much energy each building system consumes. The energy breakdown supports the engineer in estimating the potential energy savings for each recommendation.
- Level 3 – Detailed Analysis of Capital Intensive Measures.

Case Study

- Detailed calculations are performed, which may include additional data collection from the building using portable data loggers or trending from the building automation system. Since a Level 3 energy audit requires more detailed calculations, the increased cost of such a study means this type of audit is intended for major capital investments in the facility, such as a central plant upgrade or modifications to the building envelope (e.g., reskinning a building).

The energy audit provided by Colorado Springs Utilities Enhanced Service Engineering included air handling systems, chillers, boilers, irrigation and lighting. The audit can be described as an ASHRAE Level 1 Energy Audit, since it includes a list of recommendations, but does not include implementation cost estimates or estimated annual energy savings.

Facilities Overview

Colorado Springs Airport (COS) is Colorado's second largest airport. Located at the base of Pikes Peak 100 miles south of Denver International Airport, Colorado Springs Airport provides visitors with spectacular views of the Rocky Mountains from the terminal.

Since 2010, annual enplanements have ranged from 650,000 to 860,000. The airport also has significant cargo and military operations, as shown in the tables below.[1] A 2013 study by the Colorado Department of Aviation calculated the total economic output for the airport at $3.69 billion annually.[2]

[1] Source: https://www.springsgov.com/AirportPage.aspx?PageID=1874
[2] Source: http://www.coloradodot.info/programs/aeronautics/PDF_Files/2013_CO_EIS_ExecutiveSummary_WEB.pdf

Case Study

COS Airport Data	Enplanements	Freight, Cargo, Mail (lbs)	Military Cargo (lbs)
CY2013	650,529	22,975,039	5,801,676
CY2012	822,008	22,270,070	9,490,760
CY2011	814,336	21,651,560	7,511,600
CY2010	863,407	22,344,733	6,540,021

Table 1. Colorado Springs Airport Flight Data (CY2010-2013).

COS Airport Data	Aircraft Operations	Air Carrier	Air Taxi	General Aviation	Military
CY2013	127,656	11%	11%	47%	31%
CY2012	134,070	13%	11%	43%	32%
CY2011	126,764	15%	13%	44%	28%
CY2010	140,047	14%	13%	42%	31%

Table 2. Colorado Springs Airport Operations (CY2010-2013).

The City of Colorado Springs owns and operates COS, which provides air transportation services for Colorado Springs, El Paso County, and surrounding communities. The airport is located in the southeastern part of the City of Colorado Springs, Colorado.

The airport has a three-level, 16-gate terminal totaling 280,000 square feet that opened in 1994. The airport is situated on 7,135 acres at an elevation of 6,200 feet (**Figure 1**).

Case Study

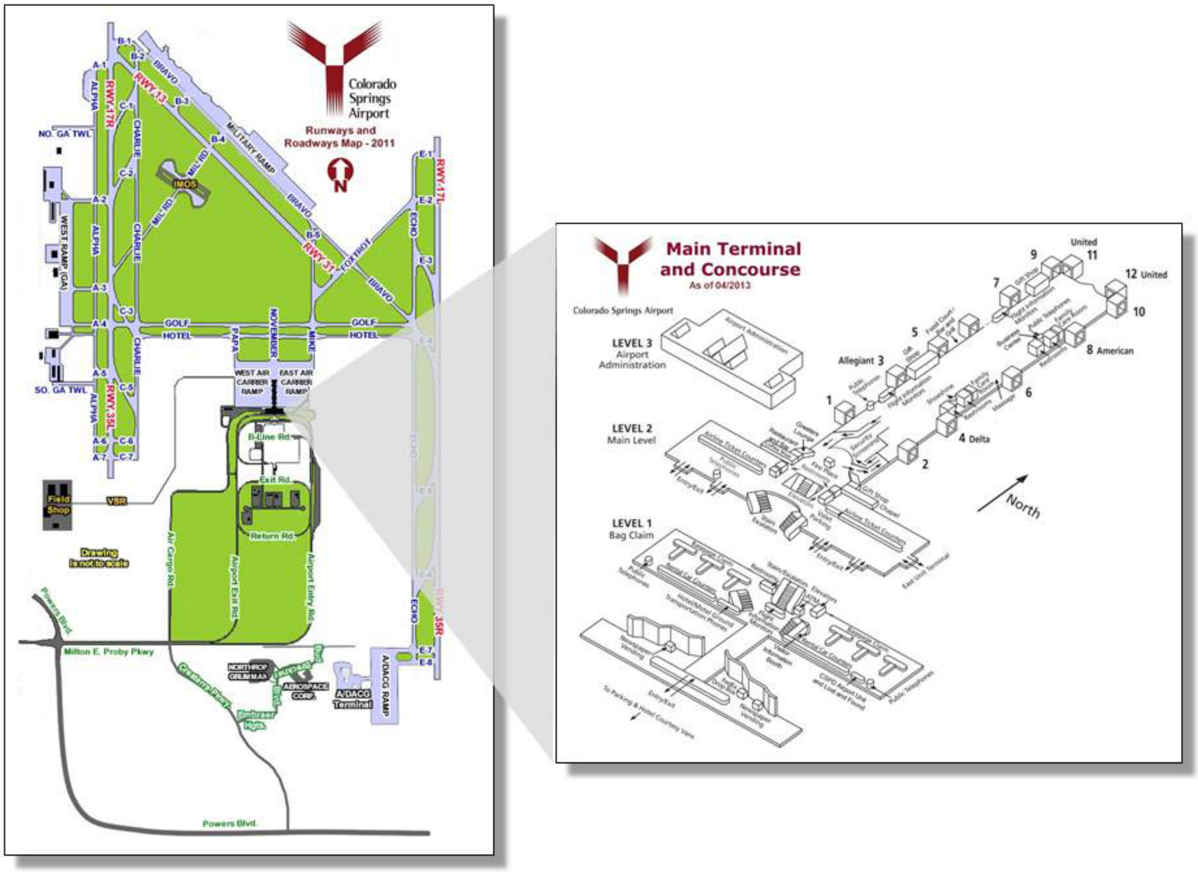


Figure 3. Location of Colorado Springs Airport.[3]

With rising fuel costs and airlines shifting their flights to large hub airports like Denver International Airport, Colorado Springs Airport has experienced declines in passenger traffic since 2007. The airport has been taking steps to reduce operating costs and lower lease rates to make terminal space more attractive. Energy efficiency improvements, like cost-effective lighting upgrades, can support this by reducing energy and maintenance costs, and renewing the aesthetics of the terminal.

[3] Source: Maps compiled from https://www.springsgov.com/AirportPage.aspx?PageID=1785

Case Study

Findings and Results

At Colorado Springs Airport, the energy audit provided great value as a collection for many improvements that can improve operations and reduce annual energy costs. The engineer from the Utility's Enhanced Service Engineering program performed a thorough site investigation and led positive discussions with airport staff to understand how the building systems were designed and operated, walked through every equipment room and reviewed the available building automation control documentation. The engineer also read TECs (control panels) and verified operation of a sample of VAVs to collect operating data. Airport staff also provided printouts from the control system for the engineer to review and develop further recommendations. Additionally, airport staff brought some of their own ideas to the energy auditor, which were included in the report for implementation planning.

When conducting energy audits, it is common to find that the operations staff has a list of projects they would like to complete that will improve operations. However, operating budgets are limited, and proposed projects are often forced to be put on hold due to budget limitations. At Colorado Springs Airport, the energy audit helped to raise the visibility of several of these projects, which have since been implemented. The resolution is discussed in the context of each measure in the following section.

Measures with Low Cost to Implement

ECM #1 – Utilize Make-Up Air Unit in Concourse Kitchen: At the time of the energy audit, an exhaust hood in a tenant restaurant kitchen was found to be not working but workers were still cooking food beneath it. The airport staff worked with the tenant manager to get this exhaust hood operating which will control indoor contaminants in the kitchen area and prevent smells from affecting the terminal. While this only required changes to tenant equipment, airport staff had to provide assistance with the fire safety lockout. The benefits to resolving these issues include improved indoor air quality and reduced energy consumption.

ECM #2 – Air Handler Return Fans Control Change: Air handling units (AHUs) can typically draw in a variable amount of outside air, mix with return air from the occupied space, condition (i.e., heat or cool) as necessary, and supply the conditioned air to the occupied space. When the building is in a cooling mode, and the outside air is cool and dry, it can be beneficial for the AHU to draw as much outside air into the building as possible to provide free cooling (i.e., avoid the use of mechanical cooling with chillers and cooling towers). This "free cooling" is frequently called an economizer mode for the AHU. The AHUs identified in this measure have an economizer mode, which was determined to be functioning improperly at the time of the site visit. It was determined that at the time, the AHUs were likely bringing in 100% outside air to cool the building, however the building pressure sensor called for the relief air (i.e., exhaust) dampers to be closed to maintain a positive pressure in the building.

Airport terminals often have trouble maintaining building pressurization due to their high ratio of exterior wall to floor area, doors at gates that do not allow for pressure control, and building orientation in prevailing winds that can place a high positive pressure on one side of the terminal and a high negative pressure on the opposite side of the terminal. Building pressure varies continuously in the airport terminal and airport staff has since revised the return fan operation to account for building pressurization needs.

ECM #3 – Overlapping Mechanical Heating and Cooling Control Change: The engineer observed simultaneous heating and cooling for different zones. Cooling one area and heating an adjacent area can cause the system to fight itself and use increasing amounts of energy. This situation can result from inadequate zoning in the terminal. As designed, the AHUs are set on either the east or west side of the terminal. A zone on the east side of the terminal may require morning cooling due to solar gain, while a zone on the west side of the terminal may call for morning heating. The engineer recommends creating a dead band of 2 psi to prevent the system from allowing simultaneous heating and cooling.

Over time, the springs on the valve actuators can fall out of setpoint. Since the study, airport staff has adjusted springs to provide a 3 psi dead band (from 6 to 9 psi) where no valves are open. Below 6 psi, the hot water valve opens. Above 9 psi, the cold water valve opens.

The terminal has some DDC (direct digital control) actuators, which rely on a 2 volt dead band to allow for voltage drop and minor fluctuations. These electronic actuators provide much better control, whereas pneumatic actuators are more apt to fall out of calibration. The airport hires an outside contractor to test all pneumatic controllers annually and prevent systemic issues from arising. The controls contractor is onsite for 8 hours per month, plus additional time as needed at an hourly rate. This controls contractor provides support for the pneumatic and digital components.

ECM #4 – Overlapping Economizer and Heating Control Change: This recommendation refers to the economizer mode references in ECM #2, which seeks to use the cooler outside air temperature to remove heat and help cool from the facility. This free cooling mode avoids using mechanical cooling (i.e., chillers and cooling towers) when the outside air temperature is at least 5 degrees below the mixed air temperature setting. However, this free cooling mode should not be used when the system is calling for heating, as excess energy is consumed to heat the outside air to meet temperature setpoint. Conversely, when outside air temperature exceeds the mixed air temperature, the amount of outside air delivered to the space should be set to minimum to reduce the load on the chillers. Airport staff continues to monitor AHU operations to minimize the amount of reheating when in economizer mode, however this depends on the cooling and heating demands of each space, as discussed in ECM #3.

ECM #5 – Optimum Supply Air Temperature Reset: Airport staff adjusts supply air temperature based on what the facility needs. On hot summer days, supply air temperature setpoint can be as low as 45 degrees F to prevent building from overheating. On coldest days, supply air temperature setpoint can be as high as 65 degrees F, even though the facility is kept at a warmer temperature for occupied areas. The remaining heat comes from internal and external loads such as lighting, equipment, people and solar gain from the building envelope. The following shows the supply air reset temperature based on outside air temperature:

If Outside Air temperature is…	Then Supply Air temperature setpoint is…
40 degrees F	65 degrees F
65 degrees F	50 degrees F
80 degrees F	45 degrees F

The supply air temperature is further refined by airport staff to optimize overall occupant comfort needs.

Reheat should be minimized as much as possible, since the reheating process uses energy. However, some reheat is required during the summer time due to the zoning of the space. The same AHU serves zones on the east and the west side of the facility. In the morning when it is 80 degrees F outside, the east-facing zones will require 45 degree F supply air temperature to meet the cooling needs, but one small office on the West side of the building may require warmer air. The VAV serving this office will back down to minimum, but still may require reheating to meet the desired space temperature and keep the occupant comfortable. This small demand for reheat has significant impacts on facility operations, since airport staff must run a boiler to provide hot water for reheat. To meet these summer heating needs, airport staff operates the smallest boiler available which is a 5 million BTUh boiler. This boiler provides much more heat than is actually required for these small loads, but is currently the only available option.

ECM #6 – VAV Heating Minimum Flows Control Change: VAV boxes provide a variable flow of air, and are controlled by sensors installed in an occupied space and at other strategic locations in the HVAC system. If an occupied space does not require any heating or cooling, the VAV box will revert to minimum flow conditions to conserve energy. During the investigation, the auditor found some VAV boxes that were set at minimum flow for heating but delivering more airflow than was to be expected. The recommendation is to reevaluate minimum flow rates in heating mode to be equal to the minimum flow in cooling mode. This can improve occupant comfort, since excess air movement can make the occupant feel a draft, which can make the space feel even colder than it actually is. However, operators should exercise caution in decreasing minimum heating flows to ensure that the heating elements can deliver their heat to the space, and not damage the equipment in the ductwork from excess temperatures. In other words, without sufficient airflow, the heat may build up in the ductwork and not reach the occupied space without sufficient airflow.

Another issue that arises with VAV systems are offices without thermostats. It is quite common for multiple private offices to be controlled based on the actual temperature in one office. If this one office is colder than setpoint, all offices are provided with heat. Conversely, if this occupant has a space heater, this one office is artificially warmer than the other offices; therefore even though the other offices need heat, they will not receive it due to the controlled office being artificially warmed with a space heater. The solution to this is to remove the space heater, and rebalance the air flows in the ductwork based on current occupancy and loads in each space in the zone. This will resolve occupancy comfort issues and optimize energy consumption in the building.

ECM #7 – Lower VAV Static Pressure: Another control strategy for a VAV system is static pressure reset. This control strategy relies upon pressure sensors installed at the downstream end of the ductwork to tell the supply air fan at the upstream end of the ductwork how much air is required. A typical static pressure requirement for a VAV box is 0.5 inches (w.c.); less pressure would deliver insufficient flow, more pressure consumes excess fan energy. The static pressure setpoint depends on the location of the sensor. The sensor is often installed upstream a distance away from the VAV box. Since this distance can result in increased pressure drop, the setpoint may need to be higher than 0.5 inches. In the energy audit report, the recommendation is to establish the static pressure setpoint as low as 0.7 inches when the system has low demand for cooling (outside air temperature of 40 degrees F). In cooling mode, the report recommends using the static pressure setpoint of 1.5 inches to provide sufficient airflow to all VAV boxes to meet cooling demands.

This is a practical energy savings measure that will maintain and may even improve occupant comfort, but may need further refinement in implementation. Airport staff needs to carefully evaluate the existing location of the pressure sensor and verify the accuracy of the sensor. This type of control strategy can cause VAV boxes to fluctuate open and closed, as the supply fan also speeds up and slows down, to maintain the desired temperature in the occupied space. If problems are encountered in implementation, the location of the pressure sensors should be evaluated and airport staff should consider airflow

Case Study

balancing by a qualified Testing, Adjusting and Balancing (TAB) contractor. After rebalancing the airflow system, the TAB contractor should provide a TAB Report[4] detailing:

1) An overview of the HVAC system design
2) Installed equipment information for the AHU
3) Results of field tests for the fan, conducted as part of the rebalancing
4) List of terminal outlets, setting and adjustment pattern employed

In discussions with the airport staff at Colorado Springs, the control system was upgraded since the original building construction. During this upgrade, the minimum setpoints for each VAV box were lost. Losing the minimum setpoints from the original balancing can throw the system into compromised operations. There are many ways these minimums can become corrupted, including power loss or inadvertent changes by a contractor. Regardless of the cause, the airflow will need to be rebalanced for the HVAC system to maintain occupant comfort and make efficient use of energy.

ECM #8 – Chilled Water Pump Optimization: A typical central plant has multiple chillers and multiple pumps for chilled water. Depending on the cooling demands from the facility, only one chiller may be required for operation on many days. In most buildings, it is most efficient to operate only one chilled water pump when operating one chiller. While more flow can be provided by running two pumps with the one chiller, the overall system performance can suffer due to the increased pumping energy and lower delta T achieved at the AHUs (delta T refers to the difference in temperature from the chilled water supply to the chilled water return – a higher delta T is better). During the energy audit, the chilled water system was found to be running on a very low delta T of 6 degrees F. As the report notes, the delta T for the system can be improved using several low-cost measures, including:

- Increase the supply air temperature setpoint for the AHUs.
- Increase the chilled water setpoint for the chillers.
- Rebalance the airflow in the HVAC system.
- Operating only one chilled water pump will also improve the delta T for the system, since the chilled water will spend more time in each cooling coil due to lower flow speeds.

ECM #9 – Consumptive Use Adjustment for Cooling Tower: A cooling tower uses water flowing over a closed loop for the condenser water to remove heat from the building and reject into the atmosphere. Since the cooling tower water is an open loop recirculating system, much of the water can be lost to evaporation. This is especially true in a dry climate like Colorado, but applies to all installations. The cooling tower water must be replenished and potable water is used as “cooling tower make-up water”. The airport is billed for this water by the water utility.

Once the water has cycled through the system, concentrations of contaminants can buildup that can make the cooling tower inefficient or require significant maintenance. These contaminants can include equipment corrosion, dust from the air, minerals from the water, or naturally occurring biological contaminants that may find the moist warm air of the cooling tower as an ideal growth location. These contaminants can be managed with a number of methods, including corrosion inhibitors, filters, biocides, and blowdown. Cooling tower blowdown refers to water that has been cycling through the cooling tower that is removed to also remove the high concentration of minerals in the system. After the blowdown

[4] ASHRAE Handbook – HVAC Applications (2011) Balancing procedures for air distribution in variable-volume systems.

water is removed, the total water capacity for the cooling tower system is restored with clean make-up water.

Water utilities typically charge sewer costs for the blowdown water, since it must be treated along with all of the other wastewater in the system. However, water utilities typically allow for meters to be installed on both the make-up water and the blowdown water, so that the facility does not need to pay sewer charges on the water lost to evaporation. This can result in significant savings for the facility. For Colorado Springs Airport, the savings are estimated as $4,300 annually. This does not affect the amount of water used at the facility, only billing.

ECM #10 – Interlock Baggage Tug Area Make-Up with Exhaust: In the west side baggage tug area of Colorado Springs Airport, the ventilation system has make-up air units and exhaust units to remove vehicles fumes. A carbon monoxide (CO) sensor is also installed to exhaust the area if vehicle fumes exceed a programmed threshold. The energy audit recommends the ventilation system operate only when the CO sensor indicates vehicle fumes exceed the programmed threshold. This will reduce the runtime for the make-up air units and the exhaust units.

Another complicating scenario that is being considered in implementation is winter operation. The make-up air units have a heating coil to condition the air, but if the make-up air units are turned off, the coil will overheat and trip the unit. A three-way valve is required to bypass the heating coil in the unit, to provide heat in the coil only when the ventilation system is on.

ECM #20 – Removing Turf and Replacing with Rock/Xeriscape: The airport has aggressively pursued xeriscaping in landscaped areas around the parking lot. A landscape that employs xeriscaping practices seeks to eliminate irrigation by using features and plants that can tolerate the amount of rainfall naturally available for the location. This has significantly reduced water cost for landscaping and eased maintenance requirements for parking staff.

Though not identified in the energy audit report, Colorado Springs Airport has tested waterless urinals in public restroom installations. However, waste piping was observed to corrode and deteriorate to the point of failure. Airport staff has since installed pint flush urinals that function well and have reduced maintenance requirements.

Capital Measures

Measures requiring large cost to implement are categorized as capital measures. As noted in the engineer's report, the capital measures require careful consideration prior to implementation. The measures are briefly discussed for this case study.

ECM #11 – Replace Cove Lighting in Concourse: Lighting projects have been undertaken by the airport as noted in this case study.

ECM #12 – Replace Fluid Cooler with Roof-Mounted Cooling Tower: The indoor cooling tower is a priority for replacement, which has a header failing and is unrepairable. The airport is pursuing replacement with competitive financing. Replacement will happen early 2015.

ECM #13 – Occupancy or CO2 Control of Ventilation: CO2 sensors have been installed on new AHUs for demand control ventilation, but the CO2 concentrations in the occupied spaces do not meet the threshold required for increased ventilation. This can be attributed to the many openings in the building where conditioned air can escape (i.e., gate doors). Therefore, airport staff is not currently pursuing CO2 sensors on existing AHUs for demand control ventilation.

Case Study

ECM #14 – Exterior Lighting Ballast Replacement: Lighting projects have been undertaken by the airport as noted in this case study.

ECM #15 – Extend Vestibule Length for Air Lock: Extending the vestibule at the main entry to the airport could improve its effectiveness in controlling building pressure and improve energy efficiency. However, this requires major alterations that are not included in current capital budgets.

ECM #16 – Jockey Boiler for Summer Reheating: Since summer heating needs require very little amount of hot water, the smallest boiler currently installed (5 million BTUh) will short cycle, meaning it turns on and off repeatedly. This is not good for the equipment life and is not an efficient use of energy. Installing an even smaller boiler (<1 million BTUh) will allow the boiler to operate more consistently during these times, reduce the short cycling, and prolong the equipment life of all assets. This is a Capital Measure that is being pursued by Colorado Springs Airport, since it will improve energy efficiency and prolong equipment life for the existing larger boilers.

ECM #17 – Install Additional Synchronous Belts: Synchronous belts are currently installed on baggage handling systems. The airport has considered retrofitting motors for building systems, but this requires a significant capital cost to replace existing sheaves with new sheaves for the synchronous belts.

ECM #18 – Snow Melt Efficiency: The snow melt options outlined in the report are not being pursued.

ECM #19 – Natural Lighting Redesign in Concourse: Lighting projects have been undertaken by the airport as noted in this case study.

ECM #21 – Various Recommendations for Tenant Kitchens: The design and contract recommendations will be taken into account in the future.

Figure 4. Colorado Spring Airport turns off escalators during periods of inactivity.

Case Study

Implementation

Implementation of the energy audit findings at COS is a work in progress. The airport has aggressively implemented lighting projects, earning rebate credits from the utility to support the economic feasibility of the upgrades. The airport received a total of $28,000 in lighting rebates from the utility in 2013. Table 3 shows a summary of lighting projects and savings based on operating schedule. For measures with a calculated simple payback of less than 5 years, the estimated implementation cost is $60,081 (before rebates) with a combined simple payback of 1.81 years. In addition to the utility cost savings, there is expected to be maintenance savings on fixtures with a longer life. Appendix A provides additional fixture information and runtimes.

Year	Location	Old Fixture	Cost per day	New Fixture	Cost per day	Fixture Cost per unit	Total Fixture Cost	Simple Payback (in Yrs)
2013	BAGGAGE MAKEUP	T-12 HO	$ 66.80	LED HIGH BAY FIXTURE	$ 17.12	$ 477	$ 25,255	1.39
2013	RAMP LIGHTS	ELIMINATE OPERATIONS WEST RAMP AND ETU	$ 21.99	ELIMINATE OPERATIONS WEST RAMP AND ETU	$ -	$ -	$ -	immediate
2013	ROADWAY POLE	EVERY OTHER POLE EXCEPT TURNS	$ 23.64	EVERY OTHER POLE EXCEPT TURNS	$ 11.82	$ -	$ -	immediate
2013	LOWER HALLWAYS	NORMAL OPERATIONS T-8	$ 3.19	LED WRAP FIXTURE	$ 0.38	$ 128	$ 1,792	1.74
2013	SOUTH TUG PASSAGE	EXISTING LAMPS	$ 2.58	LED WRAP FIXTURE	$ 0.22	$ 128	$ 2,048	2.37
2013	ATRIUM	EXISTING LAMPS - uplights	$ 22.61	LED LAMPS & FIXTURES - uplights	$ 1.79	$ 591	$ 27,186	3.58
2013	ATRIUM	EXISTING LAMPS - downcans	$ 6.88	LED LAMPS & FIXTURES - downcans	$ 3.52	$ 348	$ 9,744	7.93
2013	TICKETING SKYLIGHTS	EXISTING	$ 3.60	LED FIXTURES	$ 0.63	$ 591	$ 9,456	8.73
2013	NORTH TUG PASSAGE	EXISTING LAMPS	$ 1.40	LED FIXTURES	$ 0.18	$ 128	$ 1,664	3.72
2014	CONCOURSE	2 X 4 TROFFERS	$ 0.92	2 X 4 LED TROFFERS	$ 0.56	$ 115	$ 1,380	10.50
2014	3RD FLOOR KITCHEN	2 LAMP T 12	$ 0.24	LED TROFFER	$ 0.10	$ 115	$ 575	11.06
2014	BUILDING A - FLEET BAYS	EXISTING LAMPS	$ 7.20	LED DOWNCAN	$ 1.80	$ 348	$ 10,440	5.30
2014	JETWAY GATE	EXISTING LAMP	$ 3.60	NEW FIXTURE	$ 0.13	$ 178	$ 2,136	1.69
2014	SERVICE ELEVATORS	FLUORESCENT FIXTURES T-12	$ 0.58	LED WALLWRAPS	$ 0.36	$ 128	$ 768	9.74
2014	BUILDING B	SOUTH WALLPACKS	$ 0.30	LED WALLPACKS	$ 0.10	$ 323	$ 646	8.94
2014	ACP/FUEL ISLAND	EXISTING SHOEBOX HEAD	$ 2.88	RETROFIT	$ 1.01	$ 570	$ 6,840	10.01

Table 5. Summary of Lighting Upgrades Implemented.

Case Study

Figure 6. 'Shoebox' fixture with old lamp.

Figure 7. 'Shoebox' fixture with new LED lamp.

Case Study

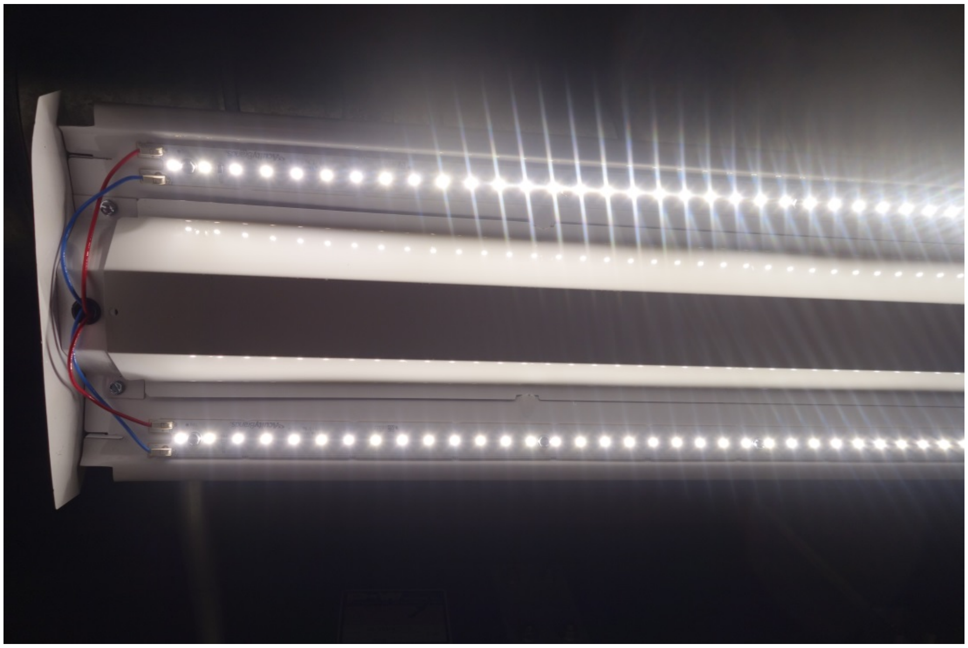


Figure 8. LED Fixture installation.

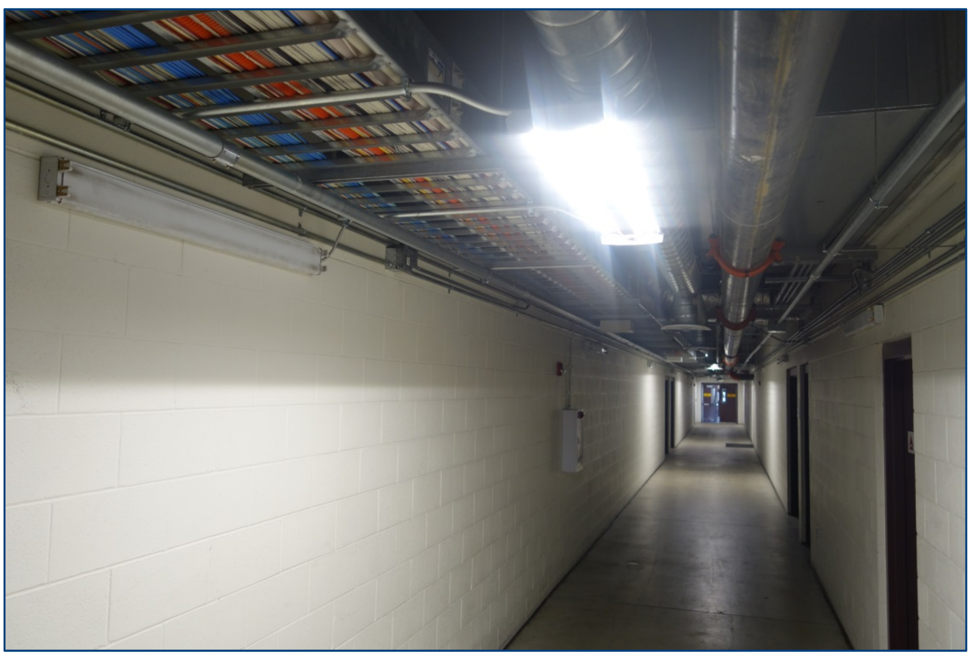


Figure 9. LED fixture shown in service corridor.

Case Study

Critical Success Factors

For Colorado Springs Airport, the energy audit was a low risk effort. The complementary service only required airport staff provide access for the engineer to conduct the study. Upon completion, the engineer presented a report to document his findings and communicate the opportunities to reduce operating costs at the airport. With an engaged airport staff, changes were made and improvements realized.

Multiple levels of airport staff engagement are required to achieve this success:

- The engineers operating the building systems need to be open to discussing how they operate their building and consider different approaches, if only to rule out other options.
- Including a representative in an administration or management role with budget authority to hear the recommendations directly from the third party engineer is important to facilitate implementation of measures and planning for future projects.
- In organizational settings, having a third party present an independent review of findings can accelerate the implementation of projects that may have otherwise been delayed for years. This third party can bring different operating groups together and stimulate facility planning conversations that may otherwise not arise.

A complimentary energy audit will only be available in a few locations in the US. For airports seeking to contract with a firm to conduct an energy audit, the following qualifications should be sought:

- Demonstrated success in identifying energy saving opportunities in existing buildings.
- HVAC design experience, since a majority of energy consumption in a building is for heating, ventilation and air-conditioning equipment.
- The ability to calibrate the energy auditing process to the airport's needs. The effort can be of minimal cost, commitment and corresponding value or it can be in an in-depth point-to-point investigation and analysis of all the energy consuming systems at a higher cost and value. The energy auditor should be able to identify how much value an energy audit can provide after a walkthrough of the building(s) and conversations with operations staff.

Consider the scope of work requested in the energy audit, and require that the deliverable include an outline specification that describes how the measure would be implemented. This can be useful to airport staff if the project needs to be provided to a service contractor for implementation.

Acknowledgements: This case study was authored by Peter Dahl and James Miller of Sebesta. Sebesta would also like to thank Kristine Andrews, Neil Ralston, and the engineers from Colorado Springs Airport for discussing the outcomes of their energy audit for this case study. This case study was completed by Sebesta as part of ACRP Project 09-04, "Airport Building Operations and Maintenance (O&M) Optimization and Recommissioning: A Whole-Systems Approach," with funding provided by the Transportation Research Board of the National Academies.

END OF DOCUMENT

Colorado Springs Utilities
Customer & Corporate Services
Enhanced Service Engineering

May 01, 2012

Kris Andrews
Environmental Health and Project Specialist
Colorado Springs Airport
7770 Milton E. Proby Pkwy Ste 50
Colorado Springs, CO 80916

Re: Energy Audit Service: Colorado Springs Airport

On April 17 and April 18, 2012 Colorado Springs Utilities visited your facility to suggest some ideas for energy savings / cost savings. This is a courtesy service of Colorado Springs Utilities, for you as our valued customer.

Financial detailed calculations outlining costs, benefits, and payback times (or rate of return) are very often required for customers to consider implementation. The information provided in this energy audit does not provide this level of detail. For added detail, especially for the capital improvement items, the Owner may wish to consider additional Energy Audit services through engineering firms in the community.

We hope this information is useful. If there are questions or comments, please feel free to contact Tyrone Johnson or myself.

Sincerely,

Steve Doty, PE CEM
Enhanced Service Engineering

P.O. Box 1103,
Mail Code 1025
Colorado Springs,
CO80947-1025

Phone 719-448-4800
http://www.csu.org

All utility-saving suggestions noted are optional. Nothing in this report is intended to supersede any law, regulation, code, local ordinance, or any Authority Having Jurisdiction, or impede with occupant comfort or facility operations. Safety, health and comfort are intended to take priority over utility conservation. If conflicts between this report and any other legal requirements exist, they are accidental and this report will defer to those requirements.

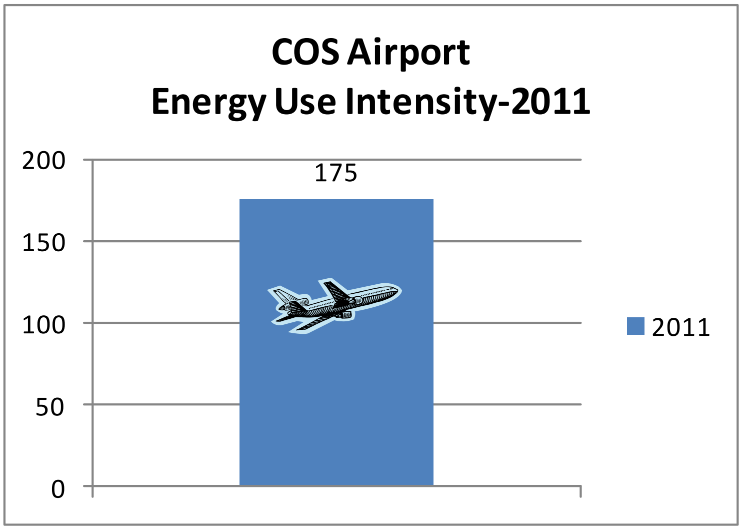
Energy savings are not guaranteed.

This information is provided in good faith, for use by the customer in conjunction with a qualified Contractor or Engineer.

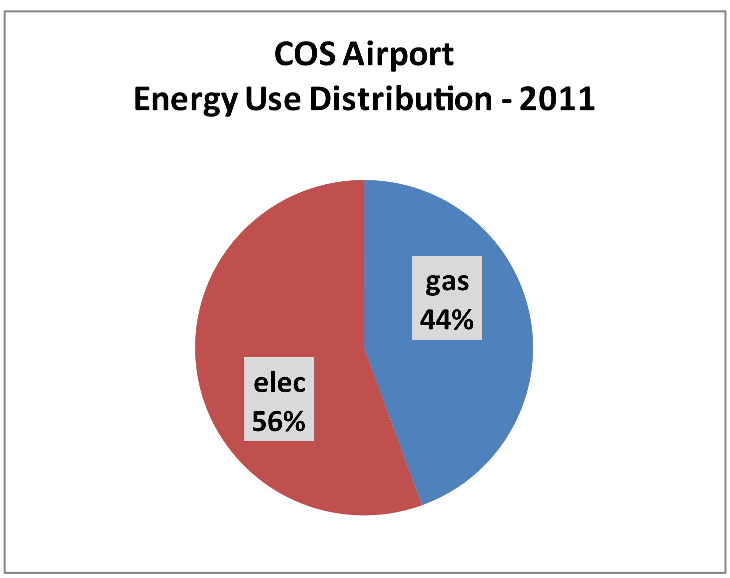
Where safety or health issues are noted in this report, it is understood by the Owner that the responsibility for maintaining a safe and healthy building is the Owner's responsibility. Colorado Springs Utilities assumes no liability for safety or health observations made in this report. As industry professionals Colorado Springs Utilities is compelled to identify safety or health concerns when they are apparent, and may also be compelled to follow–up to receive confirmation that the issues have been resolved. In all cases, the Owner shall be responsible for retaining qualified professionals for specific project recommendations and to implement changes.

SUMMARY:

Energy use for the building was tabulated on a "per SF" basis. This may be used as the baseline energy use for subsequent years. Data has been normalized to utility billing days, but not weather.

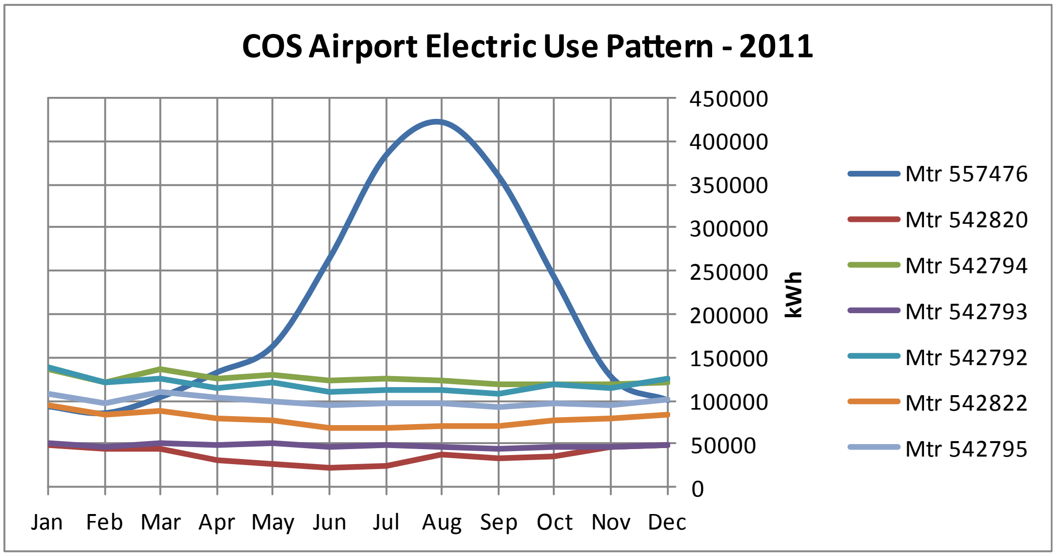


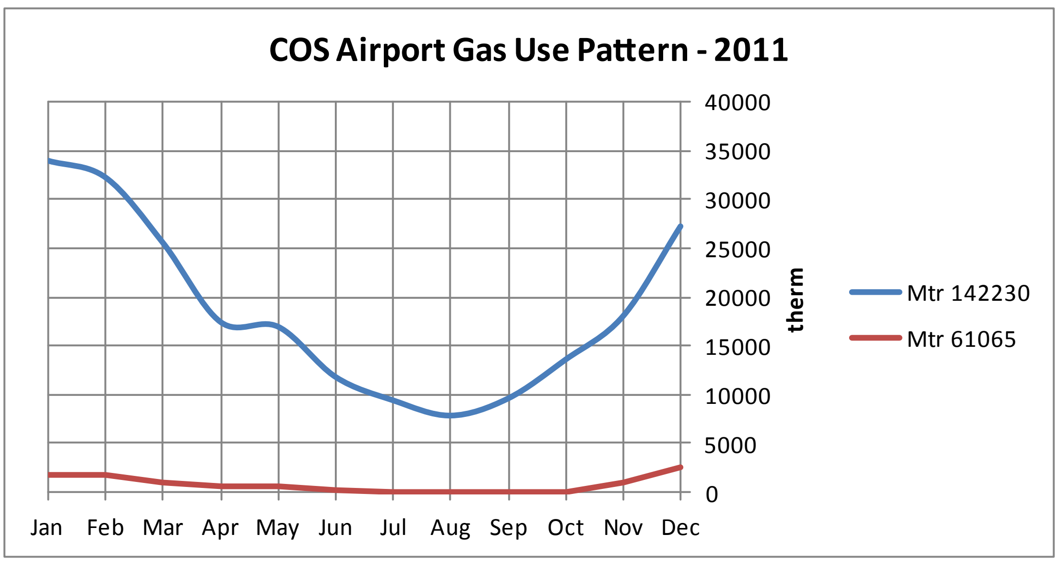
Energy use division between gas and electric is shown below. Energy cost distribution is more like 70/30 since electricity is more expensive per Btu than gas.



