Research Results Digest

MODEL FOR IMPROVING ENERGY USE IN U.S. AIRPORT FACILITIES

This digest summarizes the findings of Airport Cooperative Research Program (ACRP) Project 11-02, “Model for Improving Energy Use in U.S. Airport Facilities.” The research was conducted by the Energy Systems Laboratory at Texas A & M University.

SUMMARY

Expert guidance on reducing airport facilities’ energy use and environmental impacts can help airport management operate airport facilities more efficiently. This digest presents data on U.S. airports’ utilization of 11 major energy management practices, offers a set of best practices for reducing energy use, and summarizes three case studies of recent recommissioning projects that resulted in significant reductions in energy use. Appendixes A through D of this digest—“Study of Terminals B and D at Dallas/Fort Worth International Airport”; “Airport Rental Car Facility Case Study”; “Continuous Commissioning® of the Matheson Courthouse in Salt Lake City, Utah”; and “Airport Survey Questionnaire”; respectively—are available on the Transportation Research Board (TRB) website at http://trb.org/news/blurb_detail.asp?id=8265.

INTRODUCTION

Millions of domestic and international passengers pass through airport terminals annually and the number is increasing, driven in part by a vibrant, global economy. The Federal Aviation Administration (FAA) forecasts the number of boardings to grow from 660 million in 1999 to 1,046 million in 2011 (58.5% increase) (I). As airports have grown larger and more complex, they have also become more numerous, with over 500 commercial and 2,800 general aviation facilities. Airports have become some of the largest public users of energy. Energy is often the second largest airport operating expense, exceeded only by personnel.

Airport facility managers strive constantly to reduce operating expenses to help control costs for their airline tenants (who have been on the verge of bankruptcy, with rare exception, since the attacks of September 11, 2001). Limiting or eliminating unnecessary energy use in airport facilities can be an effective means of reducing airport operating expenses while at the same time minimizing environmental impacts.

Research Objective

This research on improving energy use in airports was identified by a panel of airport industry experts as important for airport facility managers and executives, who need guidance on reducing airport energy use and environmental impacts. The objective of this research is to provide airport facility managers with timely guidance on
significantly reducing energy use in U.S. airport facilities through the following:

- Improved energy-related operations and maintenance (O&M) procedures,
- Recommissioning/optimization of major energy-consuming systems, and
- Installation of the latest cost-effective energy conservation measures.

Energy and Environmental Issues

The operating environment for airports, both large and small, has changed dramatically over the last decade. National concern about the security of energy resources has intensified since the attacks of September 11, 2001. At the same time, worldwide demand for energy is growing dramatically, as illustrated by the ever-increasing demand from developing countries like China and India. The cost of electricity for airports has escalated to record high levels, driven by the price of natural gas, the fuel mix of generators, and utility deregulation in many states.

Air pollutants from power generation and the combustion of fossil fuels can have a major impact on airports located in areas designated by the U.S. Environmental Protection Agency (U.S. EPA) as non-attainment areas. Also, greenhouse gases from the combustion of fossil fuels are now considered a contributing factor to global warming. This complex scenario of energy and environmental factors places significant economic and political pressure on airport managers to accurately assess their airport’s performance, reduce energy use, and minimize the airport’s environmental footprint.

Airport Energy Management Research Needs

Most airport facility managers have invested in energy-efficient improvements such as upgrading heating, ventilation, and air-conditioning (HVAC) systems; upgrading building controls; and installing high-efficiency lighting. However, investments in energy improvements can be costly and often compete with other capital improvement projects. Further, from research in hundreds of buildings in the Texas LoanSTAR program in the 1990s, the Energy Systems Laboratory (ESL) at Texas A&M University found that retrofit savings are often less than projected without close monitoring; verification and proper commissioning are required to obtain projected performance (2).

At the same time, little emphasis or research has been given to low- or no-cost techniques such as O&M and building optimization techniques that can significantly reduce energy use. Also, few attempts have been made to quantify or benchmark the savings potential at airports other than through broad general statements supported with little empirical data and few case studies.

Rusty Hodapp, vice president of energy and transportation management at Dallas/Fort Worth (DFW) International Airport, stated at an airline industry facilities management conference in February 2004 that “the operations and maintenance budget for airport facilities constitutes a significant portion of an airport’s overall annual budget” and that “there are no industrywide benchmarks to enable facility managers or airport executives to assess where budget improvements—or savings—can be made.” An airport industry list of generally accepted energy-saving best practices does not exist.

RESEARCH APPROACH

This project is targeted at improving energy-saving practices in U.S. airports through a study of energy-related O&M best practices, building recommissioning, and energy conservation retrofit measures (ECRMs) for immediate use by airport managers.

The ESL assembled a team of energy engineers, building recommissioning experts, and facility energy managers who have all worked extensively in the area of building energy performance. The research team decided that the most effective and efficient approach to determining best practices in airport facility energy use was to conduct a nationwide e-mail survey/questionnaire and to examine the practices of a complex airport with a history of good energy and environmental management practices. The DFW Airport facilities management team volunteered to provide comprehensive information on their award-winning energy and environmental practices. Thus, the project involved two main efforts: an airport industry survey and an on-site assessment of DFW Airport.

Airport O&M Best Practices Survey

ESL designed an airport facilities survey to create an energy profile and to examine the utilization
of O&M, building recommissioning, and energy retrofit practices. Each airport surveyed was categorized as large, medium, or small—based on the number of annual enplanements. Enplanements are defined by the FAA as the number of passengers boarding mainline or regional carriers. Large airports had greater than 1,000,000 enplanements, medium airports had 250,000 to 1,000,000 enplanements, and small airports had fewer than 250,000 enplanements.

The survey instrument (available on the TRB website at http://trb.org/news/blurb_detail.asp?id=8265) was sent to airport managers at 78 regionally diverse airports, grouped by number of annual enplanements. The airports surveyed were selected on the basis of size from an FAA list of more than 500 airports (3). O&M practices, recommissioning practices, and ECRM practices were determined from the survey responses. The ESL evaluated the utilization of energy management best practices. Each practice was evaluated for the three predetermined size groupings as well as over the full range of airports. The ESL team also evaluated energy utilization indices (EUIs) for benchmarking airport performance.

The ESL limited the survey to two pages to increase the probability that a busy facility manager would take the time necessary to complete it. The response rate was approximately 25 percent (20 out of 78). The sample size was approximately 16 percent of the FAA list.

**On-Site Assessment of DFW Airport**

In addition to responding to the Airport O&M Best Practices Survey distributed for this research, management at DFW Airport permitted the ESL to conduct a physical inspection of the airport facility. The ESL examined the lighting, elevators, escalators, moving walkways, passenger loading bridges, and aircraft HVAC systems at DFW Airport’s Terminals B and D. The ESL also conducted an in-depth look at the energy-related O&M practices and ECRMs at the two terminals.

The ESL studied blueprints, control drawings, mechanical specifications, testing and balancing, and previous commissioning reports. An ESL engineering team also conducted walk-through inspections of the two DFW Airport terminals. The findings of the on-site assessment are incorporated into the section of this digest entitled “Best Practices for Reducing Energy Use in Airport Facilities” and are fully described in “Study of Terminals B and D at Dallas/Fort Worth International Airport” (available on the TRB website at http://trb.org/news/blurb_detail.asp?id=8265). Finally, a literature search of O&M best practices and ECRMs was conducted to help develop the survey questionnaire and the model best practices.

**FINDINGS**

The use of best practices is a proven technique for increasing effective management within an industry. The ESL utilized information gained from the e-mail survey and on-site inspections at DFW Airport to identify energy management best practices of general benefit to the airport industry. O&M and recommissioning, as well as energy upgrades are presented below.

**Airport O&M Best Practices Survey Results on Energy Management Best Practices**

The survey focused on energy-related O&M, recommissioning, and energy use improvement topics. The ESL analysis of selected survey questions follows. Table 1 and Figure 1 summarize the survey results on airport industry energy management best practices.

**Use of a Computerized Maintenance Management System (CMMS) and/or a Building Automation System (BAS)**

Forty-five percent of respondents use a CMMS, and 70 percent use a BAS. The data indicate that automated CMMSs are used predominantly by larger airports. No smaller airports in the survey used them. One reason for this disparity could be the complexity of operating automated CMMSs, the personnel skill level required, and the high front-end cost considerations. This wide disparity does not exist for use of a BAS: use of a BAS ranges from 87.5 percent for busier airports to 50 percent for airports with fewer enplanements. One reason could be that, in addition to handling energy management functions, a BAS is also necessary for fire safety, security, and indoor air quality.

**Detailed O&M Manual**

Sixty percent of the respondents indicated that they had a detailed O&M manual, ranging from a high of 83 percent (medium-sized airports) to a low...
of 33 percent (small airports). There is no obvious reason why medium-sized airports should have the highest utilization. The arbitrary survey categories (large, medium, and small airports) could account for this result.

Energy Use Tracked as a Performance Measure

Forty-five percent of respondents indicated that they tracked energy use as a performance measure for their airports, with a range of 67 percent (medium-sized airports) to 33 percent (small airports). Again, the medium-sized airports had the highest utilization. This result, again, could be due to the small sample by size category.

 Tenant Energy Sub-Metering

Sixty percent of respondents indicated that they had some level of tenant sub-metering, with a range of 67 percent (medium-sized airports) to 58 percent (small airports). This high utilization rate is not surprising since airports often pass on energy prices. Sub-metering is an excellent energy conservation tool since it sends the proper price signals, penalizing wasteful tenants.

Energy Assessment within the Past 5 Years

Forty-five percent of respondents indicated that they had performed some type of energy assessment for ECRMs within the past 5 years, with a range of 50 percent (large airports) to 33 percent (medium-sized airports). This moderate utilization rate could be due to the widespread availability of new cost-effective technologies such as lighting and digital

Table 1 Utilization of best practices—results of the Airport O&M Best Practices Survey (December 2006 to January 2007)

<table>
<thead>
<tr>
<th>Survey question</th>
<th>Overall (20 airports)</th>
<th>Large (&gt; 1,000,000 enplanements)</th>
<th>Medium (250,000–1,000,000 enplanements)</th>
<th>Small (&lt; 250,000 enplanements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CMMS Use</td>
<td>45%</td>
<td>87.5%</td>
<td>33%</td>
<td>0%</td>
</tr>
<tr>
<td>2. BAS Use</td>
<td>70%</td>
<td>87.5%</td>
<td>67%</td>
<td>50%</td>
</tr>
<tr>
<td>3. Detailed O&amp;M Manual</td>
<td>60%</td>
<td>62.5%</td>
<td>83%</td>
<td>33%</td>
</tr>
<tr>
<td>4. Energy Use Tracked as a Performance Measure</td>
<td>45%</td>
<td>37.5%</td>
<td>67%</td>
<td>33%</td>
</tr>
<tr>
<td>5. Use of Energy Baseline</td>
<td>35%</td>
<td>25%</td>
<td>33%</td>
<td>50%</td>
</tr>
<tr>
<td>6. Tenant Energy Sub-Metering</td>
<td>60%</td>
<td>62.5%</td>
<td>67%</td>
<td>58%</td>
</tr>
<tr>
<td>7. Energy Assessment within Past 5 Years</td>
<td>45%</td>
<td>50%</td>
<td>33%</td>
<td>50%</td>
</tr>
<tr>
<td>8. O&amp;M Assessment within Past 5 Years</td>
<td>30%</td>
<td>37.5%</td>
<td>33%</td>
<td>17%</td>
</tr>
<tr>
<td>9. Periodic Recommissioning or Optimization of HVAC Systems and Control Systems</td>
<td>50%</td>
<td>50%</td>
<td>67%</td>
<td>33%</td>
</tr>
<tr>
<td>10. Implementation of Energy-Related O&amp;M Measures</td>
<td>55%</td>
<td>87.5%</td>
<td>50%</td>
<td>16.6%</td>
</tr>
<tr>
<td>11. Implementation of ECRMs</td>
<td>50%</td>
<td>75%</td>
<td>50%</td>
<td>33.3%</td>
</tr>
</tbody>
</table>

Average response rate for all measures 49.5% 60.2% 53.0% 34.0%
controls. In many regions, utility cash incentives provide good economic incentives.

**O&M Assessment within the Past 5 Years**

Only 30 percent of the respondents indicated that they had conducted an O&M assessment within the past 5 years, with a range of 37.5 percent (large airports) to 17 percent (small airports). This low utilization rate could be the result of a lack of metering, which makes it difficult for airport facility managers to know the financial impact of not doing energy-related O&M assessments.

**Periodic Recommissioning or Optimization of HVAC Systems and Control Systems**

Fifty percent of the respondents indicated that they had recommissioned or optimized their HVAC systems and control systems, with a range of 67 percent (medium-sized airports) to 33 percent (small airports). The increased use of recommissioning (optimizing) existing building and utility plants may be explained by factors such as record high energy prices, an increased number of building recommissioning agents, and the increased awareness of airport executives and the public of the direct link between energy and the environment.

**Implementation of Energy-Related O&M Measures**

Fifty-five percent of the respondents indicated that they have implemented energy-related O&M measures within the past 5 years, with a range of 87.5 percent (large airports) to 16.6 percent (small airports). This high response rate indicates that respondents that have an O&M plan (60 percent) are also implementing O&M measures.

