Laboratories for the 21st Century: Case Studies

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The U.S. Environmental Protection Agency's Robert S. Kerr Environmental Research Center, Ada, Oklahoma

Introduction

The U.S. Environmental Protection Agency (EPA) Robert S. Kerr Environmental Research Center in Ada, Oklahoma (Ada Lab), has reduced the laboratory's annual energy consumption by 45% by upgrading the building mechanical system and incorporating renewable energy. This retrofit, financed with an energy savings performance contract (ESPC), implemented a geothermal ground source heat pump (GSHP) and other energy efficient systems. As a result of these upgrades and "green tag" purchases from wind power, the Ada Lab is EPA's first "zero emissions" facility.

In 2000, EPA awarded a U.S. Department of Energy (DOE) Super ESPC to Johnson Controls, Inc., an energy service company (ESCO), to replace the Ada Lab's aging heating, ventilation, and air conditioning (HVAC) system and to institute a series of energy efficient operational practices. The new HVAC system incorporates the GSHP, variable-air volume (VAV) on laboratory supply and

EPA United States Environmental Protection Agency

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Federal Energy Management Program

exhaust systems, energy recovery from the exhaust air stream, and a direct digital control (DDC) building automation system (BAS). By using the GSHP system, the laboratory operates without using natural gas for heating and reheating purposes. In addition, the April 2005 purchase of 3 million kilowatt hours (kWh) per year of green tags from wind power allows the EPA to offset the remaining conventional electricity it uses for lights, fans, pumps, etc. As a result, energy consumed by the facility is not associated with the emissions of greenhouse gases.

The new systems were accepted in 2005 and have completed their first full year of performance. This case study highlights the features of the laboratory HVAC system retrofit and presents "lessons learned" from the ESPC process.

The Ada Lab houses the EPA Ground Water and Ecosystems Restoration Division, whose mission is to provide the scientific basis for the development of strategies and technologies to protect and restore ground water, surface water, and ecosystems impacted by man-made and natural processes. This EPA Office of Research and Development laboratory is the center of expertise in the study of soil and the subsurface environment.

This study is one in a series produced by Laboratories for the 21st Century ("Labs 21"), a joint program of EPA and DOE. The program is geared toward architects and engineers who are familiar with laboratory buildings, and encourages the design, construction, and operation of safe, sustainable, high-performance laboratories.

Project Description

EPA's Ada Lab is situated on a 17-acre tract, located three miles south of Ada, Oklahoma. Completed in 1966, the three-story structure with basement provides 52,629 ft^2 of laboratory and office space in the original building. An addition to the facility in 1993 provides another 16,644 ft^2 for the library, computer support services, and a conference center. The nearby 7,460-ft^2 annex building houses a machine shop and storage facilities for field equipment and supplies. Separate facilities have been constructed for storing bulk chemicals, compressed gases, and hazardous waste. Table 1 identifies the breakout of building space by type. Approximately 160 employees work at the Ada Lab. The facility operates on a flex time schedule and is typically occupied between 6:00 a.m. and 6:00 p.m., Monday through Friday.

The EPA and Ada Lab facility staff has been proactive in managing water and energy usage: single-pass cooling water for laboratory equipment was eliminated in the early 1990s, a lighting upgrade was completed in 1995, and all chlorofluorocarbons were replaced by 1998. However, the building mechanical systems at the Ada Lab were showing their age. The electric chillers were reaching the end of their service life; the steam boilers were maintenance intensive; and there were various pieces of inefficient air handling equipment, including multiple air handling units (AHUs), laboratory fume hoods, multiple exhaust fans, and packaged split systems. In addition, EPA was facing an expensive electrical upgrade and air handling modifications for health and safety requirements at the Ada Lab.