Monthly usage patterns are shown below. The energy services for chiller and boiler are very apparent and are both weather-dependent. Other electric and gas uses are weather independent.

1 therm=100,000 Btu





IMPROVEMENT SUGGESTIONS

The link between energy reduction and cost reduction is obvious, but sometimes the link between energy savings and customer choices is not. By evaluating each suggested measure, the customer can evaluate the pros and cons and choose; in this way a greater portion of the energy use in a facility becomes a controllable cost.

Opportunities for energy savings have been identified and are grouped as follows:

Low Cost Measures with low investment requirements, and usually correspondingly small returns. Characterized as the smaller easy items, with quickest paybacks

Capital Measures requiring capital investment, but with proportionally greater returns. These are normally larger project items, with longer paybacks.

Strategic Consideration of opportunities in future projects where conservation benefits can be built-in to those future projects.

Notes:

1. The customer should review each suggestion carefully to ensure it does not impact production or product quality. Each building and process is unique and some measures may not apply. Review by qualified operations and maintenance personnel may temper some of the suggestions based on particulars of the building.
2. Suggestions that include modifications or additions to existing equipment should be carefully reviewed to avoid any unintended negative effects to the equipment. Always defer to the manufacturers requirements when in doubt. All modifications must maintain proper service access.
3. Where manufacturer names or part numbers are shown, these are intended to illustrate the technology. Colorado Springs Utilities cannot endorse specific manufacturers.
4. Where demand savings are indicated, these normally will not show up for 12 months after the change is implemented due to the 12-month demand ratchet clause in the tariff.
5. Where rebate opportunities are noted, these are contingent upon the terms of the rebate program and the customer will need to review the rebate conditions in advance of any work. Rebates may require written pre-approval. Mentioning a measure in this report does not constitute pre-approval.
6. Implementing efficiency measures is encouraged. The check box column is provided in the table of suggestions to accommodate our customer survey of completed measures which normally occurs 1-2 years after issuing the report.

Savings Calculations

1. Where savings are provided, they are in consumption units. The conversion from these units to dollars is dependent upon several factors, including the current charge rate from the utility. Since rates change often, the conversion to dollars should be made by the customer at the time of implementation. In this way, the savings figures will stay accurate much longer. For the most recent 12 month period of this report, the overall cost of energy was:

$0.0793 per kWh	$0.814 per therm	$6.19 per kgal water	$3.86 per kgal sewer

2. Where savings have been estimated, it will be the responsibility of the customer to determine implementation costs since there are many variables. Attractiveness of a measure is usually expressed as the ratio of cost-to-benefit.
3. Where savings data are shown individually, they may not be additive. For example, if more efficient lighting equipment saves 1000 kWh per month, and occupancy sensors save 1000 kWh per month, doing both would not save 2000 kWh per month since the improved lighting efficiency is applied to a smaller load. Generally, de-rating individual measures by 10-20% will allow simple adding with little risk of over-stating the savings. In cases where one measure offers equipment efficiency improvement and another measure removes it altogether, the two do not add at all.

ECM	Type	Summary of Measures	Savings Calculated √	Colorado Springs Utilities Rebate √ (note 1)	Complete √
1	Low Cost	Utilize Make-Up Air Unit in Concourse Kitchen			
2	Low Cost	Control Change: Air Handler Return Fans			
3	Low Cost	Control Change: Overlapping Mechanical Heating and Cooling			
3	Low Cost	Control Change: Overlapping Mechanical Heating and Cooling			
4	Low Cost	Control Change: Overlapping Economizer and Heating			X
5	Low Cost	Control Change: Optimum Supply Air Temperature Reset			
6	Low Cost	Control Change: VAV Heating Minimum Flows			
7	Low Cost	Control Change: Lower VAV Static Pressure	√		
8	Low Cost	Control Change: Operate Only One Chilled Water Pump with One Chiller	√		X
9	Low Cost	Consumptive Use Adjustment for Cooling Tower	√		
10	Low Cost	Interlock Baggage Tug Area Make Up with Exhaust	√		
11	Capital	Replace Cove Lighting in Concourse	√		
12	Capital	Replace Fluid Cooler with Roof-Mounted Cooling Tower	√	√**	
13	Capital	Occupancy or CO2 Control of Ventilation	√		
14	Capital	Exterior Lighting Ballast Replacement Electronic replacing magnetic	√		
15	Capital	Extend Vestibule Length for Air Lock			
16	Capital	Jockey Boiler for Summer Reheating	√		
17	Capital	Synchronous Belts	√	√	
18	Capital	Snow Melt Efficiency Options			
19	Capital	Natural Lighting Redesign in Concourse			
20	Strategic	Irrigation Removing Turf and replacing with rock/xeriscape			---
21	Strategic	For Tenant Restaurants			---

(Note 1) Rebate measures marked with (**) are candidates for the Peak Demand Rebate (PDR) program, a custom rebate program that requires written pre-approval. Contact Rich Swope at 668-5760, before acting on this measure to verify eligibility and to understand the pre-approval requirements. Mentioning a measure in this report does not constitute pre-approval.

Descriptions of Suggested Measures	Type
Utilize Make-Up Air Unit in Concourse Kitchen The main hood fan is operational; however the make-up air serving it was not running. This causes the make-up air for the hood to come from the main airport indoor volume. Using the make-up air unit reduces energy use because the replacement air in heating season is tempered to a lower level (50F vs. indoor temperature) and replacement air in cooling season is tempered evaporatively instead of with mechanical cooling. This measure consists of running the make-up air unit using an automatic interlock such that it runs whenever the hood exhaust fan runs. Additionally, verifying the temperature controls internal to the make-up unit so that heated air is not delivered over 50F. The second hood fan was turned off, but food preparation beneath it continues. This is noted separately in the report.	Low Cost
Control Change: Air Handler Return Fans Controls for the air handlers are the same, so this measure can be extrapolated to all. The return fans of AHU-6 and AHU-9 were found dead headed (operating with all outlet dampers fully closed). Fan speed was 15 Hz (25%) for AHU-6 and 30 Hz (50%) for AHU-9. The energy used by these fans provides no system benefit when all dampers are closed. The intended operating sequence is to provide an exhaust plenum static pressure such that opening the relief damper can effectively lower the building pressure. Ideally this is done with a dedicated "exhaust" fan, however this design uses the return fan. The energy waste occurs when building pressure is satisfied This measure calls for adjusting control code so that the return fans are only used when there is benefit in doing so. The adjustment will require some thought, since the return fan is used for general HVAC circulation and not just pressure relief. The error probably occurs during economizer mode when the system expects the 100% outside air to be single-pass and expelled, but for building pressure the exhaust damper is held closed. Suggested changes include: a. Calibrate the building pressure sensors. These are very low range sensors and questionable even when new, so calibration at 5-year intervals is good practice and errors in readings are no surprise. b. Calibrate the damper actuators so that when the control signal is 10, 50,100% the damper has faithfully moved to that position. This calibration procedure may involve adjustment of the I/P transducer, pilot positioners, etc. In the end, the digital command needs to have a corresponding reaction at the damper. c. Allow the return fan to operate only when at least one of the dampers is >10% open (return and relief)	Low Cost

<table>
<tr><th>Descriptions of Suggested Measures</th><th>Type</th></tr>
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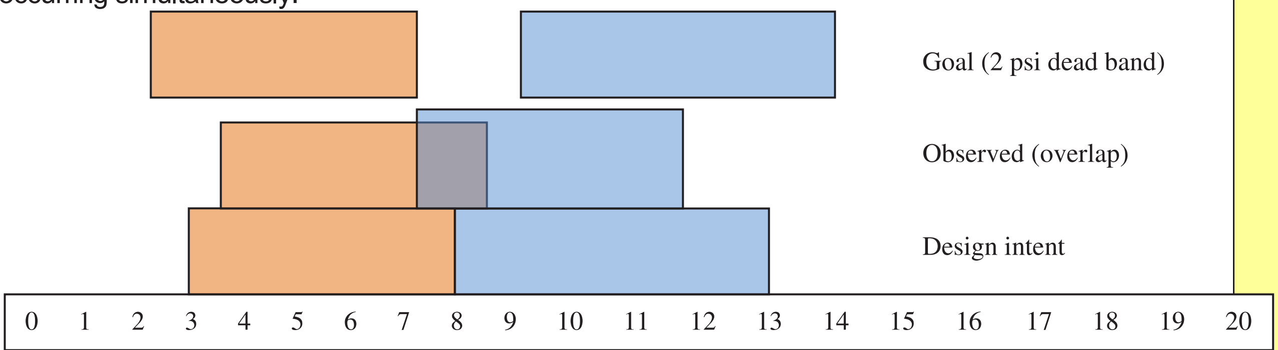
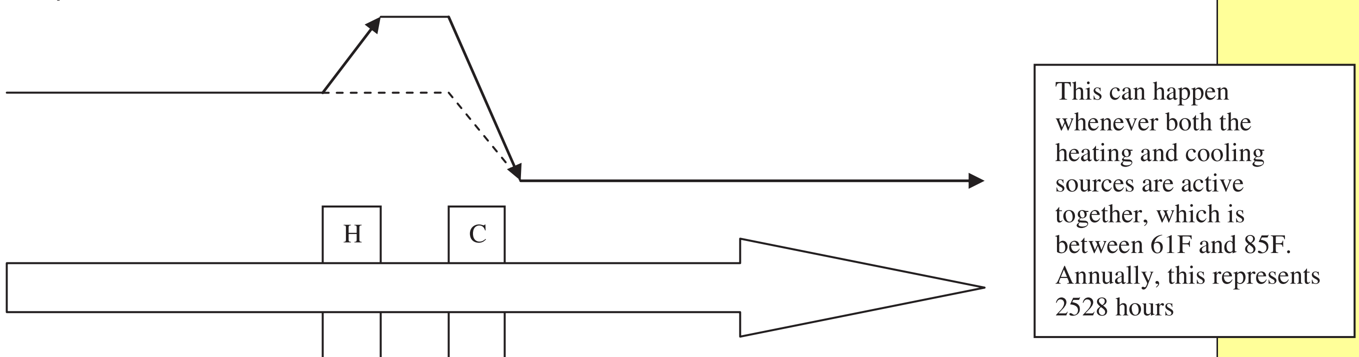
Control Change: Overlapping Mechanical Heating and Cooling

The air handler heat/cool valves are mechanically sequenced from a common pneumatic signal. This defers the sequencing of heat/cool energy to the spring ranges of the valve actuators. The specified spring ranges are 3-8# and 8-13#, and are shown in the diagram. In theory, this prevents overlap, but in practice it is easy to have overlap and overlap was observed in the field; e.g. heating and cooling occurring simultaneously.



On an airflow basis, the overlap looks like this. The dotted line shows the same process without the overlap.

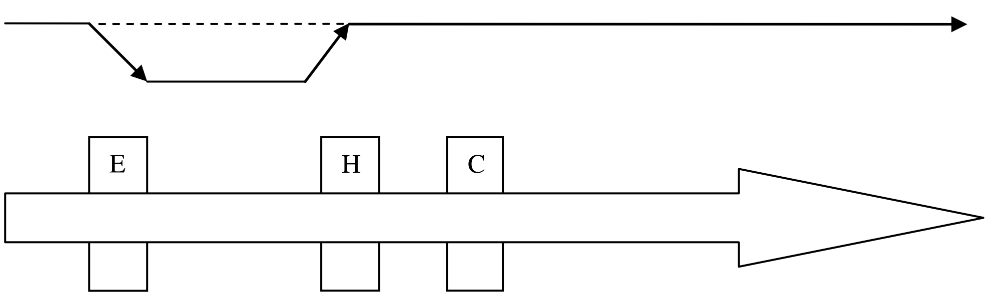


<u>Options to remove the overlap:</u>

In all options, the goal is to provide a minimum of 2 psi separation or “dead band” where neither heating nor cooling occur. This allows a little space for reality to occur as things drift over time, preventing the overlap energy waste.

1. If one of the actuators has a pilot positioner, the zero/span can be adjusted.
2. An in-line pneumatic “subtracting cumulator” can be used to retard the signal to one of the valves, creating the dead band.
3. The common signal can be removed in favor of an individual digital output and I/P transducer for each valve; then the sequencing and dead band are accomplished through software.

</td><td>Low Cost</td></tr>
</table>

Descriptions of Suggested Measures	Type
Control Change: Overlapping Economizer and Heating Control code maintains mixed air temperature at 5 degF below the supply air temperature. This functions well when OA mixing is sequenced with mechanical cooling, but it false loads the heating coil in cold weather. On an airflow basis, the overlap looks like this. The air economizer damper is shown as coil "E" for simplicity. The dotted line shows the same process without the overlap.  This can happen whenever both the economizer and heating sources are active together, which is any time below 55F. Annually, this represents 5592 hours <u>To remove the overlap:</u> 1. Whenever the chiller is off, change the <-5F> offset to zero, so the mixed air temperature setting is the same as the supply air temperature set point.	Low Cost

Descriptions of Suggested Measures	Type
Control Change: Optimum Supply Air Temperature Reset	Low Cost

Air handler supply air temperature is reset from outside air, which is reasonable. However, with DDC control to the VAV box level, which this facility has, it is possible to optimize and gain efficiency from reduced overlap.

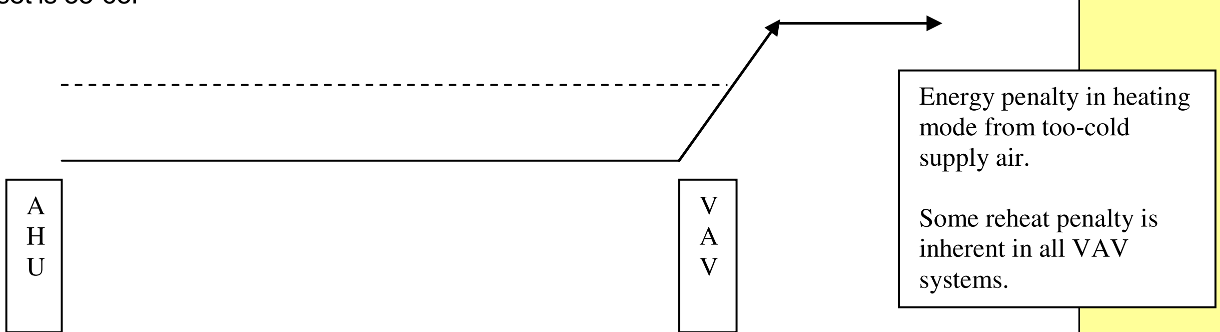
Whenever supply air temperature is colder than necessary, reheat coils in the VAV boxes make up the difference. Other than a review of control screens, this overlap goes undetected. Conversely, if the supply air temperature is too warm, this is self-alarming from hot calls. Since energy and cost are involved, the ideal supply temperature provides enough, but just enough, cooling. This must be tempered with the fact that in cooling mode, increased fan energy erases virtually all cooling savings.

This is not a simple software fix, because a give air handler serves a large number of VAV boxes and a mix of interior and perimeter zones. The optimization routine can also be spoiled by a single VAV zone with inadequate air flow (by design or otherwise), or too low of a zone setting. Barring those limitations, the optimum supply air temperature can be continuously calculated as follows:

Rough guess where a majority of VAVs are in heat mode. E.g.
<50F=heat mode.
>50F=cooling mode.

Cooling mode:
Fixed 55F (current software allows 50F)

Heating mode:
For each VAV box controller associated with a given air handler,
Find the VAV box with the highest demand for cooling
Gradually increase the supply air temperature until at least one VAV box is 95% open.
Range of reset is 55-65F



If the "polling" method of reset is not acceptable, an alternate is to revise the outside air reset schedule. Values are all degF.

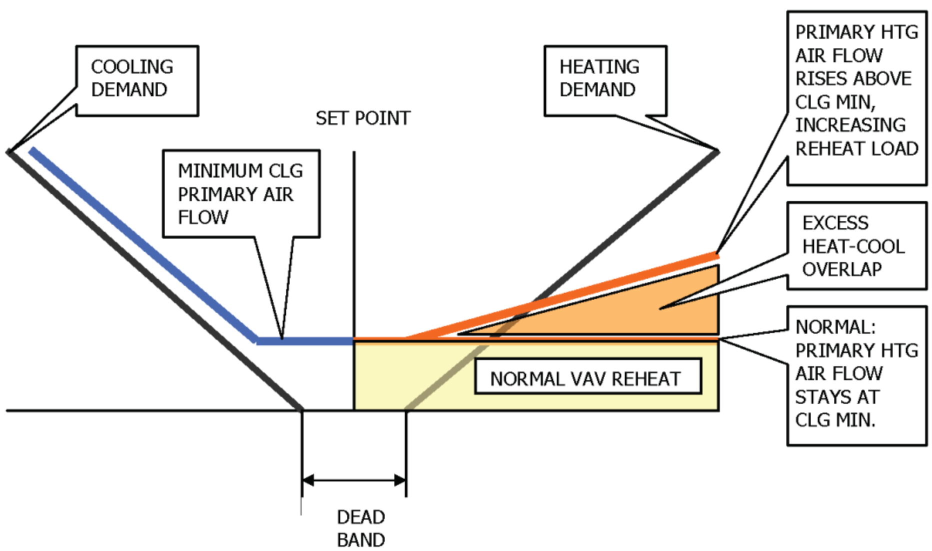
Existing

OA	SA
40	80
65	50

Proposed

OA	SA
50	60
65	55

Descriptions of Suggested Measures	Type
Control Change: VAV Heating Minimum Flows Some reheat penalty is inherent in all VAV systems; however this is reduced in magnitude in the design by using a "minimum primary air flow". Some control systems have the flexibility of "heating cfm" being different than "cooling minimum cfm". This has merit during morning warm-up, but increases energy consumption during other times and is sometimes misapplied. An example of this is shown in Appendix A. This measure calls for all VAV box heating minimum air flows to be set equal to the design cooling minimum air flows.	Low Cost



VAV BOX COOLING AND HEATING AIR FLOWS, AND INHERENT REHEAT PENALTY

Savings: 5,300 therms per year

Assumptions:
15% minimum cooling setting, 25% heating minimum setting
Heating penalty occurs at 40F and below
Heating penalty applies to 50% of VAV boxes
300,000 cfm design air flow

Descriptions of Suggested Measures	Type
Control Change: Lower VAV Static Pressure	Low Cost

Most of the energy savings potential of a VAV system is in the supply fan. The formula for air horsepower contains both volume and pressure. In a friction-only system, the static pressure reduces as the square of the volume and the power reduces as the cube of the volume. In practice, the power reduction is closer to the square, and the pressure is not reduced past a certain point because of the need for a maintained downstream pressure setting.

$$SP_2 = \left[SPx * (CFM2/_{CFM1})^{2.0}\right] + CSP$$

Where:

CSP = the constant downstream pressure (lift)

SPx = the static pressure related to friction

Commercial Energy Auditing Reference Handbook, 2nd ed, Fairmont Press

The downstream duct static pressure settings are set to 1.5 in. w.c. Excess pressure is dissipated by the VAV boxes that cut the air down by closing dampers. Thus, too much pressure is undetected unless reviewing control screens. Conversely, too little pressure is self-alarming, probably from hot calls. Since energy and cost are involved, the ideal pressure setting is enough, but just enough to satisfy the VAV box air flow demands.

To get this exactly, VAV box damper commands are polled and the pressure is reset gradually downward until at least one VAV box damper is 90% open.

Alternately, a portion of the savings can be achieved by an outdoor air reset schedule.

Existing

SP (in. w.c.)
1.5 constant

Proposed

OA (degF)	SP (in. w.c.)
80	1.5
40	0.7

Savings for the 9 air handlers can be roughly estimated.

Savings: 110,000 kWh per year

Assumptions:

40% minimum flow, which occurs at 40F

300,000 cfm design air flow, which occurs at 95F

3.0 in. w.c. static pressure associated with friction

1.5 in. vs. 1.0 in. w.c. duct static setting

Effect of lowering static in winter is not calculated and will add to savings

Descriptions of Suggested Measures	Type
Control Change: Operate Only One Chilled Water Pump with One Chiller Flow increases with two pumps, but does not double. Flow resistance through the chiller barrel increases with the square of the flow and places the two parallel pumps on a different point of the system curve. The exact flow two pumps provide requires pump curves, but a range of 50-80% (extra flow by adding a second pump) is typical. Likewise, the kW of two pumps is not equal to 2x the kW of one pump. This measure calls for running just one pump with one chiller. To do this, the system dT must be raised from 6 degF; if the air handlers can produce no more than a 6 degF rise, then the existing operation of two pumps is preferable to running a second chiller. It may be possible to raise the system dT with low cost measures. The following is suggested; however be sure to mark all original balance valve and control set points so they can be returned to original states if results are not acceptable. • Raise the supply air temperature. This is noted in a separate measure. Controlling to 50 degF instead of 55F will tax the limits of the heat exchanger coils in the air handler, creating a lower leaving temperature and lower dT. • Raise the chilled water temperature. 45F is suggested. • Adjust balance valves. (mark the valve position before making this change) On a hot day, slow or stop an air handler so as to let the room temperature rise to 75 or 80F. Command the chilled water control valve fully open. Command VAV boxes to minimum 75% open and release the fan control. With this "full load" condition, adjust the water balance valve until 55F is achieved. • Return the VAV minimum air flow settings to their normal values. **Savings: 23,000 kWh per year** Assumptions: 2500 run hours per year for the chiller. Regardless of load, when the chiller is on, the pump is at its fixed kW 20 Hp pump 80% of motor load, 90% motor e = 13.3 kW 70% flow increase with the second pump / corresponding 70% kW increase; two pumps=22.5 kW	Low Cost
Consumptive Use Adjustment for Cooling Tower Sewer billing presumes the water coming into a building leaves the building. In the case of a cooling tower, this is not true, and a sewer credit is available if utility sub metering is used. The standard factor is 82%, which means for each 1000 gallons used by the cooling tower, the sewer bill for that branch would be 180 gallons instead of 1000 gallons. The utility sub meter is a standard water meter, with an automatic meter reading point and makes the sewer flow reduction within the billing system. The fee for the meter is $0.08 per day. **Savings: Rough estimate: 950,000 gallons of sewer charges~ $4,300 per year.** Please contact your account manager if interested in the consumptive use credit. Assumptions: 450 ton chiller at half load for the entire 2500 hours that exist above 61F outside air temperature, 1.2 heat of compression, 20% blow down	Low Cost

Descriptions of Suggested Measures	Type
Interlock Baggage Tug Area Make Up with Exhaust This measure is being pursued by the customer. Basis of Savings: reduced ventilation and associated heating energy. The two make up air units run continuously at present, while the exhausters run when carbon monoxide is detected. This measure calls for the two ventilation units to operate only when the carbon monoxide detector starts the exhausters to remove vehicle fumes. With ventilation being dependent upon the CO instrument, this measure also calls for calibrating the CO alarm device initially and periodically ongoing, to assure that ventilation is provided when it is needed. **Savings: 30,000 therms per year.** Assumptions: 28,000 cfm ventilation air combined Heating supply air temperature setting 70F 50% run time reduction with the interlock added	Low Cost

Descriptions of Suggested Measures	Type
Replace Cove Lighting in Concourse	Capital

Basis of savings: Improved lighting system efficiency from better reflectivity.

Existing lighting is indirect, and depends upon the reflectivity of the ceiling panels. These panels have a rough surface and are tinted with age. Reflectivity is less than optimal for indirect lighting and may lose as much as 30-40% of light impinging upon it.

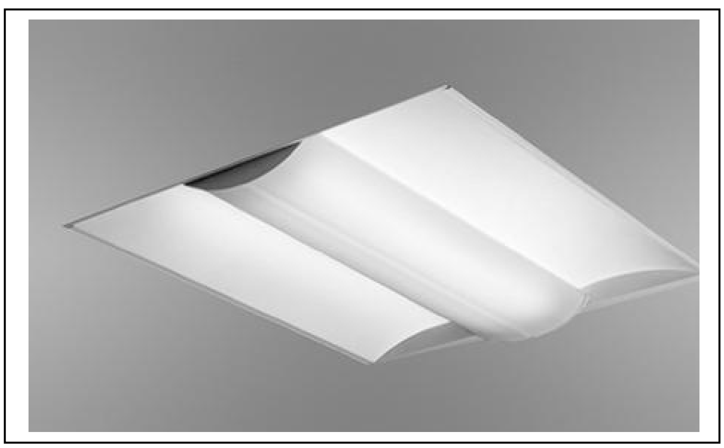
Lighting in the coves is strip fluorescent T8. The light source itself is not inefficient, however the light system is inefficient due to the absorption of the ceiling tiles.

This measure calls for calculating the existing wattage of lighting in each cove and using this as a lighting power budget for new lights. New lights would be indirect/direct fixtures. Note that these have a highly reflective “indirect surface that can be wiped down with each lamp replacement, for long term reflective performance. Perforations prevent the „dark spot appearance, and a Mylar sheet reduces the glare at the perforation holes.

The unused coves would become dark spots which may be objectionable. If so, some very low power lighting in the coves could be used, but would subtract from the available lighting power for the new fixtures. By not relying on the cove lighting for the primary source of vision light, much less power would be needed.

With all lighting design changes, taking before/after light readings is suggested to assure that proper light levels are maintained. Also, a mock-up of a small area is suggested to allow aesthetics to be evaluated and a comfort level established before a wide spread project.

Savings: NA. This measure improves light levels without increasing energy use.



Gull-wing recessed indirect/direct

Cable mounted indirect/direct

Descriptions of Suggested Measures	Type

Replace Fluid Cooler with Roof-Mounted Cooling Tower

Basis of savings:

- Avoided repair cost (Unit is near end of life)
- Elimination of forced heating of the cooling tower during winter to prevent freezing (new system would use indoor sump)
- Reduced head pressure and power requirement for the chiller (reduced heat exchanger approach; existing tubes have fouling and some are plugged from freeze damage). See photo, Appendix B.
- Reduced fan Hp (about half)
- Reduced pumping (ability to run one condenser pump instead of two)
- Eliminates one step of heat transfer which inherently improves the overall heat transfer process.

This measure calls for replacing the existing fluid cooler with a new cooling tower (not fluid cooler), to be located on a roof. An indoor sump would be used to reduce roof weight, prevent the need to drain down the cooling tower for freeze protection, and eliminate the need for basin heaters and their energy use (can be significant). To achieve the savings indicated below, cooling tower specifications:

- Cooling tower fan power budget 0.07 kW or less per ton of cooling while providing 75Fewt/65Flwt/58Fwb performance (10 degF range, 7 degF approach).
- No basin heaters

In practice, this requires a large cooling tower "box" with ample surface area for heat exchange between air and water, and minimal air pressure drop. Low velocity, low resistance air path from slow moving large diameter axial blades creates low horsepower requirements. The cooling tower can be metal or plastic body, as desired; plastic towers are sensitive to sunlight and require a suitable fire/smoke rating. Stainless steel is commonly used for cooling towers, and can be a provided fully stainless body (entire box and top) or just the upper/lower basins.

Counter-flow cooling towers take air from the bottom. These look much better, but cost more. This unit uses fiberglass panels; metal panels are also available.

Conventional cross flow cooling tower is the least costly solution. However they don't look this nice after awhile. The black sides are where air comes in, and these become discolored with lime and look poor (doesn't affect operation, but looks bad.)

Descriptions of Suggested Measures	Type
Various design options are available including # of cells (2 is suggested), fill control, fan drive, motor location, and service access. Variable speed fan control offers 10-15% energy savings improvement over 2-speed operation. Indoor sump is strongly suggested.	

Notes:
1. Moving the cooling tower to the roof will inherently improve efficiency, however structural support must be engineered.
2. This will require a change of operating procedure that includes condenser tube cleaning annually.

Comparison of heat exchanger approach with properly specified new cooling tower. All values are degF

Measured Values	Existing	Proposed
Ambient wet bulb	42.8	42.8
Leaving fluid temp (entering condenser water temp)	69.2	49.8
Approach	26.4	7.0

Extrapolated Values*	Existing	Proposed
Ambient wet bulb	63	63
Leaving fluid temp (entering condenser water temp)	89.4	70
Approach	26.4	7.0

*Field test results suggest a dysfunctional fluid cooler, but the test was limited and extrapolation may not be valid. Unknowns include plugged tubes pursuant to prior freeze damage, fan and spray pump operation, and running two pumps with one chiller (this is done to compensate for capacity reduction from freeze damage). Thus, poor heat transfer can be attributed, at least partly, to factors other than the heat exchanger tube condition.

Savings:

	therms/yr	kWh/yr
Heat loss from boiler	4,185	
Run 1 condenser pump instead of two		33,156
Run with half the cooling tower fans		101,229
Chiller efficiency gain		26,410
total	4,185	160,794

Assumptions:
900 ton nominal capacity
560,000 ton-hours cooling load per year that is rejected to the cooling tower
2500 hours per year chiller and pump operation (hours above 60F)
3100 hours per year with warm boiler water circulating through the tubes.
10% convective capacity with fans off; this is used to estimate heating losses from using boiler water to prevent tube freezing at temperatures below 40F. With intake air dampers and outlet dampers closed, reduce this by 90%.
(4) 25-Hp cooling tower fans replace (4) 50 Hp fluid cooler fans
(1) 50-Hp condenser pump runs with one chiller, instead of (2)
Condenser temperature at the chiller reduced by 10 degF.

Descriptions of Suggested Measures	Type
Occupancy or CO2 Control of Ventilation Basis of savings: Reduced ventilation	Capital

This measure consists of occupancy sensors in offices and CO2 sensors in large open areas to determine when VAV minimums can be reset to zero and when outside air minimum settings can be reduced.

Reduction of VAV flows will reduce outside air intake if all of them are at minimum. This will shift the building pressurization – it is expected that there is more than enough outside air in which case the building pressure controls will automatically adjust (exhaust dampers will close down some), but this will need to be watched.

Savings:

	kWh	therms
Heating season		17,421
Cooling season	26,710	1,908

Assumptions:
Ventilation rates are set for design occupancy
Actual occupancy is less; presumed

% time	% occ
25%	100%
50%	50%
25%	25%

HVAC systems are not single zone, so ventilation loads cannot be evaluated directly.

300,000 cfm total design air flow, all AHUs combined
Design ventilation 35,000 cfm, and reduces proportionally with supply air cfm.

Winter savings based on:
Ventilation load included below 40F (other times are indeterminate; could be beneficial for economizer)
25% of boxes are serving unoccupied areas, SA temperature of 60F, 15% VAV box minimums, with reheat to 70F
"winter" assumed to be November through March, 5 months
0.8 COP

Summer savings based on:
Ventilation load included for all air above 60F
25%of boxes are serving unoccupied areas; SA temperature of 55F, 15% VAV box minimums, with reheat to 72F
"summer" assumed to be June through August, 3 months
4.4 COP

Descriptions of Suggested Measures	Type
Exterior Lighting Ballast Replacement Basis of savings: Reduced ballast losses. Parking lot lighting was explained to use 250W High Pressure Sodium lighting with magnetic ballast. This measure proposes to replace the magnetic ballast with electronic ballast. Savings of 10-15% are typical with this type of retrofit. The parking lighting is metered separately, so the usage is known. **Savings: 31,000 kWh per year** Assumptions: 10% reduction 313,740 kWh usage in 2011	Capital
Extend Vestibule Length for Air Lock Basis of savings: Reduced infiltration. The vestibule is intended to be an air lock, where one door closes before the next one opens. The main entrance is where all customers enter the building which makes this the main point of infiltration of outside air. The doors are ill-timed and both open at the same time, however this would probably be the case anyway with a passenger with bags in tow, due to the short length of the vestibule. This measure consists of adjusting the timing of the vestibule doors so they function as an air lock, and extending the vestibule (either in, or outside the building). An approximation would be to double the length of the vestibule. Savings not calculated. Multiple variables make this difficult to estimate without more information; most notably the number of times the doors are opened annually.	Capital

Descriptions of Suggested Measures	Type
Jockey Boiler for Summer Reheating	Capital

Jockey Boiler for Summer Reheating

Basis of savings: Reduced boiler losses

There are a variety of boiler losses that occur during low load operation, mostly associated with short cycling (See **Appendix E**). These were estimated separately and shown here combined. Note the overall boiler efficiency drops sharply above 60F.
Boiler is presumed off >85F.

overall efficiency (box=useful)	OA temp
	93
	88
67%	83
67%	78
67%	73
67%	68
67%	63
65%	58
74%	53
76%	48
77%	43
78%	38
78%	33
78%	28
79%	23
79%	18
79%	13
79%	8
79%	3
79%	(3)

overall efficiency (box=useful)	OA temp
	93
	88
80%	83
80%	78
80%	73
80%	68
80%	63
80%	58

Jockey boiler stabilizes thermal efficiency

		therms
		1,979
Large boiler tot. loss	Small boiler	Small boiler savings
-	-	-
-	-	-
20,842,275	5,101,713	15,740,562
27,057,592	6,621,693	20,435,899
33,895,990	8,293,041	25,602,949
39,741,322	9,720,096	30,021,226
63,958,290	15,637,433	48,320,858
74,194,221	16,448,704	57,745,517

This measure consists of a small "pool heater" boiler (jockey) for operation during mild weather. Preliminary estimate of size would be 250,000 Btuh output (probably less). Savings presume 100F operation and condensing at 96% combustion efficiency, with a stack damper. The low temperature operation increases boiler efficiency and simultaneously lowers distribution losses. This unit would have shared duty with snow melt system in winter. (See Snow Melt Options)

Savings: 1900 therms per year

Assumptions:
5000 Mbh max load
Existing boiler 83% Ec, 7500 Mbh max input / 3500 min input
Existing chimney losses limited to 10% of theoretical, since burner dampers close off
200 Mbh load in summer, between 65 and 85F OA
New boiler operated at 100F, 90% comb eff, with stack damper
Summer operation includes 100F temperature operation
Boiler off >85F

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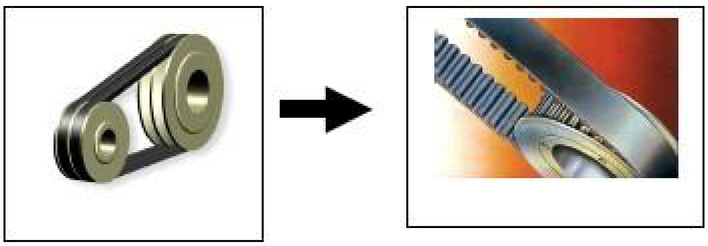
Synchronous Belts

Basis of Savings: Reduced slippage, which is dissipated as heat

Standard V-belts have a small inherent energy loss from slippage. Synchronous belts eliminate slippage by not relying on friction to transmit power. Standard V-groove sheaves are replaced with sprockets that, with the special belt, behave as a chain, with no slippage. Typical savings is 5% of power transmitted through the belt system. Synchronous belt life is similar to V-belts but can be extended by choosing larger diameter sprockets (same ratio), as this reduces the bending stress upon the belt.



Due to the cost of the sprockets and installation, the economics are more favorable for larger motors and those with high annual run hours. The main air handling unit fan motors appear to be a good fit for synchronous belts. Of those, the supply fans have the higher motor Hp and higher loading.