**Implementation of ECRMs**

Fifty percent of the respondents indicated that they had implemented ECRMs.
Airport O&M Best Practices Survey Results on Utilization of Energy Supply and Storage Systems and the Effect of Air Quality Issues on O&M Decisions

The survey examined the utilization of selected energy supply and storage systems (on-site cogeneration, on-site renewable power, thermal storage, and purchased cooling and/or heating) as well as the effect of air quality issues on O&M decisions. Survey results on use of these energy supply and storage systems and the effect of air quality issues on O&M decisions are presented in Table 2 and discussed below.

On-Site Cogeneration

Cogeneration is the simultaneous production of electricity and thermal energy. It can provide significant energy cost reduction in cases where steam and electric loads coincide or where a secondary market for excess steam or electricity exists. Absorption chillers are commonly coupled with cogeneration equipment to balance the load profiles. The use of cogeneration is not a simple decision because of fluctuating natural gas and electric prices and high capital costs. The 10-percent utilization rate indicates that it is not widely used by the airports surveyed and then only by larger airports.

On-Site Renewable Power

Renewable energy is becoming a significant contributor to the mix of U.S. energy resources. Some airports reported having green energy in their electric purchases, but none reported having renewable power sources on-site. This response is understandable, given that few airports are located in regions with adequate renewable resources, such as wind, to make these technologies economically feasible.

Thermal Storage

Thermal energy storage systems are an effective means of reducing peak electric loads. Airports using thermal storage can benefit from reduction in billed cost even if energy consumption increases by shifting the peak cooling load to off-peak periods. This technology works best at facilities with large summer cooling loads, and it requires a dedicated O&M staff and a favorable utility electric rate structure to be economically viable. The low utilization rate of 10 percent, with a range of 25 percent (large airports) to 0 percent (small airports), is therefore understandable.

Purchased Cooling and/or Heating

None of the airports surveyed purchase thermal energy for heating and/or cooling. An airport would have to be located very close to a district heating and cooling project to consider this technology as a viable option.

Effect of Air Quality Issues on O&M Decisions

Forty-five percent of all the airports surveyed and 75 percent of the large airports reported that air quality issues are affecting their O&M decisions. These relatively high percentages indicate the importance of environmental issues at the airports surveyed. Air quality tends to be a major concern in large urban centers. This could account for the fact that the highest percentage of airports responding that air quality issues are affecting O&M decisions was in the large airports category.

Table 2  Selected energy supply and storage systems and the effect of air quality issues on O&M decisions

<table>
<thead>
<tr>
<th>Technology</th>
<th>Overall (20 airports)</th>
<th>Large (&gt; 1,000,000 enplanements)</th>
<th>Medium (250,000–1,000,000 enplanements)</th>
<th>Small (&lt; 250,000 enplanements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Site Cogeneration</td>
<td>10%</td>
<td>25%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>On-Site Renewable Power</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Thermal Storage</td>
<td>10%</td>
<td>25%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Purchased Cooling and/or Heating</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Air Quality Issues Affecting O&amp;M</td>
<td>45%</td>
<td>75%</td>
<td>33%</td>
<td>33%</td>
</tr>
</tbody>
</table>
DFW Airport Responses to Airport O&M Best Practices Survey

DFW Airport management responded to the same survey questions as the other 19 airports. DFW Airport management’s responses were the following:

- **CMMS and BAS use.** DFW Airport is implementing a new CMMS.
- **Detailed O&M manual.** DFW Airport does not have an O&M procedures manual.
- **Energy use tracked as a performance measure.** DFW Airport tracks energy consumption, but does not use the data for benchmarking performance.
- **Use of an energy baseline.** At DFW Airport, baselines are established on a project-by-project basis, as required. DFW Airport does not have an overall energy baseline.
- **Tenant energy sub-metering.** DFW Airport does not sub-meter most tenant energy use. A few major clients purchase energy directly from the utility for hangars and maintenance.
- **Energy assessment within past 5 years.** Energy assessments of selected buildings have been carried out in the last 5 years.
- **O&M assessment within past 5 years.** An external O&M assessment has not been performed in the last 5 years.
- **Periodic HVAC system and control systems recommissioning or optimization.** DFW Airport management is currently recommissioning targeted facilities.
- **Implementation of O&M measures.** DFW Airport management is constantly implementing measures to improve the airport’s overall O&M program.
- **Implementation of ECRMs.** DFW Airport is implementing a variety of ECRMs.

On-Site Assessment of Best Practices at DFW Airport Terminals B and D

The ESL conducted on-site visits at DFW Airport’s Terminals B and D to develop the questions in the e-mail survey and to develop model best practices. The following observations (from the on-site visit to Terminal D) may be useful to airport managers dealing with similar issues:

- DFW Airport follows an ongoing, programmatic approach when contracting for O&M services. For example, while contracts do not contain specific energy-related procedures, the contracts do specify the contractor’s obligation to pursue potential rebate opportunities and to work with any energy consultants brought in.
- Implementing the new CMMS at DFW Airport has been a major endeavor. Incorporating energy and environmental parameters such as energy monitoring and process review functions within the CMMS is ongoing.
- DFW Airport is implementing an active recommissioning and optimization program and an aggressive 5-year plan to recommission targeted airport facilities.

On-Site Assessment of Best Practices at DFW Airport’s Rental Car Center

In 2004, a recommissioning project at the off-site DFW Airport rental car facility revealed O&M and recommissioning measures that are typical of aviation facilities that operate 24/7. The following optimization strategies were identified:

- Improved operation of the attached parking garage lights,
- Zone temperature control,
- Supply temperature reset schedule,
- Static pressure setpoints and reset schedules,
- Operation of the economizer cycle,
- Control for the return air fans to allow better control of outside airflow,
- Terminal box minimum airflow setpoints,
- Improved chiller operation,
- Reset schedule for the condenser water temperature, and
- Improved secondary pump control.

Energy Utilization Indices and Benchmarks

Airport facilities cannot be easily compared to other facilities. Terminals, through which a large number of travelers pass on a daily basis, house a variety of commercial entities (e.g., retail and entertainment stores, hotels, and restaurants) as well as equipment that supports the airline industry (e.g., jet bridges for passenger boarding and extensive baggage handling systems). Given the significant differences between airports and other facilities, one would expect that airport facility managers would use an airport-specific set of performance metrics to measure the energy efficiency of airports. However, the Airport O&M Best Practices Survey confirmed
that airport facilities have no unique performance metrics or indices for analyzing utility costs that often run into the millions annually.

The research team concluded that having a set of industry-accepted airport energy/utility indices for benchmarking would allow airport managers to compare the performance of an airport with the performance of other airports within the same size range. An airport EUI also would provide an internal gauge of the effectiveness of various measures implemented.

**Normalizing Factors**

Energy/utility indices for benchmarking should be adjusted for shifts in local conditions such as weather and use; in other words, indices should be “normalized.” Energy costs should always be normalized for variations in average annual outside air temperature using historical weather data. The amount of energy use per unit of conditioned space (square foot) is the most commonly used factor for benchmarking building energy performance. Percentage of conditioned space is not always accurate for very large airport facilities because the number of enplanements varies widely, and airports often have a large percentage of mixed-use space. Some airports also have large cargo areas that are not conditioned or are only partially conditioned.

**Enplanements as a Normalizing Factor for Airports**

A potential normalizing factor for airport facilities is the number of passenger boardings (enplanements), as these data are readily available from FAA. Enplanements can provide a product-based normalization factor that is similar to normalization factors in other industries, such as manufacturing. Enplanements are a good indicator of airport activity, which has a direct impact on energy use.

**Table 3** Potential energy indices based on the Airport O&M Best Practices Survey (December 2006 to January 2007)

<table>
<thead>
<tr>
<th>Group</th>
<th>Utility Costs/ft²</th>
<th>Energy Costs/ft²</th>
<th>Utility Costs/Enplanement</th>
<th>Energy Costs/Enplanement</th>
<th>Enplanements/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airports Overall</td>
<td>$2.71</td>
<td>$2.55</td>
<td>$1.05</td>
<td>$0.99</td>
<td>2.57</td>
</tr>
<tr>
<td>Large Airports</td>
<td>$2.79</td>
<td>$2.63</td>
<td>$1.03</td>
<td>$0.97</td>
<td>2.71</td>
</tr>
<tr>
<td>Medium Airports</td>
<td>$1.63</td>
<td>$1.53</td>
<td>$1.55</td>
<td>$1.46</td>
<td>1.05</td>
</tr>
<tr>
<td>Small Airports</td>
<td>$3.11</td>
<td>$2.98</td>
<td>$1.88</td>
<td>$1.80</td>
<td>1.65</td>
</tr>
</tbody>
</table>

**Potential Energy Utilization Indices**

Using data drawn from the Airport O&M Best Practices Survey (and the categories into which surveyed airports were grouped—large, medium, and small), the ESL put together potential EUIs for benchmarking airports. The first two columns of Table 3 show two energy indices typically used for benchmarking (utility costs/ft² and energy costs/ft²). The next two columns show two energy indices specifically tailored to airport facilities (utility costs/enplanement and energy costs/enplanement), and the last column shows the intensity of passenger boardings per square foot (enplanements/ft²). Figure 2 presents a graphic display of the data presented in Table 3.

From the airport-specific indices generated from the survey sample (utility costs/enplanement, energy costs/enplanement, and enplanements/ft²), the research team drew the following conclusions:

**Large airports.** On average, large airports require the least utility expenditure per enplanement. Large airports enplane 2.58 times as many passengers per square foot as medium-sized airports. From the perspective of overall facility effectiveness, this is good news for large airports, but that does not mean they do not have energy-saving opportunities.

**Medium-sized airports.** Medium-sized airports have on average the least utility expenditure per square foot and therefore are the most efficient from a conditioned space perspective. Medium-sized airports have the lowest number of enplanements per square foot—even fewer than the small airports surveyed. The reason for such a low number of enplanements is not clear.

**Small airports.** The small airports that were surveyed are clearly less efficient from a utility cost
perspective, regardless of whether dollars per square foot or dollars per enplanement are being considered. Small airport utility costs per square foot are approximately 90 percent greater than costs per square foot for medium-sized airports.

BEST PRACTICES FOR REDUCING ENERGY USE IN AIRPORT FACILITIES

This section will provide practical guidance for improving airport energy use through proven techniques and technologies. The guidance is based on responses to the project surveys, a review of industry literature, interviews, and years of related research by the research team.

Art Rosenfeld, California Energy Commissioner, remarked in a 2007 telephone interview that “building recommissioning and enhanced operations and maintenance of commercial buildings are two of the most cost-effective, low-cost technologies to come along in the past 15 years. The paybacks are extremely attractive and occupant productivity and health are greatly improved.” After recommissioning 50 million square feet of offices, hospitals, airports, laboratories, classrooms, central utility plants, and courthouses, the ESL recommends three major opportunities for reducing energy use that work interdependently:

- **Energy-related O&M.** This can provide savings of up to 15 percent of whole building energy cost,
- **Ongoing building recommissioning.** This can provide savings of 10 to 25 percent of whole building energy cost, and
- **ECRM.** These can provide savings of 10 to 20 percent of the whole building energy cost.

Energy-Related O&M

O&M is defined by the Federal Energy Management Program (FEMP) as “the decisions and actions regarding the control and upkeep of property and
equipment” (4). Preventing equipment failure is the traditional focus of O&M. Typically, little attention is given to how systematic operation and maintenance of building systems also saves energy.

Energy use is an excellent indicator of equipment performance, overall efficiency, and system degradation. Inadequate energy-related O&M can neutralize or reduce the benefits of energy-efficient products and systems and is often a cause of premature HVAC equipment failure. Therefore, having a good O&M program in place is critical to both energy-efficient operation and equipment maintenance.

The following energy-related O&M best practices are key components of a successful airport energy management program:

- **Comprehensive energy-related O&M plan.** Develop a comprehensive energy-related O&M program with clearly defined goals and benefits. Set aggressive goals and secure funding and senior management support. Implement and monitor benchmarked results.

- **Personnel resources.** Identify an airport O&M manager or contractor to manage/coordinate the efforts of the entities involved in performing O&M. For large airports, this position requires significant technical and managerial skills.

- **Quality control procedures.** Develop inspection procedures and identify an inspection team to provide quality control oversight for the staff and contractors performing O&M work. Inspection oversight is a necessity in large facilities.

- **Measurement and verification plan.** Develop a written measurement and verification plan for any O&M, recommissioning, or ECRMs implemented. It is recommended that the International Performance Measurement and Verification Protocols (IPMVP) developed by the U.S. Department of Energy (U.S. DOE) be used for this purpose.

- **Detailed O&M manual.** Develop detailed energy-related O&M procedures. Documenting the O&M procedures in a centralized manual reduces dependence on individual specialized knowledge or expertise regarding airport systems. Utilizing a comprehensive O&M manual helps ensure that systems will not deteriorate and that energy consumption will remain relatively constant.

- **CMMS.** A CMMS is a relatively new tool for O&M management. These systems utilize specialized computer software to help streamline virtually every aspect of defining and managing O&M programs. O&M strategies such as reliability-centered maintenance (RCM), which increases reliability while reducing unneeded maintenance, would be impossible to implement without these advanced tools. A CMMS is not cheap, and considerable commitment is required to implement it properly. The cost of these systems puts them out of reach for many small airports and even some medium-sized ones, as reflected in the survey responses.

