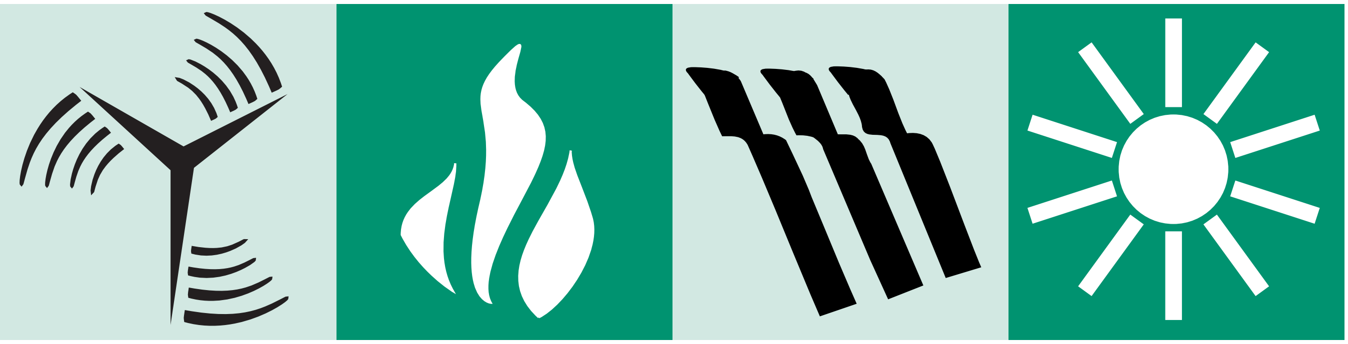

LABORATORIES FOR THE 21ST CENTURY: CASE STUDIES

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THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY, ANN ARBOR, MICHIGAN

Introduction

The U.S. Environmental Protection Agency's (EPA) National Vehicle and Fuel Emissions Laboratory (NVFEL) in Ann Arbor, Michigan, has been operating since 1971 and has a track record of pushing the limit on energy-efficient operations. Its ongoing mission is to advance clean vehicle fuels and technologies, which requires extensive testing and research in a tightly controlled environment. In 1998 the EPA established a site specific Energy Savings Performance Contract (ESPC) with NORESCO, one of the largest and most experienced energy service companies in the United States, to replace its obsolete and aging heating, ventilation, and air conditioning (HVAC) system, and institute a series of operation practices to ensure the new system would serve the needs of the laboratory while maintaining the highest possible degree of energy efficiency.

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EPA
United States
Environmental Protection
Agency

United States
Department
of Energy

FEMP
FEDERAL ENERGY MANAGEMENT PROGRAM

This study describes how the EPA was able to reduce the laboratory's annual energy cost by 60% and water consumption by 60%. It is geared toward architects and engineers who are familiar with laboratory buildings and is one in a series produced by Laboratories for the 21st Century, a joint program of the EPA and the U.S. Department of Energy (DOE). These case studies exemplify the "Labs21" approach, which encourages the design, construction, and operation of safe, sustainable, high-performance laboratories.

The new HVAC system uses state-of-the-art digital controls, incorporates variable air volume on supply and exhaust systems, provides for recirculation of air in certain testing cells, and allows for energy recovery from the exhaust air stream. The unique gas-fired chiller/heaters provide the ability to heat and cool from a single piece of equipment while avoiding the high electrical demand charges associated with more traditional electrical chillers.

The system was fully operational in March 2001 and has completed its first full year of performance. This case study highlights the features of the system and discusses the system efficiency and diagnostic monitoring points that are used to maintain peak performance and troubleshoot environmental control problems.

Project Description

The design effort was guided by the following goals established by the EPA at the beginning of the procurement process:

1. *Meet or exceed Federal energy reduction mandates*, as prescribed by the Energy Policy Act of 1992 (EPAct), which requires 20% site energy reduction relative to a 1985 baseline in Federal facilities by 2000, and Executive Order 12902, which requires an additional 10% by 2005 (30% total).
2. *Reduce power plant source emissions*, consistent with the EPA's mission of environmental protection.
3. *Optimize energy cost savings*.
4. *Restore obsolete and aging infrastructure*.
5. *Eliminate or replace* chlorofluorocarbons (CFCs) with a refrigerant material that is consistent with EPA guidance and reflects sound engineering practices.
6. *Minimize energy waste* by cost-effectively eliminating as much energy waste as possible.
7. *Maximize the use of the waste energy streams*, to feed other processes (where cost effective).
8. *Use renewable energy* to meet the requirements of sections 304 and 307 of Executive Order 12902, which establishes a goal for Federal facilities to use photovoltaic, solar thermal, passive solar, biomass, wind, geothermal, hydropower, and other alternative technologies, such as cogeneration, where cost effective.