Savings: 43,000 kWh per year

Assumptions:
All nine (9) air handler supply fans converted to synchronous belt drive systems
5% slippage of existing drive
Weighted average 50% air flow 8760 hours per year
80% full load motor duty factor

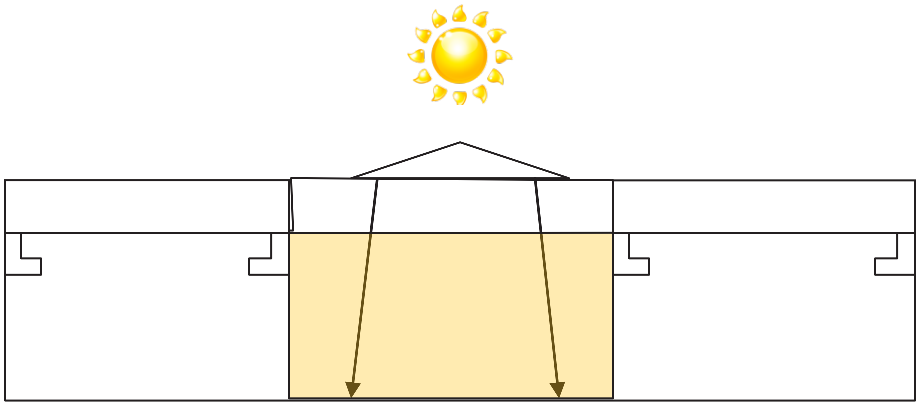
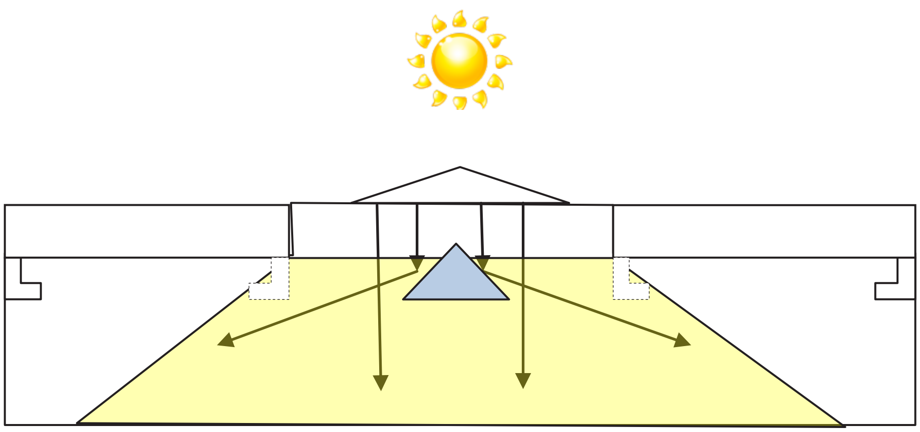
</td><td>Capital</td></tr>
</table>

Descriptions of Suggested Measures	Type
Snow Melt Efficiency Options Snow melt offers unique efficiency opportunities because it is low grade heat (low temperature). The snow melt energy usage baseline is unknown and difficult to guess, so the savings are given only in general terms. With some measurements and operator logs or trends, this could be quantified in terms of energy savings units per year. Option 1: Shared condensing heater. *Sharing* the standard condensing "pool heater" (see Jockey Boiler), the 100F snow melt water can be created with very high efficiency, 96% or higher, which uses less fuel than creating 180F water at 80% thermal efficiency and then a heat exchanger to reduce it to 100F. This measure only works if the snow melt load is a close match for the heater used for summer jockey heating. With the jockey boiler in place, this would be a very cost effective option. **Savings: 16% fuel use reduction for snow melting** Option 2: Boiler stack recovery. This measure presumes that the building heating boiler runs concurrently with a need for snow melt. Whenever the boiler is off or cycling off, snow melt would be without a source of heat, however if the running boiler is expected to be on at least low fire during snow and ice times, this will not be a concern. Using a packaged stack gas condenser, all of the snow melt energy would be provided by waste heat from the boiler. Assuming snow removal occurs below 30F, boiler capacity for space heating would be at around half capacity, which would be ~3500 Mbh input // and rejected heat from the stack of ~525 Mbh. Easily half of this can be extracted with a condensing heat exchanger, providing 250 Mbh of available heat for snow melt; similar in capacity to the proposed jockey boiler/pool heater. The measure would include combining the three boiler flues into one common flue, so that a single heat recovery device could serve the three boilers. Stack dampers would be used for each of the three inlet flues to control the path of the hot gas. Additional flue piping would be required (main flue, down to ground level) to the heat recovery unit and to prevent any condensation from traveling backwards into the boilers. This measure would likely displace existing storage shelving from the room. **Savings: All snow melt energy free.**	Capital

Condensing heat recovery unit, floor mounted. Sidel

Condensing heat recovery unit, floor mounted. AIC

Descriptions of Suggested Measures	Type
Natural Lighting Redesign in Concourse Basis of savings: turning concourse lights down or off during daylight hours. 400 foot-candles of light were measured at the seating area in the center of the concourse, which is at least 5xc more than needed. 40 feet away on each side of the skylight, are 20 foot-candles in the gate area. This measure proposes "some" method of dispersing the light from the long skylight radially to the side areas. If effective, lighting in those areas could be reduced in daylight hours and only lit at night. One example of a suspended prism below a skylight is shown below. Note also the auxiliary lighting for night time, which is absent in the concourse. This would require the services of a skilled daylight designer. Note: lighting design proposal is conceptual. There may be a valid reason for having the gate areas shielded from the sunlight. One criterion would be to assure the gate screens are not touched by direct sunlight so as to make them hard to read.  Kimbell Art Museum in Forth Worth sparcdesign.wordpress.com	Capital

Descriptions of Suggested Measures	Type
 Existing. Concourse skylight with cove light gates on either side.  Proposed. Note removal of a portion of the cove structure to eliminate the light cutoff	

Descriptions of Suggested Measures	Type
Irrigation Water use is significant, so a quick check was done for irrigation, presumed to be the large user. The reported amount of turf is (7) acres which is 304,920 SF. A rule of thumb for supplemental irrigation for Kentucky Blue Grass is 2.0 cubic feet per year per SF of turf, which would yield 609,840 cubic feet of water use in a year. (2.0 cf per SF provides the equivalent of 24 inches of annual rainfall, as a supplement to natural rainfall) The overall water use for the airport in 2011 was 3,077,201 cubic feet The overall sewer flow for 2011 was 971,381 The difference between the two is usually from a sub metered process; the cooling tower is not being sub metered, which suggests the difference is attributed to irrigation. Subtracting the two yields 2,105,820 cubic feet used for irrigation. This is 6.9 cubic feet per SF turf, several times higher than the rule of thumb would predict. This suggests either • There is more grass than 7 acres • There are more uses for the sub metered water than irrigation • The grass is being over-watered.	Strategic
For Tenant Restaurants Suggested requirements for tenant improvements involving kitchens: • 80% make-up for all hoods, within the restaurant (taking no more than 20% of hood air flow replacement air from the main building) • Clean refrigeration condensing units 4x per year, applies to walk-ins and reach-ins • Use gas-fired appliances. (electric heating comes from the airport utility meters) • Restrict cooler settings to 37F and freezer settings to 0F Suggested maintenance provision: The „hands off stipulation for tenant equipment has the unfortunate consequence of neglected and dysfunctional equipment. If a mutual agreement is available, the overall facility would be better served by having City Airport maintenance caring for the tenant HVAC, refrigeration, and kitchen equipment. This is especially true for electrically operated equipment, since these are not served by tenant sub meters.	Strategic

Descriptions of Suggested Measures	Type
Future Equipment Replacement When major equipment is due for normal replacement, the following will help "build-in" higher efficiency. Asserting owner preferences into the design phase of any alterations or additions will also help assure input on efficiency desires are heard by the design team. Right size boilers. The existing boilers are oversized. Other than during snow/ice removal, one boiler will carry the building in any weather. The resulting short cycling reduces thermal efficiency considerably. See chart in **Appendix E**. Higher efficiency equipment. Whenever equipment is replaced, opting for highest available efficiency is suggested as a way to hedge against utility increases over the next 20 years. It is suggested to determine the cost of a baseline "just meets code" option and establish this as the normal replacement cost. The cost of efficient upgrades is fair to pit against expected savings. Boiler and chiller control. The control system currently "enables" these units, but cannot perform any adjustments, so things like automatic reset are not being used. Whenever these units are replaced, in addition to high efficiency options, select equipment that can integrate with the automatic control system. Higher roof insulation. Based on the blocking at the roof scuttle access, there appears to be about 3 inches of insulation which would be around R-15. Whenever roof replacement occurs, it will be cost effective to add insulation. Skylight glazing. When these are replaced, careful selection of materials and lowE coatings can optimize performance. Triple pane systems will reduce thermal losses, which are high in winter (these are a „hole in the insulation). In a mixed climate like ours, it is not clear whether heating or cooling dominates; this must be determined before deciding on coating and tinting or a suspended screen; i.e. is the hope to keep the heat out or in? An 8760 hour model of the concourse upper level is needed to know. Hot water coil selection. When heating coils are replaced, selecting them for full capacity at 140F water will enable deep resets of hot water and full condensing for replacement boilers. A condensing boiler will condense only if the building "lets it".	Strategic

NOTABLE EFFICIENT PRACTICES

Equipment has been well maintained. Careful maintenance and knowledgeable operator attention was evident in all areas, including intimate knowledge of automatic controls and programming capability. This level of diligence will pay dividends of reliability and energy efficiency for the airport.

Exception: the rooftop equipment serving the tenant kitchens showed significant neglect.

Motors are premium efficiency type

Good use of outside air economizer, and turning chiller off in mild weather.

Ultra-low flow plumbing fixtures

Motorized valves isolating manifold-connected boilers and chillers

SAFETY AND HEALTH OBSERVATIONS

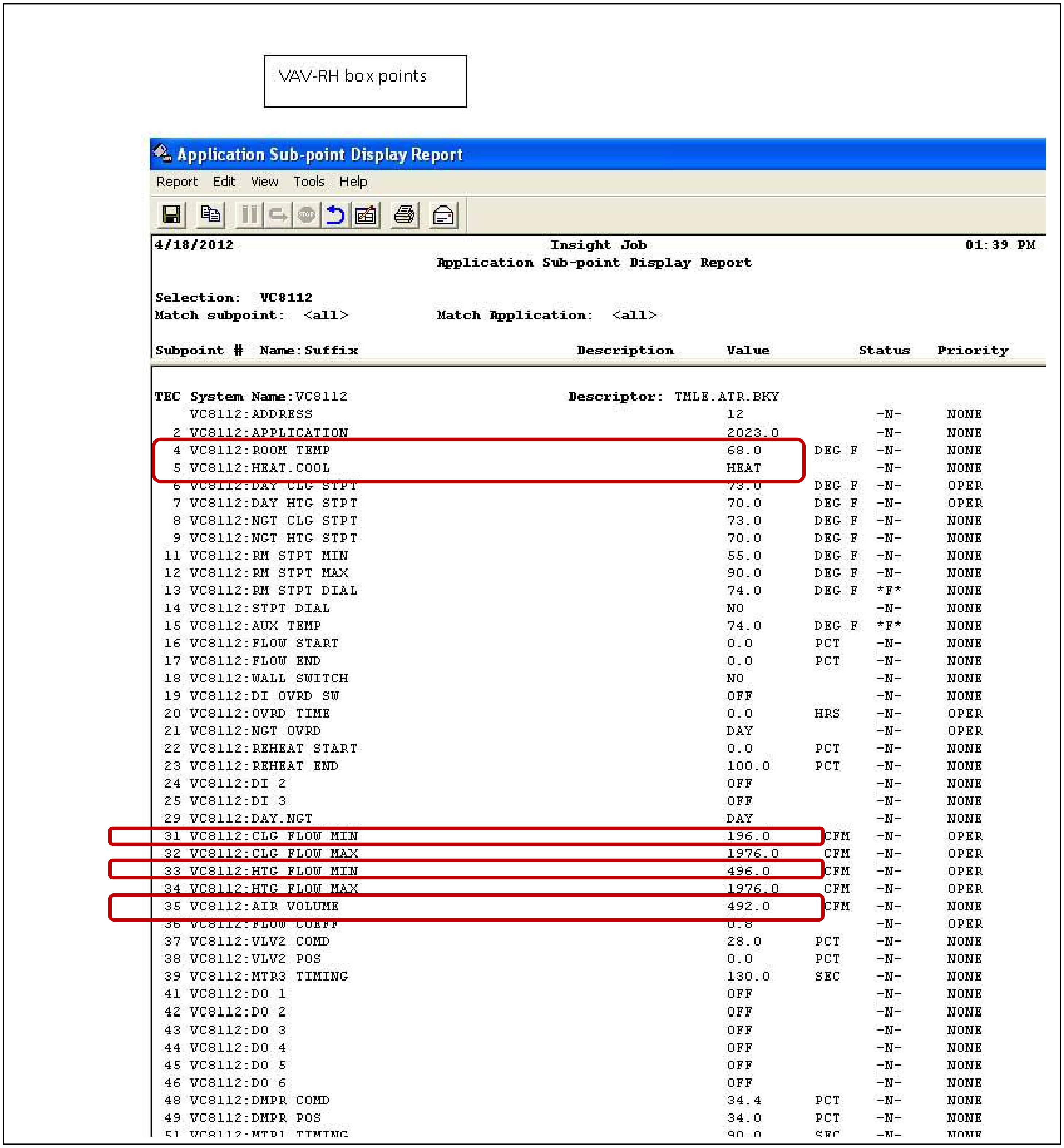
Colorado Springs Utilities strongly recommends that the Owner seek the advice of a qualified independent third-party consultant/engineer to verify and resolve the following issues.

(SAFETY ITEM) In our visits to the mechanical rooms, it was noticed that one room was being used as a storage/staging room for remodel construction. One of the equipment items in this room is gas-fired (make up unit for a kitchen hood). Storing flammable materials (boxes, carpet, etc) on and around this burner creates the possibility of fire.

(SAFETY ITEM) In our visits to the concourse kitchen, it was noticed that two hoods were not capturing the cooking fumes from the appliances below (100F ceiling temperature and discolored ceiling tiles). It was later found that the associated hood exhauster was off, evidently without a motor. The lack of hood capture means that if the cooking appliance catches fire, the fire suppression system within the hood will have impaired ability to control the fire.

Appendix A: Heating Minimum Air Flow

Control screen showing heating minimum air flow settings elevated above cooling minimum values. This false-load the room by over-cooling and adds an offsetting amount of heating energy. It was 70F outside at this time.



4/18/2012 Insight Job 01:39 PM

Application Sub-point Display Report

Selection: VC8112

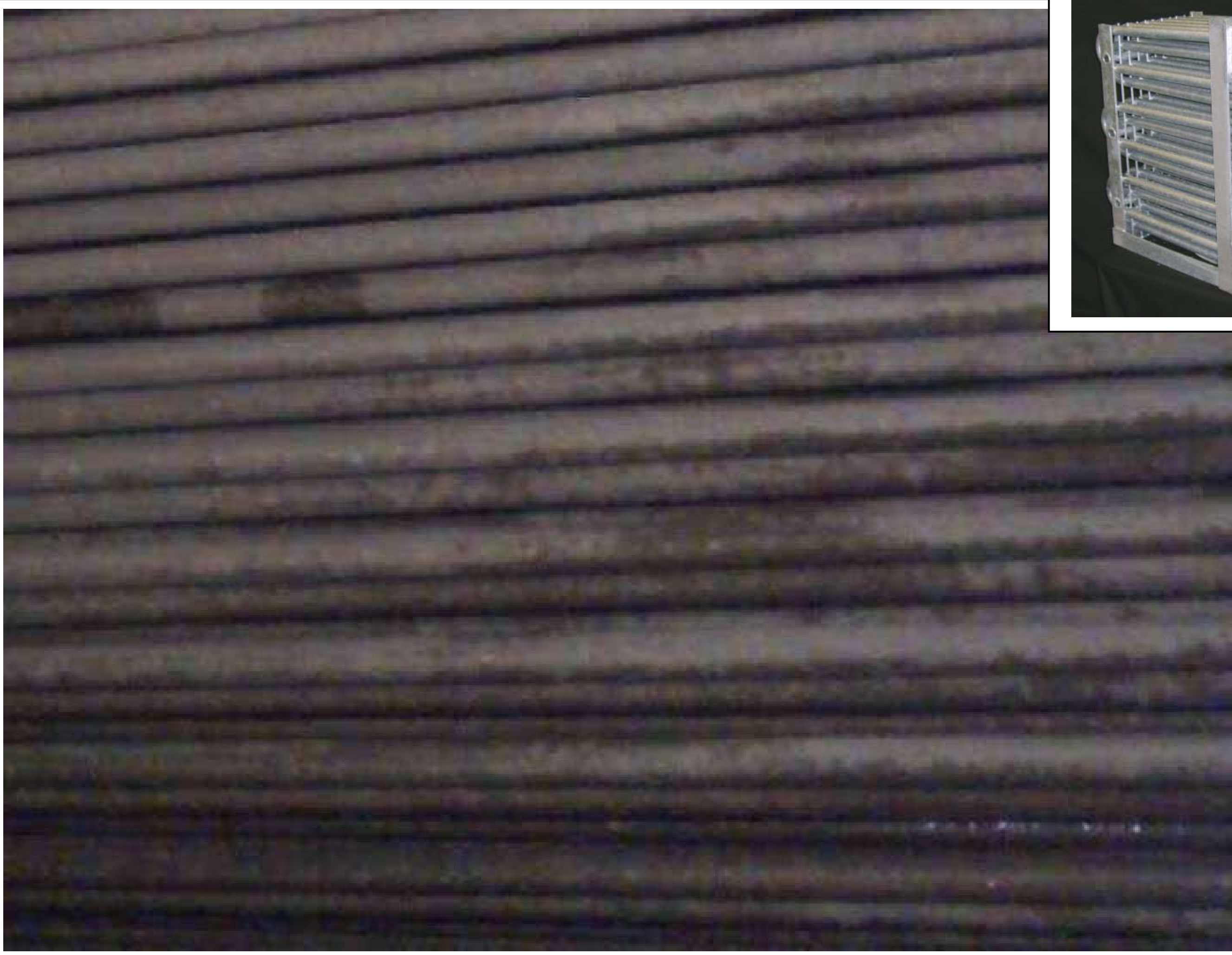
Match subpoint: <all> Match Application: <all>

TEC System Name:VC8112 Descriptor: TMLE.ATR.BKY

Subpoint #	Name:Suffix	Description	Value		Status	Priority
	VC8112:ADDRESS		12		-N-	NONE
2	VC8112:APPLICATION		2023.0		-N-	NONE
4	VC8112:ROOM TEMP		68.0	DEG F	-N-	NONE
5	VC8112:HEAT.COOL		HEAT		-N-	NONE
6	VC8112:DAY CLG STPT		73.0	DEG F	-N-	OPER
7	VC8112:DAY HTG STPT		70.0	DEG F	-N-	OPER
8	VC8112:NGT CLG STPT		73.0	DEG F	-N-	NONE
9	VC8112:NGT HTG STPT		70.0	DEG F	-N-	NONE
11	VC8112:RM STPT MIN		55.0	DEG F	-N-	NONE
12	VC8112:RM STPT MAX		90.0	DEG F	-N-	NONE
13	VC8112:RM STPT DIAL		74.0	DEG F	*F*	NONE
14	VC8112:STPT DIAL		NO		-N-	NONE
15	VC8112:AUX TEMP		74.0	DEG F	*F*	NONE
16	VC8112:FLOW START		0.0	PCT	-N-	NONE
17	VC8112:FLOW END		0.0	PCT	-N-	NONE
18	VC8112:WALL SWITCH		NO		-N-	NONE
19	VC8112:DI OVRD SW		OFF		-N-	NONE
20	VC8112:OVRD TIME		0.0	HRS	-N-	OPER
21	VC8112:NGT OVRD		DAY		-N-	OPER
22	VC8112:REHEAT START		0.0	PCT	-N-	NONE
23	VC8112:REHEAT END		100.0	PCT	-N-	NONE
24	VC8112:DI 2		OFF		-N-	NONE
25	VC8112:DI 3		OFF		-N-	NONE
29	VC8112:DAY.NGT		DAY		-N-	NONE
31	VC8112:CLG FLOW MIN		196.0	CFM	-N-	OPER
32	VC8112:CLG FLOW MAX		1976.0	CFM	-N-	OPER
33	VC8112:HTG FLOW MIN		496.0	CFM	-N-	OPER
34	VC8112:HTG FLOW MAX		1976.0	CFM	-N-	OPER
35	VC8112:AIR VOLUME		492.0	CFM	-N-	NONE
36	VC8112:FLOW COEFF		0.8		-N-	OPER
37	VC8112:VLV2 COMD		28.0	PCT	-N-	NONE
38	VC8112:VLV2 POS		0.0	PCT	-N-	NONE
39	VC8112:MTR3 TIMING		130.0	SEC	-N-	NONE
41	VC8112:DO 1		OFF		-N-	NONE
42	VC8112:DO 2		OFF		-N-	NONE
43	VC8112:DO 3		OFF		-N-	NONE
44	VC8112:DO 4		OFF		-N-	NONE
45	VC8112:DO 5		OFF		-N-	NONE
46	VC8112:DO 6		OFF		-N-	NONE
48	VC8112:DMPR COMD		34.4	PCT	-N-	NONE
49	VC8112:DMPR POS		34.0	PCT	-N-	NONE
51	VC8112:MTR1 TIMING		90.0	SEC	-N-	NONE

Appendix B: Fluid Cooler Tube Fouling Photo

View is looking at the bottom of the tube bundle.
This happens eventually, even with excellent maintenance. The tubes are 8-12 rows deep and defy cleaning. The cooling tower proposal re-locates the mineral deposits to the inside of the chiller tubes where they are readily accessible for cleaning.



Appendix C: Partial Equipment Listing

Air handlers

ID	Serves	CFM total	ESP	TSP (est)	CFM outside air	Supply fan Hp	Return fan Hp
AHU-1	Bag claim east	31385	2.0	4.0		50	15
AHU-2	Bag claim west and main elec room	26405	2.0	4.0		40	15
AHU-3	Ticketing level west	59725	1.9	3.9		75	30
AHU-4	Ticketing level east	58985	1.9	3.9		75	30
AHU-5	Admin	20145	2.0	4.0		30	10
AHU-6	Lower concourse south	25310	2.15	4.15		40	10
AHU-7	Upper concourse south	46280	2.55	4.55		75	30
AHU-8	Lower concourse north	38420	2.35	4.35		75	20
AHU-9	Upper concourse south	54545	2.6	4.6		100	30

ESP was given. TSP is estimated based on assumed pressure drops:

0.75 filters, mid-life
0.6 cooling coil
0.2 casing misc loss
0.3Fan entrance/exit loss
0.15 mixing dampers
2.0 in.w.c. total, added to ESP

Make up air

Serves	CFM OA
MUA for baggage tug	14,000
MUA for baggage tug (#2)	14,000
MUA for terminal-side restaurant	4900
MUA for concourse restaurant (#2)	4000
MUA for concourse restaurant (#2)	6000

Other

Qty		Serves	GPM	Head	Hp
3	Water tube boiler	All. 7000/3500 Mbh input ~			
3	Pump	Boiler circulator (primary)			5
2	Pump	HW distribution (secondary)			15
2	Centrifugal chiller	All. 480 tons nominal / 410 fla ~ 273 kW			
2	Pump	Chiller circulator (primary)	840	30	20
2	Pump	CHW distribution (secondary)	1100	54	30
2	Pump	Condenser water pump	1500	90	50
4	Fan	Fluid cooler fans (centrifugal)			50

Chilled water kW/ton overall, full load

Tons: 480
Chiller 273 kW
Tower fan(2) 83 kW
CHW pump 13 kW
CHW pump 20 kW
CW pump 33 kW
Total 412 kW and 0.86 kW/ton

Appendix D: Meter Listing

The following are the meters used for the main airport building. Other meters are not included, such as landing lights, parking lights, remote buildings.

Service	Rate	Acct	Meter	Serves
Gas	G1C	1726112983	142230	Boiler
Gas	G1C	0756369709	61065	Wespac
Elec	E8T	7015346786	557476	Chiller
Elec	ETL	0756369709	542820	Wespac
Elec	ETL	1364474319	542794	A section of terminal
Elec	ETL	1726112983	542793	B section of terminal
Elec	ETL	9451135032	542792	C section of terminal
Elec	ETL	8736831585	542822	Concourse
Elec	ETL	7490879865	542795	E section of concourse

Appendix E: Boiler Test Results

Boiler Cycling

55F

Time		
00:27	End post purge, all quiet	
03:51	Pre-purge start	204 seconds off
05:02	Boiler fires	71 seconds pre-purge
07:03	Boiler off, post purge begins	121 seconds boiler fires
07:20	Post purge off, all quiet	27 seconds post purge

On-time: 121 seconds
Full cycle time: 423 seconds
Pct run time: 28%

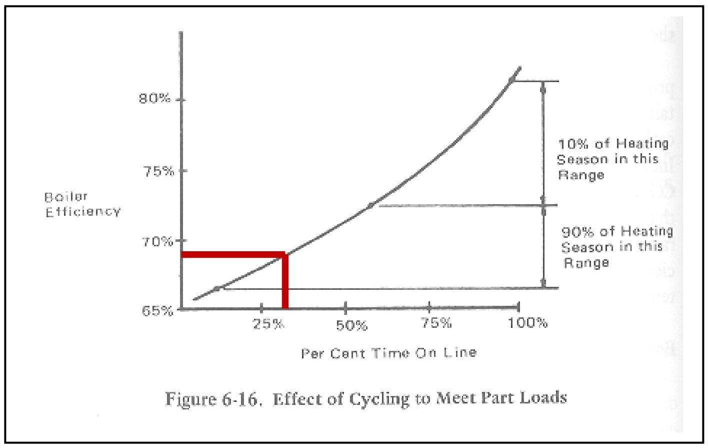


Figure 6-16. Effect of Cycling to Meet Part Loads

Boiler Combustion Efficiency

Low fire

HW	175	147 degF approach. OK
Flue	322	
Excess air	27%	
O2	4.8%	
CO2	9.5%	
Comb. efficiency	83.8%	

Lighting Savings

Year	Location	Old Fixture	Cost per day	New Fixture	Cost per day	Fixture Cost per unit	Total Fixture Cost	Simple Payback (in Yrs)
2013	BAGGAGE MAKEUP	T-12 HO	$ 66.80	LED HIGH BAY FIXTURE	$ 17.12	$ 477	$ 25,255	1.39
2013	RAMP LIGHTS	ELIMINATE OPERATIONS WEST RAMP AND ETU	$ 21.99	ELIMINATE OPERATIONS WEST RAMP AND ETU	$ -	$ -	$ -	immediate
2013	ROADWAY POLE	EVERY OTHER POLE EXCEPT TURNS	$ 23.64	EVERY OTHER POLE EXCEPT TURNS	$ 11.82	$ -	$ -	immediate
2013	LOWER HALLWAYS	NORMAL OPERATIONS T-8	$ 3.19	LED WRAP FIXTURE	$ 0.38	$ 128	$ 1,792	1.74
2013	SOUTH TUG PASSAGE	EXISTING LAMPS	$ 2.58	LED WRAP FIXTURE	$ 0.22	$ 128	$ 2,048	2.37
2013	ATRIUM	EXISTING LAMPS - uplights	$ 22.61	LED LAMPS & FIXTURES - uplights	$ 1.79	$ 591	$ 27,186	3.58
2013	ATRIUM	EXISTING LAMPS - downcans	$ 6.88	LED LAMPS & FIXTURES - downcans	$ 3.52	$ 348	$ 9,744	7.93
2013	TICKETING SKYLIGHTS	EXISTING	$ 3.60	LED FIXTURES	$ 0.63	$ 591	$ 9,456	8.73
2013	NORTH TUG PASSAGE	EXISTING LAMPS	$ 1.40	LED FIXTURES	$ 0.18	$ 128	$ 1,664	3.72
2014	CONCOURSE	2 X 4 TROFFERS	$ 0.92	2 X 4 LED TROFFERS	$ 0.56	$ 115	$ 1,380	10.50
2014	3RD FLOOR KITCHEN	2 LAMP T 12	$ 0.24	LED TROFFER	$ 0.10	$ 115	$ 575	11.06
2014	BUILDING A - FLEET BAYS	EXISTING LAMPS	$ 7.20	LED DOWNCAN	$ 1.80	$ 348	$ 10,440	5.30
2014	JETWAY GATE	EXISTING LAMP	$ 3.60	NEW FIXTURE	$ 0.13	$ 178	$ 2,136	1.69
2014	SERVICE ELEVATORS	FLUORESCENT FIXTURES T-12	$ 0.58	LED WALLWRAPS	$ 0.36	$ 128	$ 768	9.74
2014	BUILDING B	SOUTH WALLPACKS	$ 0.30	LED WALLPACKS	$ 0.10	$ 323	$ 646	8.94
2014	ACP/FUEL ISLAND	EXISTING SHOEBOX HEAD	$ 2.88	RETROFIT	$ 1.01	$ 570	$ 6,840	10.01

APPENDIX B
Minneapolis–Saint Paul Case Study

Open Architecture and Adaptive Operations
Implementing IMACS at Minneapolis-Saint Paul International Airport
Transportation Research Board, ACRP Project 09-04

Table of Contents

Section | Page

Case Study

Introduction

Most building systems are controlled by central automation systems. Software and hardware for controls and automation systems can be procured from any number of manufacturers, though components from competing suppliers may not readily communicate with each other. As building systems are added or retrofitted, the competitive procurement process typically results in multiple workstations, each controlling their respective systems. Multiple workstations complicate the task of monitoring and optimizing building performance.

One solution to ensure compatibility among controls systems is to procure components exclusively from one provider. However, in an airport environment where controls implementation is competitively bid, this limitation may not be feasible or desirable. Parallel controls systems could be built for the components from each supplier, but this approach is costly and does not provide for integration of all systems. An alternative solution is to develop an open architecture platform on which multiple communication protocols can be used – allowing controls hardware from multiple suppliers to be integrated in a unified cohesive system and to communicate seamlessly.

Facility operators at Minneapolis-Saint Paul International Airport (MSP) decided to build an open architecture controls system based on the Niagara framework to improve system monitoring capabilities and to afford operators greater control over building systems. Since components can be sourced from many vendors, competition keeps procurement costs low as the system continues to grow. Additionally, through cross training of operational staff and the ongoing support of a dedicated controls contractor, MSP's facilities team is able to more efficiently allocate labor resources to ensure continued performance of the airport's facilities. This case study explores the justification, challenges and opportunities that surrounded MSP's decision to adopt an open architecture platform. Lessons learned from this experience can be valuable for other airport facilities teams seeking to increase systems performance with new or existing resources.

Case Study

Facilities Overview

The Minneapolis-Saint Paul International Airport (MSP) is a critical part of the region's economy, connecting travelers in the Upper Midwest to 135 destinations globally. As the nation's 17th busiest international airport, MSP served 33.9 million passengers in 2013.[1] According to its website, the airport also supports the movement of 200,000 metric tons of cargo and facilitates 430,000 takeoffs and landings annually. The Metropolitan Airports Commission (MAC) is responsible for operating the MSP Airport and six regional airports in the Twin Cities area.

Since MSP first started supporting commercial flights in 1929, the airport has grown on its 3,400 acre site (**Figure 1**) to include 3.2 million square feet of terminal space [between two terminals], 9.8 million square feet of parking, 4 runways, 8 concourses and 124 gates.[1] In 2004, the two terminals were connected to each other and to downtown Minneapolis via a light rail transit corridor. MSP Airport continues to grow to support its mission to "*provide and promote safe, convenient, environmentally sound and cost-competitive aviation services for [its] customers*" and to accomplish the goals outlined in the MAC's strategic plan.[2]

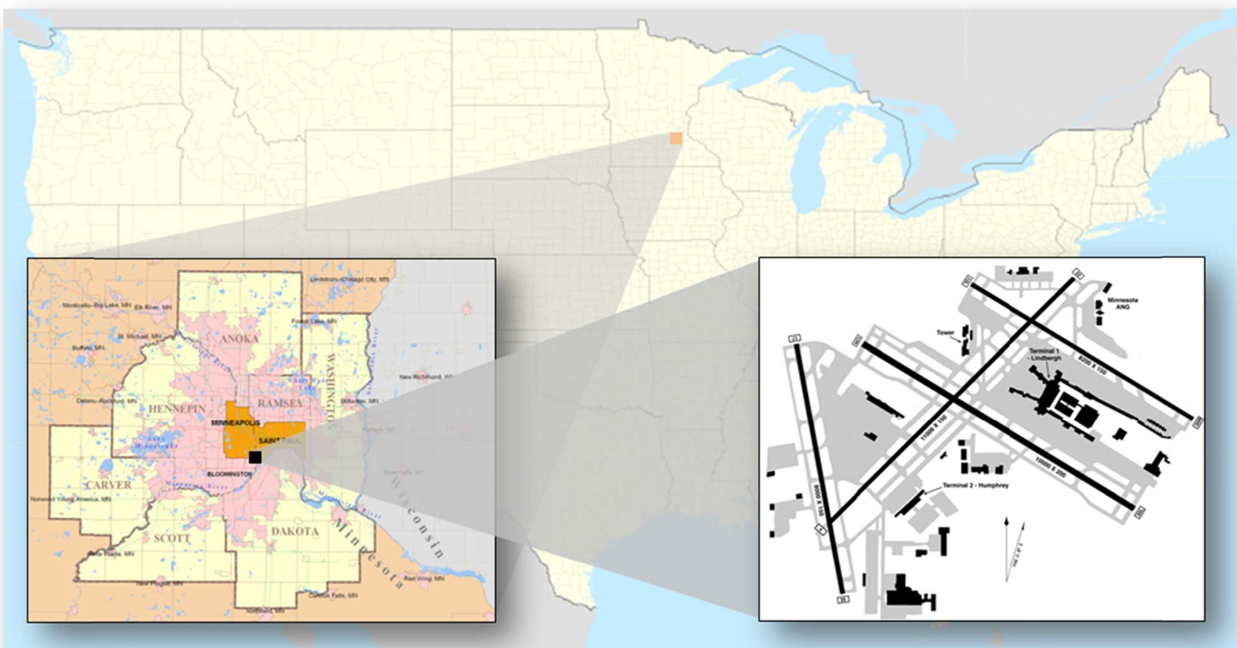


Figure 1. Location of Minneapolis-Saint Paul International Airport.[3]

[1] Source: https://www.mspairport.com/about-msp/statistics.aspx
[2] Source: http://www.metroairports.org/documents/2013-Strategic-Plan-with-2012-Results-Report.aspx
[3] Airport Image Source: http://www.faa.gov/nextgen/snapshots/airport/?locationId=52 Maps compiled from http://en.wikipedia.org/wiki/File:Twin_Cities_7_Metro_map.png and http://commons.wikimedia.org/wiki/File:Map_of_USA_without_state_names.svg

Case Study

As the Twin Cities metro area population grows, the MAC is continuously refining strategies to serve the needs of this region. Because the airport is situated in a densely developed area and in close proximity to protected natural areas, many of the MAC's efforts to expand services have been focused on improving the efficiency of existing runways and facilities at MSP. These strategies include working with the FAA to implement performance-based navigation techniques and optimized profile descents for arriving aircraft, increasing the number of aircraft that can use a runway in a given period of time while also decreasing aircraft noise and fuel consumption. While the improvements to airside operations are impressive, some of the greatest improvements at MSP Airport are in groundside operations. This is especially true for the building mechanical systems and controls at both airport terminals.

Building Systems

Like many large airports, the behind-the-scenes infrastructure at MSP includes a vast array of mechanical and electrical systems and equipment. From a mechanical HVAC perspective, MSP's Lindbergh and Humphrey terminals are served by variable air volume (VAV) air handling units throughout. A central plant in the Lindbergh Terminal (Terminal 1) provides cooling with six centrifugal chillers (five electric and one utilizing a steam turbine for power). A closed dry cooler system provides chilled water for winter cooling purposes, some critical tenant spaces where free cooling is not available, a data center, and most of the IT/comm rooms. Four steam boilers provide high pressure steam that is distributed throughout the terminal to heat exchangers which provide heating water and domestic hot water. A solar thermal system augments heating capability and serves some indoor areas, snowmelt, and supplements the main boiler loop at an ancillary building. Another central plant resides in Humphrey Terminal (Terminal 2) with three electric chillers and three hot water boilers. All of the other buildings have their own cooling and heating systems: 33 boilers of various sizes, 10 chillers, and numerous packaged HVAC units.

Interior lighting is primarily controlled through occupancy sensors in portions of the terminals though this capability is being expanded as time and budget permit. The long-term goal is to apply lighting control throughout the entire campus. Outdoor and tunnel lighting are controlled by light level sensors.

Bringing all of the systems together is IMACS, or Intelligent Monitoring and Control System, which branches into four key areas:

- **OABA**: Open Architecture Building Automation integrates all mechanical and electrical systems across the airport campus, including all HVAC.
- **FMS**: Facilities Monitoring System augments OABA and includes all door systems and conveyances, such as moving walkways, escalators and elevators.
- **TRM**: Technology Room Monitor provides a means to monitor all supporting network infrastructure, including the many IT/comm, or "TREC" rooms.
- **IM**: Intelligent Monitoring is an emerging area of the system that provides dashboards and analysis for energy and facility management.

Case Study

IMACS integrates three previously separate conventional building automation systems. It has been progressively developed over the last eight years and is expected to constantly evolve to meet future facility needs. IMACS utilizes an open architecture approach and employs industry standard communication protocols to enable communication between components from different suppliers. Equipment and systems across the airport campus are integrated into IMACS which features a customized comprehensive user interface at the front end for the EMC operations team, shown in **Figure 2**.

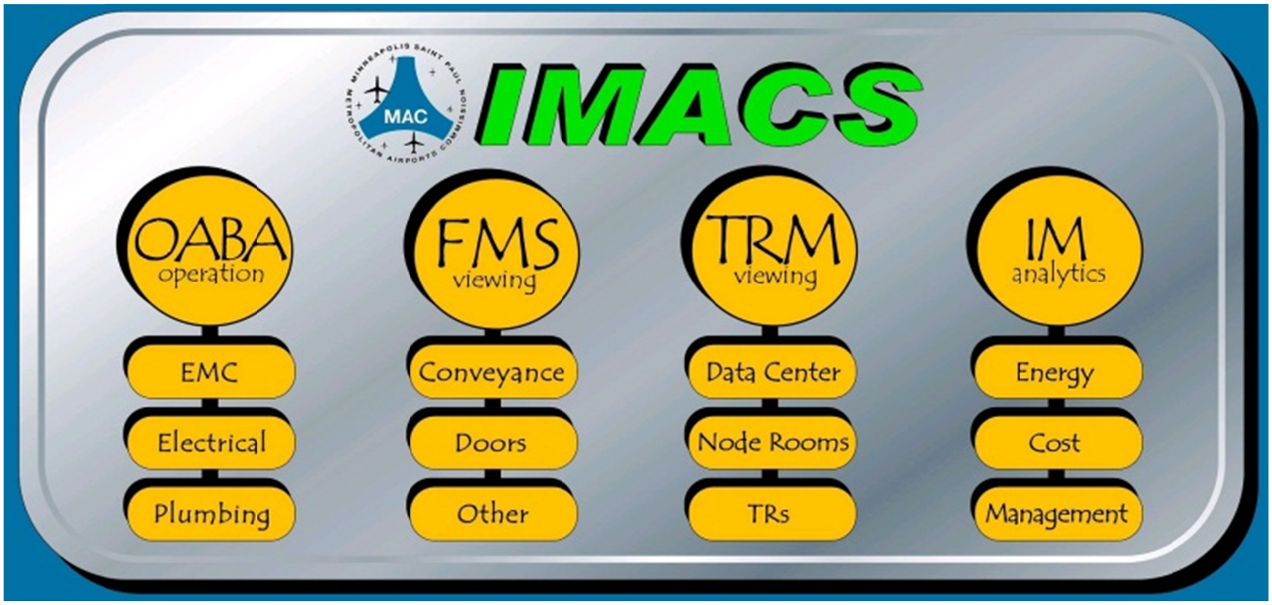


Figure 2. IMACS Home Screen.

Case Study

Concept

The integrated building system architecture in IMACS offers three levels of integration and optimization (**Figure 3**). The base level, or **Building Systems** level, optimizes the performance of the individual building systems, such as HVAC and lighting. The second level, **Systems Integration**, takes the relevant systems that have been optimized in the base level and integrates them for improved user interface. The third level, **Enterprise Integration and Operations**, centralizes the gathering and storage of facility data, and provides staff with analytical and management tools. The IM Analytics tool (a new part of the IMACS system presently under development) is an enterprise application that delivers energy performance dashboards and other data-based summaries of operational performance.