- **BAS.** A building automation system (BAS) is also known as an energy management control system (EMCS). When combined with well-trained personnel and comprehensive operating procedures, these systems allow the building HVAC and lighting systems to react automatically to the operating environment, adjust to meet load conditions, and help schedule or identify equipment needing maintenance or adjustment.

  The BAS can also detect changes in the operation of controlled equipment and signal operators that attention is needed, reducing downtime and costly repairs as well as unnecessary energy consumption. It is important to note that an improperly configured or poorly operated BAS can also result in higher energy consumption. One of the most important maintenance considerations with a BAS is sensor calibration. If sensor calibration is not performed on an ongoing basis, energy can be wasted, especially in air-handler operations.

- **Periodic HVAC system and control system optimization and recommissioning.** Periodic HVAC system and BAS recommissioning/optimization is necessary to offset the normal deterioration of mechanical equipment and related sensors. Often, stop-gap measures are taken to keep systems operating that seem to work fine, but these measures can ultimately compound a problem over time. Commissioning experts can detect these issues and correct them, saving considerable resources.

- **Development of an energy baseline.** Developing an energy use baseline for a facility is the first step in any energy conservation effort.
Neither the potential for benefit nor the resulting savings can be reliably determined without developing an energy use baseline. A baseline is also an important part of a successful recommissioning process.

- **Energy use tracked as a performance measure.** Energy consumption as a performance indicator is fundamental to energy-related O&M. The effectiveness of any measures taken to reduce energy consumption cannot be determined if energy consumption is not tracked. By tracking energy performance, maintenance personnel can know when a building needs to be recommissioned.

- **Tenant energy sub-metering.** Sub-metering tenant energy consumption and billing tenants on the basis of consumption provides them with an incentive to conserve energy.

- **O&M assessment every 5 years.** O&M assessments generally focus on O&M procedural issues. Periodic review of O&M procedures performed with the assistance of external experts can result in substantial benefits.

- **Energy assessment every 5 years.** External energy assessments are another important tool for saving energy as they identify potentially beneficial equipment upgrades, needed equipment repairs, and beneficial changes in operating procedures. Also, external assessments provide critical support for convincing management of the benefits of needed measures. It is suggested that comprehensive energy assessments be performed at least every 5 years.

Portland Energy Conservation, Inc. (PECI) has an excellent guide to O&M best practices entitled *Fifteen O&M Best Practices for Energy-Efficient Buildings* (5). Recommendations for best practices include the following items:

- Incorporate goals for energy-efficient building operations into the strategic plan.
- Include energy-efficient operations in energy management planning.
- Implement an energy accounting system to track energy performance.
- Hire an energy manager.
- Train operators in energy-related O&M.
- Ensure that building service contracts support building-efficient operations.

- Include energy-related O&M as a cross-cutting activity.
- Document O&M activities.
- Utilize O&M diagnostic tools.
- Conduct O&M assessments.
- Perform O&M optimization activities.
- Utilize automated building controls.
- Schedule energy-using equipment.
- Track performance of major energy-using equipment.
- Include energy-related O&M in the preventative maintenance plan.

### Ongoing Building Recommissioning

Ideally, recommissioning of buildings and control systems is an ongoing process that resolves operating problems, improves comfort, optimizes energy use, and identifies retrofits for existing commercial and institutional buildings and central plant facilities. Over time, a building’s HVAC systems will degrade and the function of the building or its occupants may change the way the building runs. Ongoing recommissioning involves optimizing the HVAC system and controls system in a building to improve performance.

Ongoing recommissioning is a two-step process. Step 1 is the initial assessment phase where opportunities are identified through on-site testing and analysis of energy data and HVAC systems. Step 2 is implementing the building optimization process and verifying project performance. This second step includes the following actions:

- Developing a recommissioning plan and forming a project team.
- Developing performance baselines.
- Testing the HVAC system and controls system and developing recommissioning measures.
- Implementing recommissioning measures.
- Documenting energy savings and comfort improvements.
- Recommissioning on a regular basis (4).

### ECRMs

Most energy conservation programs utilize major equipment upgrades and retrofits as primary means to reduce energy use. ECRM payback periods of 2 to 20 years are common in airports and other large institutions. ECRM payback periods are generally
much longer than the payback periods associated with instituting energy-related O&M and recommissioning measures, which are often under 2 years.

A list of energy conservation measures employed by the airports surveyed for this study (including DFW Airport) includes the following:

- Lighting and controls upgrades,
- Installation of a BAS or upgrades to an existing system,
- HVAC system upgrades,
- High-efficiency motors and motor systems installation,
- High-efficiency pump installation,
- Variable speed drive installation,
- Water and wastewater system improvements,
- Central utility plant and distribution systems improvements,
- Installation of heat recovery systems,
- Installation of electrical load management devices,
- Installation of building and roof insulation, and
- Passenger and baggage-handling system improvements.

Not all ECRMs may be applicable. ECRM choice depends on the size, location, age, application, and energy costs of an airport facility.

Lighting system controls and HVAC system controls are two of most common ECRMs. Lighting system ECRMs include the following:

- Retrofitting existing T-12 magnetic ballast fluorescent fixtures with new T-8 or T-5 lamps with electronic ballasts. This retrofit will reduce the electric power needed for lighting by approximately 20 to 25 percent and will have a simple payback period of 2 to 5 years, depending on electricity rates and utility rebates.
- Replacing incandescent bulbs with compact fluorescent (CF) bulbs. The cost of CF bulbs has dropped significantly, and there is a move to outlaw or place a “sin tax” on incandescent bulbs in a few states. CF bulbs use 25 percent of the power of the incandescent bulbs they replace and last many times longer than incandescent lights. A CF bulb will typically provide net savings of $50 to $100 during its life.
- Retrofitting or replacing inefficient exit signs with new exit signs that use light-emitting diodes (LEDs). Retrofitting existing exit fixtures is generally highly cost-effective. In 1997, the U.S. EPA Green Lights Program put the net present value of the retrofit at $540 per sign, with $0.08 per kWh electricity.
- Using any of the many approaches to, and applications for, retrofitting lighting control, such as photocells and timers to control exterior lighting. The ESL often observes control failure, which results in exterior lights remaining on all day. Most airports are designed with large expanses of windows. This provides substantial opportunity for daylighting. Since there are many types of daylighting controls, professional assistance is recommended when considering the options.
- Installing occupancy sensors, very effective energy-saving devices. They can optimize the operation of lighting systems by turning the lights off when space is unoccupied. Savings normally vary from 20 to 75 percent of the power that would be used without them. Payback periods are normally very short, ranging from 6 months to 2 years, depending on the application and energy price. Additional considerations include customer acceptance and limitations such as egress lighting.

HVAC equipment efficiency has advanced considerably in recent years. Advancements in direct expansion (DX) systems include water-source heat pumps and air-source heat pumps as well as more efficient conventional cooling-only units. ECRMs for HVAC systems and control systems include the following:

- Replacing older, inefficient DX systems with newer, more efficient, and properly sized heat pumps or DX systems. Specific evaluation is needed to determine savings, which can be significant. DX units are often used with jetways, outbuildings, and isolated portions of an airport facility.
- Using thermal storage systems can provide considerable cost savings if the utility rate schedule contains a cost penalty for high peak electrical demand.
- Replacing older chillers with newer, properly sized chillers. Because of the large initial cost involved and to provide a shorter payback period for the overall package, this upgrade is most often bundled with other retrofits, such as lighting and controls upgrades.
- Using a BAS (or an EMCS), standard equipment for controlling HVAC systems, and, in many cases, other building functions. An ef-
fective BAS requires well-trained personnel, ongoing maintenance, calibration, and well-developed control schemes.

- Upgrading to direct digital controls (DDCs) for older air-handling units (AHUs) and air-distribution equipment (variable air volume [VAV] boxes) is often very cost-effective. Replacing old pneumatic control systems that require compressed air with new DDCs can also allow the decommissioning of building control systems, which consume considerable energy and often require considerable maintenance. In cases where the compressed air system can be decommissioned, this change helps offset part of the cost of conversion to full DDC.

- Retrofitting outside air intakes for “economizer” operation in certain climate zones can result in significant savings. Full economizer operation allows the AHU to provide up to 100% outside air when the temperature and humidity of outside air will provide adequate cooling. This practice can amount to thousands of hours of free cooling and significantly reduced energy costs.

- Variable frequency drives (VFDs) can be added to many existing pumping and air-handling systems to allow dynamic control that responds to the load or ventilation requirements. Motors with more than 5.0 hp are good candidates for VFD retrofits, although some VFDs are installed on smaller motors. System-specific operating requirements and appropriate control strategies must be implemented to benefit from these retrofits.

- Heat recovery units (HRUs) are used to recover energy from the exhaust air stream. They either remove heat from the incoming air stream by transferring it to the relatively cool exhaust air during cooling operation or add heat to the incoming air stream by transferring heat from the exhaust air stream during heating operation. There are several designs, and specific expertise is needed to evaluate and apply these properly.

- Replacing older boilers, which are often oversized, with more efficient, properly sized boilers and water heating systems can provide significant energy savings. Replacing oversized boilers can also reduce maintenance costs.

- Water treatment system upgrades can provide significant savings by reducing chemical consumption and lengthening equipment life. Problems with chemical balance can lead to the overconsumption of supplies and can prevent systems from handling their design loads.

### Prioritizing Energy Retrofit, O&M, and Recommissioning Measures

Most energy conservation programs have major equipment upgrades and retrofits as primary components. Tables 4 and 5 provide basic shopping lists of equipment upgrades ranked by simple payback period. Duration of payback periods is based on experience gathered over the past 20 years by the ESL and its contractors, as well as the survey and assessments conducted as part of this research.

Often, projects with longer payback periods (such as HVAC replacements) will be grouped with projects with short payback periods (like recommissioning or lighting upgrades) to help offset initial costs and improve the return on investment. Ideally, enhanced recommissioning would also be a part of any ECRM project and prioritized like any other individual retrofit measure when calculating the overall project payback period.

ECRM payback periods are dependent on several factors: (1) utility rates, (2) hours of operation, (3) climate conditions, (4) relative efficiency of equipment and/or controls being replaced, (5) design condition requirements, and (6) interdependency of savings when more than one ECRM is installed. Therefore, the payback period ranges listed in Tables 4 and 5 are for general guidance. Table 4 shows payback periods for lighting ECRMs (short payback period), and Table 5 shows payback periods for HVAC and Mechanical Systems ECRMs (intermediate to long-term payback periods).

### Table 4 Payback periods for lighting ECRMs

<table>
<thead>
<tr>
<th>Lighting ECRMs</th>
<th>Simple payback period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replace exit lights</td>
<td>6 months to 2 years</td>
</tr>
<tr>
<td>Replace incandescent bulbs</td>
<td>6 months to 2 years</td>
</tr>
<tr>
<td>with compact fluorescent bulbs</td>
<td></td>
</tr>
<tr>
<td>Install occupancy sensors</td>
<td>2 to 4 years</td>
</tr>
<tr>
<td>Replace T-12 with magnetic ballasts with T-8 or T-5 with electronic ballasts</td>
<td>2 to 5 years</td>
</tr>
<tr>
<td>Install lighting controls</td>
<td>2 to 10 years</td>
</tr>
</tbody>
</table>
Sustainable Airport Facility Best Practices

This digest focuses on best practices for reducing airport energy usage. Reducing energy usage not only saves on utility costs, but also is a step toward more sustainable operation. Many different definitions of sustainability exist, but one of the most widely accepted definitions is the Brundtland Commission’s: “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (6). Most airport managers see minimizing their airport’s impact on the environment and conserving natural resources as critical aspects of their operations, as evidenced by the project survey.

Sustainable or “green” practices are becoming more common in commercial buildings since they not only reduce costs, but typically result in a more productive and healthier work environment for occupants. The U.S. Green Building Council created the Leadership in Energy and Environmental Design (LEED) system as a benchmarking tool for green buildings. There are many areas to consider on the road to sustainability, but effective O&M, retrofits, and recommissioning are important components.