After initiating their first ESPC at another lab facility, EPA saw the opportunity for improving energy efficiency and achieving overall cost savings at the Ada Lab, while preserving the agency's shrinking Buildings & Facilities funds for other priority projects. The design effort was guided by the following goals established by EPA at the beginning of the procurement process:

1. *Meet or exceed federal energy reduction mandates*, as prescribed by Executive Order 12902, which required 30% site energy reduction relative to a 1985 baseline in federal facilities by 2005, and Executive Order 13123, which further requires 35% energy use reduction by 2010.
2. *Reduce power plant source emissions*, consistent with EPA's mission of environmental protection.
3. *Optimize energy cost savings*.
4. *Restore obsolete and aging infrastructure*.
5. *Minimize energy waste* by eliminating as much energy waste as possible with cost-effective means.
6. *Maximize the use of the waste energy streams* to feed other processes (where cost effective).
7. *Use renewable energy* to meet the requirements of Executive Orders 12902 and 13123, which established goals for federal facilities to implement renewable energy projects and purchase electricity from renewable energy sources.

These project goals were intended to encourage the ESCO to focus on the federal energy efficiency and emission reduction goals in addition to the cost savings of the typical ESPC.

To assist EPA in meeting their goals, Johnson Controls installed the following energy conservation measures (ECMs):

1. Geothermal ground source heat pump system for space heating and air conditioning and domestic water heating
2. All new air handling equipment
3. Heat pipe heat recovery
4. Direct digital control building automation system
5. Electrical upgrade, including adding new outlets and enhancing distribution.

The ESPC process allows an agency to implement an energy efficiency project without the constraints of capital funded projects. The project cost is paid from the guaranteed energy and energy-related cost savings over the length of the contract (i.e. the same money that was used to pay high utility costs is used to repay the ESCO for the installation of new, energy-efficient equipment). Since awarding a stand-alone or site-specific ESPC can be very complex and time consuming, EPA chose to use a DOE Federal Energy Management Program (FEMP) Super ESPC.

For the Ada Lab, the awarded ESPC called for an installation period followed by 24 years of complete system operation and performance guarantees. The total investment was $4,816,614, requiring annual contract payments of $253,952. This includes annual energy cost savings of $144,906 and annual O&M cost savings of $132,532. The guaranteed first-year annual savings amount to $253,953, and the guaranteed savings over the term of the contract is $8,069,858. To offset some of the $4.8 million project cost, EPA contributed $1,725,000 from funds it had planned to use for energy efficiency upgrades. This avoided cost allowed EPA to reduce the total amount financed and ensure an adequate level of services provided by the ESCO, such as O&M and repair and replacement.

Because the new HVAC system is complex and the laboratory required the capability to conduct near normal operations during its installation, the project's construction was planned to span a 14-month period. However, a number of factors caused implementation delays. The ESCO experienced a high turn-over rate in project managers due to lack of experience in laboratory facilities, and the initial project design did not adequately address VAV operation and HVAC system size for laboratory conditions. Poor quality control of the geothermal well drilling and construction subcontractors caused delays to the project and damage to laboratory equipment. Following design and just prior to construction, EPA determined that the heat recovery system needed a substantial design change. The EPA has strict requirements for their laboratory environments such that most designs are completed and then reviewed by consultants before approved for implementation, which also added to the delays. In addition, the ESCO did not meet EPA's expectations for commissioning. As a result of these factors, elements of the system came online from 2001 to 2004, and the total project was accepted June 1, 2005.

The ESPC procurement method has the built-in advantage of being performance based. Specifically, the ESCO is required to provide a fully functional system and show savings before payments begin. In the end, both Johnson Controls and the EPA strengthened their commitments to produce a successful result, but not without some hard lessons learned along the way.

Table 1. Ada Lab Floor Space Breakdown

(Net ft^2, unless otherwise noted)

Function	Size (ft^2)	Percentage [(1)]
Laboratory & Laboratory Support Areas	27,743	45%
Offices and Office Support Areas	33,618	55%
Misc. assigned space	0	
Total net ft^2	61,361	
Other[(2)]	19,678	
Total gross ft^2	81,039	
Total gross ft^2 conditioned space	77,875	

Notes:

1. The percentage shows a breakdown of net ft^2 only. Net ft^2 equals gross ft^2 minus "other."
2. "Other" includes circulation, toilets, stairs, elevator shafts, mechanical and electrical rooms and shafts, and structural elements like columns. The net-to-gross-ft^2 ratio is 76%.