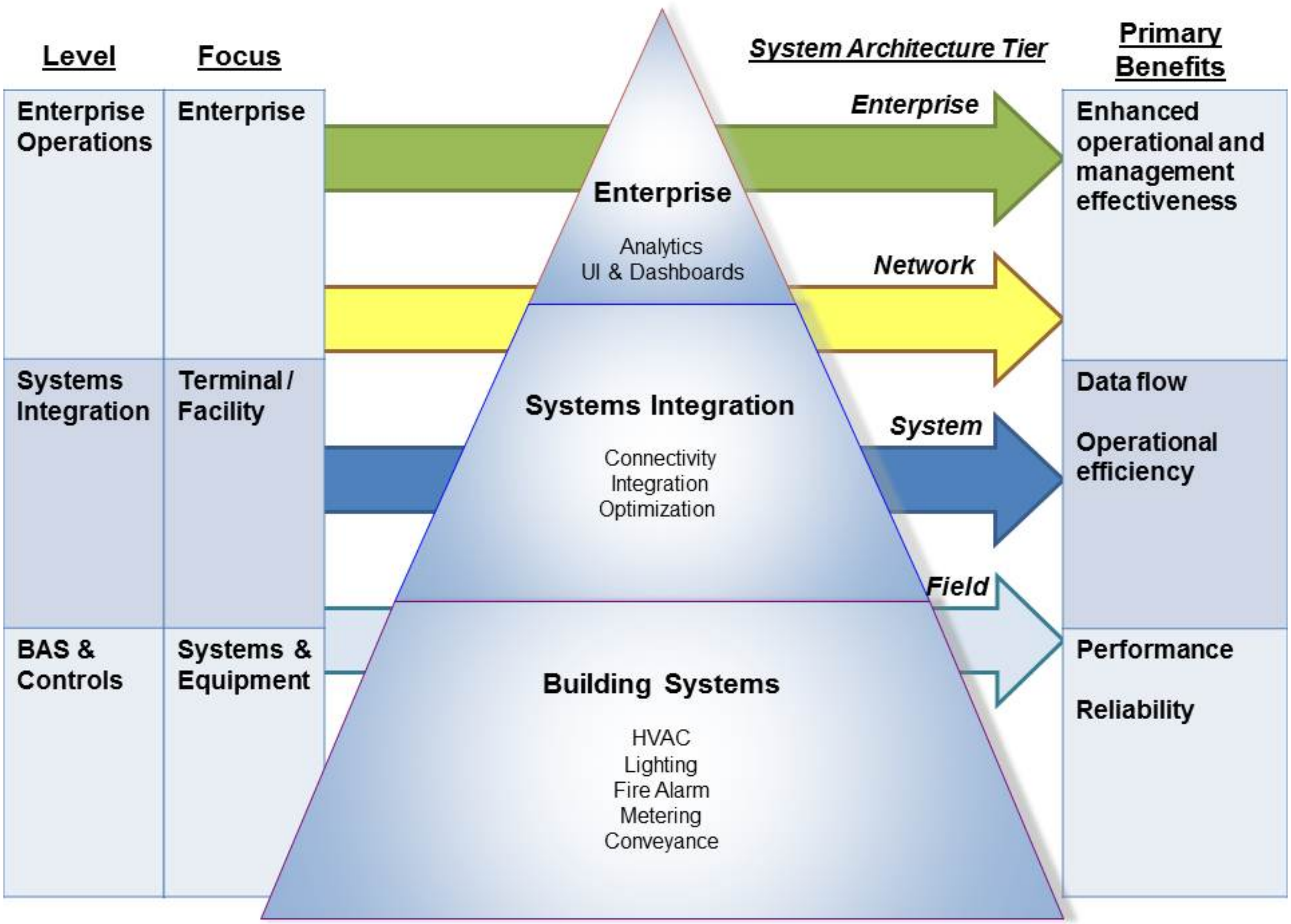


Figure 3. Integrated Building System Concept.

Case Study

Technology

The technology at the heart of the integrated building system architecture is Tridium's NiagaraAX framework, a platform for bringing together a wide range of disparate devices into a cohesive system (regardless of manufacturer or communication protocol) through the application of a common data model. Central to the application of such a technology is the availability of open standards. Open standard communication protocols such as BACnet, LonTalk and Modbus are proven means for integration of building systems and equipment, and oBIX is an emerging IT-centric XML-based standard for building system communication. Tridium's NiagaraAX technology accommodates the common open industry standards (BACnet, LonTalk and Modbus) and addresses less common and proprietary communication protocols, including legacy communication protocols. Common protocols and their uses are presented in **Table 1**.

Table 1: Prevalent Building System Open Standard Protocols.

Protocol	Standard(s)	Media	Notes
BACnet	ASHRAE/ANSI Standard 135 ISO 16484-5	TCP/IP Ethernet ARCNET EIA-485 EIA-232	Most commonly used for building automation and HVAC at system and field levels.
LonTalk	ANSI/CEA 709.1 ISO/IEC 14908-1	TCP/IP Ethernet EIA-709.1 (twisted pair) Power line	Most commonly used for building automation, HVAC, and other equipment at the field level.
Modbus	IEC 61784-2	TCP/IP Ethernet EIA-485	De-facto industrial standard, most commonly used for meters, electrical switchgear, variable speed drives and other electrical equipment.
DALI	NEMA Standard 243	Twisted pair	Digital Addressable Lighting Interface, generally for lighting controls only.
oBIX	In development under OASIS	TCP/IP Ethernet	An emerging web services protocol for building systems, oBIX stands for Open Building Information Exchange.
ZigBee	IEEE 802.15.4 ZigBee standards	Wireless	ZigBee is a standards-based wireless technology designed to address the needs of low-cost, low-power wireless sensor and control networks.

Case Study

On the user facing side of the technology, the system is entirely web-based. It is accessible on-site and remotely through a secure firewall to the appropriate airport staff and supporting controls contractors. A well-defined naming convention and consistently applied navigation scheme combine to make the system easy to use. As shown in **Figure 4**, the header provides key information about critical system parameters, such as chilled and hot water temperatures while the bar on the left side provides a way to quickly navigate by area, system, or equipment type. The various graphical screens range from concise summaries across groups of equipment to detailed representations of individual systems and equipment.

Figure 4. OABA AHU Summary.

System Architecture

Perhaps the best way to develop an understanding of how such technology is applied at MSP Airport is through illustration. **Figure 5** provides a conceptual schematic diagram of the system architecture. Key features include:

- **Tiered Architecture**: The system architecture, like many building automation and energy management systems, features a tiered architecture. At the field level, twisted pair sub-networks provide the communication pathways to field devices, such as controllers, meters, and so on. All building controllers, or JACEs, reside at the system level on the airport's IP network, and a server (Supervisor) also resides on the network.
- **Open Standard Protocols**: In the case of MSP Airport's system, LonTalk and Modbus are applied heavily on sub-networks, while BACnet is only used in small portions of the sub-network communication links. At the network level the IP protocols are used. These include Tridium's NiagaraAX FOX (a derivative of oBIX) and HTTP for user interface.
- **Common Network Infrastructure**: The entire system rides on MSP Airport's secure and extensive network, with a dual fiber optic ring backbone.

- **User Focus**: The user interface is customized for the airport, and offers features that make the system easy to use:
    - **Navigation and Status**: A consistent and pervasive navigation and status scheme allows for easy movement through the system while keeping operators aware of key operating parameters.
    - **Naming Convention**: A consistent naming convention is used throughout the system. The naming convention incorporated into IMACS is used throughout the airport, and while its creation involved a painstaking consensus process, the investment is paying off and its value has extended well beyond building systems. It is used throughout IMACS, OABA, by the carpentry shop for room numbering and naming, and by the police and fire departments even though they had to change some of their designations to comply. All bid documents and contractor correspondence also utilize the naming convention.
    - **Summaries**: A variety of summaries provide at-a-glance views of groups of equipment. For example, all air handling units in the terminal are summarized on one web page, as shown above.
    - **Color Coding**: Color coding conventions are also consistently applied in the system. For instance, air handling units are color coded to match the associated VAV terminal units enabling operators to quickly understand the relationships among groups of equipment that are dependent on one another.
    - **Hyperlinks**: Strategically placed hyperlinks promote task-specific navigation. For example, when viewing alarms, an operator can navigate directly to the alarm source.
- **Historical Data**: Many of the points in the system are trended, and the trends are archived such that data is retained indefinitely for troubleshooting and analysis. One week of data is retained on hard drive for immediate access; after one week, data is archived to a cloud server.

Each of the system architecture features comes with benefits that enhance one or more aspects of facility management and operations, described in **Table 2**.

Table 2: System architecture features and benefits.

Feature	Benefit(s)
Tiered Architecture	Competitive procurement Consistent integration
Open Standard Protocols	Competitive procurement Consistent integration
Common Network Infrastructure	Shared infrastructure Secure network IT support
User Focus	Operational productivity (ease of use) Faster response time Reduced complaints
Historical Data	Operational productivity (for troubleshooting and analysis)

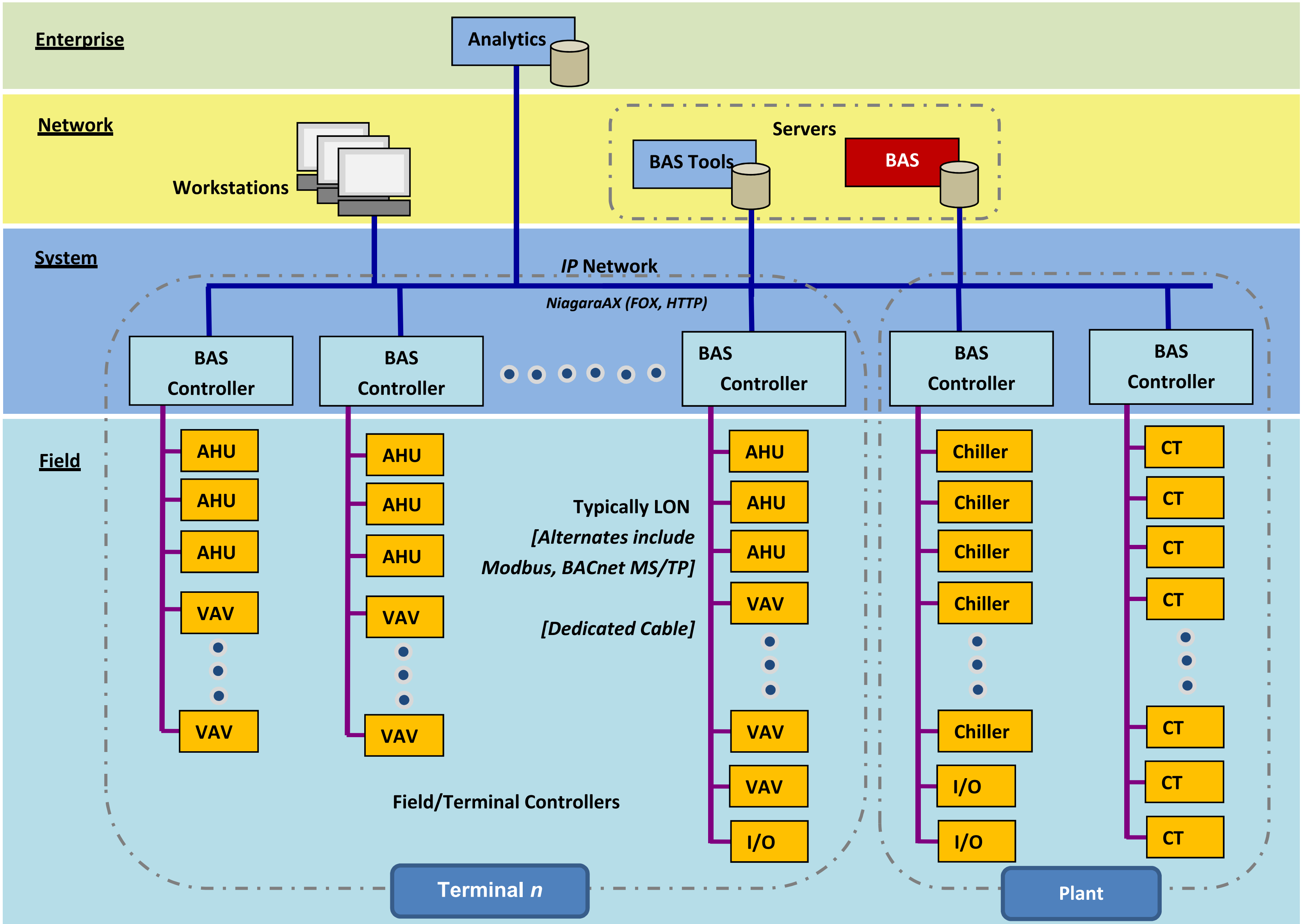


Figure 5. System Architecture Diagram.

Case Study

Operations

Improvements to mechanical systems and upgrades to controls architecture have greatly improved the infrastructure at MSP. However, the airport's continued success in facilities performance is due in large part to the operations staff. Despite the airport's extensive size, the central plant is staffed with only 2-4 operators per shift (with 24/7 coverage over three daily shifts). Operators work on a rotational schedule – spending roughly half of each pay period working in the central plant ("inside"), and the other half performing tasks throughout the airport's facilities ("outside").

Prior to consolidating the three legacy controls systems into IMACS, the airport relied on technical support from three separate controls contractors (each specialized in their respective controls package). Mastering these separate controls systems provided unnecessary complexity for the airport staff. With IMACS, the airport has one full time position who is dedicated to controls support. This full time position is staffed through a controls contractor. This position updates the system interface (**Figure 6**) and integrates new control points as sensors and communication hardware are upgraded. This position also provides controls interface training for the rest of the operations staff. Using a single "super-user" to construct the interface avoids the problems that occur when a piecemeal approach to controls system design is pursued because a single user can ensure consistency across systems and equipment. This approach has the added benefit in that one individual is the "go-to" resource for questions about the system when operators rotate through the "inside" portion of their schedule. Operators also benefit from a universal naming convention for all points in the controls system which minimizes confusion when referencing equipment.

Figure 6. MSP Controls system user interface.

This staffing configuration is cost-effective for the airport and gives the operations team more flexibility when responding to work flow. As the controls architecture and the controller interface are continuously being updated, having all operators rotate through the "inside" portion of operations ensures that everyone is up-to-date on the latest system modifications. Additionally, since operators frequently rotate

Case Study

to the “outside” tasks, they are more readily able to draw on their controls knowledge to support equipment operations.

Critical Success Factors

Operating a high-performing building automation system requires commitment of both people and financial resources. Lessons learned from MSP’s implementation of an open architecture system can be used to identify the critical success factors required to implement highly integrated building automation solutions at other airports. These lessons are presented in **Table 3**.

Once the integrated controls system is up and running, sensor calibration and functional testing need to occur on a regular basis to ensure continued controls system reliability. Planning and budgeting for ongoing preventive maintenance, field repairs, and programming updates is essential to realize the long-term benefits of a controls improvement project.

Table 3. Critical Success Factors.

Organizational	
	Obtain executive level support for the program.
	Have senior management on-board and aligned with goals of program.
	Appoint a champion to advocate for and oversee the planning, implementation and ultimately operation of the system.
	Coordinate development of controls system with Information Technology department to make best use of shared infrastructure.
	Cross-train operations staff to interface with the control system at the workstation (“inside”) and in the field with the components (“outside”).
Financial	
	Integrate first time and ongoing component procurement into appropriate budgets.
	Utilize a competitive bidding process to reduce costs.
	Budget for ongoing preventive maintenance and sensor calibration to keep the system operating accurately.
Operational	
	Delegate responsibility for updating controls systems to a single individual to ensure consistency and uniform development.
	Establish a naming convention for all types of systems and components to minimize confusion.
	Consider color coding components in the controls system to quickly show functional relationships (e.g., all VAV boxes served by an air handler are the same color on a mechanical plan).
	Have a "go-to" support person to answer questions and resolve issues with the controls interface.

Acknowledgements: This case study was authored by Jeff Seewald and Andrew Heairet of Sebesta. Sebesta would also like to thank Steve Shuppert, Jeff Klawiter and Mike Doyle from the MAC Energy Management Center for sharing their control system practices for this case study. This case study was completed by Sebesta as part of ACRP Project 09-04, “Airport Building Operations and Maintenance (O&M) Optimization and Recommissioning: A Whole-Systems Approach,” with funding provided by the Transportation Research Board of the National Academies.

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APPENDIX C
Logan International Airport Case Study

Central Plant Retrocommissioning at Logan International Airport, Boston, MA

Transportation Research Board, ACRP Project 09-04

Table of Contents

Case Study

Introduction

Nationwide, airports are adopting energy efficiency goals to improve facility performance and reduce operating costs. Boston Logan International Airport is operated by the Massachusetts Port Authority (Massport), which is participating in the Commonwealth of Massachusetts' Leading by Example (LBE) program, established by Executive Order 484. The program includes goals for energy intensity reduction, emissions reductions and renewable energy generation.

In 2010, Massport used a competitive procurement process to contract for Energy Engineering services in support of Massport's Energy Efficiency Initiative (Attachment A). Under this contract, Sebesta, Inc., a local engineering firm, has provided a wide range of services to assist Massport in evaluating performance, identifying recommendations for improvement, and implementing projects to meet the LBE program goals. These services included:

- ***Capital Projects***: Reviewing Massport's 5-year Capital Program Project Plans and working with Massport's Project Managers and design teams to integrate energy efficiency and renewable energy into selected projects. Assisting Massport to quantify and predict the impact of these projects on meeting the LBE goals.
- ***New Initiatives***: Sebesta was also tasked with identifying, evaluating, and in some cases implementing new energy initiatives that would help Massport meet its energy goals. These initiatives included a broad range of initiatives around lighting, HVAC, and controls upgrades; cogeneration and renewable energy projects; and retrocommissioning and operational improvements.

Early in the contract, Sebesta recommended and Massport authorized a retrocommissioning investigation of the central plant at Boston Logan International Airport. The goal for the retrocommissioning investigation was to identify low-cost and no-cost changes that would improve plant operations and performance, and reduce energy consumption and greenhouse gas emissions.

Case Study

Facilities Overview

Boston Logan International Airport (BOS) is the nation's 20th busiest airport serving over 30 million passengers in 2013. The airport supported the movement of 244,120 metric tons of cargo and facilitated over 361,000 takeoffs and landings in 2013[1].

Since opening as Boston Airport in 1923, the terminal has grown to 103 gates in four terminals. Terminal A was the first LEED certified airport terminal in the world, completed in 2005. Terminal C was renovated in 2005, absorbing Terminal D. Terminal B has just completed renovation, and expansion is planned for Terminal E. All terminals and many ancillary facilities are served by a central heating and cooling plant.

The central plant includes a 385,000 lb/hr high pressure steam plant and 15,850 ton chilled water plant. Overall, the central plant accounts for over 50% of Massport's energy costs and greenhouse gas emissions (from buildings); therefore opportunities for energy efficiency improvements at the central plant will have a significant impact on reducing energy costs and emissions.

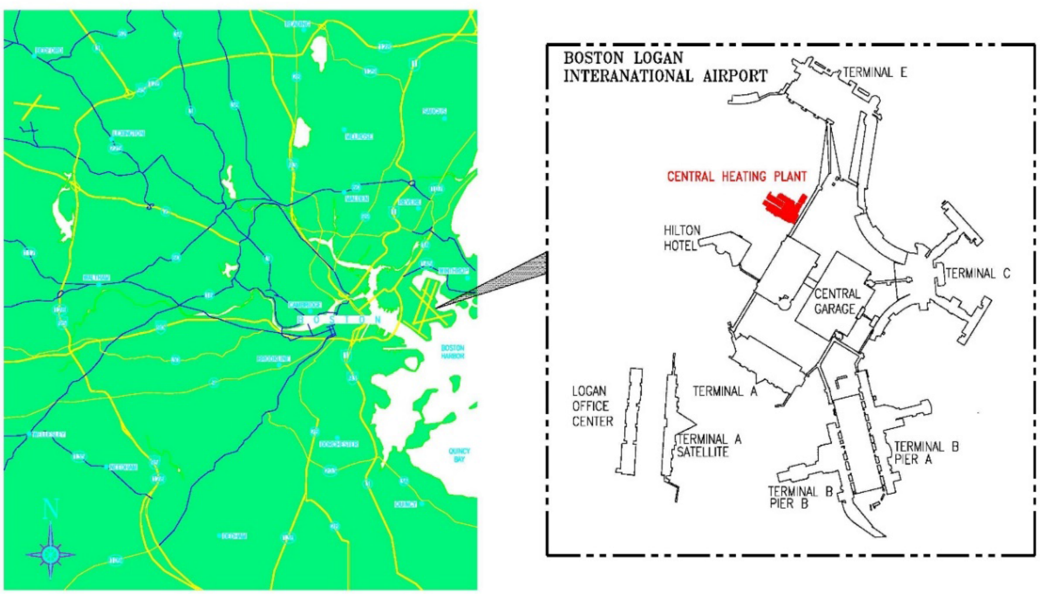


Figure 1. Location of Boston Logan Central Heating Plant.

[1] Source: http://www.massport.com/logan-airport/about-logan/ Last accessed April 25th 2014.

Case Study

The Retrocommissioning Process

The Logan Airport central plant retrocommissioning process can be divided into two phases:

- Investigation Phase
- Design and Implementation Phase

The ***investigation phase*** included a systematic review and documentation of the existing operations to identify areas where the facility does not operate as intended, or where more efficient equipment or techniques can be applied, and then to identify methods to improve its energy efficiency to current standards. At the central plant, the process focused on major energy-consuming equipment, including the boilers, chillers, pumps and associated distribution and end use systems. Air handlers and a sampling of terminal units in the terminals were investigated.

Figure 2. Boilers at Boston Logan Central Plant.

Case Study

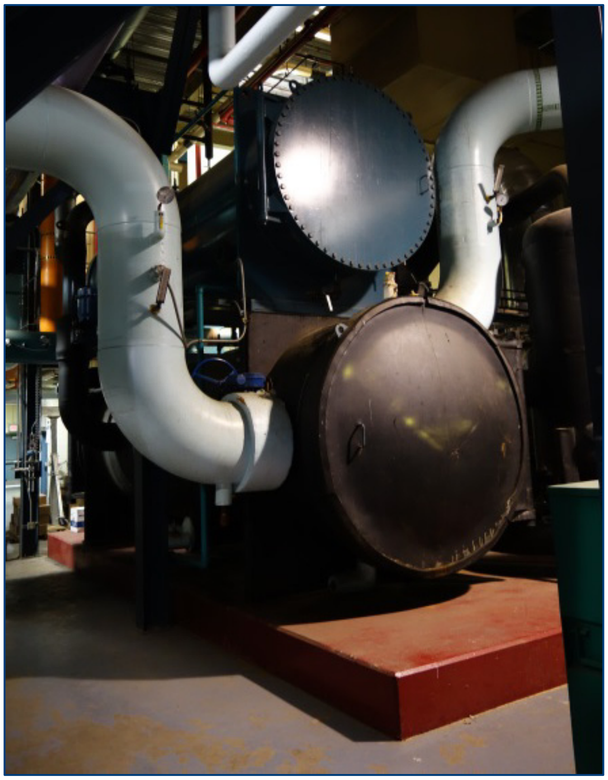


Figure 3. Chiller at Boston Logan Central Plant.

Figure 4. Chilled Water Pumps at Boston Logan Central Plant.

Case Study

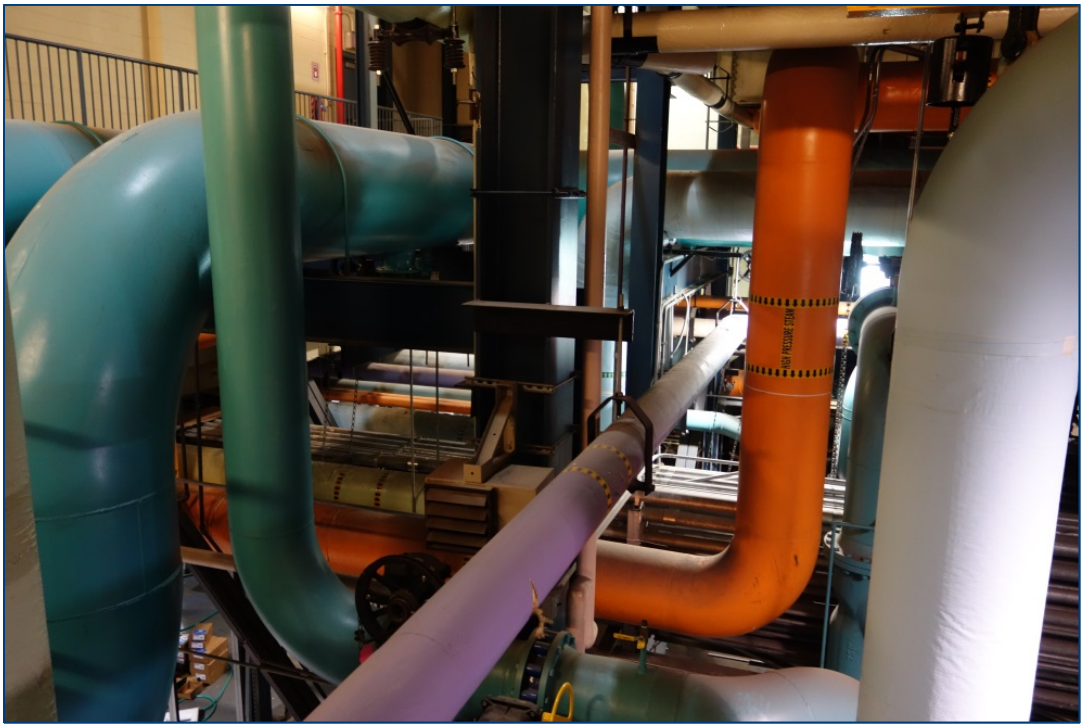


Figure 5. Distribution Systems in Boston Logan Central Plant.

A number of site visits were conducted to learn how the equipment was operated, to gather data on the equipment, and to selectively test different operating scenarios. Massport operations staff provided records of the automated operating logs. This information was compared against data collected through field checks to verify proper operations. Field and operating data was reviewed to develop recommended energy conservation measures (ECMs). An Investigation Phase Report (Attachment B) was prepared with recommended ECMs, which were developed through a conceptual level to determine budgetary cost and savings.

Energy savings projections presented in the report were calculated using measured data where possible, systems design data, and Sebesta's experience with similar equipment. Some data was gathered from the existing Building Management System (BMS). Heating and cooling loads were calculated using hourly temperature profile data for Boston, representing 30-year average weather conditions, combined with observed operating parameters. Cost estimates used industry estimating techniques and Sebesta's experience with similar installation.

Several meetings were conducted with Massport stakeholders to review the Investigation Phase report findings and recommendations, and plan implementation for selected measures. As a result of this review process, Massport selected certain projects for design and implementation under a capital project, and others to be implemented by the operations staff in conjunction with vendor term contracts. Other ECMs were incorporated in ongoing renovation projects.

Case Study

Projects were categorized as:

- Projects to be Implemented via Capital Projects
    - Bypass Building Pumps
    - Upgrade & Expand Plant Metering
    - Address Steam System Losses
    - Install VFDs on Cooling Tower Fans
    - Install VFDs on Boiler Induced Draft Fans & Forced Draft Fans
    - Replace Compressors
- Projects to be Implemented by Operations Staff
    - Decrease Differential Pressure Setpoints
    - Renovate Building Chilled Water Systems
    - Reset Chilled Water Supply Temperatures
    - Operate Only Electric Chillers

The fee for the investigation phase of the project was approximately $120,000, which included a holistic review of the airport's chilled water and steam/high temperature hot water (HTHW) generation and distribution systems throughout the airport, extensive field investigations and testing, and hydraulic modeling of the airport's chilled water system.

The ***Design and Implementation Phase*** began in December 2011 with Field Engineering for all projects. For Capital Projects, Sebesta supported Massport in preparation of design documents, competitive bidding and contractor selection, construction, and commissioning. Operations Staff are in the process of implementing the non-Capital projects.

Hydr**aulic Modeling** is an engineering tool to analyze the design and performance of fluid systems, including chilled water, hot water, and steam systems.

At Massport, Sebesta utilized a chilled water system hydraulic model to analyze the potential energy and performance benefits of changes in the chilled water distribution system. For example, during the central plant retro-commissioning investigation, the model was used to indicate that reducing system pressure losses and eliminating locations where chilled water can bypass from supply to return will give the existing secondary pumps the ability to satisfy system flow requirements (and eliminate the need to operate tertiary pumps).

Subsequent to the central plant retro-commissioning project, the CHW hydraulic model was used to identify an opportunity to eliminate a deny valve and tertiary pumps from the design of a new capital project at the airport.

Sebesta's recommendations were accepted by the designers, providing Massport with approximately $1 million in capital cost reduction, as well as significant energy savings.

Case Study

Findings and Results

Nine energy efficiency measures were recommended for implementation, including upgrades to chilled water, steam/ HTHW, HVAC, and metering systems. At the completion of the investigation phase in September 2011, total capital costs were estimated at $2 million, with estimated annual cost avoidance of $1.16 million/year. As the project proceeded to design and implementation, the scope of work was increased to over $3.2 million in implementation costs, and $1.5 million/yr in estimated annual cost avoidance. Notably, several changes were made to the scope of work during the design phase which significantly increased both the capital cost and estimated energy savings for the project. The most significant changes were:

1. The metering scope expanded from 12 meters to more than 65 meters
2. The steam trap replacement scope increased from 77 traps to 349 traps
3. Implementation of the bulk of the work through a design-bid-build capital procurement process

Table 1 is the list of no- and low-cost ECMs and associated cost and savings estimates that were in the initial Investigation Phase report. Table 2 is an updated summary of implementation costs and estimated energy savings for the projects as a result of the detailed design and bidding process.

Case Study

Table 1. Summary of Recommended ECMs from Retrocommissioning Investigation for Boston Logan Airport Central Plant.

ECMs		Implementation Plan	Estimated Implementation Cost - Engineering	Estimated Implementation Cost - Materials/ Labor	Estimated Implementation Cost - Total	Estimated Annual Utility Reductions				GHG Reduction (Metric Tons CO2)	Total Estimated Annual Cost Avoidance	Simple Payback (yrs)
ECM No.	ECM Description					Elec. (kWh)	N. Gas (Mcf)	Water (Mcf)	kBtu			
1	Bypass Building Pumps, Remove 3-Way Valves, Open Balancing Valves and Deny Valves, Piping Modifications	Facilities / Design - Bid - Build	$22,000	$78,000	$100,000	417,043			1,422,951	156	$47,126	2.1
2	Decrease Differential Pressure Setpoint/ Modify SCHW Pump Staging, Add Monitoring Points	Facilities/ Controls Contractor - Engineering Support	$6,000	$19,000	$25,000	218,713			746,249	82	$24,715	1.0
3	Renovate Building Chilled Water Systems	Facilities/ Term Contractors - Engineering Support	$41,000	$90,000	$131,000	454,668	1,586		3,137,327	255	$66,920	2.0
6	Reset chilled water supply temperature	Facilities/ Controls Contractor - Engineering Support	$8,000	$22,000	$30,000	68,000	2,800		3,032,016	174	$35,124	0.9
7	Operate Only Electric Chillers/ Upgrade Plant Metering	Facilities/ Design - Bid - Build	$65,000	$370,000	$435,000	3,041,091	110,824		100,447,798	4,744	$742,432	0.6
8	Address Steam System Losses	Facilities/ Vendors	$0	$120,000	$120,000		16,618	77	16,618,000	882	$171,856	0.7
	Totals		**$142,000**	**$699,000**	**$841,000**	**1,882,667**	**131,828**	**77**	**125,404,340**	**6,294**	**$ 1,088,173**	**0.8**

Assumes:

$0.113/kWh Electric cost
$9.8/ Mcf Gas cost
$116.9/Mcf Water/ Sewer Cost
.000375 MT/kWh
.0531 MT/Mcf Natural Gas

Case Study

It is estimated that the energy savings and greenhouse gas emissions reduction associated with retrocommissioning will have a greater impact than any other single project on meeting Massport's LBE goals. In addition, the chilled water system hydraulic model is being utilized as an ongoing tool to address chilled water system performance and design issues, providing ongoing value to Massport.

Case Study

Table 2. Summary of Recommended ECMs from Retrocommissioning Implementation for Boston Logan Airport Central Plant.

ECM No.	ECM Description	Sebesta Engineering, CA Fee	Estimated Construction Cost	Total Implementation Cost	Estimated Energy Cost Savings	Estimated Energy Savings (kBtu)	Simple Payback	Scope Change from Investigation
SCOPE IN CAPITAL PROJECT								
1	Bypass Building Pumps, Remove 3-Way Valves, Open Balancing Valves and Deny Valves, Piping Modifications	$21,812	$100,750	$122,562	$34,114	1,422,951	3.6	Terminal E removed, VFDs on Terminal B pumps added.
8	Upgrade Plant Metering • Metering scope is 67 meters.	$215,034	$2,672,790	$2,887,824	$0	0	-	Work order had 12 meters plus revenue grade meters in buildings to be defined. Current total is 67 meters and tied to MPA network in lieu of local controls.
9	Address Steam System Losses • Steam traps scope is survey, repair/replace. • Assumes 440 traps surveyed, 440 repaired/replaced.	$121,744	$343,250	$464,994	$475,169	46,000,000	1.0	Repair / replace scope increased from 77 traps to 349. Steam trap stations to be replaced as well. Testing scope removed.
CHP-CT	Install VFDs for CT1 and CT2 • New Scope	$14,654	$90,960	$105,614	$12,638	527,154	8.4	Added scope, not in original work order.
	Totals	**$373,244**	**$3,222,950**	**$3,580,994**	**$521,922**	**47,950,105**	**6.9**	
SCOPE PERFORMED BY MASSPORT DIRECTLY (TERM CONTRACTS OR CHP OPERATORS)								
ECM No.	**ECM Description**	**Sebesta Engineering, CA Fee**	**Estimated Construction Cost**	**Total Implementation Cost**	**Estimated Energy Cost Savings**	**Estimated Energy Savings (kBtu)**	**Simple Payback**	**Scope Change from Investigation**
2	Decrease Differential Pressure Setpoint/ Modify SCHW Pump Staging, Add Monitoring Points	$5,906	$25,000	$30,906	$17,891	746,249	1.7	NA
3	Renovate Building Chilled Water Systems	$43,927	$105,200	$149,127	$52,734	3,137,327	2.8	MPA contracting with Carrier directly to remedy control issues and add scheduling, MPA contracting for balancing in Terminal A
6	Reset chilled water supply temperature	$8,005	$0	$8,005	$33,002	3,032,016	0.2	NA
7	Operate Only Electric Chillers	$0	$0	$0	$538,088	100,447,798	0.0	NA
	Totals	**$57,838**	**$130,200**	**$188,038**	**$641,715**	**107,363,389**	**0.3**	
TOTAL PROJECT								
ECM No.	**ECM Description**	**Sebesta Engineering, CA Fee**	**Estimated Construction Cost**	**Total Implementation Cost**	**Estimated Energy Cost Savings**	**Estimated Energy Savings (kBtu)**	**Simple Payback**	**Scope Change from Investigation**
	Totals	**$431,082**	**$3,395,762**	**$3,826,844**	**$1,163,637**	**155,313,494**	**3.3**	

Notes:
1. Utility costs updated, current electrical, gas and water rates are lower than FY2011.

Case Study

Below are more detailed descriptions of the findings and recommendations from the retrocommissioning process.

ECM – 1: Bypass Building Pumps, Remove 3-Way Valves, Open Balancing Valves and Deny Valves, Piping Modifications

Investigation Phase Findings and Recommendations:

1. During the investigation it was determined that chilled water was unnecessarily flowing through the tertiary pumps. Sebesta recommended installation of full size bypasses with control valves which would allow Massport to shut down the tertiary pumps and maintain efficient flow, and removal of non-operating tertiary pumps. Testing was conducted during the investigation (shutting off tertiary pumps) to verify that these changes will work.
2. During the investigation it was determined that several HVAC systems had three-way valves that were causing unnecessary flow. Sebesta recommended converting several of these valves to two-way valves to reduce flow and improve CHW system performance. Replacement of a heat exchanger control valve was recommended to improve control.
3. During the investigation phase it was found that Massport had several large CHW valves, including balancing valves and deny valves that were restricting flow and causing inefficient pressure drop in the CHW system. Changes to the Terminal chilled water controls and valve controls were recommended. Testing was conducted during the investigation phase (overriding deny valves, reducing DP setpoint on central plant secondary pumps) to verify these changes would work.

Changes that Were Implemented:

Programming modified on Terminals A and E VFDs on CHW pumps so can modulate down to 16 Hz.

The pump bypass, installation of three-way valves, and additional controls changes were included in capital projects currently under construction. Also, during design phase installation of VFDs on plant chillers and Terminal B pumps were added to the scope.

Persistence:

Massport operations staff are responsible for ongoing maintenance of system operations. The CHW pump programming modifications are being maintained.

Case Study

ECM – 2: Decrease Differential Pressure Setpoint/ Modify SCHW Pump Staging, Add Monitoring Points

Investigation Phase Findings and Recommendations:

Once ECM-1 is implemented:

1. Decrease differential pressure setpoint further and implement reset schedule based upon outdoor air temperature.
2. Modify staging on secondary chilled water pump controls (DP controls) to minimize energy usage.

Changes that Were Implemented:

During the investigation phase, the central plant Secondary Pump DP setpoint was decreased from 20 psi to 15 psi. Subsequently the DP setpoint was raised to 17 psi after two days of above design day weather conditions. In addition, the Terminal A Main Logic relative to pump status was removed and the deny valve logic was altered.

Massport is currently working to optimize Deny Valve and plant DP setpoint control.

Persistence:

Massport Operations staff are responsible for ongoing maintenance of system operations.

ECM – 3: Renovate Building CHW System

Investigation Phase Findings and Recommendations:

Several opportunities were identified to improve performance of terminal equipment (AHUs, CV boxes, fan coil units, etc.), and subsequently reduce load on CHW and heating systems. Retrocommissioning implementation recommended, including testing and balancing, functional testing of controls, and correction of deficiencies.

Changes that Were Implemented:

During the initial field engineering portion of the implementation phase, Sebesta and Massport conducted functional testing of HVAC systems in Terminals A and C, and created a deficiency list to be addressed by controls contractor under term contract. Massport currently verifying deficiencies were corrected.

Balancing of selected chilled water systems in Terminal A was also implemented directly by the Facilities Department under a term contract.

Persistence:

Massport Operations staff are responsible for ongoing maintenance of system operations.

Case Study

ECM-6: Reset CHW Supply Temperature

Investigation Phase Findings and Recommendations:

At Logan Airport a CHW supply temperature of 42ºF is required during peak cooling days to provide dehumidification in humid weather. During other days, the CHW temperature can be reset up and still meet space conditioning requirements while reducing chiller energy usage. Reset is currently being implemented manually by operators. Automatic reset is recommended to ensure that CHW reset is being implemented at low load conditions.

Changes that Were Implemented:

This ECM will be implemented by Massport Facilities staff with assistance from Sebesta in conjunction with implementation of ECM-3.

Persistence:

Massport Operations staff are responsible for ongoing maintenance of system operations.

Case Study

ECM-7: Operate Only Electric Chillers

Investigation Phase Findings and Recommendations:

During the investigation phase an analysis was conducted comparing the cost of operating the steam turbine driven chillers and the electric chillers. As shown in the Figure below, the cost to operate the steam turbine chiller (Chiller #1) was found to be consistently higher than operating the electric chillers (Chillers #4, 5, 6).