The Pennsylvania Green Buildings Operations and Maintenance Manual is a green O&M manuals (7). It describes sustainable O&M procedures for landscaping, snow removal and de-icing, roofing materials, parking garages, HVAC, lighting, and cleaning that can be applied to airports. In addition, airport managers interested in “greening” their facilities may want to assess procedures in the following areas identified by the ESL in a sustainability assessment performed for Texas A&M University (8):

- **Energy consumption.** Important areas to consider are building lighting and plug loads, HVAC consumption, and transportation energy.
- **Energy sources.** Alternative sources of energy may include green power that is purchased from a utility company or on-site renewable energy generated through photovoltaics and other sources.
- **Water conservation.** Water is an essential but limited natural resource, so efficient use and pollution prevention are extremely important. Using low-flow fixtures, waterless urinals, and innovative irrigation technologies are good ways to reduce water usage.
- **Waste and recycling.** A good waste minimization program coupled with a strong recycling program can significantly reduce the amount of waste in landfills. Proper handling of hazardous waste is also important.
- **Built environment.** Indoor air quality is extremely important to the health and productivity of building occupants. Designs that require sustainable and non-toxic renewable materials in construction can help improve indoor air quality.
- **Land use.** Healthy, aesthetically pleasing, and ecologically sustainable landscapes, where storm water is well managed and pest man-

<table>
<thead>
<tr>
<th>HVAC and Mechanical System ECRMs</th>
<th>Simple Payback Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam trap O&amp;M and/or replacement</td>
<td>6 months to 10 years</td>
</tr>
<tr>
<td>Optimizing HVAC systems and controls</td>
<td>1 to 4 years</td>
</tr>
<tr>
<td>Water treatment systems upgrades</td>
<td>1 to 4 years</td>
</tr>
<tr>
<td>Variable frequency drive (VFD) replacements</td>
<td>3 to 7 years</td>
</tr>
<tr>
<td>Cooling tower VFD and pump upgrades</td>
<td>3 to 7 years</td>
</tr>
<tr>
<td>Thermal storage system retrofits</td>
<td>3 to 10 years</td>
</tr>
<tr>
<td>Economizer equipment upgrades</td>
<td>4 to 8 years</td>
</tr>
<tr>
<td>Replacement of inefficient motors</td>
<td>5 to 6 years</td>
</tr>
<tr>
<td>Cooling tower replacement</td>
<td>5 to 20 years</td>
</tr>
<tr>
<td>Oversized boiler replacement</td>
<td>6 to 8 years</td>
</tr>
<tr>
<td>DX unit and heat pump replacement</td>
<td>4 to 13 years</td>
</tr>
<tr>
<td>BAS/EMCS upgrade</td>
<td>6 to 10 years</td>
</tr>
<tr>
<td>Heat recovery unit upgrade</td>
<td>8 to 10 years</td>
</tr>
<tr>
<td>High-efficiency boiler replacement</td>
<td>8 to 12 years</td>
</tr>
<tr>
<td>Chiller replacement</td>
<td>8 to 20 years</td>
</tr>
</tbody>
</table>
agement practices do not harm the health of people or wildlife, are preferable for airports.

- **Sustainable purchasing.** Airports can help conserve natural resources by implementing sustainable purchasing programs. Examples include purchasing recycled-content paper; requiring recycled-content, reused, or regional building materials; and using ENERGY STAR equipment.

- **Food.** Healthy eating is an important component of a healthy lifestyle. Airport vendors can offer fresh fruits, vegetables, and whole grains as alternatives to refined starches and sugars, artificial preservatives, and processed foods. Airports that purchase food that is locally grown and raised can promote the local economy. Efforts can be made to minimize organic and inorganic waste in dining facilities.

- **General health and well-being.** This category includes using green custodial practices, maintaining a healthy indoor environment, and encouraging airport employees to use safe practices in all of their work.

**Recommissioning Case Studies**

The following case studies are good examples of how many of the best practices discussed in this study can produce excellent savings in large complex facilities, including airports. The first case study describes the savings realized from recommissioning a centralized rental car facility at DFW Airport. The second case study describes a large, ongoing recommissioning project at Texas A&M University, and the third describes a recommissioning project at the Matheson Courthouse in Salt Lake City, Utah.

**DFW Airport Rental Car Center**

ESL began recommissioning the DFW Airport Rental Car Center in September 2004. Metered savings were $106,000 during the first year, with a 1-year payback period and an 18-percent reduction in energy use.

Recommissioning measures included optimizing the supply air reset, chiller operations, condenser water reset, economizer cycle, garage lighting schedule, and the air distribution system, as well as eliminating simultaneous heating and cooling.

Figure 3 shows the immediate and dramatic reduction in electricity use in October 2004, one month after the recommissioning process began. (A detailed description of this project, “Airport Rental Car Facility Case Study,” is available on the TRB website at http://trb.org/news/blurb_detail.asp?id=8265.)

![Figure 3](image-url)
The ESL is systematically recommissioning the main campus of Texas A&M University in College Station, Texas. Since 1996, energy savings have been more than $35 million from in-depth recommissioning of 80 buildings (totaling 8 million square feet) and 5 central utility plants. Annual energy savings per building range from 10 to 15 percent, with some buildings achieving a reduction of more than 40 percent. The overall campus EUI has dropped 34 percent.

The Texas A&M main campus is one of the most successful, large-scale recommissioning projects in the United States and is an excellent case for large airports to examine because, like airports, large university campuses have central utility plants, 24/7 operations, a wide range of building types, and a wide range in building age and function.

The recommissioning of the Matheson Courthouse is an informative case for airport operators to study for two reasons: (1) the Matheson Courthouse is an administrative building, a kind of building that can be found at most airports, and (2) this recommissioning project illustrates the energy savings potential of recommissioning a new facility that is already relatively energy efficient.

The Matheson Courthouse, built in 1998, was designated a U.S. EPA ENERGY STAR building. It had a very low energy cost of $1.07 per square foot prior to recommissioning. After continuous recommissioning was implemented in 2002 by the ESL, energy cost was reduced by 18 percent with a 1-year payback period. At the same time, there was improved occupant comfort and a reduction in HVAC trouble calls. (A detailed description of this project, “Continuous Commissioning® of the Matheson Courthouse in Salt Lake City, Utah,” is available on the TRB website at http://trb.org/news/blurb_detail.asp?id=8265.)

CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

Airport managers and facility operators realize how important controlling utility costs and reducing environmental impacts are for cost-effective airport facility management and to benefit the community that the airport serves. Several general conclusions about controlling utility costs and reducing environmental impacts can be drawn from this research:

- **Awareness may not mean action.** Energy and environmental concerns are a major influence on airport operations, according to interviews conducted in this research. However, increased awareness does not necessarily mean action, since only 30 percent of the respondents had conducted an O&M assessment in the last 5 years.

- **Performance monitoring is minimal.** Airports are not routinely tracking energy use. Only 35 percent, overall, reported having an energy use baseline, and fewer than half the respondents tracked energy performance. The ESL estimates that as much as 20 percent of cooling and heating energy is wasted.

- **Low-cost operational improvements are underutilized.** Airports could regularly save 10 to 20 percent of their total energy use by implementing energy-related O&M and building recommissioning. For example, the ESL’s recommissioning of the rental car center at DFW Airport yielded annual savings of $106,000, a 1-year payback period, and an 18-percent overall reduction in energy use. Yet, only half of the medium-sized airports and 16.6 percent of the smaller ones reported implementing O&M measures.

- **Energy technology investments are minimal.** In the airport industry, there are significant opportunities for energy reduction through increasing the use of new, high-performance, HVAC equipment, controls, and lighting technologies. However, only 45 percent of the survey respondents had conducted a comprehensive energy assessment within the last 5 years. Only half the survey respondents indicated implementing ECRMs.

Energy-related O&M and recommissioning offer many low-cost, no-cost, and quick-payback opportunities to airport facility managers to reduce energy use up to 25 percent. The results of this research suggest, however, that airports are not taking full advantage of these opportunities, despite the significant cost savings involved and the need to reduce environmental impacts.

To significantly lower energy costs, airport managers can do the following:
• Implement the best practices reported in the section “Best Practices for Reducing Energy Use in Airport Facilities” (with emphasis on energy-related O&M, ongoing recommissioning/optimization, and ECRM installation),
• Develop and implement an energy-benchmarking and energy-tracking program, and
• Periodically investigate investments in cost-effective ECRMs.

Suggested Research

Based upon the research findings, future research areas with high potential to benefit to airport managers and facility operators include the following (in order of priority):

1. Developing airport energy benchmarks. It would be helpful if traditional benchmarks, such as EUIs, were developed for large, medium, and small airports so that comparisons could be made of energy performance within and among airports. Airport-specific benchmarks, such as enplanements per unit of space or cost, should be adequately researched, using a time-series analysis as an indicator of energy effectiveness.

2. Documenting the benefits of sustainable airport O&M. The link between energy and environment is well known, but few case studies document the actual cost savings of sustainable O&M and the environmental benefits to airport facilities and surrounding communities. General guidance exists, but no document with sufficient detail to actually guide the implementation of sustainable O&M measures was discovered in this research.

3. Developing simplified CMMS software. Because of its price and complexity, CMMS software use is prevalent in the large airports surveyed (87.5 percent), but nonexistent in the small airports surveyed. Low-cost, simplified CMMS software for smaller airports would ease implementation and enhance the effectiveness of their O&M programs.

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Diagnostics for Building Commissioning & Operation http://imds.lbl.gov/

National Institute of Building Sciences (NIBS) http://www.nibs.org/


ORNL Buildings Technology Center www.ornl.gov/sci/btc/

Portland Energy Conservation, Inc. (PECI) www.peci.org

Texas A&M Energy Systems Laboratory http://esl.eslwin.tamu.edu/

U.S. Environmental Protection Agency ENERGY STAR Program www.energystar.gov

U.S. Green Building Council www.usgbc.org


**GLOSSARY OF ACRONYMS**

ACRP—Airport Cooperative Research Program

AHU—air-handling unit

BAS—Building automation system

CC®—Continuous Commissioning®

CF—Compact fluorescent

CMMS—Computerized maintenance management system

DDC—Direct digital control

DFW—Dallas/Fort Worth

DX—Direct expansion

ECRM—Energy conservation retrofit measure

EMCS—Energy management control system

ESL—Energy Systems Laboratory

EUI—Energy utilization index

FAA—Federal Aviation Administration

FEMP—Federal Energy Management Program

HRU—Heat recovery unit

HVAC—Heating, ventilation, and air-conditioning

IPMVP—International performance measurement and verification protocols

LED—Light-emitting diode

LEED—Leadership in Energy and Environmental Design

O&M—Operations and maintenance

PECI—Portland Energy Conservation, Inc.

RCM—Reliability-centered maintenance

TEES—Texas Engineering Experiment Station

U.S. DOE—Department of Energy

U.S. EPA—Environmental Protection Agency

VAV—Variable air volume

VFD—Variable frequency drive
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Dr. W. Dan Turner, ESL Director, was the overall project director, and Malcolm Verdict and Bahman Yazdani were co-principal investigators. The other authors of this report are Harold Huff, project engineer, and Kathryn Clingenpeel, graduate research assistant.
These digests are issued in order to increase awareness of research results emanating from projects in the Cooperative Research Programs (CRP). Persons wanting to pursue the project subject matter in greater depth should contact the CRP Staff, Transportation Research Board of the National Academies, 500 Fifth Street, NW, Washington, DC 20001.

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APPENDIX A

Study of Terminals B and D at Dallas/Fort Worth International Airport

Prepared for the Airport Cooperative Research Program
Transportation Research Board of the National Academies

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College Station, Texas

April 2007
Executive Summary

Dallas/Fort Worth (DFW) International Airport generously allowed the use of their facilities and access to their personnel and contractors to help the Energy Systems Laboratory (ESL) at Texas Engineering Experiment Station, Texas A&M University to help determine a variety of best practices for energy-related operations and maintenance, HVAC recommissioning, and energy retrofit opportunities for potential use by airport facilities nationwide. Terminal B was constructed in 1972 and Terminal D, a new “state of the art” facility was completed in 2005. These terminals represent the spectrum of energy-saving opportunities for airports throughout the United States. This report identifies specific energy-related operations and maintenance (O&M), recommissioning, and energy retrofit measures for each terminal and reviews the procedures followed to evaluate and select energy conservation project components. Information gathered in the field interviews and physical observations of these facilities were used extensively by the ESL in the development of the Airport Cooperative Research Program (ACRP) e-mail survey questionnaire.

Acknowledgements

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We also would like to acknowledge Ron Blume, Asset Management – Energy Controls; Edward Kitchen and Duane Ballew -- ATAMS and CMMS systems; Dudley Dickinson, project manager, Meridian Management Corporation; and Russ Niday, site manager, FMC Technologies, Inc. Finally, our laboratory and project staff also would like to thank Michael Salamone, Program Officer, Airport Cooperative Research Program of the National Academies for his insights and guidance for this project.
Introduction

Terminal B at DFW airport was constructed in 1972, and Terminal D, a new “state of the art” facility, was completed in 2005. These terminals represent the spectrum of energy-saving opportunities for airports throughout the United States.

Physical Description of DFW International Airport

In 2005, DFW International Airport served 59,176,265 passengers. The Airport had 711,878 operations, handled 741,432 metric tons of cargo, and accommodated 5,650,733 international passengers, making it one of the busiest airports in the country. A DFW Airport traveler can
reach all major cities and 95% of the U.S. population within four hours or less. An aerial view of the airport is shown in Figure 1 above.

DFW Airport recently completed a $2.7 billion 5-year Capital Development Program (CDP) that is expected to produce a $34 billion economic impact on North Texas and create 77,000 new jobs. In 2005, DFW International Airport completed a new international Terminal D and a new Skylink automated people moving system. This system connects Terminals A, B, C, D, E, and a future Terminal F. The dual Skylink system is the largest of its kind in the world. It is bi-directional, elevated, and constructed of concrete and structural steel.

DFW Airport also recently completed a $150 million upgrade to its Energy Plaza, the airport’s central utilities plant. As part of the upgrade project, all chillers and boilers were replaced to increase capacity, improve energy efficiency, and reduce air emissions. A six million gallon thermal energy storage tank was also added to the chilled water system and a new centralized preconditioned air system was installed to support jet bridges and docked aircraft. As a result of these upgrades, NOx emissions from the facility have been reduced by 91%.
Terminal B

Terminal B in Figure 2 above is one of five major passenger terminals at DFW International Airport. It was built in 1972 with 25 aircraft gates. The terminal initially comprised three levels that included the ramp, concourse, and mezzanine. In 1998, a pier building consisting of five gates was added at the south end of the terminal. In 1999, the north end of the terminal was extended to add Gate 39. In 2004, a new upper level was added to accommodate two Automatic People Mover Stations (Skylink) to provide passenger transportation between terminals.