Design Approach/Technologies Used

The Ada Lab was upgraded with innovative and highly efficient HVAC systems by using private-sector financing through an ESPC. Had the EPA used agency Buildings & Facilities funds for the necessary upgrades, standard equipment with lower efficiency would have been installed, resulting in comparatively higher annual energy and O&M costs, and other important EPA facility upgrades and repairs would have been further delayed.

For this Ada Lab retrofit, a GSHP system replaced two existing boilers, three existing chillers and associated equipment. Water is circulated through the closed-loop geothermal system for heat gain from or rejection to the ground. Water-to-water heat pumps heat or cool a refrigerant loop to produce hot and chilled water for the AHUs. A screw chiller provides additional cooling capacity for the refrigerant loop. A water-to-water heat pump also provides domestic hot water (DHW). During the predominant cooling season, the water-to-water heat pumps with the ground loop, supplemented by the chiller with the cooling tower, remove heat from the building refrigerant loop, lowering its temperature and resulting in efficient operation for the units cooling the building air supply. Hot water for re-heat is supplied from three water-to-water heat pumps, each with two independent stages of control. Water-to-air heat pumps provide heating and cooling to select non-laboratory spaces. Figure 1 illustrates general operation of the geothermal and building loops in cooling mode, and Figure 2 shows heating mode.

The specifications of the resulting GSHP system are as follows:

- 175 wells 300 ft deep

- 125 tons cooling capacity
- 6,650,000 Btu/hr heating capacity

The screw chiller provides an additional 120 tons of cooling capacity. The Ada Lab was previously equipped with a two-cell cooling tower, rated at 450 tons of total cooling capacity. Since the GSHP system came online, the facility loads have required operation of only one of the tower cells. Additional results of the GSHP system installation is that natural gas is no longer used for heating, and electricity for cooling use has been significantly reduced.

All new air handling equipment was also installed as part of this project. Three new AHUs with high efficiency fan motors replaced 8 existing AHUs in the main building. Existing laboratory exhaust fans were removed and replaced with three high-velocity discharge, variable frequency drive, induction fans. All laboratory supply and exhaust air was changed to VAV, and fume hoods were retrofitted with room air flow and pressurization controllers. As a result, positive pressure is maintained in the offices relative to the corridors, and corridors are maintained at a positive pressure relative to the laboratories.

Heat pipe energy recovery is another innovative feature of the project. An air-to-air heat pipe exchanges energy with exhaust air to pre-heat or pre-cool intake air. All exhaust duct airflow passes through the heat pipe exchanger to remove exhausting heating/cooling energy and to reuse this energy to pre-condition the incoming makeup air. This heat pipe unit was a change from the originally proposed heat wheel heat recovery system due to concerns of air stream cross contamination by EPA's Health & Safety department. Humidifiers also had to be added due to the different thermodynamic conditions associated with the heat pipe installation. Operation of the humidifiers is required during heating mode only.

The entire existing pneumatic control system was removed and replaced with a DDC BAS and a central operator work station. The BAS monitors the HVAC systems to provide optimum HVAC performance and initiates programs to maintain building operations for maximum energy efficiency. In addition to energy, the BAS provides fire and security information and monitoring.