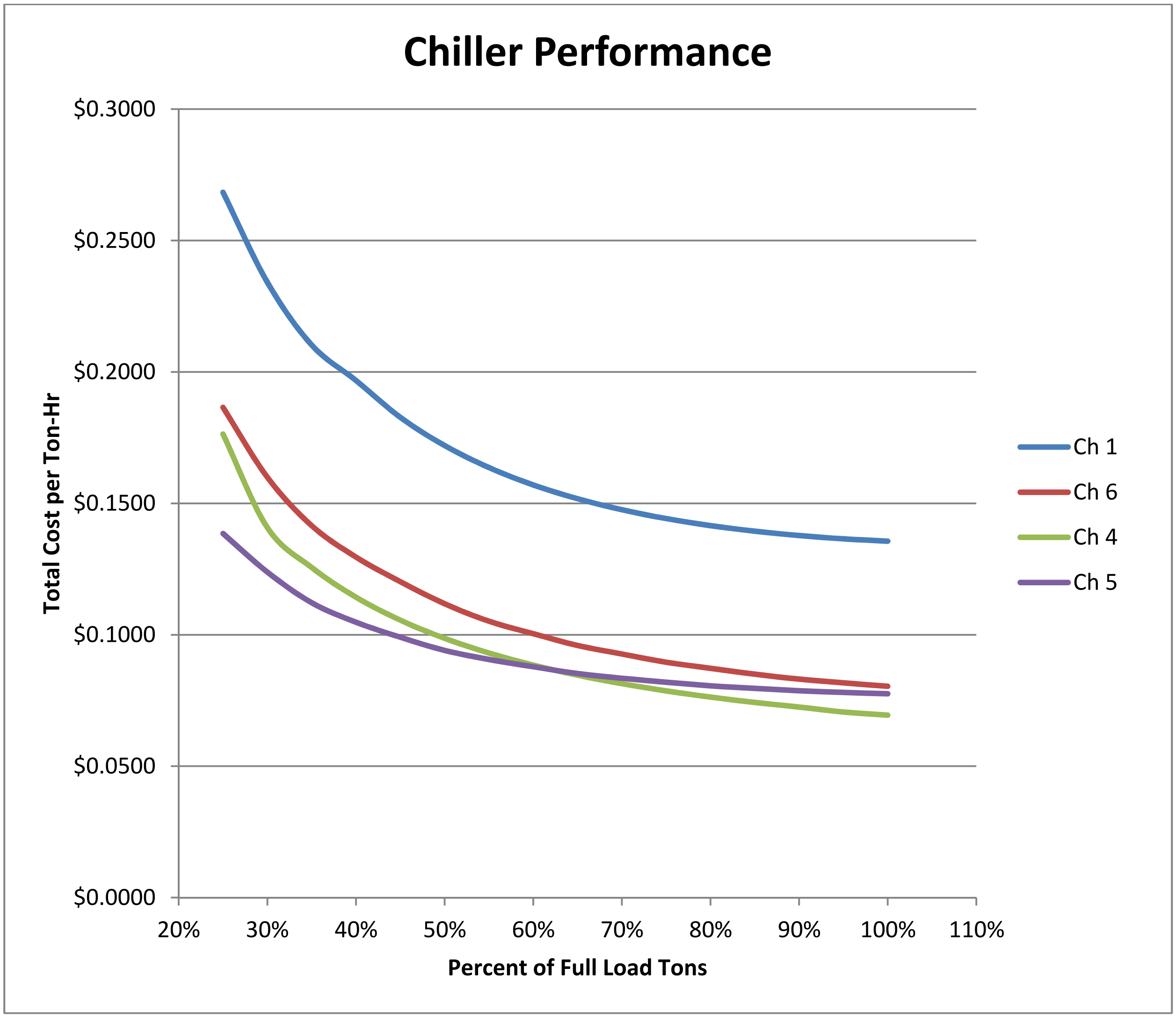


Figure: Comparison of Chiller Performance and Operating Cost

Historically Massport had been operating the steam chillers in the summer to provide enough load on the boiler plant for stable operation. Sebesta designed and Massport implemented a project to install VFDs on the boiler FD and ID fans (and associated controls) in parallel with the central plant retrocommissioning investigation. At the time of the investigation it was predicted that this project would enable the boilers to operate at low loads without operating the steam turbine chillers.

Case Study

Changes that Were Implemented:

This ECM was partially implemented by Massport Facilities staff during the summer of 2012 after implementation of the VFDs on the boiler FD and ID fans. Massport Facilities staff found that with the installation of the FD and ID fan VFDs they were able to operate the boilers without operating the steam turbine chillers during the summer months.

Massport resumed operation of the steam turbine chillers in late August 2012 to support the previously contracted gas nominations with Massport's gas supplier. Massport plans to further implement this change in operations following a 2015 contract modification with the gas supplier.

Persistence:

Massport Operations staff are responsible for ongoing maintenance of system operations.

M&V Results:

Sebesta conducted an M&V analysis utilizing metered gas and electric usage and cost during the Summer 2012 plant operation, normalized for weather conditions. The results of the analysis were that Massport avoided operating costs in the amount of $112,000 during that summer with partial implementation of the measure, even accounting for the gas settlement cost. Based upon these results, it was estimated that with full implementation of the ECM (and no nomination penalties), Massport would realize $763,000/year in energy cost savings, assuming 2011 utility rates. This is comparable to the savings estimate in Table 1 of $742,432 for this ECM, which also used 2011 utility rates. As shown in Table 2, utilizing current lower utility rates, the savings from this ECM were reduced to $538,000.

ECM-8: Upgrade Plant Metering

Investigation Phase Findings and Recommendations:

During the investigation phase, Sebesta recommended that Massport upgrade the plant metering system and provide associated dashboards to Facilities operators. By providing infrastructure to measure energy use at a more detailed level, this ECM would provide operators with improved tools to operate the plant more efficiently, and to monitor and verify performance. Installation of additional HTHW, Steam, and chilled water meters were recommended.

Note that during the investigation phase, energy savings were not directly attributed to this measure.

Changes that Were Implemented:

During the design phase of the project, Massport significantly expanded the scope of this project to triple the number of meters, and the communications protocol was changed from utilizing hard wired control panels to utilizing Massport's IT network. This measure is being implemented as part of the capital project.

Persistence:

Massport Operations staff are responsible for ongoing maintenance and calibration of system.

Case Study

ECM-9: Address Steam System Losses

Investigation Phase Findings and Recommendations:

During the investigation phase, Sebesta estimated that significant steam system energy savings could be achieved by testing and repairing or replacing steam traps throughout the plant, and repairing steam system insulation in selected areas.

Changes that Were Implemented:

During the design phase of the project Massport significantly expanded the scope of this project from repairing/replacing 77 traps to replacing 349 traps and some isolation valves, as well as installation of insulation in selected areas. Standardized traps with flanged connections were installed to enable future maintenance and replacement.

This measure is being implemented as part of the capital project.

Persistence:

Massport plans to conduct thermal inspections and maintain steam traps with in-house staff. Massport uses standardized stream traps for ease of replacement by staff pipe fitters.

CHP-CT: Install VFDs for CT-1 and CT-2

Investigation Phase Findings and Recommendations:

At the time of the investigation, Massport had existing VFDs installed on one of the two central plant cooling towers. During the investigation phase, Sebesta did not initially recommend installation of VFDs on the second cooling tower due to a relatively long payback. Subsequently, Massport requested that a second VFD and associated controls of both VFDs be added to the scope of the capital project.

Changes that Were Implemented:

This measure is being implemented as part of the capital project.

Persistence:

Massport Operations staff are responsible for ongoing maintenance of system..

Critical Success Factors

Successfully completing a retrocommissioning project with a consultant requires a collaborative and motivated facilities staff, a consulting team experienced with the design and operation of the systems and equipment at the facility under investigation, a means for implementing modifications, and a budget that matches the proposed scope of work.

The nature of retrocommissioning implementation is that it tends to be a conglomeration of multiple projects, some of which are operational in nature, and some of which are capital projects. For purposes of this case study, the project team initially struggled to define the best way to implement the recommendations from the central plant investigation. As shown in Table 1, the investigation report recommended that the ECMs be implemented internally by utilizing Facilities staff, vendor term contracts, or design-bid-build procurement. However, due to the limited capacity of the Facilities staff to implement the projects, and Massport's strict procurement requirements, this implementation approach did not prove feasible for many of the ECMs. As a result, most of the ECMs were implemented through a capital project procurement, which proved to be more expensive and time consuming than originally estimated.

Due to the protracted timeframe between completion of the investigation and implementation phases (about three years in the case of Boston Logan), maintaining ongoing communications between all parties was imperative to ensure that the original design and operations intent were being met and energy savings were being achieved.

Once a retrocommissioning investigation is complete and the documentation is delivered to the facilities staff, action is required to implement the recommended projects. Only through project implementation will performance improve. Success may be more likely by ensuring the following factors are met:

- Clearly define the scope of each recommended project, since implementation will require multiple parties.
- Identify available funds for project implementation.
- Retain the retrocommissioning consultant to support project implementation and navigate unforeseen conditions to ensure that the intent of the project is met.
- Provide staff training and ongoing commissioning procedures to ensure persistent performance from the implemented projects.
- Establish a baseline and perform M&V to confirm that the implemented projects are delivering the required performance and anticipated financial return.

Case Study

***Acknowledgments**: This case study was authored by Abbe Bjorklund of Sebesta. Sebesta would like to thank Jason Survilas, John Schanda, and Wendy Riggs-Smith from Massport for sharing their experiences for this case study. This case study was completed by Sebesta as part of ACRP Project 09-04, "Airport Building Operations and Maintenance (O&M) Optimization and Recommissioning: A Whole-Systems Approach," with funding provided by the Transportation Research Board of the National Academies.*

Glossary

Massport: Massachusetts Port Authority

LBE: Leading By Example

HTHW: High Temperature Hot Water

HVAC: Heating, Ventilation and Air Conditioning

ECM: Energy Conservation Measure

BMS: Building Management System

CHW: Chilled Water

VFD: Variable Frequency Drive

DP: Differential Pressure

Psi: Pounds per square inch

SCHW: Secondary Chilled Water

CV box: Constant Volume air terminal unit

ºF: degrees Fahrenheit

boiler FD fans: boiler forced draft fan

boiler ID fans: boiler induced draft fan

Attachments

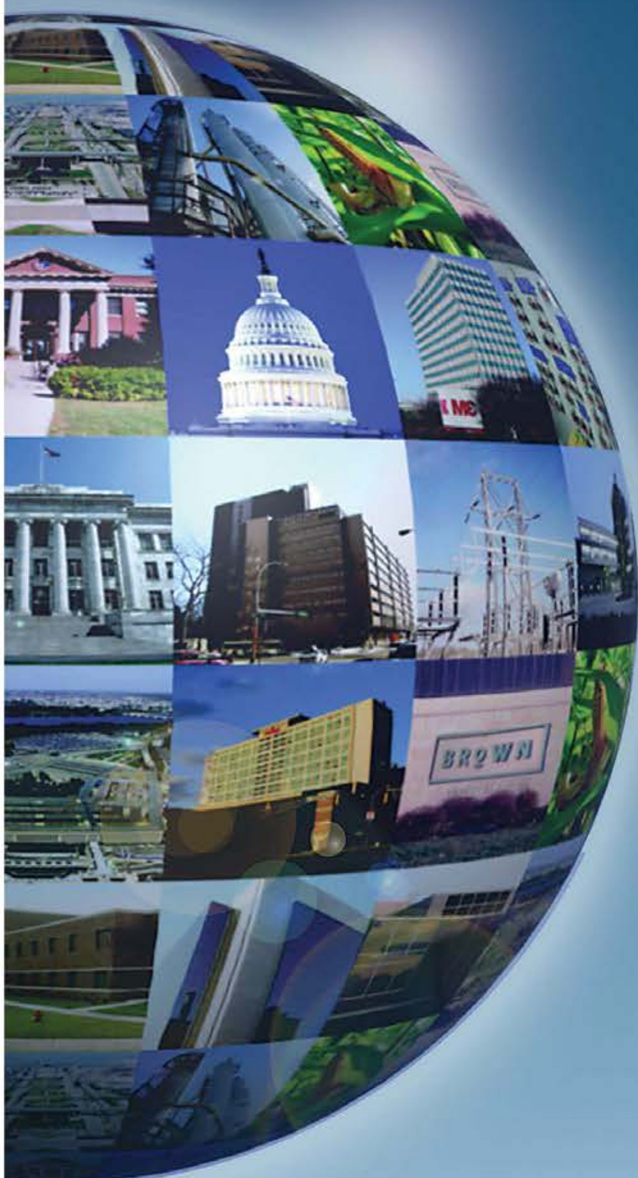
Massport CHP Retrocommissioning Investigation Report

Massport Energy Engineering Procurement RFQ

END OF DOCUMENT

Retro-Commissioning Investigation

Central Heating Plant



Massport

Boston, MA

September 23, 2011

Sebesta Blomberg Project No. 700665.02

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Table of Contents

Section Page

List of Figures and Tables

1.0 Executive Summary

As part of Massport's Energy Initiative, Sebesta Blomberg has conducted a Central Heating Plant (CHP) Retro-commissioning Investigation. The goal of this effort was to identify and quantify low cost/ no cost, and additional capital projects as applicable, that will reduce energy and greenhouse gases and improve plant operations and performance. As part of the CHP Retro-commissioning investigation, Sebesta Blomberg has also conducted Technical Review and CostBenefit analysis of Chilled Water System Upgrades in conjunction with Massport project L962.

Retro-commissioning is a systematic review of an existing facility's operations to identify areas where the facility does not operate as intended, and identify methods that can be implemented to improve operations and reduce energy consumption. The Massport CHP retro-commissioning effort has included site investigations and testing, design and operations data collection and review, and evaluation of current operation of steam, high temperature hot water (HTHW), chilled water, controls, balance of plant, and distribution systems.

CHP Retro-commissioning accomplishments to date:

- Reviewed chilled water and steam systems operation and performance
- Installed temporary chilled water flow meters to diagnose current chilled water system operations
- Created computerized hydraulic model of Massport CHW system to simulate different design/ operation scenarios; working session with Facilities on model
- Tested tertiary loops in Terminals A and E for different operating scenarios
  - Shut off building pumps
  - Overrode deny valves
  - Monitored impact on CHP and building conditions
- Identified pump operation and control issues – reviewed programming on select pumps/ controls
- Decreased CHP secondary pump DP setpoints
- Altered deny valve logic
- Tested CHW temperature setpoint adjustments
- Tested cooling tower performance
- Created operational model of plant CHW equipment (chillers/ pumps/ cooling towers) to simulate efficiency of different operating strategies
- Reviewed plant metering status and needs

As a result of the retro-commissioning investigation, up to eight Energy Conservation Measures (ECMs) are recommended for implementation, as summarized in Tables 1A and 1B. These Tables summarizes estimated implementation cost, annual utility (electric, natural gas, and water) reduction, kBtu savings, greenhouse gas (GHG) reduction, annual cost avoidance, and simple payback for each measure. They also include the implementation plan, and estimated energy savings achieved to date, for each ECM.

Tables 1A and 1B represent the costs and savings associated with two possible plant operating scenarios, depending upon the outcome of capital project L963-C2. This project, which is currently beginning construction, includes installation of variable frequency drives on the FD and ID fans, and associated controls, on the plant's boilers. This project will not only improve plant efficiency, but also improve boiler operation under low load conditions. Currently plant personnel have been operating steam turbine chillers during the summer months to maintain sufficient steam load to operate the boilers during the summer months. It is anticipated that with implementation of L963-C2 it may be possible to operate only electric chillers during the summer months, which have significantly lower energy and GHGs and associated operating costs.

Scenario 1A, as represented in Table 1A, summarizes estimated capital costs and energy savings if the plant is operated with only electric chillers. The total estimated implementation cost for Scenario 1A is $841,000, and the total estimated annual cost avoidance is estimated to be $1.088 million, for a simple payback of 0.8 years. This cost savings represents an approximately 22% reduction in 2010 plant utility costs of approximately $5 million. As shown, under Scenario 1A, it is estimated that Massport will *increase* overall electric use in the plant by about 1.9 million kWh/year, and *decrease* natural gas usage by about 132,000 Mcf/year, with a net savings of 125 million kBtu/year and 6,294 MT CO2 per year.

Scenario 1B, as represented in Table 1B, summarizes estimated capital costs and energy savings if the plant is operated with one steam turbine chiller, in addition to the electric chillers. This scenario includes two additional energy conservation measures than Scenario 1A, ECMs 4 and 5, which will improve the performance of steam turbine chiller #1. The total estimated implementation cost for Scenario 1B is $1.0 million, and the total estimated annual cost avoidance is estimated to be $859,000, for a simple payback of 1.2 years. This cost savings represents an approximately 17% reduction in 2010 plant utility costs of approximately $5 million. As shown, under Scenario 1B, it is estimated that Massport will *increase* overall electric use in the plant by about 736,000 kWh/year, and *decrease* natural gas usage by about 95,000 Mcf/year, with a net savings of 93 million kBtu/year and 4,777 MT CO2 per year.

It should be noted that in conjunction with the retro-commissioning investigation, portions of ECMs 1, 2, and 8 have already been implemented, and are already delivering energy and GHG reductions to Massport.

Report Organization

Sections 2 through 5 describe Sebesta Blomberg's approach to conducting the site assessment and analysis, the Central Heating Plant and distribution system's design and operation, and energy and water usage in the plant.

Section 6 describes the hydraulic model that Sebesta Blomberg developed for the chilled water (CHW) distribution system, and the conclusions and recommendations developed from that modeling exercise to improve distribution system operation and performance. Note that the hydraulic model can be used as a tool by Massport going forward to analyze the impact of adding loads and chilled water system distribution design changes. This section includes specific recommendations to add monitoring points to the CHW distribution system, and to establish cooling coil and control valve standards.

Section 7 describes the recommended Energy Conservation Measures (ECM). Section 7.9 includes descriptions of additional measures that are recommended for further investigation, and Section 7.10 includes descriptions of measures that were considered but are not recommended.

The Appendices include backup support data, including chilled water modeling inputs and outputs, and detailed cost and savings estimates for the recommended ECMs.

Implementation Plan

Table 1C provides an estimated implementation schedule for each ECM. See Section 7 for more detailed implementation plans for each measure.

Acknowledgements

Sebesta Blomberg would like to thank the Massport facilities staff, including John Schanda, Tom St. Pierre, Jason Survilas, Steve Coleman, and the rest of the plant operations staff for their cooperation and invaluable assistance in sharing their knowledge of the facility and providing the site data and tours, as well as freely discussing the areas of opportunity outlined in this report.

Table 1-A: Recommended Energy Conservation Measures (ECMs) – Scenario 1A – ECMs 1-3, 6-8

Energy Conservation Measures (ECMs)						Estimated Annual Utility Reductions						
ECM No.	ECM Description	Implementation Plan	Estimated Implementation Cost - Engineering	Estimated Implementation Cost - Materials/ Labor	Estimated Implementation Cost - Total	Elec. (kWh)	N. Gas (Mcf)	Water (Mcf)	kBtu	GHG Reduction (Metric Tonnes CO2)	Total Estimated Annual Cost Avoidance	Simple Payback (yrs)
ECM-1	Bypass Building Pumps, Remove 3-Way Valves, Open Balancing Valves and Deny Valves, Piping Modifications	Facilities/ Design - Bid - Build	$22,000	$78,000	$100,000	417,043			1,422,951	156	$47,126	2.1
ECM-2	Decrease Differential Pressure Setpoint/ Modify SCHW Pump Staging, Add Monitoring Points	Facilities/ Controls Contractor - Engineering Support	$6,000	$19,000	$25,000	218,713			746,249	82	$24,715	1.0
ECM-3	Renovate Building Chilled Water Systems	Facilities/ Term Contractors - Engineering Support	$41,000	$90,000	$131,000	454,668	1,586		3,137,327	255	$66,920	2.0
ECM-6	Reset chilled water supply temperature	Facilities/ Controls Contractor - Engineering Support	$8,000	$22,000	$30,000	68,000	2,800		3,032,016	174	$35,124	0.9
ECM-7	Operate Only Electric Chillers/ Upgrade Plant Metering	Facilities/ Design - Bid - Build	$65,000	$370,000	$435,000	-3,041,091	110,824		100,447,798	4,744	$742,432	0.6
ECM-8	Address Steam System Losses	Facilities/ Vendors	$0	$120,000	$120,000		16,618	77	16,618,000	882	$171,856	0.7
	Totals		**$142,000**	**$699,000**	**$841,000**	**-1,882,667**	**131,828**	**77**	**125,404,340**	**6,294**	**$ 1,088,173**	**0.8**

Assumes: *$0.113/kWh Electric cost*

$9.8/ Mcf Gas cost

$116.9/Mcf Water/ Sewer Cost

.000375 MT/kWh

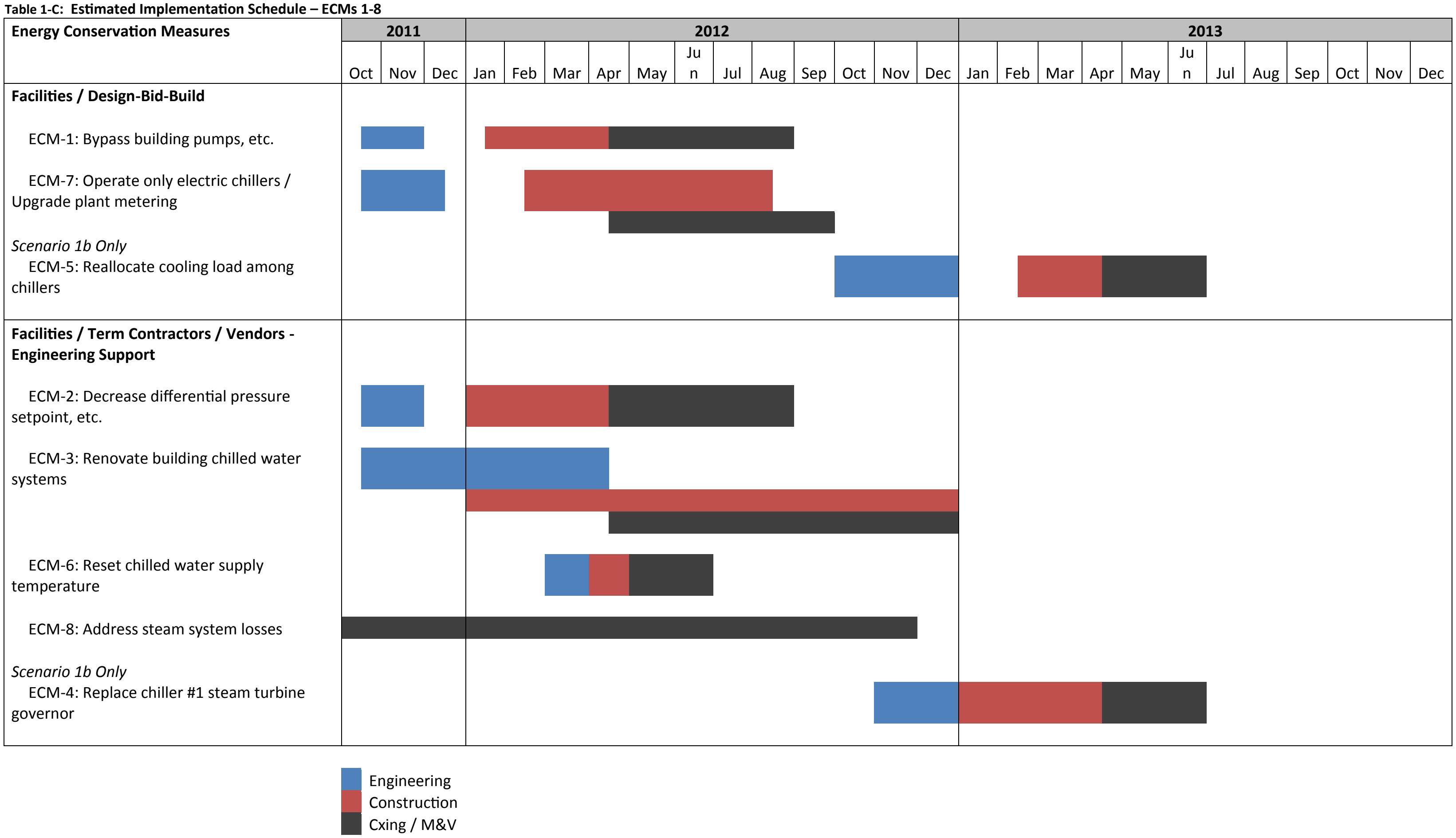
.0531 MT/Mcf Natural Gas

Table 1-B: Recommended Energy Conservation Measures (ECMs) – Scenario 1B – ECMs 1-8

Energy Conservation Measures (ECMs)		Implementation Plan	Estimated Implementation Cost - Engineering	Estimated Implementation Cost - Materials/ Labor	Estimated Implementation Cost - Total	Estimated Annual Utility Reductions				GHG Reduction (Metric Tonnes CO2)	Estimated Annual Cost Avoidance	Simple Payback (yrs)
ECM No.	ECM Description					Elec. (kWh)	N. Gas (Mcf)	Water (Mcf)	kBtu			
ECM-1	Bypass Building Pumps, Remove 3-Way Valves, Open Balancing Valves and Deny Valves, Piping Modifications	Facilities/ Design - Bid - Build	$22,000	$78,000	$100,000	417,043			1,422,951	156	$47,126	2.1
ECM-2	Decrease Differential Pressure Setpoint/ Modify SCHW Pump Staging, Add Monitoring Points	Facilities/ Controls Contractor - Engineering Support	$6,000	$19,000	$25,000	218,713			746,249	82	$24,715	1.0
ECM-3	Renovate Building Chilled Water Systems	Facilities/ Term Contractors - Engineering Support	$41,000	$90,000	$131,000	454,668	1,586		3,137,327	255	$66,920	2.0
ECM-4	Replace Chiller #1 Steam Turbine Governor	Facilities/ Vendors - Engineering Support	$7,800	$36,800	$45,000		3,890		3,890,000	207	$38,122	1.2
ECM-5	Reallocate Cooling Load Among Chillers	Facilities/ Design - Bid - Build	$18,000	$100,000	$118,000	-1,894,000	70,272		63,809,672	3,021	$474,644	0.2
ECM-6	Reset chilled water supply temperature	Facilities/ Controls Contractor - Engineering Support	$8,000	$22,000	$30,000	68,000	2,800		3,032,016	174	$35,124	0.9
ECM-7	Upgrade Plant Metering	Facilities/ Design - Bid - Build	$65,000	$370,000	$415,000	0	0		0	0	$0	0.0
ECM-8	Address Steam System Losses	Facilities/ Vendors	$0	$120,000	$120,000		16,618	77	16,618,000	882	$171,856	0.7
	Totals		**$167,800**	**$835,800**	**$984,000**	**-735,576**	**95,166**	**77**	**92,656,215**	**4,777**	**$858,507**	**1.1**

Assumes: *$0.113/kWh Electric cost*
$9.8/ Mcf Gas cost
$116.9/Mcf Water/ Sewer Cost
.000375 MT/kWh
.0531 MT/Mcf Natural Gas

Table 1-C: Estimated Implementation Schedule – ECMs 1-8



2.0 Site Assessment Approach and Methodology

A retrocommissioning process is a systematic review and documentation of an existing facility's operations to identify areas where the facility does not operate as intended, or more efficient equipment or techniques can be applied, and then identify methods to improve its energy efficiency to current standards. At the CHP, the process focused on major energy-consuming equipment, including the boilers, the chillers, pumps and associated systems.

A number of site visits were conducted to learn how the equipment was operated, to gather data on the equipment, and to selectively test different operating scenarios. Massport CHP operations staff provided records of the automated operating logs. This information was compared against data collected through field checks to verify proper operations. This field and operating data was reviewed to develop a list of possible Energy Conservation Measures (ECMs). Section 7 contains the resulting recommended ECMs, which have been developed through a conceptual level to determine budgetary cost and savings.

Energy savings projections presented in this report were calculated using measured data where possible, systems design data, and our experience with similar equipment. Some data was gathered from the existing Building Management System (BMS). Heating and cooling loads were calculated using hourly temperature profiles data for Boston, representing 30-year average weather conditions, combined with observed operating parameters. Cost estimates are order of magnitude using conventional estimating techniques and our experience with similar installation.

3.0 Central Heating Plant Description

The Central Heating Plant (CHP) provides heating (via high pressure steam and high temperature hot water) and cooling (via chilled water) to the majority of the major buildings at Logan Airport.

Steam is generated in three Keeler field erected boilers with a total capacity of 385,000 lb/hr. #1 boiler is rated at 150,000 pounds per hour, #2 is rated at 135,000 pounds per hour, and #3 is rated at 100,000 pounds of steam per hour. Each boiler has a maximum working pressure of 250 psi, and a normal operating pressure of 150 psi. The boilers have dual fuel burners allowing use of both #6 oil and gas. The boilers are of balanced draft design, with both forced draft fans and induced draft fans. The plant has a 100,000 gallon fuel oil storage tank. At the present time, the plant burns gas almost exclusively due to the relatively low cost of gas vs. oil.

Support equipment for the boiler plant includes two deareators, 5 boiler feed pumps, and a condensate tank with two full size condensate pumps.

Steam is sent out to the steam distribution system through several steam headers, located in tunnels. HTHW is produced in four steam to HTHW heat exchangers, each rated at 30,000 BTU per hour each. The HTHW system has its own pumps to circulate HTHW through the distribution system.

The boiler plant runs year round. In addition to supplying steam for heat in winter, it supplies steam and hot water in summer for domestic hot water and reheat for temperature control in some of the HVAC systems in the airport.

Chilled water is produced by 6 chillers, ranging in size from 1950 tons to 3500 tons. Design data for the six chillers is summarized in the table below. The plant renovation in 1999 was based on 5 chillers installed, or planned, with total plant capacity of 13,800 tons. In 2003, an electrically driven chiller of 1950 tons capacity was purchased from York (chiller #6). This essentially replaces chiller #3, a nominal 2,000 ton York machine dating from 1985. Cooling water for the chillers is provided by a 4 cell tower. Cooling water is circulated from the tower to the chillers by 5 vertical turbine pumps located outside by the cooling towers above the tower basin. While the 250 hp cooling tower fans operate at 480 volts, the 300 hp condenser water pumps operate at 4160 volts. The pumps are manifolded, but the sizing of the pumps represents one pump for each of the chillers installed at the time of the plant renovation in 1999. Chiller #6 is served by the same condenser water pump as chiller #3 in an either-or arrangement. The chiller plant is designed for 42 degF chilled water supply temperature, 14 degF temperature differential.

The chilled water system is a primary-secondary system, with each chiller having a dedicated primary chilled water pump. The motors on these pumps range from 100 hp to 125 hp at 4160 volts; pump 10 that serves Chiller 6 has a 460 volt motor. The chillers discharge into a common header that is connected to the secondary chilled water pump suction header. A decoupler line runs between the secondary return header and the secondary chilled water pump suction header. This accommodates differences in flows between the primary and secondary loops.

Table 2: CHP Chillers

Chiller Plant Data						
Number	1	2	3	4	5	6
Manufacturer	Carrier	York	York	York	Carrier	York
Approx. Install Date	1970/1995	1975	1985	1998	1999	2003
Current Rated Capacity (tons)	2400	2500	2000	3500	3500	1950
Drive	Steam Turbine	Steam Turbine	Electric Motor	Electric Motor	Electric Motor	Electric Motor
Refrigerant	R134a	R-500	R22	R134a	R134a	R134a
Rated Motor kW	N/A	N/A	1140	2120	2170	1268
kW/ton Rated	N/A	N/A	0.63	0.61	0.62	0.65
Lb steam/ton-hr	14.6	14.0	N/A	N/A	N/A	N/A

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Central Heating Plant Description

4.0 Energy and Water Usage in the Plant

4.1 Boiler Plant

Energy and water use and costs of operating the CHP were estimated using 2010 plant operating data. The plant operating data was not all complete, and it was necessary to estimate some of the energy flows. In estimating water costs, a distinction was made between water that would be drained to the sewer, such as cooling tower blowdown, and water that did not go to the sewer, such as boiler makeup, and cooling tower evaporation.

The boiler plant utility use and cost primarily associated with burning fuel to make steam. It requires some electric power to run the fans that force the air into the boiler, and to run the pumps to put water into the boiler. It also requires some water to make up blowdown and losses in the system. By far the largest amount of cost and energy is for boiler fuel. Based on the combustion efficiency of 83% for the boilers, we estimate the overall plant efficiency, including parasitic losses, to be about 80%.

The total annual utility cost to operate the boiler plant during the heating season is estimated at approximately $3 to $4 million, depending upon how severe the winter is. About 90% of the cost of operating the boiler plant is fuel cost. Electric power and water make up the rest. The following chart shows the percent of total estimated boiler plant operating cost attributable to each utility use:

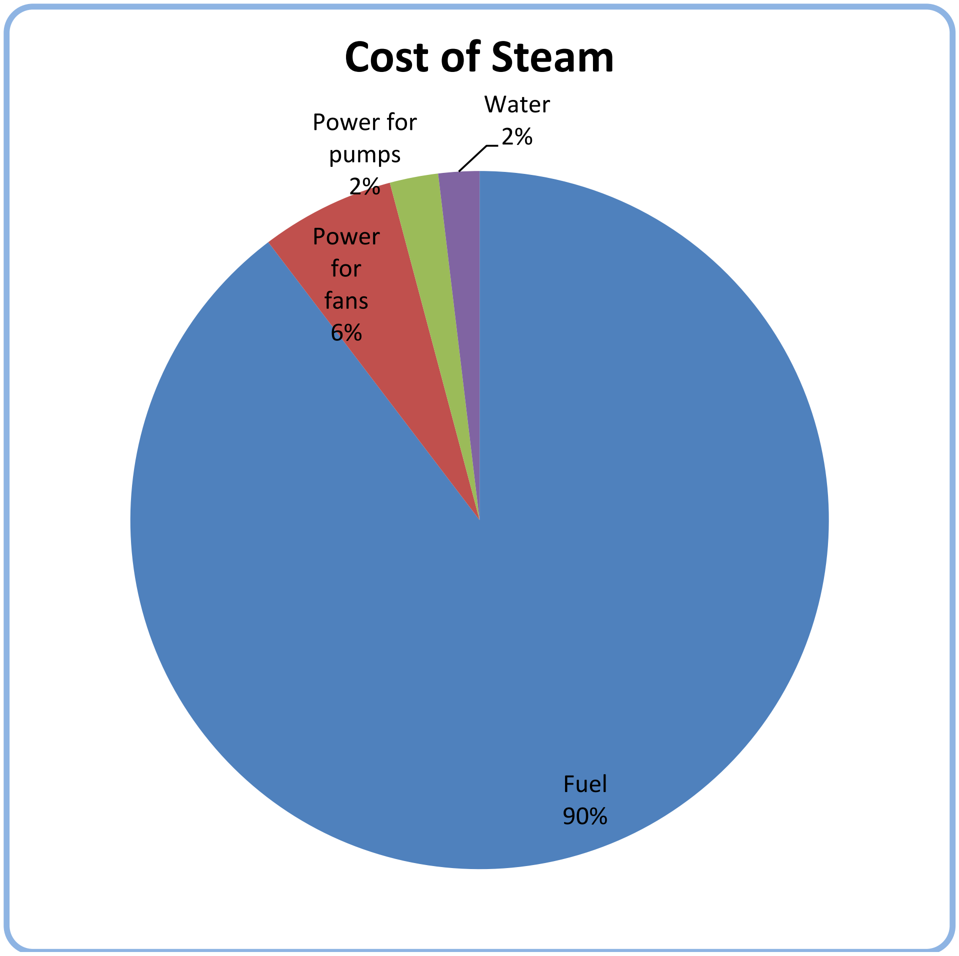

Figure 1: Cost of Steam

4.2 Chiller Plant

The chiller plant uses a combination of electric and steam turbine driven chillers to cool chilled water. The heat removed from the chilled water is dissipated in a cooling tower. The cooling tower requires fans to move air through the cooling tower and dissipate heat by evaporation. It evaporates approximately 36 to 45 million gallons of water per year, with another 7 to 12 million gallons bled to the sewer to control the concentration of solids in the water. The cooling water system also requires pumps to move the water from the tower through the water chillers and back again. The cooling system requires pumps to move chilled water through the chillers, and additional pumps to move the chilled water through the distribution system.

The chiller plant also uses steam to drive steam turbine driven chillers. The cost for energy and water for the chilled water plant is estimated at approximately $2.5 million to $3million per year. The breakdown of cost for the chilled water plant is shown in the figure below:

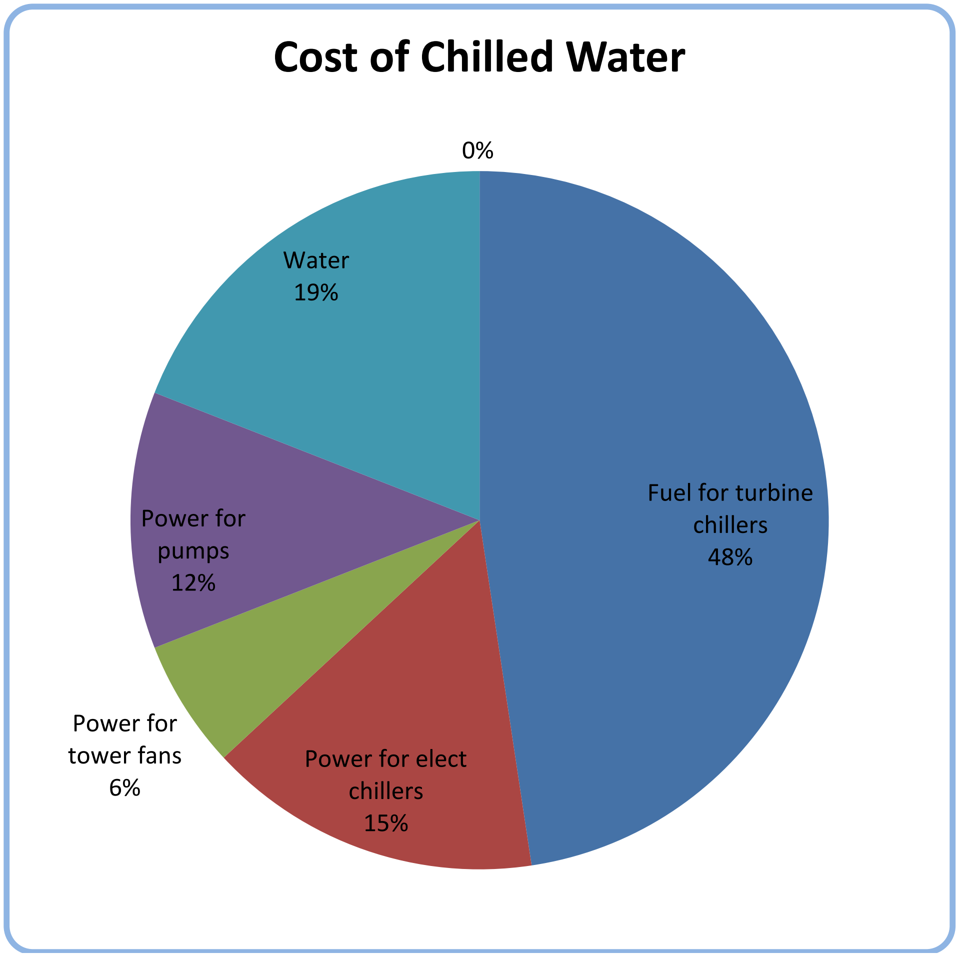

Figure 2: Cost of Chilled Water

The cost of water is significant, due to the amount of water that is evaporated, and the amount that is drained to the sewer to control solids concentration. The tower blowdown incurs both water costs and sewer costs, and therefore is more expensive than water that is evaporated.

