Model for Improving Energy Use in U.S. Airport Facilities

DETAILS

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Research Results Digest 2

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.

CONTENTS

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) (*1*). 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

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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

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

Survey question	Overall (20 airports)	Large (> 1,000,000 enplanements)	Medium (250,000–1,000,000 enplanements)	Small (< 250,000 enplanements)
1. CMMS Use	45%	87.5%	33%	0%
2. BAS Use	70%	87.5%	67%	50%
3. Detailed O&M Manual	60%	62.5%	83%	33%
4. Energy Use Tracked as a Performance Measure	45%	37.5%	67%	33%
5. Use of Energy Baseline	35%	25%	33%	50%
6. Tenant Energy Sub-Metering	60%	62.5%	67%	58%
7. Energy Assessment within Past 5 Years	45%	50%	33%	50%
8. O&M Assessment within Past 5 Years	30%	37.5%	33%	17%
9. Periodic Recommissioning or Optimization of HVAC Systems and Control Systems	50%	50%	67%	33%
10. Implementation of Energy-Related O&M Measures	55%	87.5%	50%	16.6%
11. Implementation of ECRMs	50%	75%	50%	33.3%
Average response rate for all measures	49.5%	60.2%	53.0%	34.0%

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.

Use of an Energy Baseline

Thirty-five percent of respondents indicated that they utilize an energy baseline for monitoring energy performance, with a range of 50 percent (small airports) to 25 percent (large airports). A lack of trained personnel could account for this smaller utilization rate as well as the frequent lack of sub-metered data at airport facilities.

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

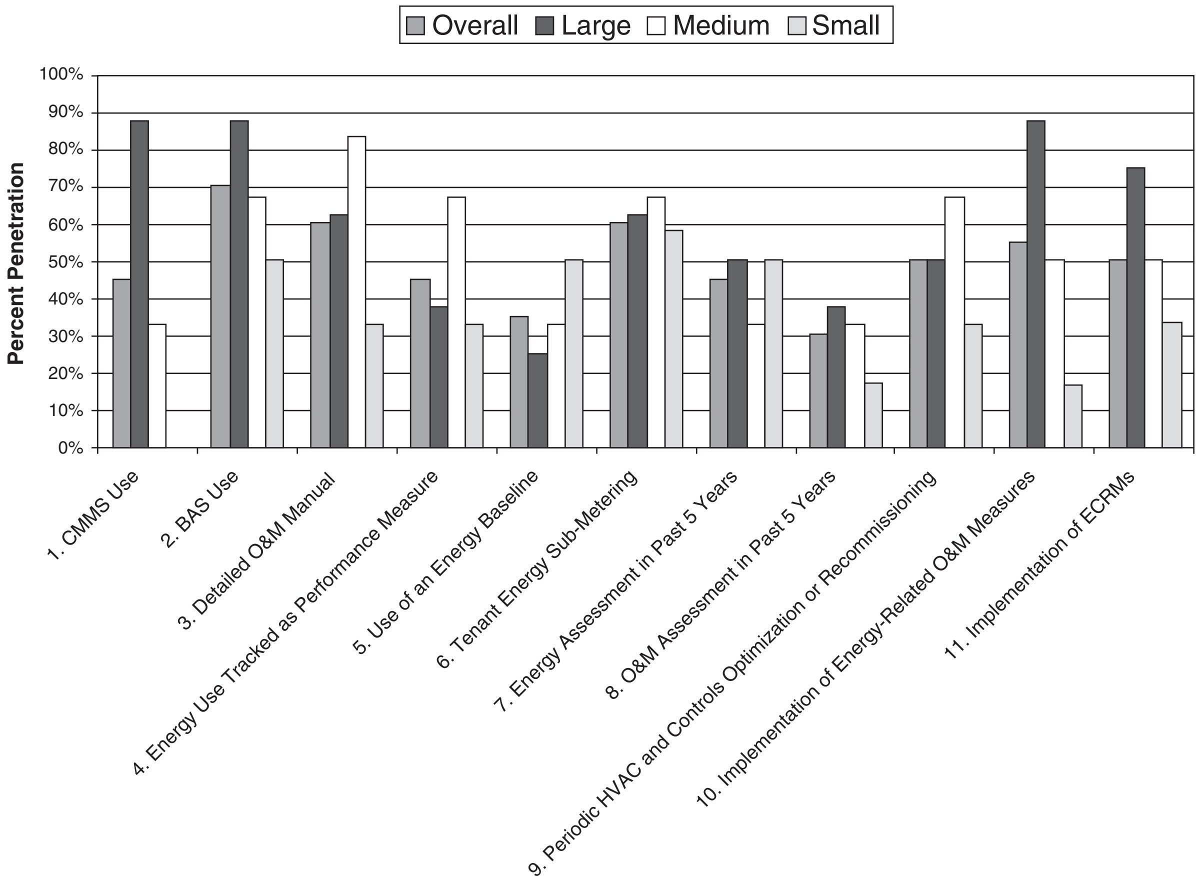


Figure 1 Identification of best practices—Airport O&M Best Practices Survey (December 2006 to January 2007).