Several aspects of this final system installation were not part of the original ESCO project proposal. The initial project design did not have a holistic design approach for the efficient operation of laboratory building systems. A lack of understanding of VAV laboratory air systems caused an unexpected need to train the contractors. The HVAC systems were undersized for the load of the laboratory space requirements. And the temperature and humidity operation requirements of the labs were not properly addressed by the design or the construction schedule. Some of these issues arose from following the standard ESPC approach of final proposal submission at 30-35%

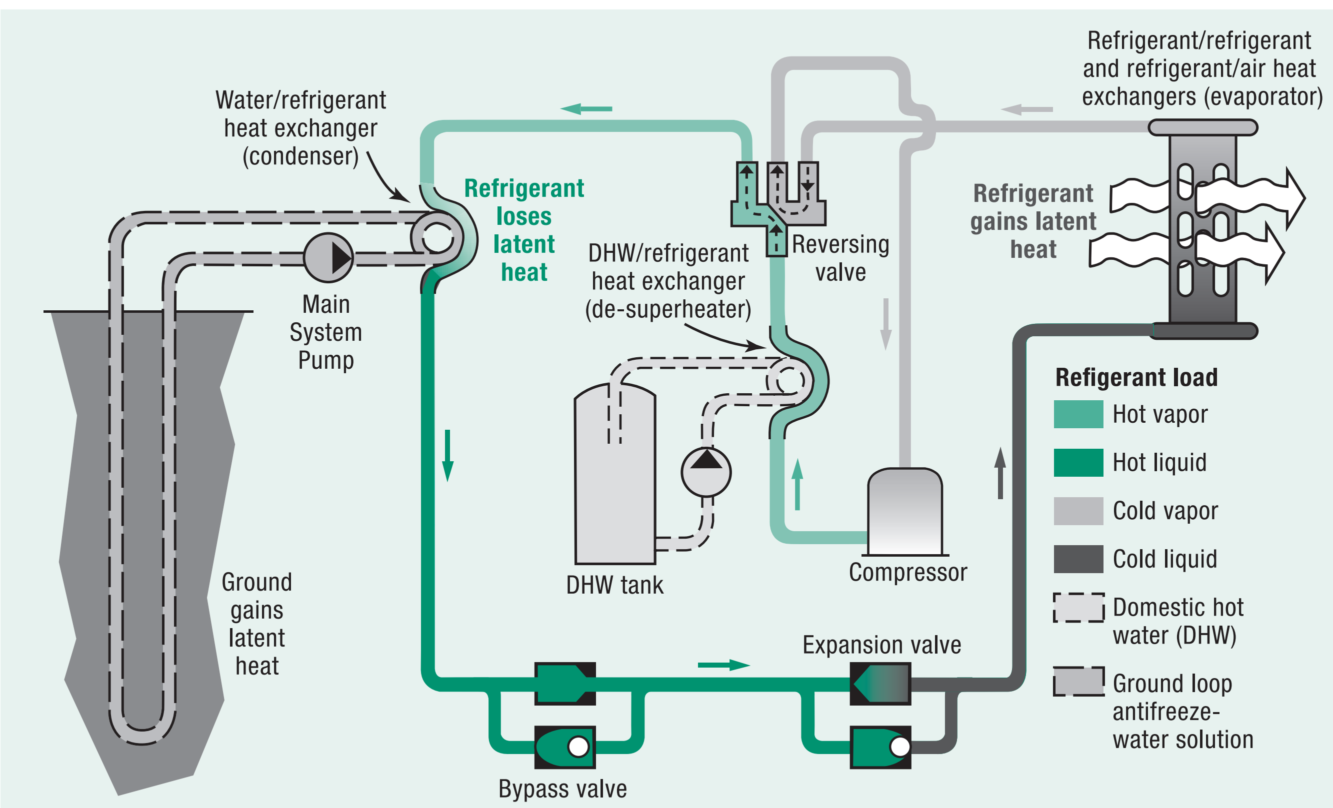

Figure 1. The GSHP system in cooling mode. *Source: http://www.geo4va.vt.edu/A3/A3.htm*

design completion. The problems then compounded as construction began prior to completion and approval of the final system designs. Typically, the design is completed following award and construction begins upon review and approval of all design submittals.