The breakdown of the major energy and water costs for the entire CHP facility is shown on the chart and tables below:

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Energy and Water Usage in the Plant

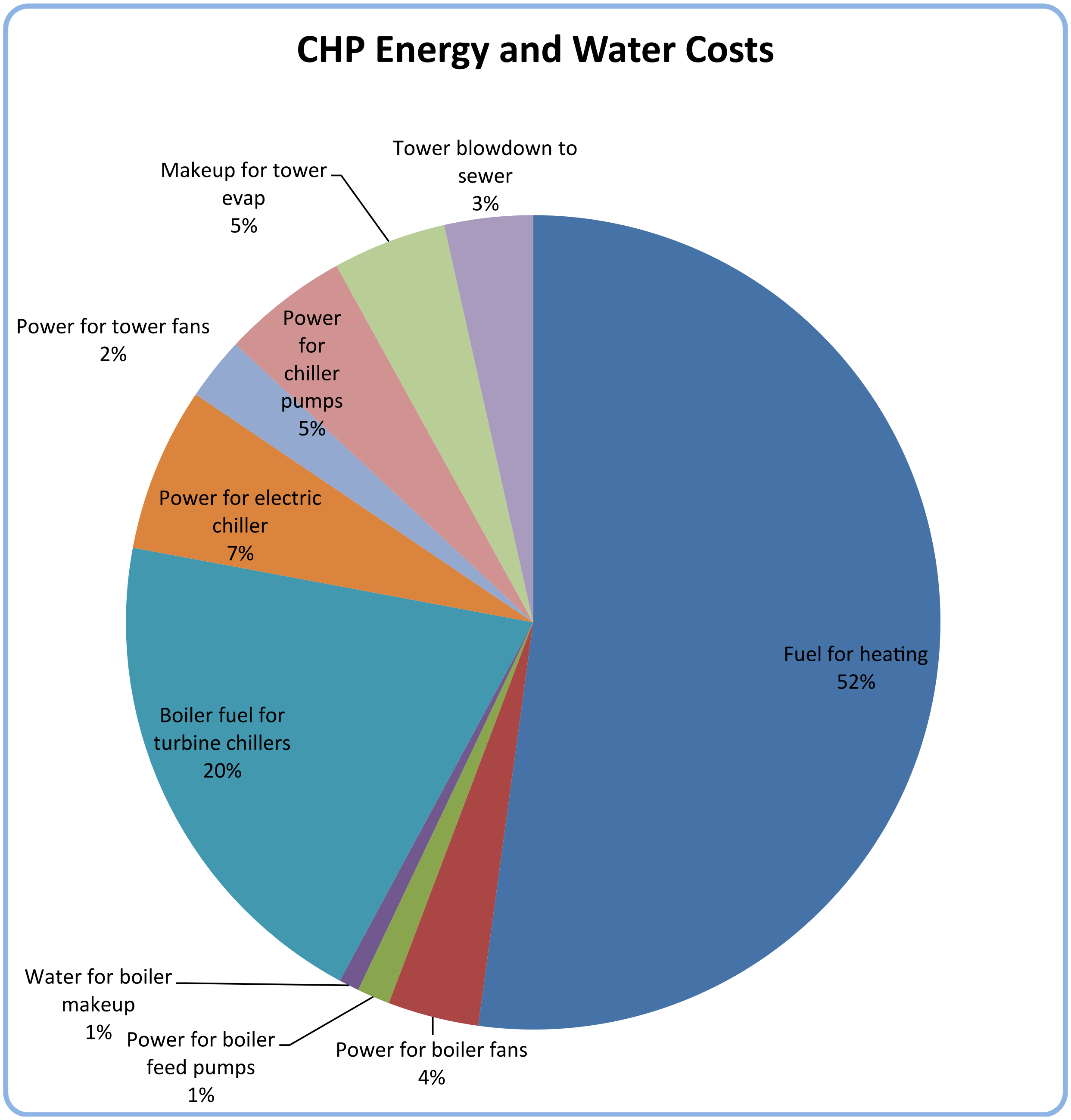

Figure 3: CHP Energy and Water Costs

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Energy and Water Usage in the Plant

Table 3: Utility Usage

Total Plant Yearly Utility End Use (2010)	Est. Cost	Est. Usage	Units	% of Total
Fuel for heating	$2,600,000	300,903	Mcf	52%
Power for boiler fans	$180,000	1,500,000	kwh	4%
Power for boiler feed pumps	$65,000	500,000	kwh	1%
Water for boiler makeup	$40,000	4,000,000	Gallons	1%
Misc plant water	$15,000	1,000,000	Gallons	0%
Boiler fuel for turbines	$1,000,000	110,824	Mcf	20%
Power for electric chiller	$325,000	2,747,701	kwh	7%
Power for tower fans	$125,000	1,085,161	kwh	3%
Power for chiller pumps	$250,000	2,170,321	kwh	5%
Makeup for tower evaporation	$225,000	30,500,000	Gallons	5%
Tower blowdown to sewer	$175,000	9,500,000	Gallons	4%
Estimated Totals	$5,000,000			

Estimated Utility Totals (2010)				
Natural Gas	$3,500,000	411,727	Mcf	70%
Electric	$840,000	8,003,183	kwh	17%
Water/ Sewer	$660,000	45,000,000	Gallons	13%
Total	$5,000,000			

The breakdown of plant water usage is shown on the accompanying chart:

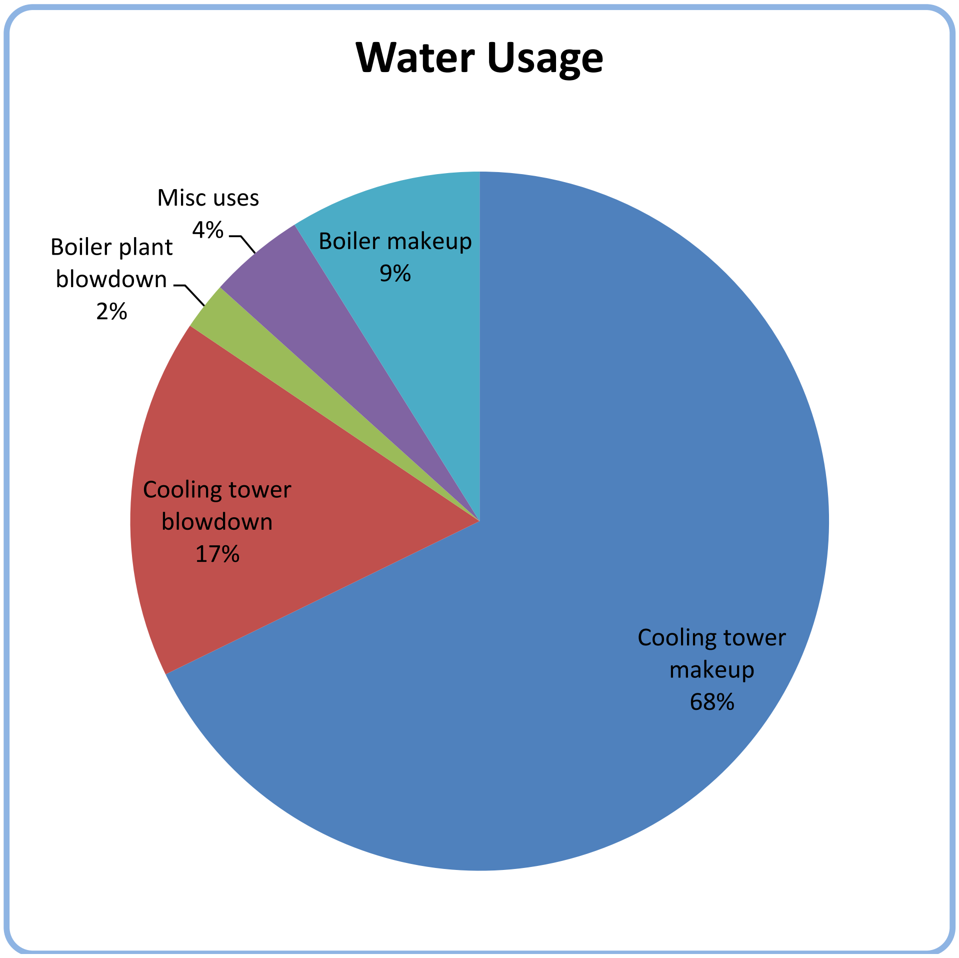

Figure 4: CHP Water Usage

4.3 CHP Operation Overview

The boiler plant has a relatively simple operation. Massport has recently switched to running only one boiler and keeping a second one warm, instead of running two boilers to meet the load. This will increase the plant efficiency by reducing standby losses. There is a planned project to install VFDs on the boiler fans and condensate pumps, which will reduce the cost of operating the boilers, especially at low loads. The plant utilizes modulating burner controls and oxygen trim to optimize burner efficiency.

The chilled water plant, with a mix of steam turbine driven and electrically driven chillers, is more complex to operate. It is difficult to equate pounds of steam per ton hour for a turbine driven chiller with kwh per ton hour for an electrically driven chiller. They can best be equated with the common denominator of cost.

Sebesta Blomberg has created an operational model of the chiller plant in an effort to understand where the energy goes, and in order to evaluate ways to reduce operating costs, based upon available equipment performance data. Quadratic curve fits were developed for chiller performance within about 5% accuracy, except at 10% load, where the error increased to between 8 and 20%. This was of little consequence, as the chillers will not be operating at this load.

Sebesta Blomberg discussed chiller operation with plant personnel, gathered operating data from the plant control system screens, and reviewed previous studies. We learned that the plant personnel usually keep one turbine chiller loaded, in order to provide some load on the boilers, to facilitate control of the boilers when the only load on them is domestic hot water and reheat for building temperature and humidity control. The Carrier turbine driven chiller has both inlet guide vanes and hot gas bypass control to regulate capacity. Examination of the control system screens shows that the chiller is on hot gas bypass control a fair amount of the time.

Using the model data, it is possible to compute overall utility cost per ton hour for the various chillers. In addition to the chiller itself, each chiller requires cooling tower fan energy, a cooling water pump, and a primary chilled water pump. These costs have been added to the chiller energy use data to develop the chiller performance curves shown below.

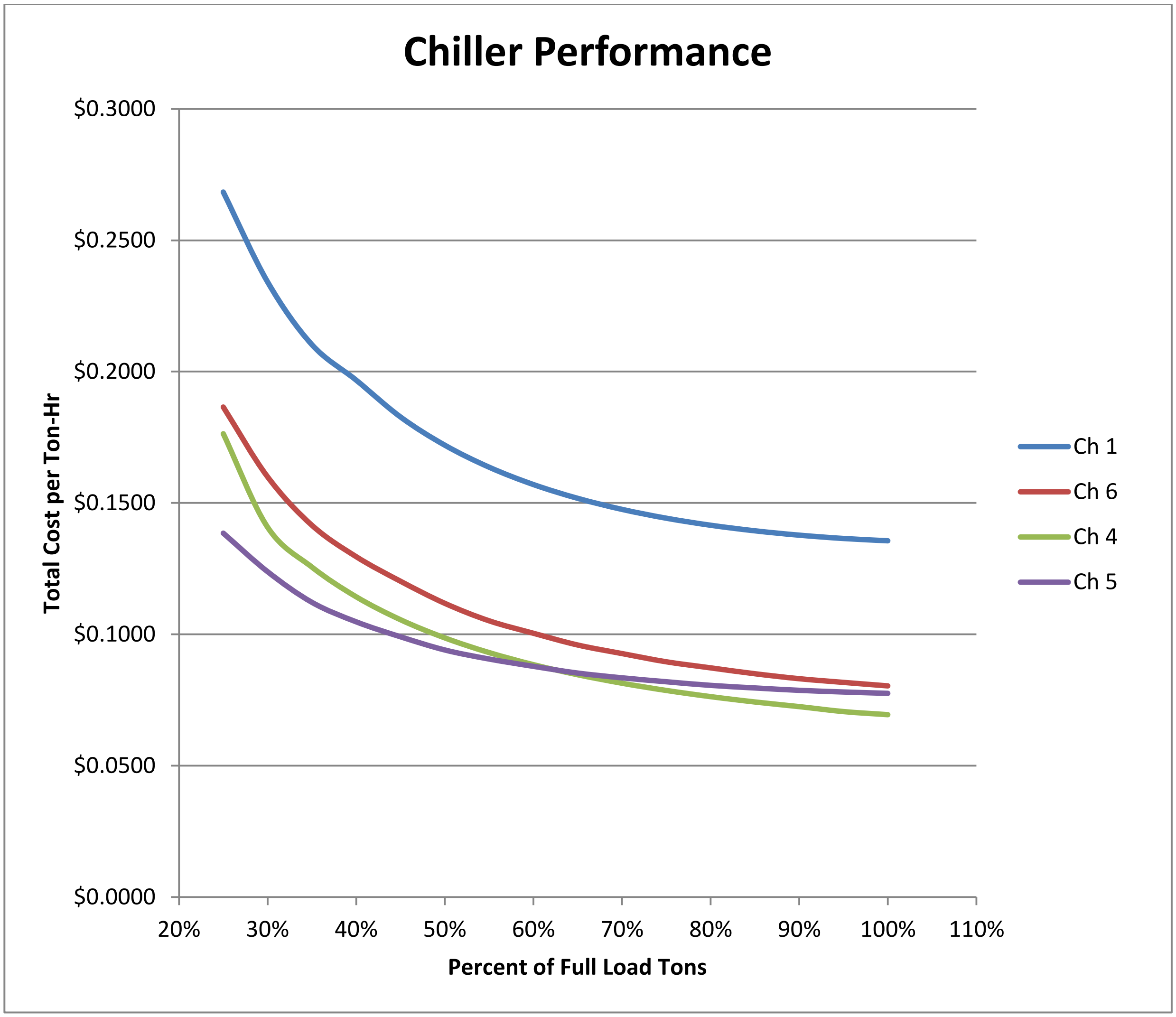

Figure 5: Chiller Performance

The data is plotted as total cost per ton-hour versus the % load, so that the actual loads are a fixed percentage of maximum load. For example, 50% load for Chiller 1, which is rated at 2400 tons after refrigerant conversion, would be 1200 tons, while 50% load for Chiller 4 would be 1750 tons. Chiller 6, the new 1950 ton chiller has performance slightly poorer than Chiller 4, the 3500 ton York, until about 10% load, where it is uneconomical to run the chillers. The cost curve of Chiller 5, the 3500 ton Carrier machine, crosses that of Chiller 4, the 3500 ton York. At loads below 55%, Chiller 5 has a lower cost. At loads above 55%, chiller 4 has a lower cost. Since these chillers usually operate at higher than 50% load, Chiller 4 is the more efficient. On a cost basis, the steam turbine chillers are considerably more expensive than the others. At full load, the 3500 ton machine has an operating cost of about $0.07 per ton hour, while the turbine chiller has an operating cost of about $0.136 per ton hour, or almost twice as much. Part of the added cost is the higher cooling cost of the turbine chiller: the cooling towers have to carry off both the heat from the building, and the heat from condensing the steam to drive the turbine. All of the machines have much better performance at loads above 50%.

See Energy Conservation Measures (ECMs) 5 and 6 for specific recommendations on optimizing chiller plant operations.

5.0 Secondary Chilled Water and Distribution System

5.1 System Description

Massport's chilled water system is a constant flow primary-variable flow secondary system. The two systems are hydraulically decoupled via a 20" decoupler. The secondary chilled water system is comprised of four chilled water pumps. The pumps supply water directly to 21 buildings on campus via two underground piping segments, North and South Loops. The distribution system was originally a complete loop with radials serving the terminals. At some point of time, the northern loop that connected Terminal E with Terminal C was severed; consequently the north and south loop serve distinct loads. The North Loop serves Terminal E only and the South Loop serves the remainder of the airport complex.

The buildings have a mix of chilled water system designs ranging from constant to variable flow with multiple interface arrangements to the CHP. Three buildings interface with the CHP via plate and frame heat exchangers; the secondary side of these heat exchangers are glycol systems. Multiple buildings have tertiary pumps, but many are not in use. Some buildings also have a deny valve system, described in more detail later in this report. The CHP chillers were designed to deliver 42°F chilled water supply and operate at a 14°F temperature differential. Table 4 Building Information lists pertinent design and operational information about the buildings that are directly connected to the CHP system.

Table 4: Building Information

Building Directly Connected to CHP CHW Loop	HX	Pump	Pump in Use	Variable Flow	Deny Valve
International Gateway South Bldg #19	N	Y	**Y**	Y	**Y**
Terminal E Main Building #19	N	Y	**Y**	Y	**Y**
West Parking Garage Bldg #81	**Y**	N	N	**N**	N
Terminal E Walkway Bldg #87 (Mech Rm)	N	Y	**Y**	**N**	N
Terminal A Building #31	N	Y	**Y**	Y	**Y**
Terminal A Satellite Bldg #31	N	Y	**Y**	Y	**Y**
Terminal A Walkway Bldg #88	N	Y	Y	**N**	N
Central Garage Bldg #30	**Y**	N	N	Y	N
Control Tower Bldg #26	**Y**	N	N	Y	N
Boutwell Building #24	N	Y	**Y**	Y	N
Old Tower	N	Y	N	Y	N
Terminal C Bldg #22	N	N	N	Y	N
Terminal C Pier B	N	N	N	Y	N
Terminal C Pier C	N	N	N	Y	N
Terminal C Pedestrian Walkway Bldg #36	N	Y	N	Y	N
Terminal C Pier A Bldg #20	N	N	N	Y	N

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Second Chilled Water and Distribution System

Building Directly Connected to CHP CHW Loop	HX	Pump	Pump in Use	Variable Flow	Deny Valve
Terminal B Pedestrian Walkway East Bldg #90	N	Y	N	Y	N
Terminal B Pedestrian Walkway West Bldg #95	N	Y	N	Y	N
US Airways Shuttle Building #29	N	Y	N	Y	N
Terminal B US Airways Bldg #29	N	Y	N	Y	N
Terminal B AA Bldg#27	N	Y	N	Y	N

The Old Tower is fed via the Boutwell Building. Terminal B-Pier B has four air handlers that are served by booster pumps, but the remainder of Terminal B is pumped via the CHP. Valve Rooms 1 and 2 formerly served Terminals B and C, but these pumps are no longer in use. Most of the building pumps that are not in use are not bypassed either; the CHP secondary chilled water pumps produce enough pressure to flow through the building pump and meet the flow requirements of the coils. Note that the buildings closest to the CHP have building pumps in use but the further away buildings do not!

Table 5: 3-Way Valve List

- lists buildings with HVAC equipment that has 3-way chilled water control valves. The remaining systems have 2-way chilled water control valves.

Table 5: 3-Way Valve List

Building	Equipment	Directly Tied to CHP
Terminal B Pier A	AHU 30 & 35	Yes (Tenant Equip)
Terminal B pier C	AHU 1 thru 4	Yes(Tenant Equip, w/Booster Pump)
Terminal C Checkpoint	RTUs 1-5	Yes (Needs Confirmation)
Central Garage	AHU's 1 thru 4	No
Control Tower	AHU's 106 thru 109 and AHU-5	No
West Garage	AHU 1 thru 6, 39 FCU's, 2 CRU's	No
Terminal B Walkway	FCU -WB-2	No
Terminal A Walkway	AHU-WA-1	Yes
Terminal E Walkway	AHU-WE-1	Yes
Terminal A Walkway	AHU-WA-2	No
Terminal E Walkway	AHU-WE-2	No

5.2 Distribution System Trend Data Review

Once the building equipment and distribution was understood, trend data was reviewed to gain an understanding of how the chilled water load varies over time. Figure 6 depicts how the secondary chilled water load varies with the outside air dry bulb temperature. As shown, there is a good correlation between the two, which allows using dry-bulb temperature to predict load with confidence based upon the correlation shown.

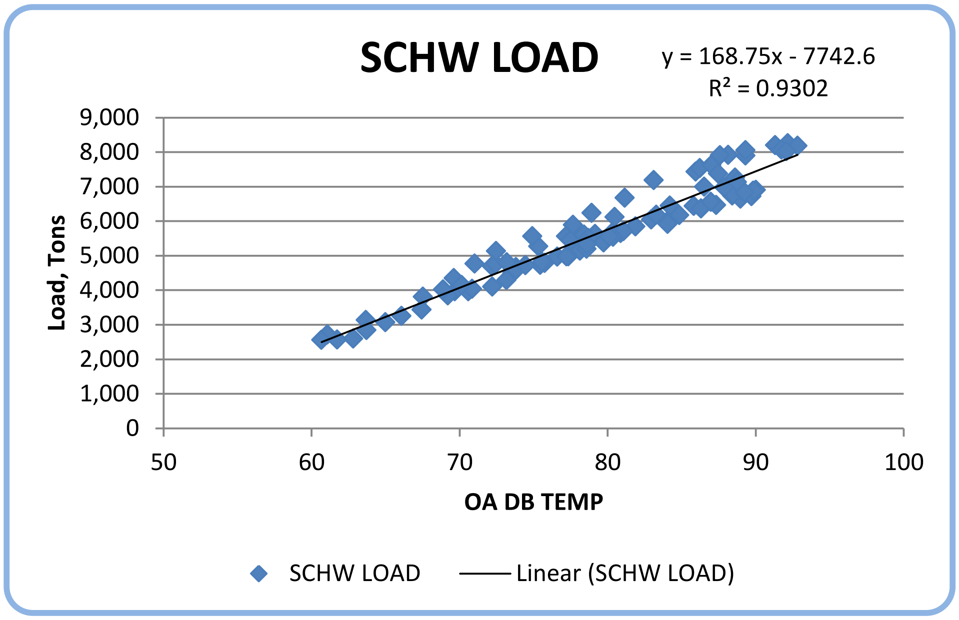


Figure 6: Secondary Chilled Water Load Relative to Ambient Dry Bulb

Figure 7 shows another relationship, but this time chilled water load versus ambient enthalpy. The relationship is fairly accurate but not as accurate as estimating using ambient dry-bulb.

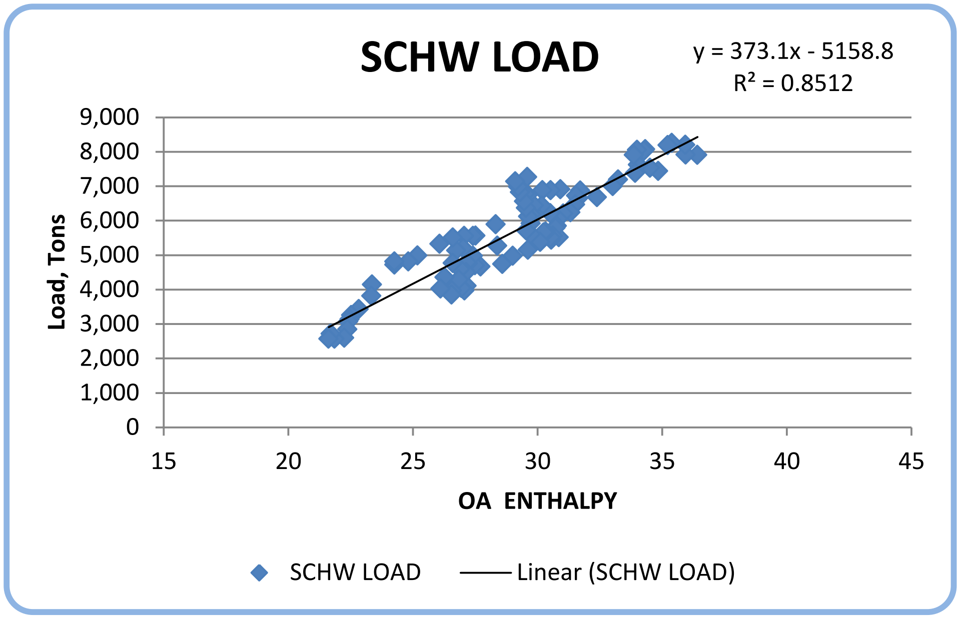


Figure 7: Secondary Chilled Water Load Relative to Ambient Enthalpy

Figure 8 shows a 24-hour trend from August 31, 2010 which was essentially a design day for Boston per ASHRAE standards, 91°F and 73°F wet-bulb. The coincident wet-bulb was actually 72°F with a 92°F dry bulb temperature. System trends are revealed in this Figure. The impact of occupant and solar cooling loads are evident. The load is fairly flat until roughly 0700 then rises until peaking at 1600 then declining sharply after 2100 when the sun is down and the Terminals are beginning to close down.

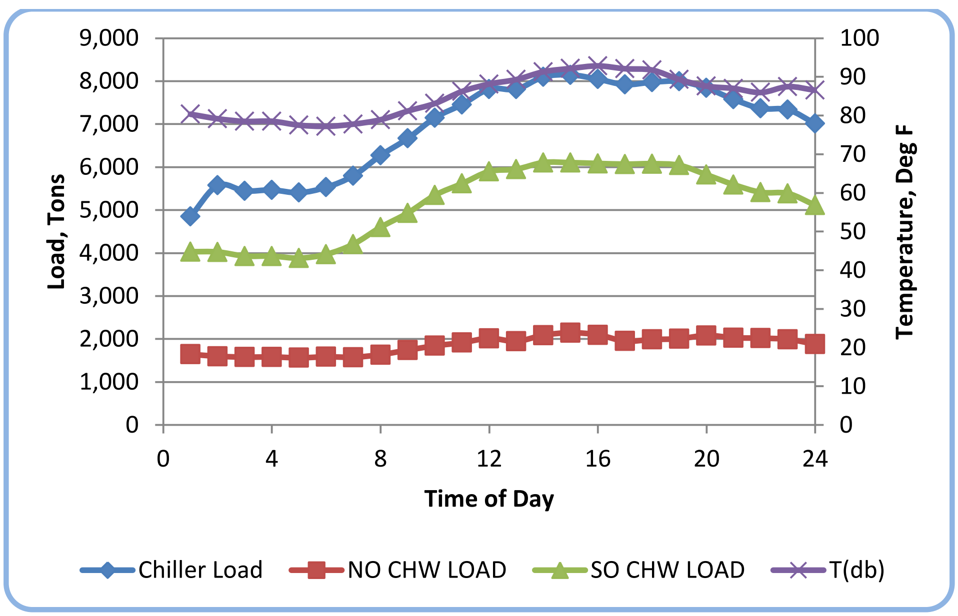


Figure 8: August 31, 2010 Chilled Water Loads

Figure 9 shows the data solely for the North Loop in order to provide better granularity than the composite graph shown in the previous Figure. The flow increase from the lowest value to the peak for this day was 28%. The differential temperature and flow behaved erratically between the hours of 1200 and 1700. The flow increased rapidly between 1300 and 1500 then decreased just as rapidly. As the flow increased, the differential temperature fell, not in as steep a fashion but almost mirrored. One plausible cause could be the operation of the deny valve system or the air handlers losing temperature control. Design differential temperatures were achieved while design cooling loads were occurring.

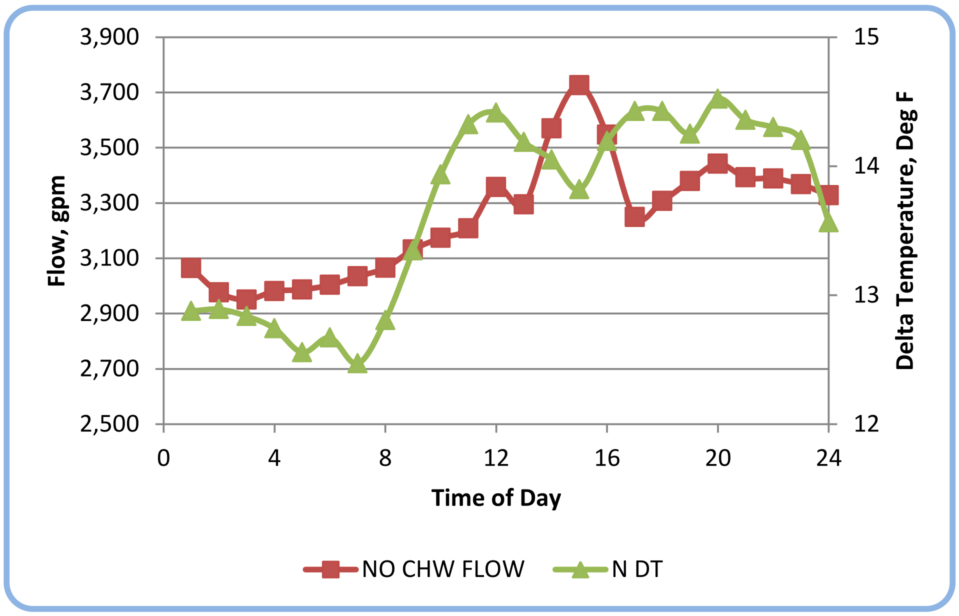


Figure 9: August 31, 2010 North Loop Chilled Water Flow and Differential Temperature

Figure 10 shows the data solely for the South Loop in order to provide better granularity than the composite graph shown in Figure 8. The South Loop did not quite develop design differential temperature and had similar flow and differential temperature profile as the North Loop did. The percentage of load for the South Loop associated with deny valves is only 31% while the North Loop has 97% of the load affected by deny valves. This helps explain why the north loop has a better differential temperature profile at the building entrance, when in reality the building side differential temperature most likely is lower than depicted. As the cooling demand increases, the differential pressure in the system increases which will allow more water to be bypassed by 3-way valves and other open paths. The South Loop had the same drop in differential temperature

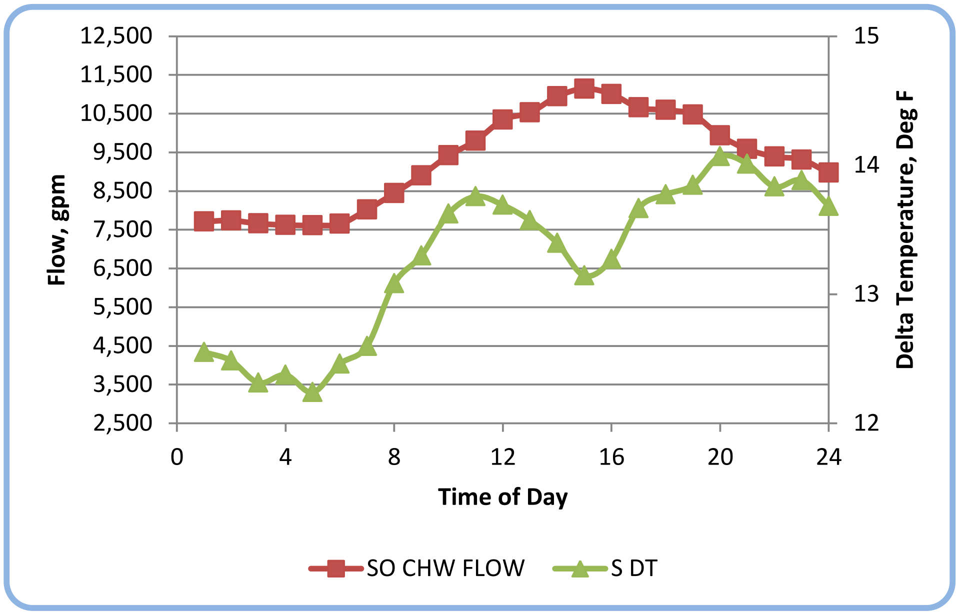


Figure 10: August 31, 2010 South Loop Chilled Water Flow and Differential Temperature

Figure 11 shows a milder day which was preceded by days that were of below average temperature, August 28, 2010. As you can see, the load profiles are similar to those seen in Figure 8: August 31, 2010.

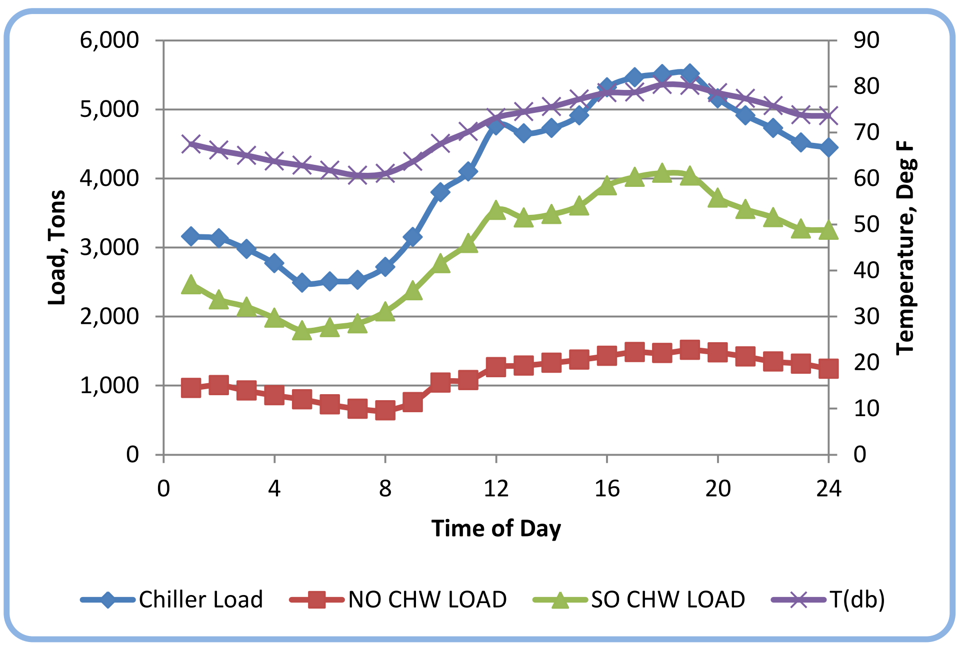


Figure 11: August 28, 2010 Chilled Water Loads

Second Chilled Water and Distribution System

Figure 12 and Figure 13 show the North and South Loops respectively, and show that neither loop operated at the design differential temperature during milder weather. Both loop peak flow rates and maximum differential temperatures occurred at the same time of day. Both systems oddly enough peaked prior to the most demanding ambient temperatures of the day.

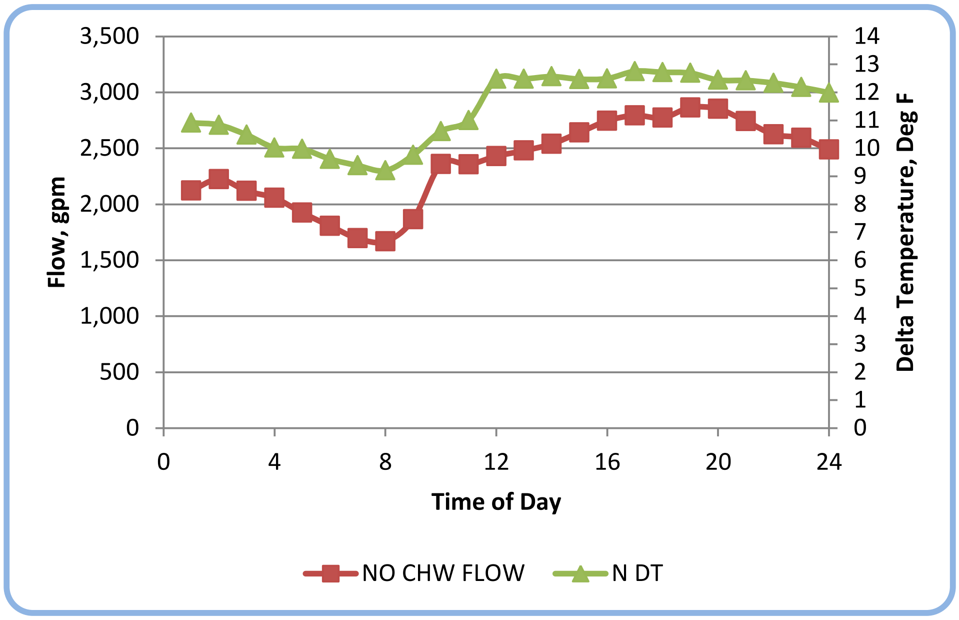


Figure 12: August 28, 2010 North Loop Chilled Water Flow and Differential Temperature

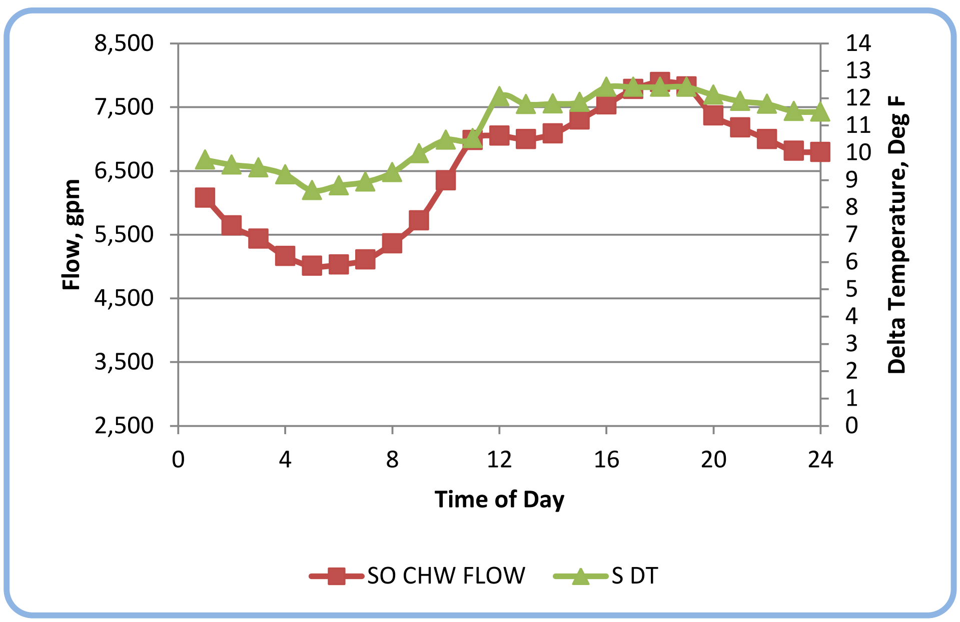


Figure 13: August 28, 2010 South Loop Chilled Water Flow and Differential Temperature

5.3 Site Review and Chilled Water Testing

On June 8th and 10th, Sebesta Blomberg conducted a site walk through with Jason Survilas of Massport. The distribution system was walked down and flow schematics were reviewed and marked-up. Spot checks of mechanical rooms were also conducted. This visit allowed the current documentation to be reviewed for accuracy and pipe lengths and fittings to be determined.

On June 29th, testing was performed on the tertiary loops of Terminal A Main, Terminal A Satellite, Terminal E Gateway, and Terminal E Main by Sebesta Blomberg and Massport. Also on this day, a flow meter was installed to monitor the flow rate in the 14-inch line that feeds Terminal C after the Boutwell Building. A round of the CHP was performed prior to testing. Table 6: CHP Pump Operating Data shows the data that was recorded for the operating chilled water pumps.

"X" indicates that the data does not exist or did not seem reasonable.