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

Technology	Overall (20 airports)	Large (> 1,000,000 enplanements)	Medium (250,000–1,000,000 enplanements)	Small (< 250,000 enplanements)
On-Site Cogeneration	10%	25%	0%	0%
On-Site Renewable Power	0%	0%	0%	0%
Thermal Storage	10%	25%	0%	0%
Purchased Cooling and/or Heating	0%	0%	0%	0%
Air Quality Issues Affecting O&M Decisions	45%	75%	33%	33%

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.

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/ft^2 and energy costs/ft^2). 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/ft^2). 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/ft^2), the research team drew the following conclusions:

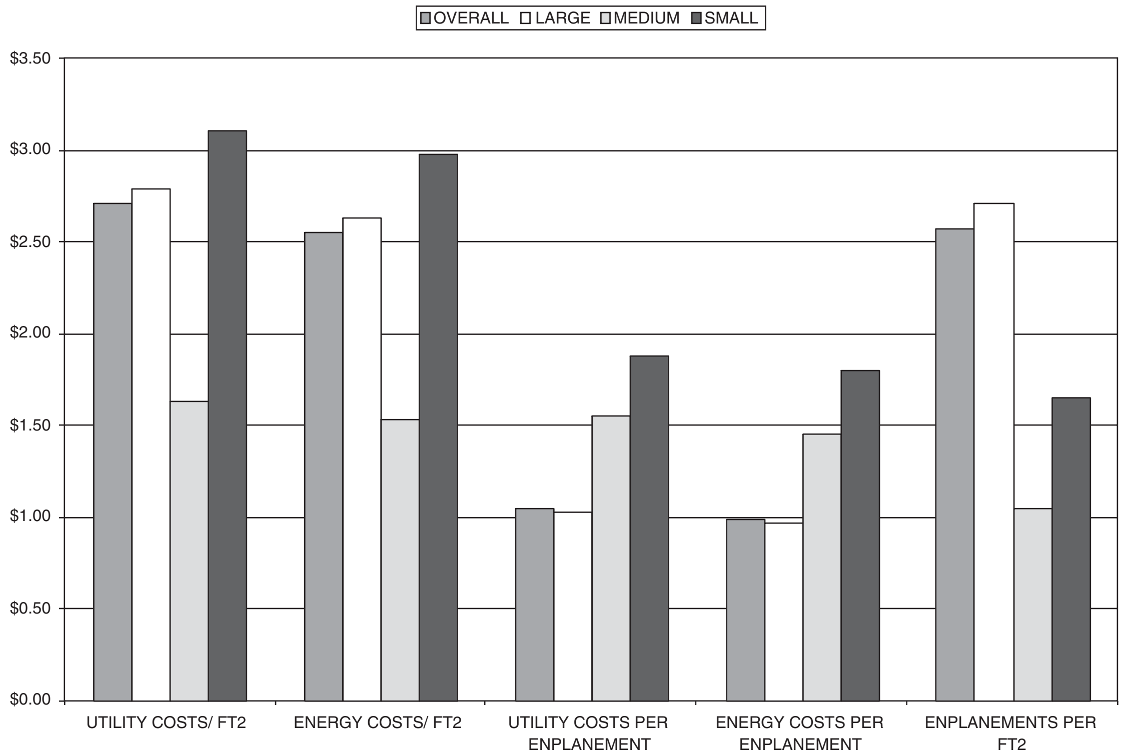
Large airports. On average, large airports require the least utility expenditure per enplanement. Large airports enplane 2.58 times as many passengers per square foot as medium-sized airports. From the perspective of overall facility effectiveness, this is good news for large airports, but that does 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

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

Group	Utility Costs/ft^2	Energy Costs/ft^2	Utility Costs/ Enplanement	Energy Costs/ Enplanement	Enplanements/ft^2
Airports Overall	$2.71	$2.55	$1.05	$0.99	2.57
Large Airports	$2.79	$2.63	$1.03	$0.97	2.71
Medium Airports	$1.63	$1.53	$1.55	$1.46	1.05
Small Airports	$3.11	$2.98	$1.88	$1.80	1.65



Note. Utility costs often include water and wastewater, which may be hidden in electric costs at airports that do their own water treatment. Energy costs, which often do not include water pumping/treatment, are the most reliable data in this survey sample.