Terminal B currently has 31 aircraft gates and a gross square footage of 784,131. The terminal is supplied with chilled water and heating hot water from the Energy Plaza.

Thirty-seven escalators and moving walkways have a total nameplate rating of 682 horsepower.
Terminal B has 39 air handling units (AHUs). These AHUs are single-duct variable air volume (VAV) systems. There are 350 variable air volume terminal units. These units operate 24 hours per day, 7 days per week. The current Energy Management Control System (EMCS) has been upgraded many times over the past 35 years. It utilizes the EMCS systems -- a Johnson Controls DSC-8500 System, a Johnson Controls Metasys System, and an Invensys UltiVist System.

The physical condition of the Terminal B is excellent. The terminal has concrete wall construction and a flat built-up roof. Its estimated remaining life is 50 years.

Facility maintenance and operations are outsourced. FMC Technologies, Inc. is responsible for the daily operation of Terminal B.

*Terminal D*

![Terminal D](image)

*Figure 3. Terminal D*
The $1.7 billion International Terminal D (Figure 3) is the flagship of the five major terminals. It opened in late 2005. This 1,600,408 square-foot facility is a world-class international terminal equipped with a three-level roadway system and 29 swing-gates capable of handling narrow or wide-body aircraft.

International Terminal D will provide service for 37,000 passengers per day and 12,800,000 annually. Terminal D contains 99 ticketing positions, and a federal inspection system capable of screening 2,800 passengers per hour.

This concrete, steel and glass facility includes 91 elevators, 59 escalators, and 34 moving walkways. It has a stainless steel roof, a skybridge to Terminal C, and an 8,100 space parking garage. Terminal D also includes a 303,675 square-foot Grand Hyatt Hotel that is independently operated.

Terminal D has 60 variable air volume air handling units with variable frequency drives on the supply and return air fans, 73 constant-volume air handling units, 166 outside air, return air, exhaust, and ventilation fans and 1,364 fan-powered terminal box units. The facility introduces 539,780 CFM of outside air for ventilation, conditioning and building pressurization. It has a Johnson Controls BAS.

Facility maintenance and operations functions are outsourced. Meridian Management Corporation is responsible for the daily operation of Terminal D.
Energy-Related Operations and Maintenance

DFW International Airport has developed an Airport Total Asset Management System (ATAMS) that incorporates all aspects of facility maintenance, operations, and preventive maintenance. The DFW International Airport developed specifications that provide the outsourcing contractor with their intent and direction in the performance of facilities maintenance activities. The contract is designed to maximize the efficiency of operation and the useful life of equipment, systems, component, material, product, and structures.

DFW Airport looks to the creativity of the O&M contractor to efficiently operate all facility systems. All of these actions are coordinated with the energy engineer who is continually implementing energy efficiency strategies for implementation in Terminal B. Although there is no specific directive for the contractor to pursue energy efficiency objectives, they are charged with obtaining all utility company energy conservation rebates to which the owner is entitled. They are further required to obtain, complete, and submit the required forms and follow up to assure that the owner has received the appropriate rebate forms.

Observations of Energy Saving Opportunities

The following recommissioning opportunities were identified in the Terminals B and D. Field inspections plus contractor and staff interviews were utilized to identify new or reconfirm previous findings.
**Terminal B**

1. Inspect and repair non-functioning roll filters and replace dirty filters as required.
2. Calibrate damper linkage controls where necessary.
3. Inspect and calibrate thermostats.
4. Repair or remove inlet guide vanes as required where VFDs are installed.
5. Inspect and repair any leaking heating water control valves on fan-powered terminal boxes.
7. Fine tune chilled water control valves as required to eliminate hunting inefficiencies.
8. Replace heating water isolation valves for supply to the VAV terminal boxes where required for reheat to optimize heating and cooling.
9. Insure that all VFDs are functioning in an automated fashion.
10. Repair any identified air duct leakage.
11. Inspect all air handling units and insure that outside air damper linkages are connected.
12. Inspect all air handling units and replace dirty filters to prevent a significant increase in fan power requirements.
13. Inspect test ports for TAB purposes to insure that they penetrate internal duct insulation.
14. Inspect and fine-tune control for air handling units.
15. Convert remaining magnetic (T-12) light fixtures to electronic (T-8).
16. Control mechanical room lighting.
17. Optimize control for escalators and moving sidewalks.
18. Inspect and calibrate outside air sensors for the terminal if required.
19. Optimize control of infrared heaters in baggage conveyor areas.
20. Inspect and replace temperature sensors where required on VAV terminal boxes.

21. Eliminate outside air infiltration where possible.

**Terminal D**

1. Evaluate air handling unit operation.

2. Optimize air handling unit performance.

3. Optimize VFD operation.

4. Fine tune supply and return air fans to insure proper tracking.

5. Optimize the EMCS operation for the terminal.

6. Replace filters and clean heating coils on fan-powered terminal units where required.

7. Evaluate space conditioning and lighting control for low-occupancy areas.

8. Optimize moving walkway and escalator operation.


10. Optimize EMCS lighting control.

11. Review terminal pressurization and adjust as required.

**Major Energy Retrofit Practices**

**Terminal B** – This terminal has experienced system retrofits over the years, including but not limited to variable air volume conversions, lighting, and building automation system upgrades.

A recent energy assessment identified the following retrofit opportunities.

**Energy Conservation Retrofit Measures**

- Provide lighting retrofit where required throughout terminal.
• Provide motion sensor lighting control.
• Provide Jetway RTU controls upgrade.
• Provide infrared heater control for baggage handling area.
• Replace/Upgrade EMCS/BAS.
• Implement continuous recommissioning practices.

Terminal B Prioritized Project Alternatives

The two tables of potential ECRM alternatives presented here, Table 1 and Table 2, were developed as part of a full energy assessment report on Terminal B performed by the Energy Systems Laboratory (ESL). It is important to note that projects of this scale are made up of interactive components and will not perform the same if broken into segments. The two alternate lighting projects included in the energy saving options packages developed here demonstrate some of the issues involved in prioritizing energy project components even within the same facility.
### Table 1. Summary of Energy Conservation Retrofit Measures (Alternative #1)

<table>
<thead>
<tr>
<th>ECRM TITLE</th>
<th>Annual Savings</th>
<th>Implementation Cost ($)</th>
<th>Simple Payback Period (Yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electric (kWh/Yr)</td>
<td>Demand (kW/Yr)</td>
<td>Utility Saving ($/Yr)</td>
</tr>
<tr>
<td>Lighting Retrofit</td>
<td>747,298</td>
<td>1,024</td>
<td>48,335</td>
</tr>
<tr>
<td>Occupancy Sensor Lighting Control</td>
<td>157,680</td>
<td>0</td>
<td>9,173</td>
</tr>
<tr>
<td>Jetway RTU Controls Upgrade</td>
<td>56,343</td>
<td>0</td>
<td>3,208</td>
</tr>
<tr>
<td>Baggage Handling Area Infrared Heater Control</td>
<td>80,275</td>
<td>0</td>
<td>4,571</td>
</tr>
<tr>
<td>Replace/upgrade EMCS</td>
<td>568,935</td>
<td>0</td>
<td>87,213</td>
</tr>
<tr>
<td>recommissioning</td>
<td>1,164,573</td>
<td>0</td>
<td>150,182</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>2,775,103</strong></td>
<td><strong>1,024</strong></td>
<td><strong>302,683</strong></td>
</tr>
</tbody>
</table>

- Alternative #1 includes a limited lighting upgrade which retrofits old T-12 magnetic ballast fluorescent fixtures to new T-8 electronic ballast fixtures.
- This alternative also includes motion sensors on selected fixtures.
Table 2. Summary of Energy Conservation Retrofit Measures (Alternative #2)

<table>
<thead>
<tr>
<th>ECRM TITLE</th>
<th>Annual Savings</th>
<th>Implementation Cost ($)</th>
<th>Simple Payback Period (Yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electric (kWh/Yr)</td>
<td>Demand (kW/Yr)</td>
<td>Utility Savings ($/Yr)</td>
</tr>
<tr>
<td>Lighting Retrofit</td>
<td>2,347,303</td>
<td>3,215</td>
<td>153,038</td>
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<tr>
<td>Occupancy Sensor Lighting Control</td>
<td>157,680</td>
<td>0</td>
<td>6,015</td>
</tr>
<tr>
<td>Jetway RTU Controls Upgrade</td>
<td>56,343</td>
<td>0</td>
<td>3,208</td>
</tr>
<tr>
<td>Baggage Handling Area Infrared Heater Control</td>
<td>80,275</td>
<td>0</td>
<td>4,571</td>
</tr>
<tr>
<td>Replace/upgrade EMCS</td>
<td>568,935</td>
<td>0</td>
<td>87,213</td>
</tr>
<tr>
<td>Recommissioning</td>
<td>1,164,573</td>
<td>0</td>
<td>150,182</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>4,319,921</strong></td>
<td><strong>3,215</strong></td>
<td><strong>404,228</strong></td>
</tr>
</tbody>
</table>

- Alternative #2 retrofits the T-12 magnetic ballast fixtures to T-8 electronic with self-dimming ballast in selected locations.
- Alternative #2 also has motion sensors on the same fixtures as alternative #1.
- It is important to note that the simple payback period of the motion sensor upgrade is 9 years in the second alternative compared to 5.9 years in the first alternate. This is because much of the energy reduction had already obtained from to the use of the self-dimming ballasts.
• The $404,228 energy savings per year for the second alternative is 25% higher than for the first and therefore will result in greater overall benefit to the airport.

Description of Current Operations and Maintenance Strategies

Terminal B – A contractor manages this site. Terminal B was the first to be outsourced for operations and maintenance. The contractor is developing and implementing PM processes and procedures for approval by DFW Airport. ATAMS provides work orders including preventive maintenance (PM) tasks. The contractor creates additional work orders that are directed to ATAMS.

Terminal D – A contractor also manages this terminal. The contractor is also under contract to provide accurate as-built drawings for Terminal D to DFW Airport. The contractor is developing and implementing PM processes and procedures for approval of DFW Airport. ATAMS provides work orders including PM tasks. The contractor creates additional work orders that are directed to ATAMS.

Recommendations

1. Develop a comprehensive O&M program that is clearly defined for all parties. This program should be applied to both in-house and outsourced maintenance. Terminals B and D with different contractors are developing O&M programs that focus on a common DFW Airport strategy in concert with its ATAMS program.
2. Develop guidelines for operation and maintenance of all equipment.

DFW Airport has developed general specifications and provisions to guide the contractor in developing a management plan that will provide all labor, supervision, training, testing, technical services, and consulting services.

3. Develop maintenance procedures for each piece of equipment.

DFW Airport has developed forms that identify mechanical services, plumbing services, and ramp services tasks. The type of work required is cross-referenced with the specific piece of equipment, frequency, etc. Forms focus on specific functions such as HVAC systems, chilled water systems, exhaust systems, glycol systems, heating hot water systems, pre-conditioned air, etc.


DFW Airport requires each contractor at Terminals B and D to maintain highly qualified technical BAS/EMS staff to monitor and control HVAC operations. The contractor is expected to professionally manage and efficiently operate the facility in accordance with the strategies determined by the DFW Airport energy engineer and its consultants.

5. Develop performance benchmarks for operating and maintenance procedures.
DFW Airport has developed a performance evaluation program that incorporates ongoing building assessment, customer service, response to service calls, discrepancy/deficiency correction, development and reporting of ATAMS, and project management.

6. Develop an evaluation team to ensure quality control of the O&M process performed by contractors/staff.

DFW Airport has established an evaluation committee to evaluate the performance of the operations and maintenance services (OMS) contractors. This strategy may also be applied to in-house activities. Evaluations are conducted quarterly.

7. Provide periodic energy assessments for each facility.

DFW Airport performed a comprehensive energy assessment on Terminal B. The recommendations from this assessment have been evaluated and are now incorporated in future retrofit plans for the airport. DFW Airport plans to provide energy assessments for all major DFW Airport properties.

8. Provide enhanced recommissioning services on a continuous basis for all HVAC equipment and controls. DFW Airport has begun a five-year process to assess and continuously commission HVAC systems throughout airport properties.

9. Manage utility consumption for the facility.
DFW Airport has a highly skilled in-house energy management program that oversees utility consumption, energy efficient operations, and procurement.

Summary

ESL conducted on-site interviews that allowed a much deeper understanding of the issues when implementing O&M, recommissioning, and energy retrofits. On-site visits at Terminals B and D of DFW International Airport were instrumental in developing the best practices which were included in the email survey sent to participating airports.

The following observations may also be useful to airport managers dealing with similar issues.

1. When contracting out O&M functions, an ongoing programmatic approach was followed at DFW Airport. For example, while specific energy related procedures are not defined in the contracts, the obligation to pursue potential utility rebate opportunities and to work with DFW Airport energy consultants are specified.

2. Implementing the new CMMS system at DFW Airport is a major endeavor. The energy and environmental parameters such as energy monitoring and process review are still being developed.