Table 6: CHP Pump Operating Data

Pump	Service	Ps	Pd	Amps	Evap dP	Hz	Flow
CHWP-5	Chiller 5	54	74	14.3	9	X	5,880
CHWP-3	Chiller 1	51	76	13	10	X	4,437
CHWP-10	Chiller 6	X	79	77	13	X	3,374
CHWPs-7,8,9	Secondary	55	92	163	X	40	10,775

Testing was performed to do the following:

1. Shut off Building Pumps-Lead and Standby
2. Override Deny Valves to Fully Open
3. Monitor Impact on CHP

At the start of the test, the pumps in Terminal E, Main and Gateway, were operating at the lowest commanded speed from the Carrier system. The differential pressure setpoint that the CHP secondary chilled water pumps were operating to maintain was 20 psi; 3 pumps were online at 42 Hz each. Terminal E had the highest differential pressure and Terminal C the lowest. Terminal E Gateway was shutdown first at 1315 with no impact to the system; then Terminal E Main was shutdown with the same result. Terminal A Satellite and Terminal A Main were shutdown subsequently. The differential pressure in Terminal A spiked. Control logic was found that closes the chilled water valves in Terminal A Main whenever there is no status from the associated tertiary pumps. Pump status was overridden on and the chilled water valves returned to normal operation. Cooling was not available in Terminal A for some time due to the troubleshooting process, so test results were distorted. All of the buildings were returned to normal operation by 14:30. Test results were inconclusive relative to Terminal A Main and Satellite due to the control logic in Terminal A. Results from this test and subsequent corrections made by Massport were:

1. CHP Secondary Pump DP Setpoint decreased from 20 psi to 15 psi. Subsequently the setpoint has been raised to 17 psi after two days of above design weather conditions.
2. Terminal A Main Logic relative to pump status has been removed.
3. Deny Valve logic altered. Deny valve setpoints are determined by an outside air reset schedule.

Massport HVAC technicians and Plant Operators have reported an overall system improvement and reduced complaints as a result of these changes.

On July 6, Sebesta Blomberg and Massport walked the chilled water system in Terminals A and E and retrieved the flow meter. The pumps in Terminal E were found to have a programmed minimum speed in the VFD of 30 Hz which explains why the differential pressure is always over setpoint. The Carrier system could only control the pumps between 30 and 60 Hz, the VFD programming would not allow the pump to operate at a lower frequency. Massport planned to reduce this setting at a later time. Five DeZurik plug type balancing valves were observed to be installed as listed in Table 7: July 6, 2011 Field and Balancing Valve Data

"NA" means the information exists but was either not available or accessible to determine.

Table 7: July 6, 2011 Field and Balancing Valve Data

Building	Size	% Open	Pump Hz	Pump Ps	Pump Pd	Pump gpm
Terminal A Main	NA	NA	34	63	76	1,762
Terminal A Satellite	10"	50%	40.6	68	90	1,500
Terminal E Main	10"	10%	30	94	109	NA
Terminal E Gateway	10"	10%	30	80	94	NA
Terminal E Walkway	4"	100%	X	66	77	NA
Boutwell Building	X	X	NA	70	82	X
Terminal A Walkway	4"	50%	CS	66	77	105

The Terminal A Main valve is mounted approximately 20 feet above the floor so the valve position could not be confirmed; the valve is assumed to be 10". The triple duty valve on the pump discharge was only 70% open. The Boutwell building VFD is old and did not display the pump frequency or % speed. Also noted was the Terminal A and Terminal E Walkways each have a crossover bridge with a standard balancing valve installed, which are approximately 50% and 100% open respectively. There are multiple balancing valves in the system that require unnecessary pumping power to flow through. In cases such as Terminal A, balancing devices are throttled on both the suction and discharge side of the pumps!

The data from the flow meter is depicted in the following two figures.

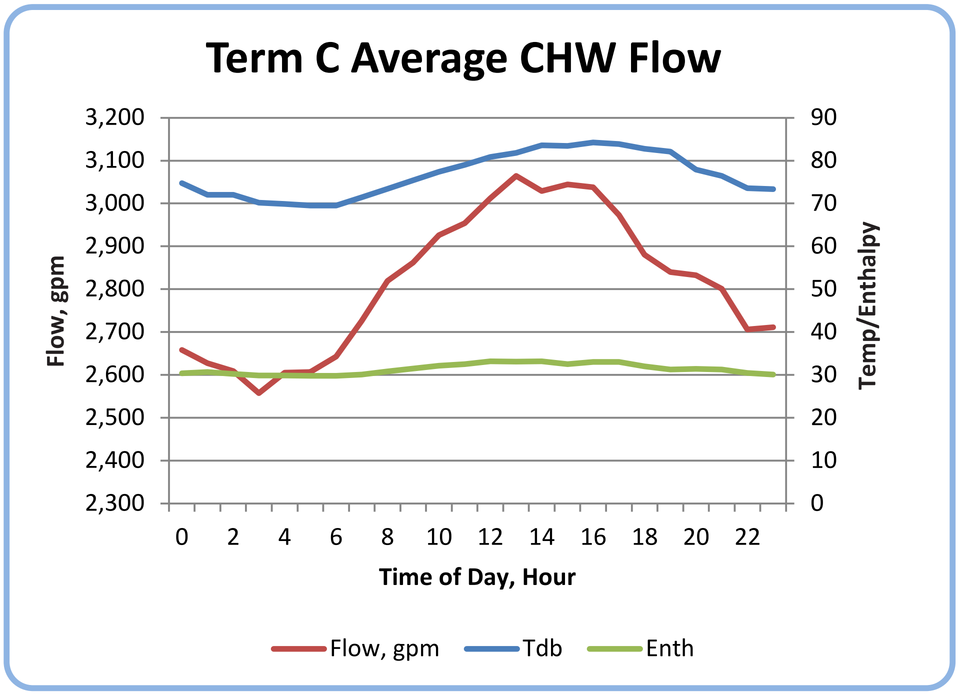


Figure 14: Terminal C Average Chilled Water Flow per Hour

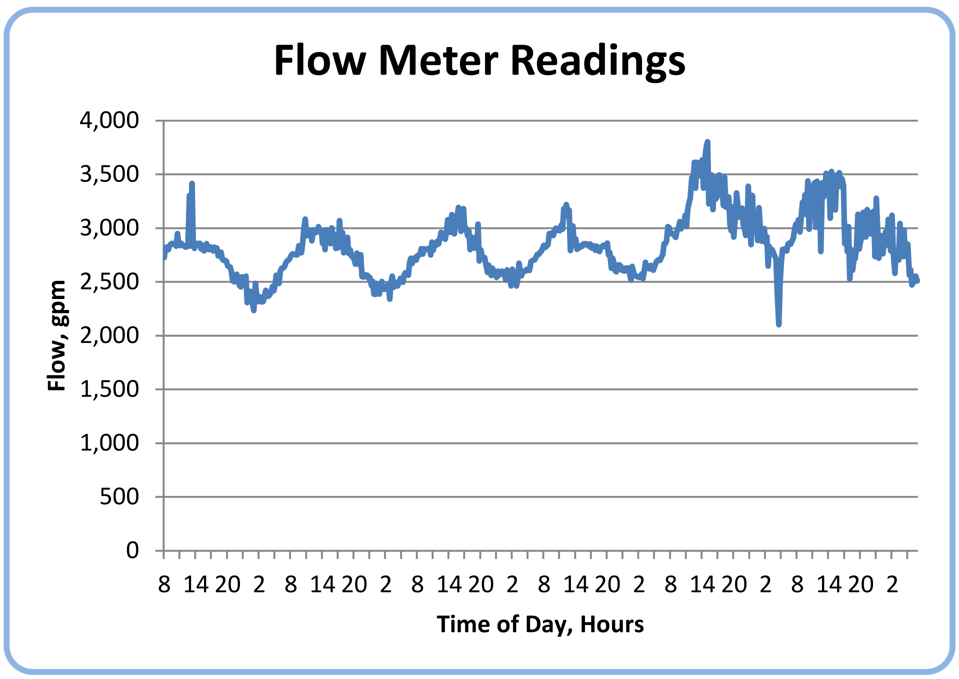


Figure 15: Terminal C Flow Meter Readings

A few things are apparent upon review of the information. The flow never drops below 2,200 gpm even while the terminals are unoccupied. This is evidence that many pieces of equipment are operating 24x7 even though the application does not require this and that the outside air dampers are still open. The effect of ambient temperature and solar and occupant cooling loads are evident while observing the loads at sunrise to 9-10 pm when the sun has set and the terminals are largely unoccupied.

The available chilled water system graphics from the Carrier system were later reviewed

Table 8: July 6, 2011 Carrier BAS Screen Shots

Building	CHS	CHP CHR	Valve % Open	Pump Hz	Pump dP Setpoint	Bldg dP	Primary gpm
Central Garage	41.7	49.6	100	X	X	X	230
Terminal A Main	NA	51.4	48	26	14	16.7	2,139
Terminal A Satellite	42.6	52.8	55	42	12	10.4	1,319
Terminal E Main	43.5	53	100	30	16	19.5	2,159
Terminal E Gateway	43.8	53	99	30	12	28	
West Garage	42.7	NA	X	X	X	X	X
New Tower	43	52.7	75	X	X	X	262

For the buildings with a deny valve, the valve % open shown in Table 8 is for the deny valve, and for the other buildings it represents the control valve to the heat exchanger. There is one flow meter to monitor both the Terminal E Main and Gateway systems. There were no control values shown for the West Garage except the primary supply temperature. All of the buildings observed were operating at below design differential temperatures. Three buildings had pumps operating at their minimum programmed speeds, balancing valves throttled, and were over their programmed differential pressure setpoints despite receiving elevated supply water temperatures due to their deny valves. Lots of opportunities for pumping power reduction were apparent after this day's efforts!

Results from this test and corrections made by Massport were:

1. Terminal E Main and Gateway pumps can now modulate down to a minimum speed of 16 Hz now that the VFDs have been reprogrammed.

The fieldwork coupled with data and drawing reviews along with Massport's input laid the groundwork for the production of the chilled water hydraulic model.

6.0 Hydraulic Model Development & Results

6.1 Why Model?

A primary-secondary chilled water system provides constant flow through the chillers while allowing the flow to vary in the distribution system. The two piping systems are separated hydraulically via a decoupler which allows the flow rate in each system to be unaffected by the other. One purpose for designing a chilled water system with high design differential temperatures, such as 14°F, is to reduce the first costs and operational costs of the system by reducing the flow rate required per ton of cooling. This results in smaller distribution piping and pump horsepower versus those found in a plant designed for a traditional 10°F temperature differential.

A chiller plant cannot dictate the system's differential temperature just because of a chiller's design rating. The differential temperature developed at each coil is the result of incoming water temperature, the coil design parameters, and conditions at the coil. The 14°F design differential temperature that the chillers in the plant have been selected for can be achieved through a process of design, installation, controls, and operation and maintenance upgrades throughout the facility for the components of the chilled water system in each building.

One of the most important concepts to understand regarding plant operations or their optimization is the differentiation between load control and flow control. Chilled water load and chilled water flow are obviously related, but controlling both is a different matter. Flow rate and differential temperature are inversely proportional for a specified load. As one increases, the other decreases within minimum and maximum velocity criteria. The higher the differential temperature maintained throughout the system the smaller the volume of water that needs to be pumped for the equivalent cooling capacity, hence the less energy needed to deliver each ton of cooling to a coil. Conversely, increased pumping power, a direct result of low system differential temperature, is required to flow the greater volume of water. Additional chillers may need to be brought online if the secondary flow exceeds the primary to the point that building supply water temperature is compromised. The coils that are located closest to the CHP experience the highest differential pressures in the system. When control valves are exposed to excessively high differential pressures, they tend to stay open or even lift when they should be closed. The age of control valves typically defines what is “excessive” differential pressure. Problems with excessive differential pressure at coils closest to the pumping source can be eliminated with the use of pressure regulating systems, or by replacing coil control valves. These measures would reduce or eliminate many of the current cooling difficulties.

As mentioned, a common problem in all of the buildings is chilled water conditions which are beyond the design criteria for many of the loads on the system. A coil that receives a water supply temperature above its design value will typically produce a reduced chilled water temperature differential while simultaneously requiring an increased flow rate to satisfy the control parameter. An increase from 40°F to 42°F chilled water supply temperatures requires the need for a flow rate equal to approximately 120% of the design flow rate. When the chilled water reaches 44°F, the approximate flow increase necessary to maintain the control parameters is 150% of the design value. This increased flow rate results in increased pressure drops in the heat transfer device as well as in piping to and from the device, etc… When this condition is applied to an entire building, the building pumps will no longer be able to flow the required amount of water to the system. As mentioned, with increased flow rates the system pressure drop increases by a power of 2 relative to the increase in flow and the pumping power increases by a power of 3 relative to the increase in flow based upon the characteristics of its curve. The result is that the remote cooling devices in the system will not be supplied with the necessary water to satisfy their control parameters.

This issue is compounded when the affect of increased flow rate for the coil is further analyzed. A ton of cooling needs to be specified to specific parameters, supply temperature and flow rate or temperature differential. This begs the question, "When is a ton a ton?" The formula below is typically used to determine the tonnage consumed by each coil:

Tons = 500 * Metered Flow Rate(gpm) * (Return Temp –Supply Temp) °F / 12.000 BTUH/ton

For a given flow rate the tonnage will vary based upon the temperature differential temperature. Mathematically, a 40°F supply temperature and a 55°F return temperature will result in a 15°F differential and provide the same "tonnage" as a 60°F supply temperature and a 75°F return temperature when the flow rate is held constant. Note a small error is introduced due to the very slight variation in density of the water at these temperatures. Obviously, 60°F supply water will not accomplish the same type of cooling that a 40°F supply temperature. There is a definite affect on a system's cooling capacity dependent upon the actual chilled water supply temperature relative to the design value even for the apparent slight difference between receiving water at 40°F or 42°F.

Deny valves are controlled to return water to the CHP that meet a minimum value. If the building's return water temperature is too low, the water is recirculated within the building causing elevated building supply water temperatures. From here the problem gets compounded, the more re-circulation that occurs within the building to maintain the chilled water return temperature above the deny valve setpoint, the more flow (building pump power) each and every heat transfer device in the system will need to satisfy its control parameters. At some point, equilibrium will result in the building's distribution system because the system will be at its flow limit based upon the increased drop in the building and finite pump capacity. Ultimately, the remote heat transfer devices in the system will be starved of chilled water flow.

The essence of flow control is determining what the minimum system differential pressure is and at which coil this occurs such that all other coils are simultaneously satisfied. Pumps must be able to generate enough differential pressure and deliver the water at sufficient pressure to this coil to meet its load. Anything beyond this wastes pumping energy. Excessive differential pressure will cause some valves to lose control, and the chilled water will then simply take the path of least resistance and overflow those particular valves and associated coils, rather than going to the critical coil requiring the additional flow. The result of this is a cooling deficiency somewhere in the system, typically beginning at the hydraulically most remote coil.

Determining what this minimum ΔP is and at which User this occurs such that all other Users are simultaneously satisfied is the essence of flow control. Pumps must be able to generate enough lift to overcome friction losses and deliver the water at sufficient ΔP to this User to give it the flow it requires. Anything beyond this wastes pumping energy. Excessive ΔP will cause some valves to lose control and the CHW will then simply take the path of lesser resistance and overflow those particular valves rather than going to the User requiring the flow. A hydraulic model allows the analysis of a system at various configurations and flow rates and allows the minimum differential pressures to achieve flow balance to be determined.

6.2 Model Development

This hydraulic model was developed to simulate Massport's chiller plant and chilled water distribution system. The software used for this project and most other incompressible fluid systems that Sebesta Blomberg models is Applied Flow Technology (AFT) "Fathom" hydraulic modeling software, version 7.0. This is a Windows-based program that uses junctions, pipe segments and custom flow fittings as the building blocks to define a system. The program arbitrarily assigns junction and pipe numbers which were altered where possible for better identification of the system components. The first step in setting up a model is to produce a schematic layout of the system. This was done through a combination of reviewing the drawings supplied and through field inspections.

Each coil is modeled with a flow control valve (FCV) located downstream of its coil which has a prescribed flow rate based upon the conditions of the scenario. Also utilized in the model is a Heat Exchanger icon (HX) which represents the chiller barrels or system heat exchangers. Pressure losses for each heat transfer device were assigned design values and will behave in an exponential fashion as the flow rate passing through them varies. A pump icon is used to represent the primary chilled water and secondary chilled water pumps. Pump curve information was entered in order to simulate most accurately the actual pump performance for all the scenarios. The tertiary pumps were not modeled, and are assumed to have no hydraulic effect on the system. Other icons used in the development of the model are tees, elbows (shown as 90 degree but angle is manually entered), isolation valves, check valves, and reducers.

With flows specified at each coil, the model calculates what pressure drops are required across the FCVs to balance flows throughout the entire system. In reality, each FCV's calculated pressure drop is the pressure drop available in the system at the building entrance to flow the building or for the tertiary pumps to boost to meet the flow requirements of the building's coils. Consequently, the model calculates the pump differential pressure necessary to satisfy the most hydraulically remote building – when this building is satisfied, all the other buildings, by definition, will also be satisfied. This pump differential also defines the developed system differential pressure. Therefore, the critical FCV, set up in the model to have a minimum pressure drop in the system, FCV wide open, corresponds with the most hydraulically remote building – the "Critical Building". Determining this building is an iterative process after successive runs of the model.

Lengths and sizes of pipe were taken from available drawings and field observations. Some major fittings and valves are shown on the model schematic. Other fittings are defined as part of the piping and are not visible in the model schematic. For simplicity, pipe lengths were generally rounded to the nearest 10 and/or 25 feet. All piping was assumed to be standard-sized or Schedule 40 carbon steel pipe.

The flow rates utilized are based on peak system flow rates and metered data where available. Flow rates for buildings where metered data was not available were estimated based upon the building's equipment and size. Once a reasonable scenario of flows and loads was established, it was possible to begin to develop a hydraulic model of the cooling loop.

Output from the Fathom software includes velocity and pressure values along pipe segments and junctions in the system. Pressure readings and pipe velocities are used to identify areas where piping is undersized and to evaluate the impact of critical pipe segments on the overall system. The return pressure at the chiller plant is 55 psi, corresponding to the observed pressure at the expansion tank, (a point of no pressure change).

The underlying purpose of the model is to determine what the natural developed system differential pressure would be under the most efficient and simplistic conditions – those being based solely on 2-way control valves and without any booster pumps. As such, all known supply-to-return bypasses (from 3-way valves and otherwise) have been assumed to be closed, any booster pumps that may exist within the buildings have been turned off and bypassed with a pipe segment, and each User has been modeled as being controlled solely by a 2-way valve. Actual pump curves were used in the model. Differential pressure setpoints were initially modeled to allow the building pumps in Terminals B and C to remain off.

6.3 Results and Evaluation of Modeled Scenarios

Table 9: Modeled Scenarios

No.	Modeled Scenario	Remote Bldg/Differential Pressure (dP)	2nd Most Remote Bldg/Differential Pressure (dP)	SCHW gpm	SCHP BHP
1	Base Scenario-Peak Flows	US Airways Shuttle #29/34.6'	Term E Main #19/42.4'	14,788	494
2	80% Peak Flows-15 psi	Term E Main #19/29.8'	US Airways Shuttle #29/34.6'	11,895	296
3	80% Peak Flows-20 psi	Term E Main #19/41'	US Airways Shuttle #29/46'	11,895	334
4	Open Balancing Valves	US Airways Shuttle #29/34.6'	Term C #22/45.5'	11,895	299
5	Use Bldg Pumps	US Airways Shuttle #29/4.61'	Term C #22/15.5'	11,895	205
6	Reconnect Loop	US Airways Shuttle #29/4.61'	Term A Sat. #31/15.9'	11,895	165
7	Reconnect Loop-15 psi	US Airways Shuttle #29/34.6'	Term A Sat. #31/45.9'	11,895	254
8	Install 20" X-Connect	US Airways Shuttle #29/4.61'	Term A Sat. #31/8.0'	11,895	161
9	Install 20" X-Connect-15 psi	US Airways Shuttle #29/34.6'	Term A Sat. #31/40.9'	11,895	256

Scenario 1: Base Scenario. Existing piping system. Flow proportioned to buildings with sum equaling observed flow limit on peak day. US Airways Shuttle pressure setting equal to 15 psi.

Scenario 2: Same as Scenario 1 but with flow reduced to 80%.

Scenario 3: Same as Scenario 2 but with DP setpoint equal to 20 psi.

Scenario 4: Same as Scenario 2 but with Balancing Valves opened at Terminals E and A.

Scenario 5: Same as Scenario 4 but with DP setpoint equal to 2 psi. Building Pumps in Use.

Scenario 6: Same as Scenario 5 but with old loop between Terminals E and C re-connected.

Scenario 7: Same as Scenario 4 but with old loop between Terminals E and C re-connected.

Scenario 8: Same as Scenario 5 but with new 20" loop between Terminal A and B.

Scenario 9: Same as Scenario 4 but with new 20" loop between Terminal A and B.

Scenario 1 is a depiction of the system to determine what the distribution system would function under a peak load scenario. This is a diversified load not a sum of the peak loads in the system. There are a limited number of hours in the year that this flow rate would be seen. The scenario shows that the CHP has pumping capacity to adequately flow the system. The FCV that depicts the US Airways Shuttle Building was selected to have a 15 psi differential pressure. This building has tertiary pumps which are not used and is flowed directly by the CHP.

Scenario 2 is a more likely to occur scenario with the system at 80% of the flow rates shown in Scenario 1. The loops peak together so each coil's flow was reduced by 80%. The most remote building in this Scenario is Terminal E Main. The balancing valve, per the DeZurik flow curves for this valve, creates an undue pressure drop equal to 47 feet or 20 psi which is adequate to flow the building without its pump. The pump's differential pressure setpoint, as seen in Table 8: July 6, 2011 Carrier BAS Screen Shots is only 16 psi

Scenario 3 depicts Scenario 2 but with a 20 psi differential pressure setpoint for the CHP secondary chilled water pumps. With all flows being equal, this operation increases the secondary pump break horsepower by 38 HP. As previously stated, the higher the differential pressure in the system, the more likely old, worn valves will not be able to close and the more water will flow through bypasses. Field testing showed that this high setpoint is not necessary except at ambient weather in excess of design.

Scenario 4 depicts what would happen in the system if the four major balancing valves were fully opened with zero pressure loss. The overall pump power has increased slightly but the pressure available at these four buildings is more than sufficient to flow the buildings. This result aligns with the field testing proving that the CHP can flow Terminals A and E without the need for tertiary pumps, even with the building pumps present.

Table 10: Differential Pressure Available from Balancing Valve Removal

Building	dP at Bldg Entrance per Model	Pump dP Setpoint
Terminal A Main	31	14
Terminal A Satellite	24	12
Terminal E Main	33	16
Terminal E Gateway	33	12

Scenario 5 depicts how the secondary pumps would react if the loop was kept slightly positive to ensure sufficient flow at a positive pressure to all building entrances so tertiary pumps can adequately operate. The US Airways Shuttle Building was modeled with a 2 psi pressure differential. The CHP pumping savings is equal to 94 HP at this flow rate. The building pumps are not as efficient as the larger CHP pumps, their wire to water efficiency is less. Assuming that the average building pump would operate at 65% speed, the horsepower required would be 138 HP which negates the savings. Note that motor efficiency was not used, which would tip the scales in even more favor to using the CHP pumps without the building pumps.

Scenarios 6 through 9 depict what would happen to the loop if cross connects /sub-loops were installed. The pumping power savings between the two options is virtually identical; however, reconnecting the loops by Terminals E and C as was originally installed is much simpler and cheaper. This option should be pursued. It provides great operational flexibility at the very least. The pumping savings alone is not sufficient to justify the construction costs.

6.4 Conclusions and Recommendations

Reducing system pressure losses and eliminating locations where chilled water can bypass from supply to return will give the existing pumps the ability to satisfy system flow requirements. The modeled Scenarios indicate that the existing secondary pumps are sufficiently sized to allow this to happen without the need for tertiary booster pumps within the system. Along with the aforementioned changes, steps should be taken to prevent certain users from robbing chilled water from the rest of the system when their control valves are forced open because of high pump differentials.

From the findings of the modeled scenarios, experience with cooling systems across the country, and an understanding of Massport's chiller plant and distribution systems, the following recommendations are presented. Specific Energy Conservation Measures that provide quantifiable energy savings are discussed in Section 7. Sebesta Blomberg recommends the following for improving the performance of the facilities' chiller plant.

1. <u>Additional Monitoring Points:</u>

A Central Utility System exists to serve the end users, not to be a stand-alone operation. To be successful, there needs to be coordination between the two entities. This includes following standards of design and operation as well as regular communication. More interconnection of the chiller plant controls with the Carrier Control system should be provided to allow the plant to be controlled based on actual conditions in the system. System needs can be evaluated to determine if it is more economical to stage another chiller, increase the secondary pump differential pressure setpoint, or stage on a tertiary pump.

More differential pressure and chilled water temperature sensors should be installed in the system and brought into the PCS to allow the operators to be more aware of what is going on in the buildings and drive their operation. More input will allow for control sequences to be able to react to actual conditions with the proper feedback in place to optimize the CHP. Major pipe runs should all have a means to verify the differential pressures and temperatures within them through improved instrumentation, remote monitoring and local gauges in order for the facility staff to more quickly diagnose the cause of problems in the system. This will allow an immediate means to evaluate which sections are adversely affecting the loop. Through trending, information can be gathered to evaluate when the temperature problems are occurring to narrow down which piece of equipment could be at fault.

Flow meters should be installed on all major runs along with temperature sensors to be able to profile and benchmark the operation of the chilled water system and the buildings it serves.

Provision for installation of additional monitoring points has been included in the implementation budget for ECM-2.

2. <u>Coil Selection Design Standard:</u>

Implement a chilled water design standard to ensure that all future cooling coils installed meet the needs of the chilled water system in order to help maintain the chilled water differential temperature of the system. New coils should be selected to match the chilled water parameters that the chillers were designed for: a 14°F temperature differential with 43°F supply temperature (to compensate for heat gain to the chilled water piping from equipment and surroundings). The Terminal C Checkpoint RTU chilled water coils were selected, per drawings dated April 2010, for only a 12°F temperature difference. This slight 2°F difference results in 17% more flow needed than if the coils were selected for the plant's design. With constant flow chillers, their capacity is flow limited if the temperature differential is below design. Low temperature differentials in the system require that more chillers need to operate to accommodate the flow rates in the system.

Based upon the aforementioned item, the implementation of a design standard is highly recommended for air handling units as well as fan coil units and other smaller equipment. For air handling units this standard would specify the desired chilled water temperature differential, and minimum required tube and fin velocities. Fan coil units should have oversized coils to achieve the best possible temperature differential. Most coils in variable airflow systems spend most of their operating life at part load conditions, so ensuring that both the air and water sides do not approach laminar flow will ensure good heat transfer throughout a larger range of operating conditions.

3. <u>Control Valve Standard:</u>

As with item 2 above, a control valve standard should be implemented to ensure that all control valves are capable of controlling flow over their entire expected range, and close-off against the differential pressures produced in the system. Valves that cannot close off waste energy by overcooling at the air handlers, increasing the need for additional reheat and humidification and reduce the system wide temperature differential, which increases the horsepower required to meet to the system differential pressure setpoint. Additionally valves should be checked to ensure that they are able to tightly close off and able to control flow. New standard temperature control valves are generally able to function through a pressure differential of no more than 25 to 30 psi. As system differential pressure rises with increasing demand for flow, the system differential pressure could ultimately exceed the throttling capability of the valves and force them completely open. This is of particular concern in valves closest to the pumping source. Once a valve is forced open, an effective chilled water bypass is created, which signals a false indication to the plant that more flow and cooling are required in the system, thus compounding the problem. At the specific coil, over-pressurization results in over-cooling and increased energy costs by unnecessarily operating re-heat coils. If this occurs, industrial duty or pressure independent control valves may need to be installed on the individual coils, or some other pressure-compensating means such as may be necessary to handle the system differential pressure in lieu of installing the industrial control valves.

ECM-1 includes converting existing 3-way valves to 2-way valves, and ECM-3 includes testing and replacing other existing valves that are not performing.

4. Hydraulic Model Training:

Training may be provided by Sebesta Blomberg on how to develop and manage a hydraulic model using the Massport model as the basis of instruction. This will allow Massport to utilize the chilled water model as an analysis tool going forward for future infrastructure requirements. Another alternative would be for representatives of Applied Flow Technology to come on-site to train Massport staff. AFT also produces software to analyze compressible fluids such as steam, so this software could be reviewed as well. The software is similar to Fathom. More information can be found at www.aft.com/training.

The model should be updated and calibrated annually as changes to the site and system are made. Conversely, the model can be used to evaluate whether new connections to the distribution system are feasible, and how and where they could be tied in.

7.0 Energy Conservation Measures (ECMs)

The following Energy Conservation Measures (ECMs) are based upon the results of the body of work discussed in this report. In multiple site visits, discussions of operations with facility personnel, equipment vendors, reviews of floor plans, equipment schedules, record drawings, building automation system programming and trends, field measurements and operating procedures. ECMs 1 to 2 are based upon the hydraulic model and the remaining are based upon analysis of the entire Central Heating Plant.

Estimated implementation costs, energy and greenhouse gas savings estimates, and operating cost savings for each ECM are summarized in Table 1 in the Executive Summary. Note that energy savings are calculated assuming that the previous ECMs have been implemented.

7.1 ECM-1: Bypass Building Pumps, Remove 3-way Valves, Open Balancing Valves and Deny Valves, Piping Modifications

Current operation has the CHP secondary pumps flowing through the building pumps. Sebesta Blomberg recommends the installation of full size bypasses with check valves. Each pumping system in Table 4 will need to be reviewed individually to determine if the bypass should be a simple bypass, have 1 control valve, or a 1/3-2/3 valve arrangement. The control valves will be industrial quality, robust valve and actuator combination with sufficient close-off pressure to allow full control under all operating scenarios. Even the pumps that are currently not in operation should have a bypass installed. The pressure loss through the non-operating pumps has not been quantified. Larger pumps are more efficient as are larger motors, hence the wire to water efficiency is higher for the CHP secondary pumps than the building tertiary pumps. Booster /tertiary pumps only make sense to serve long runs with higher pressure drops to avoid the high horsepower secondary pumps to operate at higher differential pressures for small percentage of the overall system load.

Three-way valves are not designed to handle differential pressures, and thus will leak by when kept in place during variable flow retrofits. These valves are old and worn, which is also a contributing factor to poor performance in each building. The valves listed in Table 4 should be evaluated for replacement. Other 2-way valves, beginning closest to the plant where the highest differential pressures are found, should be checked in order to ensure that they are not leaking by. This is an issue during low loads when valves are trying to stay closed but the system differential pressure is still high.

As shown in Scenario 4, the opening of the balancing valves in the aforementioned buildings will allow those pumps to be bypassed and not used except for possibly elevated ambient temperatures (less than 100 hours a year).

The West Garage heat exchanger should be fitted with a properly sized control valve. This heat exchanger is close to the plant and does not have means to control flow. The flow through the heat exchanger is a function of the differential pressure in the system.

Deny valves should be locked 100% open. Dehumidification at the buildings' cooling coils is adversely affected due to the higher chilled water supply temperatures that result from the action of the deny valves. While the CHP may benefit from this application, the coils and occupants will suffer as a result. Elevated chilled water supply temperatures cause excessive moisture content in the air which may lead to IAQ issues. They also increase the energy usage of the building pumps because more water to satisfy the cooling demand is required due to the elevated chilled water supply temperatures.

Accomplished to Date

- On July 6, Sebesta Blomberg and Massport walked the chilled water system in Terminals A and E. The pumps in Terminal E were found to have a programmed minimum speed in the VFD of 30 Hz which explains why the differential pressure is always over setpoint. The Carrier system could only control the pumps between 30 and 60 Hz, the VFD programming would not allow the pump to operate at a lower frequency.
- Results from this test and corrections made by Massport were:
    - Terminal E Main and Gateway pumps can now modulate down to a minimum speed of 16 Hz now that the VFDs have been reprogrammed.
- Site walkdown with Massport
- Computerized Hydraulic Created of Massport Chilled Water System including CHP and distribution to Terminals constructed.
- Installed flow meter for 1-week on 14-inch piping feeding Terminal C below Boutwell Building.

Next Steps/Outline Specification

1. Identify 3-way valves (13 estimated) and bypasses to be replaced/isolated. Information to be described on drawings.
2. Develop drawings detailing which pumps are to be bypassed, size of bypass, and how bypasses will be controlled.
3. Develop revised sequences of operation for terminal chilled water flow control including deny valves.

4. Develop M&V Plan
5. Develop specifications and schedules for new equipment such as control valves.
6. Organize design/installation packages for separate Terminals.
7. Utilize pipefitters under a term contract to implement the work detailed in items 1, 2 and 4 above.
8. Utilize Carrier to implement control changes detailed in items 3 and 4 above.
9. Verify work has been properly completed, and commission the installation.

Implementation Plan/Schedule

Massport to issue work order:	10/28/2011
Design documents complete 4-6 weeks from Notice to Proceed:	12/02/2011
Contracts/Work Orders issued to implement work:	12/30/2011
Work to be performed one Terminal at a time. Commence construction:	01/03/2012
Completion, including Commissioning, no later than:	06/13/2012
M&V Activities, Completed by:	08/31/2012

7.2 ECM-2: Decrease the Differential Pressure Setpoint/Modify SCHW Pump Staging, Add Monitoring Points

The differential pressure setpoint that the secondary chilled water pumps modulate to maintain should be decreased once all the control valves are verified to be under control. The higher the differential pressure setpoint, the more pumping energy necessary to achieve this setpoint and cause poor control valve performance for valves not designed to operate under those conditions.

Reducing the pressure setpoints is a simple task to implement and can be completed over the course of a couple of days to ensure all the areas of the facilities are satisfied. A reset schedule based upon outside air temperature is recommended to be implemented in order to reduce the setpoint during part load operation. More pressure, critical AHU cooling valve position, or other critical input that provides feedback should be made available to allow the algorithm to be biased based upon feedback from the spaces served. As usual, any abnormalities should be investigated to ensure that a device that has gone out of calibration or failed does not drive the entire loop. The cost to add distribution system pressure and temperature monitoring points to the CHP control system via the Carrier system is included in this measure.

Also, the secondary chilled water pumps' staging will be modified to keep the minimum pump speed at approximately 55% if more than one pump is operating, and vary the upper limit accordingly so the lag pump will start once the lead pump reaches 75% to 80% speed. It is more efficient to operate more pumps at a reduced speed than to operate fewer pumps at higher speeds, due to the cubic relationship between flow and power.

Accomplished to Date:

- On June 29th, testing was performed on the tertiary loops of Terminal A Main, Terminal A Satellite, Terminal E Gateway, and Terminal E Main by Sebesta Blomberg and Massport.

- Testing was performed to do the following:
  - Shut off Building Pumps-Lead and Standby, Override Deny Valves to Fully Open, Monitor Impact on CHP
- Results from this test and subsequent corrections made by Massport were:
  - CHP Secondary Pump DP Setpoint decreased from 20 psi to 15 psi. Subsequently the setpoint has been raised to 17 psi after two days of above design weather conditions.
  - Terminal A Main Logic relative to pump status has been removed.
  - Deny Valve logic altered. Deny valve setpoints are determined by an outside air reset schedule.

Next Steps/Outline Specification

1. Identify points on the Carrier control system to be linked to the CHP control system.
2. Develop revised sequences of operation for CHP secondary chilled water flow control including reset schedule for differential pressure setpoints and pump sequencing.
3. Contract with Control System vendors to implement the work detailed in items 1 and 2 above.
4. Commission/ monitor and verify work has been properly completed.

Implementation Plan/Schedule

Massport to issue work order:	10/28/2011
Design documents complete 4 weeks from Notice to Proceed:	12/02/2011
Contracts/Work Orders issued to implement work:	12/30/2011
Commence construction:	01/03/2012
Completion, including Commissioning, no later than:	03/16/2012
M&V Activities, Completed by:	08/31/2012

7.3 ECM-3: Renovate Building Chilled Water Systems

This effort will be focused on determining if any chilled water valves are unable to control at low flows, determine which coils are in greatest need of replacement, and implement these repairs or replacements. Secondary focus will be on other equipment/system control components and schedules. A cooling system retro-commissioning strategy with the focus on lowering the chilled water system's secondary flows by increasing system differential temperatures and reducing chilled water demand during unoccupied hours will greatly improve system performance. We recommend starting closest to the chiller plant where the highest differential pressures exist then move on throughout the facility. By improving the differential temperature in the system, there is a significant reduction in the amount of differential pressure needed to satisfy the cooling loop due to the reduced secondary flows, which decreases the electrical load due to pumping horsepower incurred by the system. As building HVAC equipment is improved through maintenance, control and schedule modifications and selected coil/equipment replacement, it should be very easy to reduce flow requirements without reducing the level of cooling (tons) provided. In some instances increased cooling will be provided to the spaces when fouled equipment is replaced. Sebesta Blomberg will work with Massport to identify which equipment containing a chilled water coil should be replaced in its entirety depending upon the age and condition of the unit.

The retro-commissioning effort would consist of a coil by coil check to verify the efficiency of each unit's operation by verifying control calibration, overall heat transfer effectiveness (both air and water side), coil configurations, and overall unit efficiency (leaking heating valves, damper binding, etc.). Water analysis shall be performed on the loop to ensure that there are no underlying issues with the water quality that would not show up in a standard analysis. Control valves will be evaluated with an ultrasonic flow meter to ensure the valves are capable of tightly closing off and have an acceptable rangeability. Any suspect valves will be replaced with two-way valves sized to handle the system differential pressures. Initial testing could be performed by the building's staff or incorporated in the retro-commissioning effort.

The setpoint of the cooling coils will also be verified to ensure the setpoints match the actual design of the particular coil. If the setpoint is lower than design, the control valve will stay fully open longer trying to achieve a parameter that the coil was not designed to achieve, causing low temperature differential and elevated part load system flow rates. Also, most HVAC equipment operates on a 24 hour, 7 day a week schedule despite periods when many areas have low occupancy. As seen in Figure 15, system flows remain high even when there is no solar or occupant cooling loads. It is suspected that outside air dampers do not close and units remain operational even when continuous operation is not needed. Sebesta Blomberg will identify areas that can be scheduled off or setback through the BMS, such as areas with newer more reliable units, and ensure the outside air dampers are closed during these times.

The retro-commissioning of systems will establish a new performance benchmark for the cooling loop that could be used when new loads are added. A record document will be produced which will be an invaluable reference for the troubleshooting of any future problems. This will alleviate some of the time constraints on the O&M staff.

<u>Accomplished to Date:</u>

- Opportunities Identified Including:
    - Air Handlers operate 24x7
    - Terminal temperature settings are very conservative
    - Aged equipment including control valves and coils
    - Focus will be on Terminal E, Terminal A, and Terminal C Piers B & C

Next Steps/Outline Specification

1. Identify equipment that will be renovated and balanced.
2. Produce testing plan and procedures.
3. Provide scope of work document for TAB contractor.
4. Test equipment with support from Carrier and Massport personnel as appropriate. Tested items include:
    - Verify Start/Stop Control
    - Verify VFD Modulation
    - Verify Damper Control
    - Verify Operation and Close-Off Capability of All Control Valves
    - Verify Chilled Water Flow
    - Verify Cooling Coil Heat Transfer
5. Compile deficiency list and recommended corrections.
6. Issue monthly reports with updated energy savings estimates.
7. Develop monthly scope of work for equipment repairs to procure services from appropriate term contractors.
8. Verify deficiencies have been properly repaired/corrected.