A number of quality control problems also plagued the project. During project design, construction, and commissioning, the ESCO experienced a high turn-over rate in project managers, mechanical engineering firms, and construction subcontractors. The geothermal well drilling struck a shallow natural gas reservoir, ruptured a natural gas distribution line, and caused excessive tailings run-off. Poor quality control and negligence by one of the construction subcontractors caused roof damage and leaks that destroyed over $60,000 in lab equipment. In addition, the ESCO's commissioning effort did not meet the expectations of EPA; however, those expectations were not clearly stated in the contract.

To complete implementation of the contract and produce a successful project, both the ESCO and the EPA bolstered their commitments. The ESCO executive management stepped in with a senior level management team and provided a top-notch architectural and engineering (A&E) firm to address the design and quality control issues. The EPA funded additional system commissioning and fume hood certification.

Once fully operational, this package of upgrades has resulted in highly successful annual energy and cost savings. The Ada Lab has achieved an estimated total annual cost savings of $319,138 of which $65,185 is retained by EPA, as summarized in Table 2. The O&M savings include labor, in the form of two positions reduced from Ada Lab staff, and deferred maintenance, including items such as air handler parts, chiller replacement, and boiler maintenance. The deferred maintenance cost savings is an estimate derived from the ESPC calculations. Figure 3 shows the energy cost savings by the annual trend of energy consumption (for electricity and gas, in Btus) per gross square foot (GSF).

Commissioning Process and Measurement and Verification

As the final step in the equipment installation process, the ESCO performs ECM commissioning to assure the government agency that ECMs perform in accordance with the design intent. The commissioning process typically occurs from design phase through construction acceptance to ensure that all ECMs perform interactively, in accordance with the design documentation and design intent, in accordance with facility requirements, and includes complete functional performance testing not limited to energy efficiency.