3. DFW Airport is moving forward with an active recommissioning and HVAC optimization program as well as evaluating capital projects that can improve the energy performance of all of their facilities.
APPENDIX B

AIRPORT RENTAL CAR FACILITY CASE STUDY

CONTINUOUS COMMISSIONING® OF AN AIRPORT RENTAL CAR FACILITY

World Energy Engineering Congress
Austin, Texas

By

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Jerry Dennis, CEM, CEP
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November 2005
ABSTRACT

This paper presents the Continuous Commissioning® (CC®) of a rental car facility at a major airport. The CC process was carried out by highly skilled engineers who quickly zeroed in on sub-optimal operating strategies that waste energy, and developed and implemented optimal control strategies which in this case include improving the zone temperature control; resetting supply air temperature and duct static pressure; reducing excessive outside air flow, adjusting the terminal box air flow settings, improving the economizer cycle control; modifying the return air fan control algorithm; and optimizing the chiller plant operation. The whole process was carried out in less than four months. Analysis shows that annual energy cost savings are $106,000, or 18% of the whole building utility consumption, giving a payback period of approximately one year on total project cost.

INTRODUCTION

Continuous Commissioning is an ongoing process, developed and refined by engineers at the Energy Systems Laboratory (ESL) at Texas A&M University, to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities. The CC process has consistently resulted in sustained energy savings that range from 10 to 25%. It is not a capital intensive process and the payback periods are typically less than three years. The CC process also reduces O&M costs and upgrades the operating staff’s skills by allowing their direct participation in the process.

ESL was contracted by the Texas State Energy Conservation Office (SECO) to conduct Continuous Commissioning at the Dallas/Fort Worth (DFW) International Airport Rent-A-Car (RAC) facility. The CC work began in September 2004 and was substantially completed by December 2004. Observations from existing operation and the implementation of major CC measures are described in detail in this paper.

1 Tim Giebler is now with the Trane Company.
2 Continuous Commissioning® and CC® are registered trademarks of Energy Systems Laboratory, Texas Engineering Experiment Station, Texas A&M University Systems.
BUILDING DESCRIPTION

The DFW International Airport Rent-A-Car Center is two-story, 130,000 square foot facility that houses all the rental car companies serving the airport. The building was opened in March 2000. Most of the first floor is counter space for the rental companies and open area for the customers to pass through. The second floor is mostly offices and storage space. Attached to the building is a two story, 1.8 million square foot parking garage. The garage is not air-conditioned but it does have lighting that is fed from the same meter as the main building. Both the building and garage are in continuous use 24 hours a day.

Six single-duct variable air volume (VAV) air handling units (AHUs) provide conditioned air to the building. Each unit has a supply and return fan that are both equipped with variable frequency drives (VFDs).

Chilled water for the AHUs is provided by two 280-ton centrifugal chillers. The chilled water system is arranged in a primary-secondary loop configuration. There are two constant speed primary pumps that circulate water through the chillers. Two variable speed secondary pumps supply water to the AHUs. Two constant speed pumps and two cooling towers with variable speed fans provide condenser water for the chillers.

There are 133 terminal boxes controlling airflow to the building. Each box has a damper and a circulation fan. All of the boxes on the second floor and the boxes on the first floor serving exterior areas have electric resistance heaters.

All HVAC systems in the building are controlled by a modern direct digital control (DDC) system.

OBSERVATIONS ON EXISTING OPERATION
In August 2004, ESL conducted an initial assessment of the facility to determine the potential for energy savings from CC. Overall, the building was well run, but many savings opportunities were found. During the CC plan development phase, all of the systems in the building were investigated to determine their existing condition and operation. More opportunities were uncovered that could improve the building performance. This section describes various observations on existing system operation.

**Bypassed Lighting Control**

Lighting for the second deck of the south parking garage is connected to photo sensors that turn them off in the day. An electrical contactor for the lights on the south side of the garage had been bypassed after the photo sensor went bad. However, the bypass on the contactor was not removed after the photo sensor was repaired. Consequently, the south lights remained on all day.

**Simultaneous Cooling and Heating**

Excessive electric reheat in the terminal boxes was observed – even during summer time. When the outside temperature was above 90°F, 25 to 30 boxes were observed in heating mode.

Investigation revealed three contributing factors that resulted in the simultaneous cooling and heating – no deadband between cooling and heating setpoints, conflicting space temperature setpoints, and high terminal box minimum air flow settings.

The boxes had one single temperature setpoint that controlled both cooling (VAV damper) and heating (electric reheat). Many boxes would switch back and forth between heating and cooling modes in an attempt to maintain the space temperature.

In the large open areas of the building air flows freely between zones served by different boxes. However, the space temperature setpoints were found to vary widely, from 65°F to 80°F. A different setpoint for each box can cause simultaneous heating and cooling of the same space.
It was also found that the minimum air flow setting at many of the terminal boxes were higher than necessary. This caused an over supply of cold air from the AHUs when the boxes were attempting to run at minimum flow. Consequently, the reheat circuits in some boxes had to be energized to maintain space temperature.

**Excessive Outside Air Intake**

Large amounts of outside air flows were measured at several AHUs. Some of the units had over 60% of outside air, far exceeding the ventilation requirements.

Close examination of the control sequences revealed that the terminal box air flow sensor accuracy and return air fan control algorithm were the causes for excessive outside air intake. The existing return air fan VFD control was based on the following formula that uses design conditions and the airflow reported by the boxes:

\[
\text{Fan Speed (\%) } = \frac{\sum \text{BoxAirFlow} - \text{DesignOAFlow}}{\text{DesignRAFlow}}
\]

However, the box air flow readings were found to be lower than the actual flows. This resulted in a lower calculated return fan speed. Therefore, the units were using less return air and more outside air than desired. On the other hand, when both the supply and return air fans were running at minimum speed, there were too much return air.

**Lost of Redundancy on Chillers**

The chillers should be large enough so that only one is required to cool the building. However, the unnecessary reheat and excessive outside air intake created extra cooling loads on the chillers. Both chillers had to be turned on during hot weather. This reduced the plant reliability since there was no backup available.
**Isolated Secondary Chilled Water Loops**

A closed valve between the secondary pumps prevented a single pump from serving all of the AHUs. This caused both pumps to run at all times, even when there was little need for chilled water. Opening up the valve would allow one pump to serve the entire building while the other pump is on standby mode.

**High Duct Static Pressure Set Points**

The supply fan speed was modulated to maintain a constant duct static pressure setpoint (1.5” of water column for most units). Since the static pressure sensors are located towards the end of the ductwork, duct static pressures of 1.0” H₂O or more were measured at the farthest boxes from the units. This amount of pressure is higher than necessary for operation of the boxes. Lowering the static pressure setpoint and giving it a reset schedule will reduce the fan-power consumption and decrease the unnecessary reheat caused by air leakage at the terminal boxes.

**Economizer Cycle Not Fully Utilized**

The AHUs went into economizer cycle when the outside air was between 36°F and 52°F. When in economizer cycle, the chilled water valves were locked out and the units were able to operate without using any chilled water. If the chilled water valves were allowed to open, the economizer cycle could be used at higher outside temperatures and get more use of free cooling from outside air.

**CC MEASURES**

After taking extensive field measurements, reviewing the trend data, and examining the control program, a comprehensive commissioning plan that could improve comfort and reduce energy consumption was developed. The following is a list of major CC measures identified.

1) Correct the operation of the south garage lights
2) Improve Zone Temperature Control
3) Optimize the supply temperature reset schedule
4) Optimize the static pressure setpoints with reset schedules
5) Improve the operation of the economizer cycle
6) Modify the control for the return air fans to allow better control of outside airflow
7) Change terminal box minimum airflow setpoints
8) Optimize the chiller operation
9) Implement a reset schedule for the condenser water temperature
10) Optimize secondary pump control

The identified CC measures were presented to and approved by the airport management. They were subsequently implemented by ESL with the help of DFW Airport personnel. The details of how these measures were implemented are listed below.

**Correct the Operation of the South Garage Lights**
ESL reported the problem with the South Garage lighting control and the airport had the problem corrected. ESL verified the lights were off during the daytime, and measured the daytime South Garage load reduction of 46.3 kW.

**Improve Zone Temperature Control**
As noted earlier, the boxes originally had one single temperature setpoint that controlled both cooling and heating. Giving an offset between the heating and cooling setpoints prevents the boxes from switching modes due to small changes in temperature. It also prevents having adjacent boxes in different modes because of small differences in setpoints or temperature readings. All boxes were given separate heating and cooling setpoints. An offset of 3°F between the setpoints was given for most boxes. Boxes serving mechanical rooms or storage rooms were given offsets of 8°F.

Prior to commissioning, each box’s temperature setpoint was controlled individually and there was no standard for the building. The setpoints varied widely throughout the building causing some areas to be
heated and cooled at the same time. A standard setpoint of 73°F for cooling was established for the building. The occupants retain the ability to adjust this setpoint by up to 2°F at the thermostat. Larger adjustments will only be made for special circumstances by the building maintenance operators.

**Optimize the Supply Air Temperature Reset Schedule**

The original supply air temperature reset schedule was based on the speed of the supply fan. The setpoint varied between 54°F and 58°F depending on the speed of the supply fan. When the supply fan was running at 60 Hz, the setpoint was 54°F. When the supply fan was running at 40 Hz, the setpoint was 58°F. Basing the schedule on outside air temperature will allow better humidity control of the building. The optimal reset schedules were determined from an analysis of supply air temperature and humidity compared to the desired temperature and humidity of the space. The result of this analysis was to maintain occupant comfort and reduce the amount of heating necessary at the terminal boxes.

The maximum supply temperature setpoint was determined to be 62°F and the minimum 55°F. A three part reset schedule was implemented so it is constant at minimum when the outside temperature is above 75°F and constant at maximum when the outside temperature is below 40°F. Between those two temperatures, the supply temperature varies linearly according to the formula:

\[
T_{\text{supply set}} = T_{\text{OA}} \times (-0.2) + 70
\]

**Optimize the Static Pressure Set Points with Reset Schedules**

For all six AHUs, measurements of the static pressure were taken at the duct static pressure sensors and at the box at the far end of the duct. These measurements revealed an excessive amount of static pressure for all the units.

The maximum setpoint was determined by the amount of pressure needed during the summer. Lower setpoints were tested while the weather was warm. After the setpoint was lowered, new measurements were taken for static pressure and airflow at the far boxes. It was determined that AHUs 1, 2, 3, and 6
could meet their cooling needs with a static pressure setpoint of 0.8” H₂O while AHUs 4 and 5 needed setpoints of 1.0” H₂O.

As the outside air temperature decreases, the cooling load on the building decreases. The decreased load reduces the amount of airflow needed so the static pressure can be further reduced. It was determined that the minimum amount of static pressure needed to supply the terminal boxes was 0.5” H₂O. A reset schedule was developed that varied the static pressure setpoint in three stages. When the outside air temperature is above 80°F it will be at maximum (0.8” or 1.0”), when the outside air is below 50°F it will be at minimum (0.5”). Between 50°F and 80°F the setpoint will vary linearly between minimum and maximum. The equation used to determine the setpoint for AHUs 1, 2, 3, and 6 when outside temperature is between 50°F and 80°F is:

\[ P_{set} = T_{OA} \times 0.01 \]

Similarly, the equation for AHUs 4 and 5 when outside temperature is between 80°F and 50°F is:

\[ P_{set} = T_{OA} \times 0.0167 - 0.333 \]

At night the building load drops because ambient temperature and the number of people in the building decrease. The effects of this load reduction are similar to what is caused by lower outside air temperatures. A night setback was given to the AHUs to make their static pressure setpoints go to minimum between 10:00pm and 6:00am.

**Improve the Operation of the Economizer Cycle**

As originally configured, the chilled water valves were not able to open when units were in the economizer cycle. Not using chilled water limited the temperatures at which the economizer cycle could be used. The valve control was changed to allow chiller support for the economizer cycle. The new upper range of the economizer cycle was set at 65°F.
Originally, the outside and return air dampers would modulate to maintain the mixed air temperature at 54°F in economizer mode. The control was changed to be based on the supply temperature and setpoint. With the supply temperature on a reset schedule, the dampers could no longer be controlled by a constant setpoint for mixed air temperature. The new setpoint for the dampers is 1°F below the supply temperature setpoint.

**Modify Return Air Fan Speed Control to Allow Better Control of Outside Air Flow**

The control of the return fan VFDs was intended to make the outside airflow meet its design. Due to inaccuracies in the box air flow readings, the return air fans were not being commanded to the correct speed.

A new control sequence was proposed to control the return air fan speed and the return air damper based on the static pressure of the mixed air chamber when the unit was not in the economizer mode. At each AHU, there was a static pressure sensor before the return air fan that was not being used for control. It was proposed to relocate the sensor to measure the static pressure at the mixed air chamber. Since the minimum outside air damper was open whenever the AHU was running, the new control logic would adjust the return air fan VFD to maintain a constant static pressure in the mixed air chamber in order to maintain a constant minimum outside air intake. Once the return air fan is at minimum speed and the static pressure is still too high, the control sequence would modulate the return air damper to maintain the pressure. Refer to Figure 1 for a schematic of the AHU. The mixed air chamber static pressure setpoint was determined by flow measurements taken on each unit.
Using the air flow measurements taken it is estimated that the total outside air flow will be 16,000 cfm when the mixed air pressure setpoints are achieved. The design exhaust air flow is 6,200 cfm; leaving an excess of 9,800 cfm of outside air. ASHRAE standard 62.1-2004 requires 0.06 cfm of outside air per square foot of building space and 5 cfm per occupant. The building has 130,000 ft² requiring 7,800 cfm. This leaves enough outside air to pressurize the building and satisfy 1,640 occupants, which is more than will be present in the building.