Implementation Plan/Schedule

Massport to issue work order:	10/28/2011
Issue Commissioning Plan and draft Test Procedures:	12/02/2011
Issue Final documents after Massport review:	12/30/2011
Commence field testing activities (non-weather dependent sequences):	01/03/2012
TAB contractor to commence work once cooling system placed on-line:	04/16/2012
Commence field testing activities on cooling dependent sequences and equipment.	04/23/2012
Complete field testing no later than	06/08/2012
Equipment repairs/replacements (may need to be deferred to post cooling season)	TBD
Monitor and verify performance	TBD

7.4 ECM-4:Replace Chiller #1 Steam Turbine Governor (Scenario 1B only)

Chiller #1 is controlled with both inlet guide vanes and hot gas bypass. Hot gas bypass is a way of controlling the capacity of a refrigeration system by bypassing some refrigerant vapor from the condenser back to the evaporator, to maintain a minimum flow through the compressor. This bypass takes compressor power, but produces no refrigeration, so it is inherently inefficient. Inlet guide vanes change the angle at which the refrigerant vapor enters the condenser. They are more efficient than hot gas bypass. The Carrier chiller operates at a fixed speed set by the operator. In response to decreases in load, the inlet guide vanes close, and when they are at their lower limit of travel, the hot gas bypass valve opens.

If it is determined during the cooling season of 2012 that regular operation of a steam turbine chiller is still needed to maintain summer boiler load after implementation of the L963 project, it is recommended that a new governor be installed that would vary the turbine speed to maintain constant leaving chilled water temperature at a predetermined load. This would require a replacement governor, and a control system tied into existing flow and temperature monitoring points. Based on our experience, we estimate that a new governor and associated controls on Chiller #1 would save about 5% of the operating cost of the turbine.

Accomplished to Date

- Analyzed performance of chiller
- Estimated cost and savings from improved governor

Next Steps/Outline Specification

- Obtain detailed information on turbine and control system
- Specify new governor
- Specify control integration
- Purchase governor
- Installation by Massport/turbine service contractor
- Controls integration by plant control system service contractor
- Commission/monitor and verify performance

Implementation Plan/Schedule

Massport to issue Work Order		10/28/2012
Assess governor and controls	by	12/15/2012
Specify new governor	by	12/30/2012
Massport to purchase governor	by	1/30/2013
Manufacturer to deliver governor	by	3/30/2013
Massport/Turbine Services Contractor install and test new governor	by	4/15/2013
Commission/monitor and verify performance		Spring 2013

Note that Massport could chose to initiate this ECM earlier if deemed appropriate

7.5 ECM-5: Reallocate Cooling Load Among Chillers (Scenario 1B only)

At present the operational loading on the individual chillers seems to be somewhat arbitrary, according to some rules of thumb. Sebesta Blomberg has analyzed 2010 chiller system operating log data to evaluate approximate costs to produce chilled water by the different chillers in the plant. The costs include chiller, pumping, and cooling tower energy costs.

By analyzing the relative cost to provide an increment of chilled water capacity, the chillers can be loaded for the lowest cost. Economic dispatch theory is widely used in the electric power industry to assign loading to individual generators. Basically it assigns the next unit of output to the generator with the lowest incremental cost to provide it. The chiller models are equations that relate power (or steam) input to the required output. The derivative of the input-output equation is the incremental cost of an additional unit of output. The next increment of cooling capacity is assigned to the chiller with the lowest incremental cost.

The present plant energy usage to run the chillers is about 111,000 thousand cubic feet of natural gas to generate steam, and 2,748,000 kwh of electric power. In analyzing the optimum allocation of load among chillers, Sebesta Blomberg tried to keep the minimum number of chillers on line, to minimize the overall power input. For this ECM it is assumed that Chiller 1 (Carrier Turbine Driven Chiller) is kept running during the cooling season to provide some steam load on the boiler, *if it is determined during the cooling season of 2012 that regular operation of a steam turbine chiller is still needed to maintain summer boiler load after implementation of the L963 project.*.

The recommended sequencing schedule for the chillers based upon plant cooling load is summarized in the following table:

Table 11: Recommended Chiller Dispatch Schedule

% load	Tons	Chillers	Ch 1 load	Ch 6 load	Ch 4 load	Ch 1 steam
0.10	785	1	785	0	0	10,810
0.15	1,178	1	1,178	0	0	13,266
0.20	1,570	1 & 6	214	1,400	0	8,013
0.25	1,963	1 & 6	336	1,657	0	8,534
0.30	2,355	1 & 6	458	1,914	0	9,097
0.35	2,748	1 & 6	794	1,950	0	10,862
0.40	3,140	1 & 6	1,190	1,950	0	13,348
0.45	3,533	1 & 6	1,587	1,950	0	16,280
0.50	3,925	1,4,6	473	996	2,381	9,169
0.55	4,318	1,4,6	506	1,059	2,698	9,329
0.60	4,710	1,4,6	539	1,122	3,016	9,493
0.65	5,103	1,4,6	572	1,184	3,333	9,660
0.70	5,495	1,4,6	638	1,310	3,500	10,003
0.75	5,888	1,4,6	802	1,623	3,500	10,907
0.80	6,280	1,4,6	933	1,873	3,500	11,684
0.85	6,673	1,4,6	1,196	1,950	3,500	13,389
0.90	7,065	1,4,6	1,623	1,950	3,500	16,568
0.95	7,458	1,4,6	2,017	1,950	3,500	19,955
1.00	7,850	1,4,6	2,400	1,950	3,500	23,664

Note that in the above dispatch schedule, Chiller #2 would function as backup for Chiller #1, and Chiller #5 would function as backup for Chiller #6.

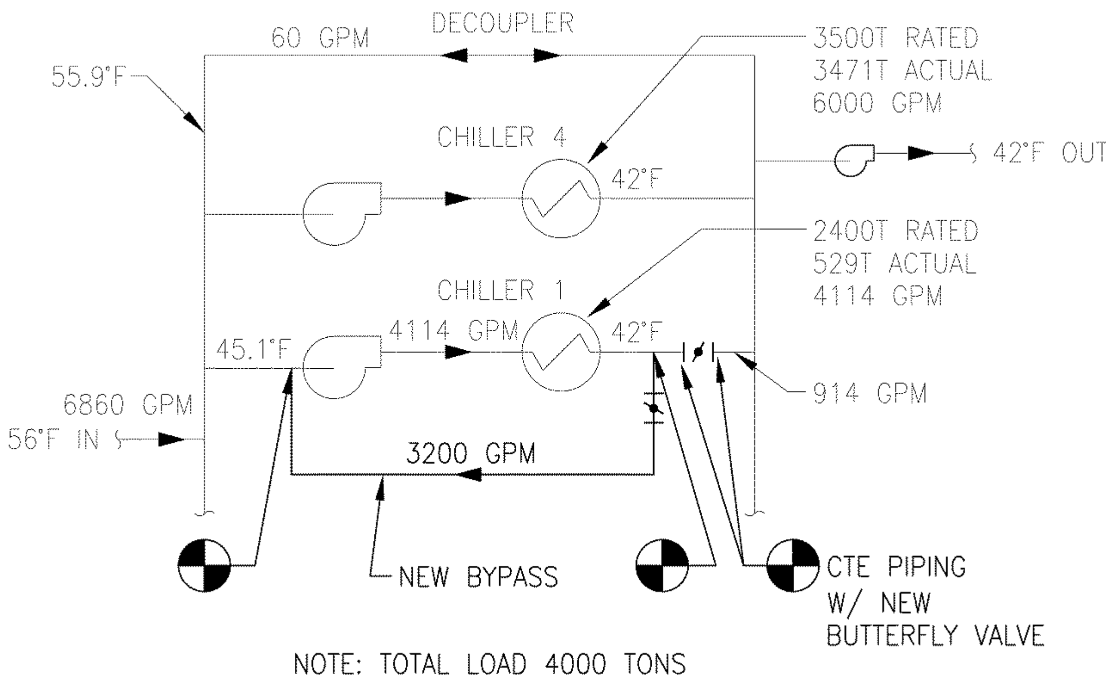
The operating strategy would be that Chiller #1 takes the load swings, Chiller #6 is base loaded when running only with chiller 1, but once chiller 4 comes on line, it takes much of the load. In order to allow for this new load distribution strategy, modifications to Chiller #1 will be required, as discussed below.

The chiller plant is now controlled for each chiller to maintain a constant leaving chilled water temperature. The operators have more cooling capacity on line than is necessary to meet the load. The constant speed pumps deliver a fixed volume of chilled water at the setpoint to the secondary chilled water header. Excess flow over that needed by the buildings recirculates back to the chilled water pump inlet header, where it mixes with the return water, and lowers the temperature of the incoming water to the chillers. This has the effect of lowering the loading on the chillers, as they now operate at reduced temperature differential. With this arrangement, all the chillers operate at approximately the same percent load.

A limited amount of load adjustment can be done by modifying the control setpoints. Once the loading on a chiller is down below perhaps 75% of the load on the other chillers, there are likely to be issues with chilled water temperature control. Recirculating water from the chiller discharge back to the suction of the primary chilled water pump is preferred over variable speed drives because it maintains constant flow through the evaporator. Recirculation would be required for Chiller #1. Because the relative pressures in the various headers will fluctuate with the chilled water load and the number of chillers operating, circulating pumps will be necessary. The high flow at low head dictates two pumps to serve Chiller #1, with the bypass pump on the order of 15 hp. A bypass line for Chiller #1 and its associated pump, VFD, and controls will be required to implement this measure.

See the flow diagrams below for a schematic representation of configuration and flow rates under different operating loads for Chiller #1 under this measure.

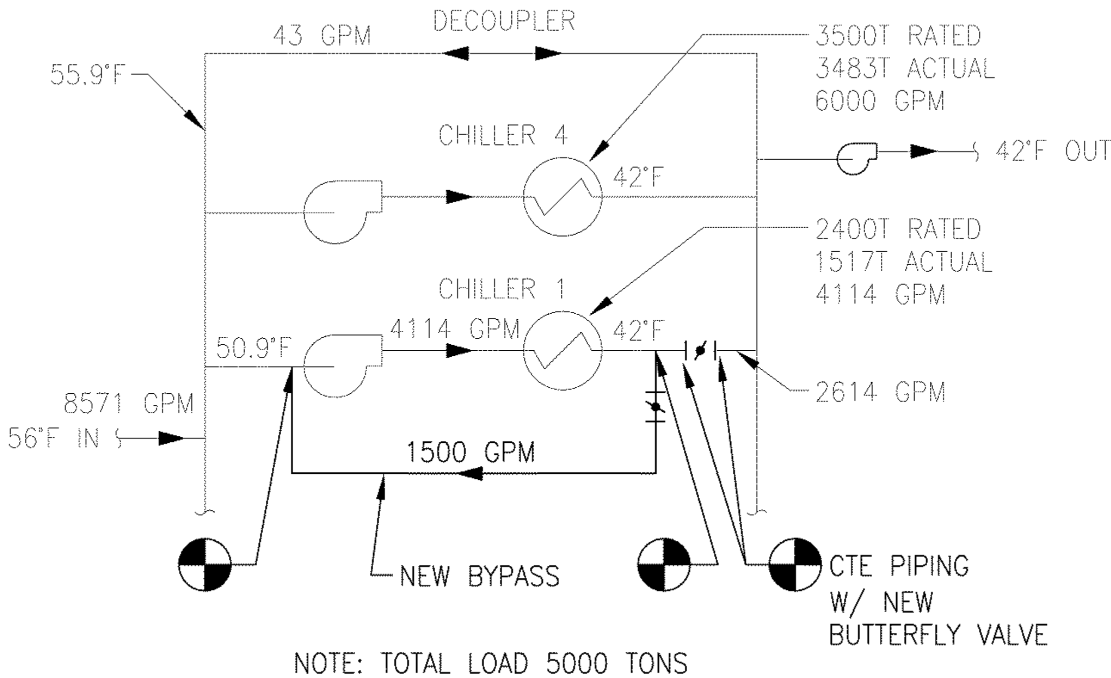
Energy Conservation Measures (ECMs)



EXAMPLE 1

SEBESTA BLOMBERG

Energy Conservation Measures (ECMs)



EXAMPLE 2

Accomplished to Date

- Modeled Chillers
    - Used model to evaluate present energy consumption for cooling
    - Used model to evaluate different operating scenarios
    - Used model to optimize allocation of load between chillers, under differing conditions
- Developed a piping modification to permit reallocating the load between chillers

Next Steps/Outline Specification

- Design recirculation piping and pump, controls
- Develop revised operating procedures
- Procure equipment and piping and electrical installation, and controls
- Commission/monitor and verify performance

Implementation Plan/Schedule

- Massport to issue work order by 10/1/12
- Design Documents Complete by 12/30/12

- Bid and award project — by 2/15/13
- Contractor to complete installation — by 4/15/13
- Commission system — by 5/1/13

Note that Massport could chose to initiate this ECM earlier if deemed appropriate

7.6 ECM-6: Reset Chilled Water Supply Temperature

The chilled water supply temperature of 42ºF is needed to provide dehumidification in humid weather. At lower cooling loads, the chilled water supply temperature can be increased and still meet space conditions, while reducing chiller energy usage.

A 1degF increase in chilled water temperature will save about 2% of the chiller energy usage. This measure can be implemented automatically through the plant control system. The automatic reset schedule would be initiated for operating chillers by adjusting discharge chilled water temperature setpoint at each chiller based upon outdoor temperature or enthalpy. Testing will be required to verify facility temperature and humidity control requirements are being met, and the reset schedule adjusted accordingly.

Note that this measure is currently being implemented on a manual basis by plant operators. Automatic operation will ensure that this measure is implemented during low load conditions, and capture additional energy savings.

Accomplished to date

- Developed Model of Chillers
- Discussed concept with Massport Facilities personnel
- Cooling water system at the CHP was tested to determine the impact of lowering the supply temperature setpoint on chiller operation.

Next Steps/Outline Specification

- Develop sequence of operation for chilled water temperature reset
- Plant controls contractor to implement
- Commission/monitor and verify performance

Implementation Plan/Schedule

- Develop design sequence — by 4-1-2012
- Controls modification implemented — by 5-1-2012
- Commissioning/Monitoring and Verification — by 6-1-2012

7.7 ECM-7: Operate Only Electric Chillers (Scenario 1A only)/ Upgrade Plant Metering

The steam turbine chillers are the most expensive ones to operate (refer to Figure 5). Besides providing enough load on the boiler plant for stable operation, and providing some cooling capability in the event of very high power costs, they have little economic justification. It is possible that with the VFD installation on the boiler FD and ID fans under project L963, the boilers will be able to run at low loads without the turbine chillers during most of the cooling season.

As summarized in Table 1A, operating only electric chillers would result in significant energy cost savings. The most efficient dispatch of the chillers under this scenario would be to have Chiller #6 take the first increments of load alone. When the load exceeds the capacity of Chiller #6, Chiller #4 should be brought on line, and Chiller #6 shut down. At loads greater than the capacity of Chiller #4, Chiller #5 should be brought on line as well.

One cannot control what one cannot measure. Upgrading the plant metering system and generating daily and monthly reports and dashboards will provide plant operators with the tools necessary to operate the facility more efficiently, and to monitor and verify performance. All metering should be transmitted to the plant computer system, and selected points should be exported to the FRED system.

Estimated metering requirements:

HTHW: BTU Meters on Sendout, on both lines out of the plant
Steam: Meters on all lines out of the plant, and on internal use
Chilled Water: Meters on the two lines out of the plant
Power: Monitor power to the chillers (turbine chillers have flow meters on them).

HTHW:

There are ultrasonic flow meters on the HTHW lines. Supply temperature is measured. Return temperature may or may not be measured, but it is not recorded. The return temperature for each line will vary, independently of each other. The heat delivered to each line is not known unless both supply and return temperature for each line are known along with flow. A BTU meter would provide an integrated measurement.

Steam:

There are steam flow meters on each of the three boilers, and on two of the steam lines leaving the boiler room. One of those lines is in a vertical drop down to the crawl space near #3 boiler. The other line leaves overhead near #1 boiler. It is not completely clear how the piping is run after that, but presumably it is the line that exits in the South tunnel. There does not appear to be any metering on the line to the North tunnel (it was not evident by field tracing the lines, or by examination of the drawings). There are no meters on the lines to the deareators, nor to the HTHW, nor to the low pressure lines for building heat. At least steam to the deareators should be measured. It would be advisable to measure the steam to the

HTHW, either on the line to the HTHW heaters or on the common line to the HTHW heaters and turbine chillers. The calibration of the meters on the boilers, and the orifice plates, should be checked.

Chilled Water:
There are flow meters on Chillers 1,2, 3 and 4. Flow meters were not visible for Chillers 5 or 6. They should be added. There are no flow meters, nor BTU meters on the chilled water leaving the plant. Meters should be added on the chilled water leaving the plant, the data sent back to the plant computer, totalized, and compared with both the chiller output data, and the load data from the buildings. This, and chiller power, are the highest priorities.

Chiller Power:
The steam turbine chillers have steam meters. These meters do not show up on the plant computer system. Their calibrations should be checked and they should be added to the plant computer system. There does not appear to be any measurement of chiller power; it does not show up on the log sheets or any of the data in the plant computer system. If there are any measurements of chiller power internal to the chillers, they should be added to the plant computer system. Power for groups of chillers can be measured at the 13.8 kV substations. An approximation to power for the individual chillers can be obtained by measuring power at various load points of each electric chiller, while simultaneously measuring the output of the chiller motor current transformers. From this, a correlation between current and power can be made. The current transformer output can then be sent to the plant computer system as a proxy for power.

Accomplished to Date

- Modeled Chillers
    - Used model to evaluate present energy consumption for cooling
    - Used model to evaluate different operating scenarios including run only electric chillers
    - Used model to optimize allocation of load between chillers, under differing conditions
- Performed survey of thermal energy metering needs
- Assessed electrical metering needs by examination of schematic diagrams
- Obtained data on meter costs

Next Steps/Outline Specification

- Prepare plans and specifications for installation of thermal meters and control system interface, and integration of chiller power monitoring with control system
- Bid and install thermal energy meters and controls system interface
- Monitor and verify performance
- Engineer to prepare loading schedule for the chillers.
- Massport staff to determine if they can run a boiler in summer without the turbine chiller to provide additional load on the boiler.

Implementation Plan/Schedule:

- Work Order issued — by 10/28/11
- Metering System Design Documents Completed — by 12/15/11
- Metering System Project Bid — by 2/15/12
- Metering System Installation Complete — by 8/1/12
- Commissioning/Monitoring & Verification — by 10/1/12
- Massport to determine minimum practical load on boiler plant with new FD/ID fans and controls: — by 7/1/12
- Develop and implement electric chillers only operating protocol — Summer 2012

7.8 ECM-8: Address Steam System Losses

Steam systems and their accessories such as traps and pressure reducing valves, require periodic maintenance to keep from wasting energy. Insulation gets knocked off steam lines which also causes energy waste.

The need to maintain traps has led plant operators and designers to install bypasses around traps, so that a process can be kept going in spite of a failed trap. Bypasses are frequently oversized, and are sometimes left open, wasting a lot of steam. During Sebesta Blomberg's site surveys, we observed excessive steam system blowdown and leakage occurring in the tunnel serving Terminal C and in the crawl space near the badging area at Terminal C.

Steam traps have a finite life. Thermostatic radiator traps usually last around 5 years. Other types of traps will have longer life, but all must eventually be replaced. Steam lost though a leaking trap is energy wasted. Sebesta Blomberg recommends that Massport institute an ongoing program to reduce steam system waste.

The first step in a steam system maintenance program would be to survey existing traps, PRV stations, and major valves, all over the airport. They should be tagged, and keyed to a piping plan. Areas with excessive leakage should be identified and repaired. Repairing insulation has a short payback, so missing pipe insulation should be noted for quick repair. During the survey, traps should be tested where possible, and loading on PRV stations noted.

There are several methods of testing traps, measuring the temperature either side of the trap, or using a stethoscope to listen for the sound of the trap opening or closing, or using a device which is sensitive to the high frequency sounds of steam leaks. The sound of water hammer, when steam gets into a return line, is a non-specific indicator of trap problems.

A record should be kept of all steam traps, including make, model, service, approximate age, and date of last test. Traps should be tested every year to 18 months. While the steam trap is tested, the strainer upstream of the trap should be blown down. Traps should be repaired as soon as a problem is evident.

Sebesta Blomberg estimates that maintenance of the steam system at Massport would require approximately half of the time of a pipefitter. He/she should be supported with a proper supply of tools and equipment, and replacement traps. Tools and supplies should be readily available near major crawl spaces and mechanical rooms. A rolling tool cart in each terminal, equipped with pipe wrenches and a pipe vise or high quality combination pipe and machinist vise would be a good investment.

It is usually not economical to repair steam traps in the field. Instead, the trap should be changed out, and the defective trap repaired or disposed of. This requires an inventory of traps, so that a defective trap can be replaced in kind. The defective trap would either be discarded, or if it appeared to be repairable, be brought back to the shop. Repairing of steam traps would require a work area, with a stock of spare parts. The decision to repair or replace would have to be made on the basis of relative cost.

One way to reduce the cost of steam trap maintenance is to standardize steam trap installations. This cannot be done all at once, but can be done by introducing a standard, and implementing it on all new projects. The standard would specify the type of steam trap, the pipe size for each service, that the trap be equipped with unions on inlet and outlet, and would specify the face to face dimension for the unions. The standard would specify a series of traps that would not be interchangeable between different applications, so that a trap designed for a steam to water convertor could not be misapplied on an end of main application. There would not be bypasses, as the standard trap would be designed for quick replacement.

With standardized traps, Massport would stock completed trap assemblies. A pipefitter would take a replacement assembly and two pipe wrenches out to the site. The strainer upstream of the trap would be blown down. Steam would be turned off, and the two wrenches would be used to break the unions and remove the defective trap. The new trap would be installed, and steam would be turned back on. The defective trap would be taken back to the shop, where it would be repaired or replaced. If it is replaced, pipe fittings of the correct length to achieve the standard end to end dimension would be installed. The trap assembly would be put in storage to be used again.

By saving time, a standard trap assembly would speed trap repairs, thereby saving steam.

The implementation cost in Table 1 are for the first year to conduct an inventory and establish an ongoing trap repair program. Ongoing implementation costs are estimated to be roughly half of first year costs, which annual energy savings will be ongoing.

Work Accomplished to date

- Work with Facilities personnel to estimate amount of steam traps
- Estimate losses from bad traps
- Estimate probable fraction of traps that are bad.

Next Steps/Outline Specification

- Facilities to complete survey and inventory of traps
- Facilities (Plant and HVAC depts.) to continue to develop maintenance plans
- Facilities to set up maintenance procedures, facilities, and spare parts/traps
- Facilities to hire such additional personnel as necessary to support the effort
- Facilities to set up program to repair damaged insulation, perhaps with Term Contractor

Implementation Plan/Schedule

- Facilities to complete survey and inventory of traps by 12-1-2011
- Facilities to have maintenance plan in place by 12-30-2011
- Facilities to have maintenance plans implemented by 1-30-2012
- Facilities have insulation repair program underway by by 11-30-2011

7.9 Measures Recommended for Further Investigation

The following measures are beyond the scope of this retro-commissioning analysis, but do have potential for operations cost reduction and are therefore recommended for further investigation.

MRFI-1: Run Turbine Chillers at Times of High Electric Costs

Each turbine driven chiller takes about 2,000 kW off the grid, giving Massport the potential to reduce their load at times of very high demand on the power grid. At present gas prices, the break-even price to run the steam turbine chillers is about $0.19 per kwh, or $190 per megawatt hour. Under the current power purchase contract, the marginal power comes from the ISO-New England, the administrator of the Power Pool. The pool price is readily available on their website, both in real time, and the forecast price a day ahead. Massport could use that information in deciding which, if any turbines to run.

At the present time, ISO-New England experiences prices above $0.19 per kwh very infrequently.

Additional revenues could be obtained if Massport were to enroll in the ISO-New England Forward Capacity market. Massport could receive payments to utilize the turbine chiller(s) (and other load shedding measures) for the Demand Response program, and also as a load shift asset for economic dispatch.

MRFI-2: Supply Makeup Water to Deareator

The present operating arrangement supplies makeup water to the condensate tank. Makeup water contains dissolved oxygen, and can corrode the condensate tank. The makeup water system has provision to put makeup water into the deareator as well. Supplying makeup to the deareator will eliminate the dissolved oxygen, and reduce corrosion. Based on our experience, Sebesta Blomberg recommends using the connection to the deareator.

MRFI-3: Replace Non-Electric Condensate Pumps

Condensate is returned to the deareator from the HTHW heaters by 4 pressure operated condensate pumps, which use high pressure steam to push the condensate back to the deareator. These pumps have experienced high maintenance for some time.

Part of the problem may be that the heaters do not appear to have additional heat exchangers to cool the condensate below the saturation point, which is frequently done to reduce problems in pumping hot condensate.

For HTHW temperatures above about 310°F, the condensing pressure is high enough to push the condensate back to the deareator without a pump. Below that sendout temperature, a pump will be needed.

In order to use the condensing pressure to move the condensate back to the deareator, it is necessary to have some way to regulate the condensate flow from the individual heaters, so that the heater with the lowest pressure does not flood. At present, the non-electric pumps perform this function. Instead, a control valve and level controller could be substituted for the pumps. The level controller would regulate valve position to maintain the level in the condensate receiver under each heater. The control valves should be selected for low pressure drop, to keep the system pressure drop within limits.

The condensate leaving the valves will be approximately at the saturation temperature corresponding to the pressure in the receiver. Because of this, a small amount will flash into steam as friction and changes in elevation reduce the pressure in the line. This will increase the velocity in the line to about 2.5 times the design velocity. While this is high for pipes carrying water alone, it is not unusual for mixtures of steam and water, but increased wear can be expected on the line near the deareator, where the pressure is the lowest.

The control for back pressure regulator near the deareator will have to be modified to maintain the back pressure to the pressure at the condensate receivers, less an allowance for the difference in elevation between the deareator and the condensate receivers, and less an allowance for pressure drop.

At sendout temperatures below about 310, the pressure in the receiver is insufficient to raise the condensate to the deareator, and to overcome the deareator pressure. Some sort of pump will be required. Centrifugal pumps designed for the process industries have low enough NPSH to work well as condensate pumps. At sendout temperatures below 310°F, the HTHW heating load is below design, so centrifugal pumps need only be added to the heaters needed to supply the low load. It may be desirable to run a new condensate discharge line from the new pump directly to the deareator, so that pressure conditions from the pump are not imposed on the rest of the system.

Since this is a maintenance cost reduction item, savings are hard to predict, and costs and savings have not been evaluated.

MRFI-4 Shut Down Boiler Plant In Summer

The boiler plant runs at low load in summer. The only steam loads are the turbine driven chillers and a limited amount of steam and HTHW supplied to the terminals for DHW and reheat. The thermal energy used for reheat is more than the slight amount that might be required for humidity control. It is required for temperature control as well. Many of the HVAC systems have been designed with hot water coils in the ducts to provide final temperature control. Discussion with the HVAC maintenance personnel provide the information that the HVAC systems can and have been operated without reheat for periods as long as a month, but it requires additional HVAC maintenance labor to reset temperatures at individual units, and causes complaints in the terminals. Were control systems improved in the terminals, it is possible these issues could be mitigated.

Other options to meet summer heating requirements include installation of small boiler(s), heat pumps, or other heating devices for summer steam/ HW use at the plant or in the end use locations. The installation of VFDs on the boiler fans is expected to make the CHP boilers easier to control at low loads. With the VFDs it may be possible to shut down the turbine driven chillers for most of the time, and just run the boilers for heat.

MRFI-5: Increase Cooling Tower Capacity

Based on the rating, the cooling tower appears to be oversized for the cooling load most of the time. In many cases, only 3 fans are operated, out of the 4 installed. Theoretically, all the tower fans could be run, using its reserve capacity to produce colder tower water, and produce a net reduction in the operating cost of the plant, after deducting the additional power for the tower fans.

However, Sebesta Blomberg's tests indicate that the tower could not actually produce colder water by running more fans. It appears that recirculation of warm air from the fans to the tower air inlet is causing the problem.

The possible energy cost savings are on the order of $150,000 per year, which may be large enough to merit spending money on the tower to improve its performance. In order to reduce recirculation, it will be necessary to extend the outlets on the tower fans. They would probably have to be extended by about 25 feet, to direct the air above the CHP building. They would not be as high as the stacks.

A computational fluid dynamics analysis would need to be done to evaluate the feasibility of extending the fan stacks.

MRFI-6: Install New High Efficiency Chillers

Sebesta-Blomberg estimates that a new 2000 ton chiller would cost about $2.5 million and a new 3500 ton chiller would cost about $4.2 million to install. Although these costs cannot be justified based upon energy savings alone, new chillers will be needed in the future, likely within the next 5 to 10 years, to replace one or more of the oldest chillers. At that time, it would be advisable to evaluate high efficiency chiller options.

Below is a preliminary discussion of chiller replacement options.

1. Future of Turbine Driven Chillers
   These two chillers are the oldest machines in the plant, the Carrier dates from 1970, and the York dates from 1975. Despite their age, it is desirable to have one steam turbine driven machine in the plant to provide limited cooling in the event of power problems, and to provide load shedding capability.

   a. Carrier Chiller #1: This chiller was installed in 1970, but was converted to R-134a in 1995. The operating data shows that this one is run more frequently than the York chiller. Because this machine is charged with R-134a, it is recommended that this steam turbine chiller be retained, and used for back-up/load shedding purposes.

   b. York Chiller #2: With an installation date of 1975, this is the second oldest chiller, and is steam turbine driven, using R-500 refrigerant. Two steam turbine driven chillers will not be needed when VFDs are installed on the boilers. The tower water flows for the turbine drive chillers are high due to the need to condense the steam from the turbines. This high condenser water flow would support a 3500 ton or slightly larger chiller. A capacity greater than 2500 tons will require replacing the primary chilled water pump, and the chilled water piping to and from the main chilled water header. Determining how large a chiller would fit in the available floor space and headroom will require a detailed engineering design, with proposal drawings from several manufacturers. This new chiller would have high efficiency for base load service, and a variable frequency drive integral with the chiller to permit operating at very high efficiency at part loads, especially with low tower water temperatures.

2. York 2000 Ton Chiller #3
   This machine was built 1985. It has only a 10F temperature rise on the cooling tower water, and an 11F temperature drop on the chilled water. It uses R-22, which is not permissible for new equipment, but which may be retained in existing equipment with good leak detection programs. The efficiency of the machine is good, but the operating data shows that it was not used in the

past year. Because this machine uses the same tower water supply as the #6 chiller, it is essentially a spare for Chiller 6. Due to the common tower water supply, replacing it with another chiller is problematic. The chiller should be replaced as part of a long range program to phase out ozone depleting refrigerants. Because of its high tower water and chilled water flows, the replacement chiller for this one could be rated at around 2700 tons, so it would supplant the present Chiller 6, which would become the standby for chiller 3. A detailed engineering study with manufacturer's proposal drawings would be required to determine if a 2700 ton machine would fit in the available space.

3. Chiller Lineup after Replacements:

Chiller #	Year Built	Capacity	Refrigerant
1	1970/1996	2400*	134a
2	Future	3750	134a
3	Future	2750**	134a
4	1999	3500	134a
5	1999	3500	134a
6	2003	1950**	134a
Capacity		13,500	

*Condenser water requirements of chiller 1 do not permit full load operation of the rest of the plant with chiller 1 in operation. Capacity based on chillers 2,3,4 and 5

**Chillers 3 and 6 could not run at the same time due to tower water flow limits. Capacity based on new chiller 3

7.10 Measures Considered but Not Recommended

The following measures were considered as part of this retro-commissioning evaluation, but are not recommended, as discussed below.

MCNR-1: Install VFDs On Chillers

This measure would install a VFD on one or more chillers, to improve the performance.

Performance data was provided by Carrier for a variable frequency drive to be installed on their 3500 ton machine. The drive showed an improvement in performance at 75°F tower water. It would show a greater improvement in performance at 65°F tower water, but the cooling tower cannot deliver 65°F water. The VFD shows a cost savings of about $60,000, and an electric power savings of about 551,226 kwh. The cost of the VFD alone was estimated at $500,000 by Carrier. The drive installed is likely to cost on the order of $1,200,000, for a 20 year payback.

MCNR-2: Install VFDs on Cooling Tower Fans That Lack Them

The use of VFDs on the tower fans is not necessary. The tower fans should run at full speed to maintain the lowest practical cooling water. Power supplied to cooling tower fans saves more by reducing chiller power.

MCNR-3: More Aggressive Reset Schedule For HTHW

At present, the temperature of the HTHW loop is reset in summer, when the only load is reheat for temperature control. The temperature is manually controlled, and is set as low as 120°F.

Discussions with the HVAC maintenance personnel provide the information that the present temperatures are at times too low for the existing HVAC systems to function properly. They advise keeping the water temperature up at about 140°F to provide 130°F water supplied to the building. Heat losses in the piping will not be much different between 140°F and 120°F, so a 140°F temperature is advisable.

MCNR-4: Provide Free Cooling for Chilled Water Systems

The Central Plant shuts off cooling when the wet bulb temperature is in the range of 47°F to 50°F. Wet bulb temperatures at this temperatures or below are necessary for free cooling off the main cooling tower, so free cooling is not achievable, nor is it necessary, as the plant shuts down at low wet bulb temperatures.

There are a number of small air cooled chillers that provide cooling when the central plant shuts down chilled water. It is relatively impractical to use a wet tower for these small loads, during the hours of the year between the shutdown of the central plant, and freezing weather. The cooling systems in the buildings use glycol, and so it might be possible to install dry cooling units to cool the glycol directly with ambient air. The savings from using dry coolers for these 3 towers is about 85,000 kwh per year, or approximately $9,000 per year. The cost is approximately $125,000 for a payback of 14 years.

8.0 Appendices

8.1 APPENDIX A – Chilled Water Model

8.2 APPENDIX B – Energy Savings Estimates

8.3 APPENDIX C – Cost Estimates

8.4 APPENDIX D – Support Data

Note: Sections 8.0 through 8.4 have not been reproduced in *ACRP Report 139* as they are not needed to support the basic purpose of the case study. Readers who wish to access information from these sections may contact Abbe Bjorklund at Sebesta.

LEGAL NOTICE
REQUEST FOR QUALIFICATIONS

The MASSACHUSETTS PORT AUTHORITY (Authority) is soliciting professional consulting services for **MPA Capital Project A259-D1, Energy Efficiency Initiatives.** The Authority is seeking a qualified energy engineering firm with proven study, design and construction management experience related to the identification and implementation of energy efficiency improvements to a variety of aviation and maritime building types and systems, including but not limited to: lighting retrofit and design, civil, mechanical, electrical, structural, plumbing, and sustainable design engineering work.

The Authority has identified over $10 million of energy efficiency improvement opportunities and is actively seeking to incorporate energy efficiency system design into its capital program. As part of its implementation of an Energy Master Plan for all Massachusetts Port Authority properties, the Authority has voluntarily committed to three energy management targets; 20% reduction in energy intensity per square foot, development of 15% of its electricity needs from renewable energy, and a 25% reduction in Greenhouse Gas emissions. The Authority has identified measures required to achieve these targets which include; LED lighting retrofits, Demand Controlled Ventilation, HVAC retro-commissioning, high voltage transmission and distribution infrastructure system design and configuration, and cogeneration. The Authority desires to engage an energy engineering consultant to further identify and evaluate energy efficiency opportunities and to support the implementation of the Energy Master Plan through the study, design and development of bid documents for stand-alone retrofits, bid phase services and services during construction. The Consultant must be able to evaluate each initiative and provide supporting data on the potential energy efficiencies. The Consultant will also be required to monitor and track energy savings from all Capital Programs projects and to produce a quarterly report on the target achievement goals. The Consultant will also help establish and support an "Energy Center of Excellence" involving industry leaders in energy efficiency programs.

The Consultant's fee shall be negotiated however the total fee for the contract shall not exceed $500,000.

Each submission shall include Architect/Engineer & Related Services questionnaire SF330 with the appropriate number of Part IIs, highlighting the firm's experience and capabilities, and identifying all subconsultants, including any D/M/WBE participation. D/M/WBE Certification of the prime or any subconsultants shall be current at the time of submittal and the Consultant shall include a copy of the D/M/WBE certification letter from the State Office of Minority and Women Business Assistance (SOMWBA) within its submittal. If M/W/DBE firms are proposed, provide a description of the scope of work proposed in Section H of the SF330. The Consultant shall also provide litigation and legal proceedings information, signed under the pains and penalties of perjury, in a separate sealed envelope entitled "Litigation and Legal Proceedings". See www.massport.com/business/capit_resou.html for more details on litigation and legal proceedings history submittal requirements.

The submission shall be evaluated on basis of: (1) current relevant experience on projects of similar complexity, (2) experience and geographic location of the Project Manager and experience of other key personnel to be assigned to the project, (3) experience and expertise of sub consultants, (4) familiarity with MGL, (5) cost management capabilities, (6) M/W/DBE and affirmative action efforts, (7) current level of work with the Authority (8) experience with sustainable design concepts and (9) past performance for the Authority, if any.

The selection shall involve a two-step process including the short-listing of a minimum of three firms based on an evaluation of the Statements of Qualifications submitted in response to this solicitation, followed immediately by a final selection**.** The Authority reserves the right to require proposals or to interview the firms prior to final selection if deemed appropriate.

By responding to this solicitation, consultants agree to accept the terms and conditions of Massport's standard work order agreement, a copy of the Authority's standard agreement can be found on the Authority's web page at www.massport.com. The exception to this standard agreement is the insurance requirements as follows; (1)

$1,000,000 of commercial general liability and (2) $1,000,000 of automobile liability insurance. The Consultant shall specify in its cover letter that it has the ability to obtain requisite insurance coverage.

In order to be eligible for selection, all aspects of Section 38A1/2, Chapter 7 of the General Laws of the Commonwealth of Massachusetts shall be satisfied including the majority of the firm's Board of Directors or ownership shall be registered in the Commonwealth of Massachusetts in accordance with the applicable provisions of the statute. Consultants shall acknowledge in the cover letter that the firm meets this requirement. All individuals responsible for technical disciplines shall, upon commencement of the project, be registered Architects or Engineers, in that discipline, in the Commonwealth of Massachusetts.

Submissions shall be printed on both sides of the sheet (8 ½" x 11"), no acetate covers. Fifteen (15) copies of a bound document each consisting of: 1) an SF 330 including the appropriate number of Part IIs including an organizational chart identifying specific project responsibilities for key staff including subconsultants, and 2) no more than 5 sheets (10 pages) of other relevant material not including covers and dividers shall be addressed to Houssam H. Sleiman, PE, CCM, Director of Capital Programs and Environmental Affairs and received no later than 12:00 Noon on Thursday, August 19, 2010 at the Massachusetts Port Authority, Logan Office Center, One Harborside Drive, Suite 209S, Logan International Airport, East Boston, MA 02128-2909. Any submission which exceeds the page limit set here or which is not received in a timely manner shall be rejected by the Authority as non-responsive. Any information provided to the Authority in any Proposal or other written or oral communication between the Proposer and the Authority will not be, or deemed to have been, proprietary or confidential, although the Authority will use reasonable efforts not to disclose such information to persons who are not employees or consultants retained by the Authority except as may be required by M.G.L. c.66.

All questions relative to the submission shall only be directed to Catherine Wetherell, Deputy Director of Capital Programs and Environmental Affairs at (617) 568-3501.

MASSACHUSETTS PORT AUTHORITY
Thomas J. Kinton, Jr.
CEO and Executive Director

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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