Figure 2 Bar graph of potential energy indices based on the Airport O&M Best Practices Survey.

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
- **ECRMs.** 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 compressed air 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

Lighting ECRMs	Simple payback period
Replace exit lights	6 months to 2 years
Replace incandescent bulbs with compact fluorescent bulbs	6 months to 2 years
Install occupancy sensors	2 to 4 years
Replace T-12 with magnetic ballasts with T-8 or T-5 with electronic ballasts	2 to 5 years
Install lighting controls	2 to 10 years

Table 5 Payback periods for HVAC and mechanical system ECRMs

HVAC and Mechanical System ECRMs	Simple Payback Period
Steam trap O&M and/or replacement	6 months to 10 years
Optimizing HVAC systems and controls	1 to 4 years
Water treatment systems upgrades	1 to 4 years
Variable frequency drive (VFD) replacements	3 to 7 years
Cooling tower VFD and pump upgrades	3 to 7 years
Thermal storage system retrofits	3 to 10 years
Economizer equipment upgrades	4 to 8 years
Replacement of inefficient motors	5 to 6 years
Cooling tower replacement	5 to 20 years
Oversized boiler replacement	6 to 8 years
DX unit and heat pump replacement	4 to 13 years
BAS/EMCS upgrade	6 to 10 years
Heat recovery unit upgrade	8 to 10 years
High-efficiency boiler replacement	8 to 12 years
Chiller replacement	8 to 20 years

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-

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

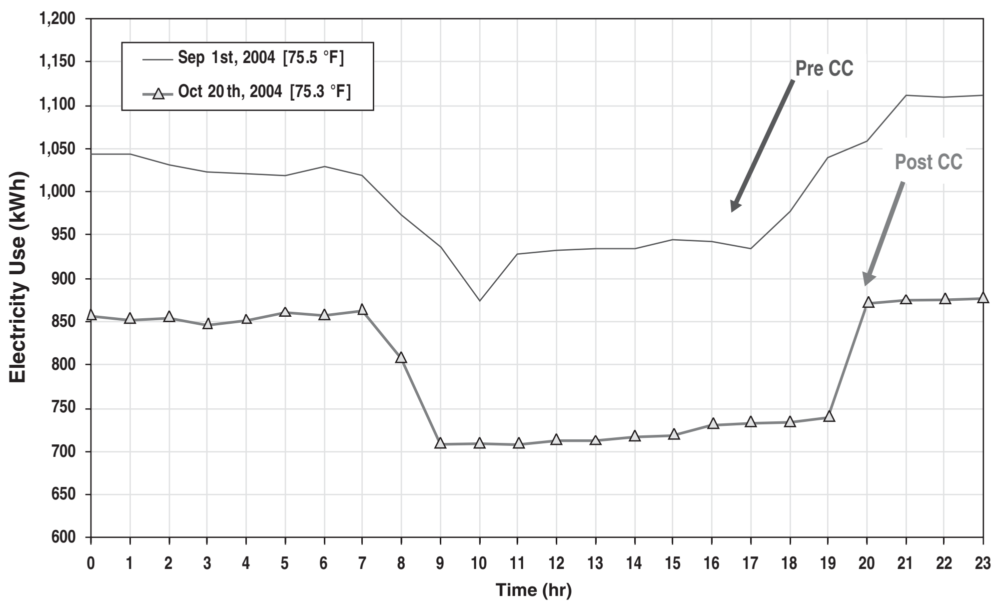
The following case studies are good examples of how many of the best practices discussed in this study can produce excellent savings in large complex facilities, including airports. The first case study describes the savings realized from recommissioning a centralized rental car facility at DFW Airport. 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.)



Note. CC = Continuous Commissioning®

Figure 3 Electricity use at DFW Airport Rental Car Center before recommissioning and 1 month after recommissioning began.

Texas A&M Main Campus

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.

Matheson Courthouse, Salt Lake City, Utah

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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RESOURCES

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE).
www.ashrae.org

Building Commissioning Association (BCA)
www.bcxa.org

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

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

Oregon Office of Energy
http://search.oregon.gov/query.html?col=allore&qc=allore&qt=buildings+and+commissioning

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

U.S. Department of Energy/Energy Efficiency and Renewable Energy
www.eere.energy.gov/

U.S. Department of Energy/Federal Energy Management Program
www1.eere.energy.gov/femp/

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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