During the economizer mode, the return air fan speed was modulated to track the supply air fan speed.

**Change Terminal Box Minimum Air Flow Setpoints**

The original minimum air flow setpoints for most boxes were found to be about 30% of their maximums. For the other boxes, the minimums ranged from 10% to 50%. An over supply of cold air from the AHU was causing some boxes to heat much more than they should have. The minimum air flows of all the boxes were changed in order to get the proper amount of air to the building without over cooling it. All the boxes serving open areas were given minimum air flows of 0 cfm. Boxes serving counter areas and offices were given minimum air flows 20% of their maximum flows.

**Optimize the Chiller Operation**

A change in the operating procedure of the chillers was needed to allow them to work properly with the new AHU economizer cycle. The control sequence was modified to enable the chiller if the economizer
cycle is on and the outside temperature is above 57°F. This will allow the chiller to assist cooling when in economizer cycle.
The reset for the chilled water supply temperature was previously based on trying to maintain the chilled water return temperature at 55°F by varying the supply temperature from 42°F to 56°F. That was changed to make the setpoint based on outside air temperature. As the outside temperature rises the supply temperature will decrease to meet the higher cooling load of the building. A reset schedule with three stages was given to the supply temperature. When the outside air temperature is above 70°F the setpoint is a constant 42°F and when the outside temperature is below 50°F the setpoint is a constant 48°F. Between these temperatures, the setpoint varies linearly according to the equation:

\[ T_{\text{supply}} = T_{\text{OA}} \times (-0.3) + 63 \]

**Implement a Reset Schedule for the Condenser Water Temperature**
The efficiency of the chillers is related to the supply temperature of the condenser water. Originally the condenser water setpoint was a constant value of 85°F. When outside conditions are favorable, that temperature can be lowered and the chillers will run more efficiently. The condenser water setpoint was changed to be 8°F above the outside air wet bulb temperature. A low limit of 70°F and a high limit of 85°F were given to protect the chillers from extreme temperatures. A representative from the chiller manufacturer was contacted to confirm that these temperature limits would be acceptable.

**Optimize Secondary Pump Control**
Unlike the other pumps in the building, the secondary pumps were not operating with a lead/lag sequence. A valve between the pumps was closed so that each pump could only serve one side of the building. The valve was opened allowing either pump to send water to the entire building. A lead/lag sequence was implemented so that both secondary pumps were used only when a single pump was not adequate to meet the differential pressure (DP) setpoint.
The differential pressure setpoint for the secondary loop was originally 12 psi. At this high of a pressure the chilled water valves on the AHUs did not have to open more than half way even in hot weather. Tests were conducted on the system and it was found that a DP setpoint of 8 psi was adequate during hot weather. A reset schedule was added to make the setpoint lower as the outside air temperature lowered. The reset schedule equation is:

$$DP_{set} = T_{OA} \times 0.16 - 4.8$$

The maximum DP is 8 psi at 80°F and minimum is 4 psi at 55°F.

**CC RESULTS**

The implementation of CC measures started in September 2004 and was substantially competed by early December 2004. Figure 2 compares the whole building electricity consumption profile for two typical weekdays when the ambient conditions were similar. Although that was just one month into the implementation process, significant reduction in electricity consumption had been achieved.

![Figure 2. Comparison of typical weekday whole building electricity consumption profile under similar ambient conditions.](image-url)
Baseline Model and Savings Determination

The savings for CC are determined by developing a baseline model of the energy use of the building from the consumption data measured before any CC measure is performed. This model is then used to predict what the building consumption would have been if the CC had not been performed. This prediction is made using the post-CC period weather data. The savings are then determined by subtracting the measured post-CC energy use from the baseline predictions of the building use without the CC.

Hourly building electricity use data for the year prior to CC was obtained from the utility company. Average hourly temperature data for Arlington, Texas was obtained from the National Weather Service. These two variables were used to determine a baseline model for the amount of electricity used by the building at any given outside air temperature. Figure 3 shows the baseline as a function of temperature along with data points taken before and after commissioning. The circles in Figure 3 represent the baseline period consumption data. The regression line shown in the graph is the baseline regression model as a function of the ambient dry-bulb temperature. The squares in Figure 3 represent the post-CC period consumption data.

Energy savings of 934,700 kWh were determined by analyzing the measured whole building electricity consumption data from the time commissioning began (September 22, 2004) through April 2005. With an average cost of $0.0674/kWh, that is a saving of approximately $63,000 and 18% of whole building energy use, including the 1.8 million square foot parking garage. Figure 4 shows the accumulation of savings during this period.
Assuming the energy savings will remain approximately the same throughout the year, projected annual cost savings are $106,312, as shown in Figure 4.

**Figure 3.** Pre-CC energy use and measured energy use after CC for the Rent-A-Car Center at DFW International Airport.

**Figure 4.** Projected annual cost savings for the Rent-A-Car Center at DFW International Airport.

**SUMMARY**

This paper presented the CC project at an airport rental car facility. Observations of the existing operation and major CC measured implemented were discussed in detail. The results are impressive – with improved building comfort and 18% reduction in annual utility cost, it clearly demonstrates the impact and value of the CC process.
ACKNOWLEDGEMENTS

Funding for this technical assistance was provided by a grant from the U.S. Department of Energy administered by the State Energy Conservation Office, contract CM438.

The authors greatly appreciate the assistance provided by the DFW Airport building and energy management staff as well as the personnel of FACService and Entech. Their assistance was vital to the successful completion of the RAC CC project.

The authors would like to extend their thanks and appreciation to DFW Airport Board and its staff for assistance on the procurement of building data and operation schedules. Special thanks go to Jerry Dennis (Energy Manager), Robert Barker (Acting Vice President), Rusty Hodapp (Managing Director), Rene Palacios (Fac. Serv. Coord.), Lenanne Nance (Administrator), Jim Jeppson, Roger Davis, and James Hudgins, for devoting time, insight and resources throughout the project. Further thanks are extended to Fred Hetherington (Energy Analyst) and other operation and maintenance personnel for their support and helpfulness. The authors would like to also thank Mr. Dave Waltzman, Rebuild America Program Manager, United States Department of Energy Central Region, Mr. Dub Taylor, Director of the Texas State Energy Conservation Office (SECO) and Mr. Perry Been, Deputy Director of SECO for their continuing support and, especially, Glenda Baldwin, Program Manager.
APPENDIX C

CONTINUOUS COMMISSIONING® OF THE MATHESON
COURTHOUSE IN SALT LAKE CITY, UTAH

William D. Turner, P.E., Ph.D.  Song Deng, P.E.

Energy Systems Laboratory
Texas A&M University System
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Dept. of Natural Resources  Dept. of Facilities Construction and
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Salt Lake City, Utah
ABSTRACT

The Utah Energy Office, located in the Department of Natural Resources (DNR), Utah Department of Facilities Construction and Management (DFCM), and engineers from the Energy Systems Laboratory at Texas A&M University teamed to perform Continuous Commissioning® 1 of the Matheson Courthouse in Salt Lake City, Utah. The Matheson Courthouse is a relatively new building, well-run, with a modern controls system. It is one of the most efficient buildings in Utah, averaging only $1.08 per square foot per year prior to the building and thermal plant commissioning. The project started with a walk-through commissioning audit in February 2001, and the CC® process began in January 2002. Details of the CC® process and the measures implemented are included in this paper. The 2002 energy bills for Matheson dropped by $116,000, down to $0.77 per square foot per year. Approximately 80% of the reduction in bills can be attributed to the Continuous Commissioning process, with the remaining savings coming from lower gas and electricity prices.

INTRODUCTION

The Matheson Courthouse in Salt Lake City is the main state courthouse, built in 1997. A photograph is noted in Figure 1. The multi-story building includes 37 courtrooms, offices, holding cells, and a three-level underground parking garage. The total square footage is 420,000, with 370,000 of conditioned square feet. The 2001 Energy Cost Index (ECI) of $1.08 per square foot per year is based on conditioned square feet. The Utah Department of Natural Resources (DNR) contracted with the Energy Systems Laboratory to conduct preliminary CC® audits of seven state buildings in 2000 and to present a CC workshop for facilities managers and operators. Metering and monitoring is an integral part of the CC process, and most of the initial state buildings audited did not have meters in place and did not have interval metering from the local utility, Utah Power. The decision was made by the State Energy Office to look for additional candidate buildings which had interval metering. The Matheson Courthouse did have an interval data recorder, and it

1 The terms Continuous Commissioning and CC are registered trademarks of the Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, Texas.
was selected as a potential candidate building for Continuous Commissioning. In Utah, electricity is the dominant utility for most state buildings, generally representing from 75% to 100% of the building’s energy requirements. A DNR program decision was made to use the interval electricity utility data and monthly gas bills for the savings analysis.

The CC walk-through was conducted in February 2001. Despite the efficient building operation, the CC team identified sufficient measures to justify choosing Matheson as a viable CC candidate. The cost proposal estimated at least $35,000 in savings, with a commissioning cost of roughly $70,000, for a two-year simple payback period. This was an acceptable savings and payback period criteria, and a contract was established between DNR and the Laboratory, effective in October 2001. The commissioning team consisted of an engineer from DNR Energy Office, the building facility manager from DFCM, a controls specialist from DFCM, and two CC engineers from the Energy Systems Laboratory. The team was structured such that the CC measures would largely be identified by the CC engineers, would be discussed with the team, and those measures accepted for implementation would then be carried out by the DFCM team. This approach has several advantages:

1) All team members are part of the CC process.
2) Overall costs are minimized since the ESL was not providing technician or programming support to the project, thus reducing both manpower and travel costs.
3) The DFCM would gain valuable first-hand knowledge of the CC process.

It should be mentioned that this approach also has a major disadvantage. While the CC work was important to the team, the two DFCM team members had major responsibilities other than the CC of the Matheson Courthouse. Their other responsibilities had to be taken care of, and the CC work often did not get top priority, thus lengthening the CC process.

The Continuous Commissioning process was initiated in January 2002 and continued throughout much of the year. Over 30 separate Continuous Commissioning measures were identified during the course of the CC process, and most have been implemented. The measures can be roughly broken into:
FACILITY DESCRIPTION

The courthouse was first occupied in 1997. It is a very modern facility, containing three levels of underground parking, six stories of offices, courtrooms, holding cells, library, cafeteria, etc. and a sixth floor, largely mechanical rooms. Some facts about the building include:

1) 420,000 square feet (covered); 370,000 square feet (conditioned)
2) One (1) 400 ton and one (1) 800 ton chiller
3) Six (6) single duct, VAV AHUs, with hot water terminal reheat
4) Two (2) 500-hp hot water boilers
5) Modern DDC building automation system
6) Annual utility bills of $400,000 ($300,000 electric; $100,000 gas)

CONTINUOUS COMMISSIONING PROCESS

Continuous Commissioning is defined as the process of analyzing and optimizing the HVAC energy systems in a building or central plant to reduce energy consumption, improve comfort, and increase productivity of the occupants. The process can also identify potential capital retrofits that may be needed to further improve energy efficiency. CC can be performed as an existing stand alone measure, which has been documented in a number of papers (1-xx). It can also be conducted after major capital retrofits, such as the Texas LoanSTAR program (xxx-xxxx), which is where the CC process began. CC can also be included as an Energy Conservation Measure as an integral part of a major capital retrofit program for energy efficiency (paper at NCBC on PVA&M and ACCD).

The major steps of the CC process are as follows:
1) Conduct a CC walk-through of the building. This preliminary audit is targeted at identifying operational problems that are preventing optimum operation. This audit may take several days in a large or complex building and involves detailed measurements of air handler operation, central plant operation, and a review of the building automation system (BAS) operation. If trend logs are available, they will be reviewed. If BAS trend logs are not available, key trend logs may be set up to help with the preparation of the initial commissioning plan.

2) Prepare a commissioning implementation report, describing measures identified, potential savings, and cost for the Continuous Commissioning of the facility. The cost of the CC process may include several options, ranging from a “turnkey” quote, where the ESL engineers and technicians will do all the CC work, including purchase of sensors and valves, and minor repairs, to providing primary CC project management services, with the receiving entity doing most of on-site CC implementation.

3) Initiate a contract to do the CC work. Include in the statement of work the division of responsibilities for the various parties involved, i.e., the team.

4) Conduct an initial team meeting to go over the CC process, the various roles of the team members, and the schedule. Utility bills should have been provided and reviewed at this stage, as well as metered data or trend logs from the building automation system.

5) Conduct the detailed CC audit, identifying the potential measures to be implemented. Quantification of savings by measure should be made to the extent possible.

6) Discuss the potential measures with the team and determine which measures can be implemented, who is going to implement them, and the schedule. There are some measures which can be implemented immediately, while others may require purchase of sensors, recalibration, or equipment repair. Prepare a detailed implementation plan.

7) Implement the CC measures. Over the course of the implementation process, additional measures may be identified.

8) Track the building operation from building meters, the BAS, and/or utility metering. Make sure the measures are performing, and fine tune, if necessary.