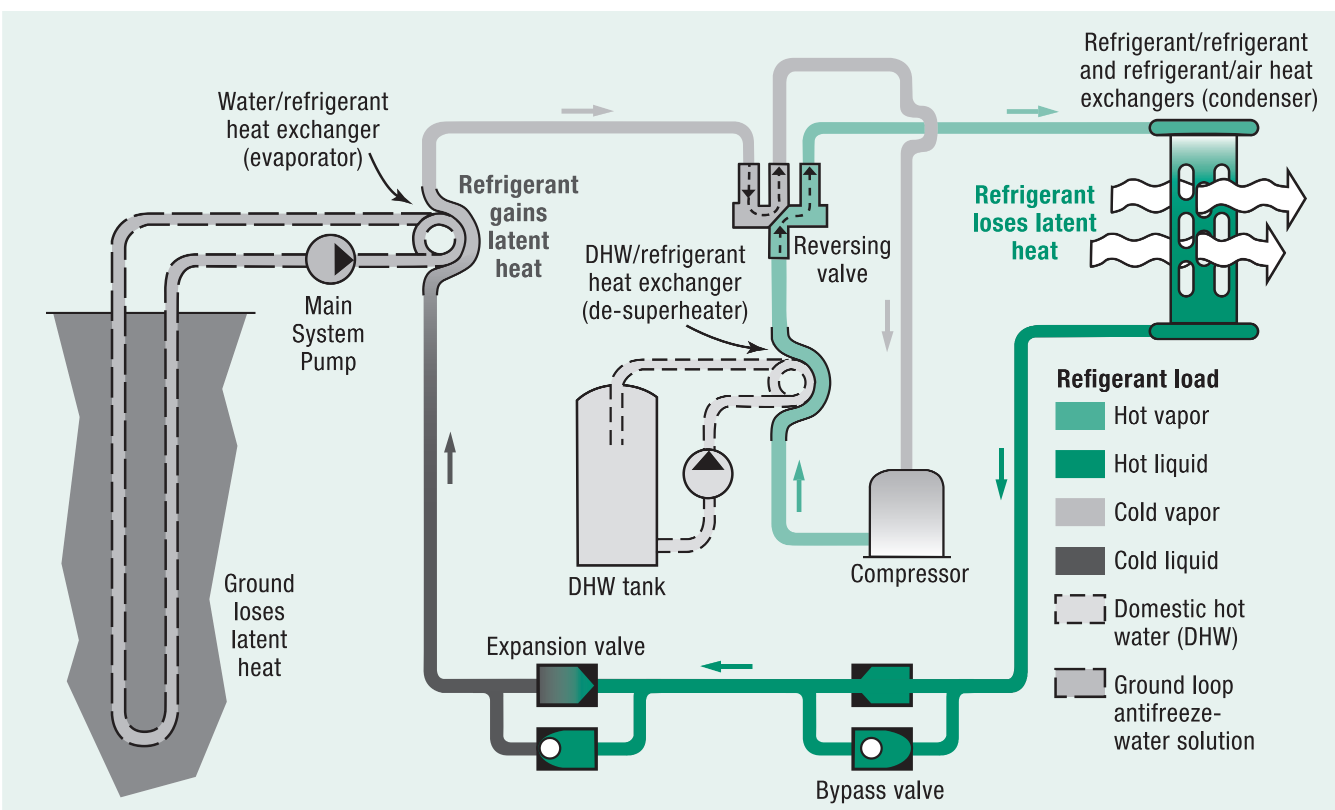

Figure 2. The GSHP system in heating mode. *Source: http://www.geo4va.vt.edu/A3/A3.htm*

Table 2. Cost savings estimated from first year of operation

Savings Type	Cost ($/year)	Notes
O&M Savings	$161,292	Includes labor and deferred maintenance savings.
Energy Savings	$157,846	Savings of FY2004 actual energy cost compared to 1994-96 average baseline consumption at the FY2004 average unit energy cost
Total Savings	$319,138	
ESPC Guaranteed Savings	$253,953	EPA payment to the ESCO
Savings in Excess of ESPC	$ 65,185	Retained by EPA

For the Ada Lab, final commissioning was hampered by the project team not having achieved full understanding of facility performance requirements (especially regarding VAV laboratory systems), construction beginning prior to full design completion, and redesigns occurring without full knowledge by the commissioning subcontractor. To address the performance issues caused by these oversights, Johnson Controls augmented the cooling system by installing the 120-ton chiller, bringing one cell of the cooling towers into the system for additional heat rejection, and adding water-source heat pumps for some of the labs. Exhaust fan capacity was increased, and the control system was also modified to incorporate the new equipment.

Prior to a 2004 modification, the Super ESPC contract requirements for commissioning were less stringent. As a result, EPA retained an outside commissioning firm, Facility Dynamics Engineering (FDE), to augment and improve upon the commissioning performed by Johnson Controls. This effort paid off for the EPA by identifying problems that could have impacted performance and energy savings. FDE documented some component failures and configuration issues that needed correction to achieve proper system efficiency. In addition, suggestions were provided to EPA that will assist in troubleshooting and sustaining system efficiencies.