9) Determine savings and write a report to the client, documenting the operational and comfort improvements and energy/dollar savings.
10) Continue to work with the client to ensure savings persist, i.e., the “continuous” portion of the Continuous Commissioning process.

At the Matheson Courthouse, approximately 30 CC measures were identified. Some were major, while others were minor improvements. The measures, by category, are listed below:

SENSOR CALIBRATION
1) Three of the six CO₂ sensors controlling outside air were out of calibration. Two were reading low, which did not have energy implications, but one sensor had failed with a reading of 2000 ppm, which resulted in 100% outside air being used for that air handler all year long. Several duct static pressures were reading high, and several supply air temperature sensors were off 1-3°F.

2) Outside air temperature and relative humidity sensor calibration and location were problems. The outside air temperature sensor was found to be reading as much as 6°F too high during some parts of the day, and the relative humidity was reading high by 35-40%. The RH sensor had failed (it would saturate in wet weather or when snow was on the building roof), and the temperature sensor was out of calibration.

   1) The delta pressure (ΔP) sensor on the chilled water loop was out of calibration. Later it was found to be a static pressure from the supply line rather than a ΔP signal. A recommendation was made to install a ΔP sensor in order to optimize the operation of the chilled water loop.

   2) The building static pressure sensors were out of calibration and were re-calibrated.

   3) Major problems were found with the VAV box calibration. Over 70% of the boxes were providing erroneous readings. Boxes were showing large amounts of flow even when AHUs were off, flow stations were broken, or dampers were not functioning properly. As a result an outside firm was hired by the State of Utah to re-calibrate the boxes. This slowed the CC process until the boxes were completed, but it was absolutely necessary to carry out the CC process.

OPERATIONAL PROBLEMS IDENTIFIED
1) Boiler operation—Two large boilers were used to provide heating hot water to the courthouse. Both boilers were being used, each starting up on high fire, which resulted in large swings in hot water
temperature and pressure. One boiler can easily carry the courthouse hot water needs, starting on low or medium fire.

2) Pump operation—The Matheson Courthouse was regularly using two pumps for operation of their glycol, chilled water, and hot water loops, when one-pump operation will carry the load much of the time.

3) Glycol loop operation—A glycol loop is used to melt snow on the garage ramp. A programming error turned the de-icing system on when the outside air temperature was below 38°F or the outside relative humidity was above 80%. This turned on the de-icing system anytime, fall, spring, summer or winter, when the outside RH exceeded 80%. When this measure is combined with a faulty RH sensor discussed in item 1 under sensor calibration and item 2 above on two-pump operation, this meant the two small glycol pumps and the glycol loop were operating far too much.

   1) Chiller start-up procedures in spring—A review of the 15-min load data from the electric utility indicated an electrical “spike” of several hundred kW in the spring. This was attributed to a refilling of the chilled water systems and turning on the chillers, pumps, and condenser equipment for operational verification. By changing the normal start-up procedures to make sure the equipment is not run at the same time during a weekday, this will save several thousand dollars. It is not an energy saving measure, but an electrical demand management measure.

   2) Early morning building warm-up/cool-down measures—Prior to CC the building was generally started up sometime after midnight on Monday mornings and somewhere between 2 a.m. and 4 a.m. on other mornings, depending on the season. Although the Building Automation System has a feature called Optimum Start (or O-Start), it was not starting under optimal conditions. For example, in the winter the building start-up conditions would typically be as follows:

1. Temperature inside AHU might reach 120°F when AHU was off and hot water was being circulated for freeze protection.

2. AHU would start for building warm-up but would try to maintain occupied discharge air temperature typically around 55°F.

3. When the stagnant air inside the air handling unit reached the discharge air temperature sensor, the temperature would be too high, and the signal would be sent to open the full economizers.
4. Opening the economizers now meant that very cold air would enter the AHU, and the DAT would drop rapidly.

5. The now low DAT would cause the heating valve to open and would also drive the economizer dampers to start to close.

6. This extreme instability of temperature conditions required more than an hour to achieve equilibrium and wasted a lot of energy in the process.

The result of this operation was to devise/create a semi-occupied start-up mode which reduced the warm-up/cool-down period dramatically.

MAINTENANCE ISSUES

1) Damper adjustments. Several of the outside air dampers were out of adjustment and required adjustment for proper operation and control. This is particularly important for economizer operation, minimum air settings, and early morning start-up.

2) Building static pressure sensors and damper maintenance. During the calibration phase of CC, the building static pressure sensors could not be located or verified, but from the BAS readings, they were known to be off calibration. None of the sensors, for example, read zero when all the AHUs were off. There was also a failure of the program logic which allowed the exhaust dampers to remain open on some of the building core shafts when the exhaust fans were off. This allowed outside air to be “sucked” into the building when the exhaust fans were off. Since most of the core shafts exhausted into the parking garage, this also created an indoor air quality issue because exhaust fumes from the garage were entering the building. Some programming logic was changed for this measure as well.

3) Leaking control valves. Maintenance was not a big issue at Matheson, as the building was well maintained. However, two control valves were leaking and were repaired/replaced.

4) Small chiller isolation valve. There was a problem with the isolation valve on the small chiller, which was handled manually by the Matheson maintenance staff. This sticking valve would prevent the proper sequencing of the large (800-ton) and small (400-ton) chillers.
5) Missing insulation on one AHU. During the sensor calibration/verification phase, one return air sensor was reading several degrees lower than the other return air sensors. A careful investigation revealed missing seal insulation around some outdoor access areas which was allowing outside air to be mixed with return air prior to the mixed air chamber. These areas were insulated by the Matheson maintenance staff.

OPTIMIZATION MEASURES

1) Hot water and cold deck reset schedules. An optimized cold deck reset schedule was developed for Matheson, resetting the cold deck temperature as a function of outside air temperature and enthalpy. The AHU discharge air, mixed air, and return air temperatures were measured, and the optimum schedule was established. Temperatures were also reset in accordance with ambient air temperature.

2) Duct static pressures were also reset in accordance with outside air temperature. A semi-occupied mode was devised, and duct static pressures were reset also depending on occupied vs. semi-occupied modes.

3) Air flow adjustments on VAV boxes. The minimum air flow was reset for VAV boxes in accordance with a semi-occupied mode. Also, the semi-occupied mode reduced total outside air flow since the building occupancy was lower.

4) Lower hot water supply temperature. The boilers were both running, supplying nominal 180°F water to the building year round. The water temperature was lowered to 155°-160°F, which was as low as the boiler controls would allow.

5) Add a new boiler controller and turn off boiler in summer. These two recommendations are still pending, awaiting boiler maintenance, additional VAV box maintenance, and the installation of a new controller for the boiler.

6) Improve the chiller sequence. Prior to CC, the BAS program allowed both chillers to run while switching from the small chiller to the larger chiller. The sequence was changed to eliminate two-chiller operation and reduce demand costs.

COMMISSIONING RESULTS
Except as noted above, all the commissioning measures identified were implemented. Sensors were recalibrated or replaced, operational changes were implemented, and maintenance issues were handled by the Matheson staff.

The analysis group within the Energy Systems Laboratory developed baseline models from monthly utility bills and determined the savings from commissioning to be in the range of $75,000 to $80,000 per year, based on 2001 energy prices. Sixty percent of the savings were from natural gas, resulting from changing the boiler operation, reducing the hot water temperature, changing the winter early morning start-up requirements, and reducing the amount of simultaneous heating and cooling required.

Monthly bills were used for the savings analysis for electricity because the interval electric utility data was erroneous for several months during the 2001 baseline period. The electric demand monthly model could not accurately predict the savings from the chiller spring start-up and chiller reprogramming changes, which saved approximately 400 kW at $8.01 per kW. The monthly demand model only predicted about 200 kW in demand savings for the entire year.

Because of lower gas and electricity prices in 2002 vs. 2001, the utility bill at Matheson reduced from about $400,000 ($300,000 for electricity, $100,000 for natural gas) to $284,000 ($249,000 for electricity, $35,000 for natural gas). The ECI for Matheson reduced from an already low $1.08 per square foot per year to $0.77 per square foot per year, based on the conditioned square feet. More than 700 hours of AHU operation were eliminated by optimizing the start-up and shut-down sequence of the HVAC system.

CONCLUSIONS

The Continuous Commissioning of the Matheson Courthouse was a team effort and a resounding success. The utility bills were reduced approximately 20% from the CC process, and, because of lower energy prices, actually dropped nearly 30% from the 2001 baseline year. A second building commissioning at the Salt Lake Community College is now underway, and a recommendation has been made to DFCM to form a state retro-commissioning team to continue this work at various other state buildings in Utah.
In summary, the CC process can save energy, reduce the number of comfort complaints, and improve worker productivity, if the tenants are happy with the building.

The simple payback period for the ESL charges, the TAB firm, and parts purchased by DFCM, was roughly 1.2 years; therefore the project was paid back in the spring of 2003, and the state is now experiencing a positive cash flow from the project.

Since several of the recommended changes have not been implemented to date, i.e., shutting off the boiler in the summer, further reducing the hot water supply temperature, and adding a ΔP sensor for the chilled water supply loop, additional savings will result when these measures are implemented.

ACKNOWLEDGMENTS

The Continuous Commissioning of the Matheson Courthouse was funded by contract #66200 between the Utah State Department of Natural Resources and the Texas Engineering Experiment Station, Energy Systems Laboratory. The contract monitor for DNR was Mr. Jim Hood, P.E.
Figure 1

Chart: Matheson Courthouse Natural Gas Usage
REFERENCES


17. LoanSTAR Energy Assessment Report for Prairie View A&M University, August 2002

18. Energy Assessment Report for Alamo Community College District, April 2002
APPENDIX D

Airport Survey Questionnaire
# Airport O&M Best Practices Survey

**Date Completed:**

## Contact Information

<table>
<thead>
<tr>
<th>Airport Name</th>
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## Facility Operations

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## Building Information

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<th>Percentage of Area controlled by Building Automation System</th>
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<th>Projected Growth (gross sq. footage) next 5 years</th>
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<th>Thermal Storage Capacity (ton/hrs)</th>
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## Utility Expenses

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<th>Annual Electricity Bill</th>
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<th># of Electricity Meters</th>
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<th>Annual Electricity Use (Kwh/yr)</th>
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<th>Annual Water/Sewer</th>
<th>$</th>
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<th>Purchased Thermal Cooling MMBTU/yr</th>
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<th>Purchased Heating MMBTU/yr</th>
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</table>
Energy-Related Operation and Maintenance (O&M) Practices Questionnaire

Please answer the following questions. Enter comments in the space following each question or on the last page.

1. Is a Building Automation System (BAS) used to control the HVAC systems? Yes __ No __

2. Is a Computerized Maintenance Management System (CMMS) used to schedule and track Predictive, Preventive and Reactive maintenance? Yes __ No __

3. Do you have an O&M manual with specific procedures and schedules? Yes __ No __

4. Is energy consumption tracked as a performance measure? Yes __ No __

5. Has an energy baseline and tracking system used for the facility? Yes __ No __

6. Are O&M Procedures reviewed on a scheduled Basis? Yes __ No __

7. Is tenant area electric consumption metered separately? Yes __ No __

8. Does Air Quality affect the airport’s O&M procedures? Yes __ No __

9. Has an external Energy Assessment been performed in the last 5 years? Yes __ No __

10. Has an external O&M Assessment been performed in the last 5 years? Yes __ No __

11. Describe any cost-effective or unique O&M procedures implemented at your airport.

12. Describe any recent cost-effective or unique energy upgrades/retrofits at your airport.

13. Do you re-commission and/or optimize your HVAC and control system periodically? Yes __ No __

14. What percentage of your energy-related O&M is conducted by private contractors? _____%

D-3
15. What position/function in your organizational structure is responsible for O&M and associated budgets? ____________________ [position title(s)]

16. What would you do to improve energy-related O&M at your facility, if anything?

Table A: Scheduled Walk-Through Inspections -- Please mark the frequency of walkthrough inspections. Varying levels of inspection are expected.

<table>
<thead>
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<th>Area or Equipment</th>
<th>Daily</th>
<th>Weekly</th>
<th>Monthly</th>
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<td>Ramp Area</td>
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<tr>
<td>Concourse and Parking Lighting</td>
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<tr>
<td>Heating Ventilation Air Conditioning (HVAC) Systems</td>
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<td>Bathrooms</td>
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<td>Chilled Water (CHW) &amp; Hot Water (HW) Pump Rooms</td>
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<tr>
<td>Air Handling Units (AHU) &amp; Fan Coil Units (FCU)</td>
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<td>Jet Bridges</td>
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<td>Pre-Conditioned Air (PCA) Systems for Aircraft</td>
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<td>Elevators, Escalators, and Moving Walkways</td>
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<td>Direct Expansion (DX) HVAC systems</td>
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<td>Boilers and Heat Exchangers</td>
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Table B: Scheduled Preventive Maintenance Schedule-- Please mark the frequency of PM.

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<th>Monthly</th>
<th>Quarterly</th>
<th>Semi-Annually</th>
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</tbody>
</table>

Final note: Would you be available for a brief telephone interview if we need additional information? If so, what time of day and phone number is best to reach you? Time (AM/PM)

____ Phone _________

Comments: Please use this space for any additional comments on questions in the survey or for anything you may want to add.