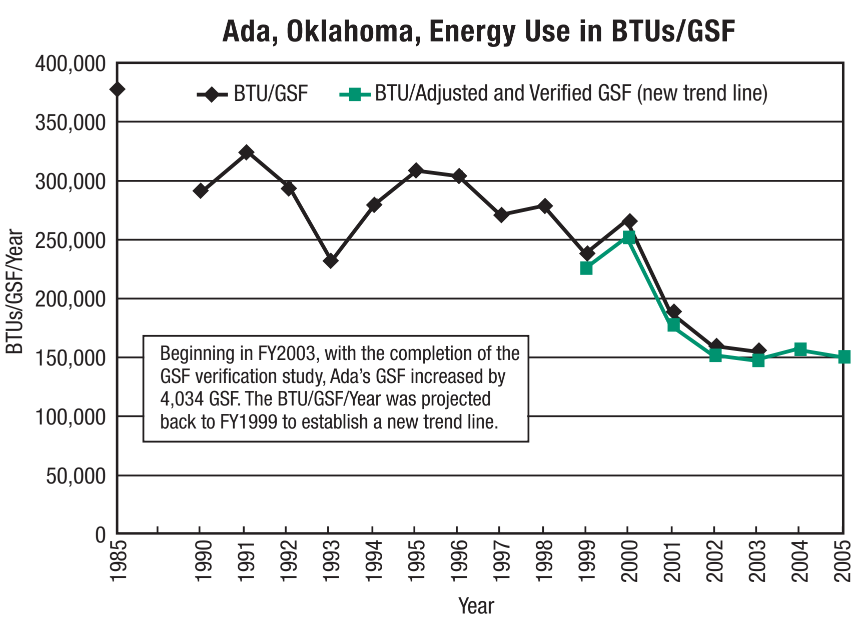

Figure 3. Energy consumption history for the EPA Ada Lab.

Following ECM commissioning, post-installation measurements are performed to verify the efficiency of the new equipment. The objective of measurement and verification (M&V) is to validate the energy savings realized by implementing the ESPC project measures. The M&V strategy that the ESCO is applying to this project is the "Option A" approach from the International Performance Measurement Verification Protocol. An Option A-based M&V approach is intended for retrofits when either performance or operational factors can be spot-checked or short-term measured during the baseline and post-installation periods and to minimize ongoing M&V costs to the agency.

During and after commissioning of the installed systems at the Ada Lab, measurements of system component performance and operational characteristics were completed to verify conformance with specifications. The measurements indicated a potential to generate more than $23,500 in savings above the guaranteed amount. Annual M&V reports present the energy baselines, the energy and demand reduction savings verified during commissioning, confirmation of preventive and repair maintenance, and operational anomalies that may have occurred during the year. The BAS provides control of the installed systems and allows tracking and trending of system operating parameters to ensure optimal performance. The following HVAC control strategies are governed and monitored by the BAS:

- Geothermal pump loop control
- Geothermal system temperature control
- HVAC systems temperature control
- Variable-air-volume control
- Space temperature setback/set forward
- Supply air temperature reset
- Fume hood control
- Humidity control

The BAS also monitors total electrical use and the HVAC portion of that energy use, including 27 points of electric demand, electricity

Table 3. Building Metrics for the Ada Lab

System	Key Design Parameters	Annual Energy Usage (based on audit and design data calculations)	Annual Energy Use (based on utility bill data for FY2005)
Ventilation	Supply = 1.11 W/cfm Exhaust = 0.97 W/cfm Total = 1.04 W/cfm (1) 0.51 cfm/gross ft^2 (2)	10.0 kWh/gross ft^2 (3) 12.5 kWh/net ft^2	Not separately analyzed (NA)
Cooling plant	125 ton GSHP, 1 kW/ton 122 ton chiller, 0.69 kW/ton	6.5 kWh/gross ft^2 (4)	NA
Lighting	1.56 W/gross ft^2 (5)	5.6 kWh/gross ft^2 (6)	NA
Process/Plug	1.20 W/gross ft^2 (7)	6.4 kWh/gross ft^2 (8)	NA
Heating Plant	6,650,000 Btu/h GSHP, 3.2 COP	4.4 kBtu/gross ft^2 (9) 15.1 kBtu/gross ft^2 (electricity)	NA
Total		33.0 kWh/gross ft^2/yr for electricity	44.4 kWh/gross ft^2/yr for electricity
		0 Btu/gross ft^2/yr for natural gas	54.3 Btu/gross ft^2/yr for natural gas
		112.7 kBtu/gross ft^2/yr site energy total	151.6 kBtu/gross ft^2/yr combined site for electricity and gas (10)
			\$2.71/gross ft^2/yr for electricity and gas

Notes:

1. W/cfm for the supply and exhaust air handlers represents the fan nameplate horsepower and flowrate. (68 hp (supply) + 52 hp (exhaust)) x 746 W/hp / (45,500 cfm (supply) + 39,809 cfm (exhaust)) = 1.04 W/cfm
2. 39,809 cfm (total cfm based on exhaust) / 77,875 gross ft^2 = 0.51 cfm/gross ft^2
3. ((1.11 W/cfm x 45,500 cfm (supply)) + (0.97 W/cfm x 39,809 cfm (exhaust))) / 77,875 gross ft^2 x 8760 hours / 1000 = 10.0 kWh/gross ft^2
4. ((1 kW/ton x 125 tons x 2891 hours) + (0.69 kW/ton x 122 tons x 1752 hours)) / 77,875 gross ft^2 = 6.5 kWh/gross ft^2 (assumes the GSHP runs 1/3 of the year in cooling mode and the chiller annually runs 20% full load equivalent)
5. 121,500 W (from ESPC audit data) / 77,875 gross ft^2 = 1.56 W/gross ft^2
6. 438,295 kWh (from ESPC audit data) / 77,875 gross ft^2 = 5.6 kWh/gross ft^2 (equates to lighting average on-time of 3607 hours/yr)
7. 93,600 W (from ESPC audit data) / 77,875 gross ft^2 = 1.20 W/gross ft^2
8. 500,906 kWh (from ESPC audit data) / 77,875 gross ft^2 = 6.4 kWh/gross ft^2 (equates to process load average on-time of 5352 hours/yr)
9. 345,353 kWh (from ESPC proposal data) / 77,875 gross ft^2 = 4.4 kWh/gross ft^2/yr (equates to heating plant operation 567 hours full load equivalent)
10. Data presented as site Btu (1 kWh = 3412 Btu). To convert site to source Btu, multiply site Btu for electricity by 3. Note: Ada has approximately 3659 heating degree-days base 65°F and 1859 cooling degree-days base 65°F (Oklahoma City weather data).

consumption, flow rates, and temperatures. Run times of equipment can be verified along with totalization reporting. This system can produce real-time energy reports, and the information is available electronically on-site and by remote access.

Lessons Learned

The final outcome of the ESPC project at the Ada Lab is very positive in terms of the energy and cost savings and reduced environmental impacts being realized by the EPA. However, the project experienced significant delays and additional expenses due to several factors that could have been prevented if addressed by both the agency and ESCO during the early development stages. Therefore, for future projects:

- The ESCO project management, designers, and construction subcontractors should be selected with demonstrated expertise in laboratory systems and high performance buildings (i.e., VAV laboratory ventilation system requirements).
- Greater development of ECM system designs in ESPC final proposals and more detailed design requirements for laboratory facilities is warranted due to the more stringent operating requirements and more complex systems (compared to typical office buildings).
- The agency should provide an on-site, full-time project manager with appropriate experience and continuity to serve as single point-of-contact for oversight, approvals, and review comment consolidation.

- The agency should also identify key reviewers at the beginning of the project, including reviewers for engineering, safety, security, maintenance, and operations.
- The agency team must be especially involved during project development and design approvals and tightly enforce submittal and approval requirements.
- The system design must be fully completed, reviewed, and approved prior to issuing the Notice to Proceed with installation.
- The performance contract should include clear scope and specifications for laboratory system retrofit commissioning to ensure a common understanding of design intent and successful results. Commissioning experts should be involved beginning at the pre-design phase.
- And any ground source geothermal heat pump system installation should include bore field survey and mapping for underground conditions and utilities before drilling wells.

Summary

The EPA used an ESPC to upgrade the entire mechanical system at the Ada Lab at no initial capital or construction cost, although costs were incurred to address unplanned project implementation issues. As a result of the ESPC, annual energy consumption has been reduced by 45%. The ESCO also provides operation and maintenance services. Although several difficulties were encountered that resulted in significant project delays, the lessons learned are invaluable to both agencies and ESCOs pursuing ESPCs in laboratory and high performance facilities. The ongoing attention to energy use and system efficiency through the ESPC assures that the Ada Lab will be able to meet its programmatic mission for many years in an environmentally responsible manner.

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