The project goals were intended to push the contract bidders to focus on many of the Federal energy efficiency and emission reduction goals in addition to the cost savings of the typical ESPC.

To fulfill its contract, NORESCO accomplished the following:

1. Installed two York Millennium two stage absorption chiller/heaters rated at 440 tons and 575 tons of cooling, respectively, a new cooling tower, and one 3200 MBtu/h Bryon hot water generator.
2. Installed 34 air handling units (AHUs), customized according to planned operation.
3. Installed a 1200-point energy management system.
4. Replaced old motors with high-efficiency equivalents.
5. Converted once-through cooling water systems to closed loop cooling.
6. Installed power factor correction.
7. Installed a 200-kW ONSI fuel cell.

The awarded project includes full operation and maintenance for 22 years as allowed by ESPC legislation. The EPA selected this option to ensure efficient operation and performance of the retrofit as guaranteed by NORESCO.

The ESPC process allows an agency to implement an energy efficiency project without the usual constraints of capital funded projects. The project cost is paid from the guaranteed savings over the length of the contract. For this project several energy service companies (ESCOs) were given the opportunity to provide an initial project proposal. Each proposal was reviewed and scored according to source selection criteria, and one ESCO was chosen to provide a detailed proposal. Following approximately 6 months of detailed proposal development the NORESCO final proposal was again reviewed and negotiated to receive the final award. The total process took approximately 18 months. Today, EPA could use the DOE Regional Super ESPC contract to achieve the same result in less time.

The awarded contract called for an installation period followed by 22 years of complete system operation and performance guarantees. The total investment was slightly in excess of $10.5 million, requiring annual contract payments of approximately $1 million, including annual operation costs of $200K. The annual savings guarantees are slightly in excess of the required payment. The EPA could have lowered the annual payment by some small margin to retain some of the savings, but that would have added one or more years to the contract length and increased the total amount of interest.

Because the system is very complex and because the laboratory was required by contract to maintain the ability to conduct near normal operations, the installation of this project required 24 months. Normal operation was a considerable challenge, as the new central plant was based on hot water distribution while the previous central plant was steam based. This meant that both systems had to operate simultaneously until the HVAC system could be completely switched over.

Design Approach/Technologies Used

By opening up the entire facility to the retrofit effort, NORESCO was able to design a fully integrated system that provided a level of redundancy and flexibility that was not present in the original system.

The previously installed CFC refrigerant chiller capacity of more than 2000 tons had contributed to system peak electrical demand of 2700 kW. The installed gas-fired York chiller/heaters, in conjunction with the other system improvements, reduced the system peak to slightly more than 900 kW.

The electrical demand and usage graphs show similar dramatic impacts. (All graphs are measured data.) During 2001, the on peak demand was reduced by 1800 kW, and energy use was reduced by 6 million kWh compared to the baseline. The limited 2002 data available indicate similar performance.

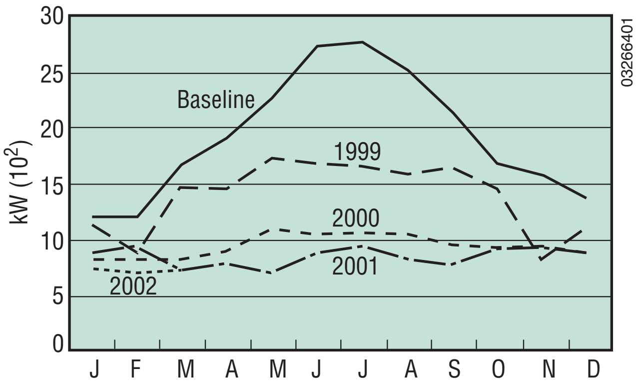

Figure 1. On peak demand

From a regional perspective, this reduced electrical requirement further translated to significant power plant emission reductions: 8910 tons of CO_2, 16.5 tons of NO_x, and 26.5 tons of SO_2 power plant emissions were eliminated with this project. The ability to run the chillers in simultaneous heating and cooling modes also allowed chilled water supply throughout the year for process cooling loads, which eliminated the practice of using once through domestic water for cooling, thereby reducing domestic water consumption by 60%, or more than 14 million gallons of domestic supply.

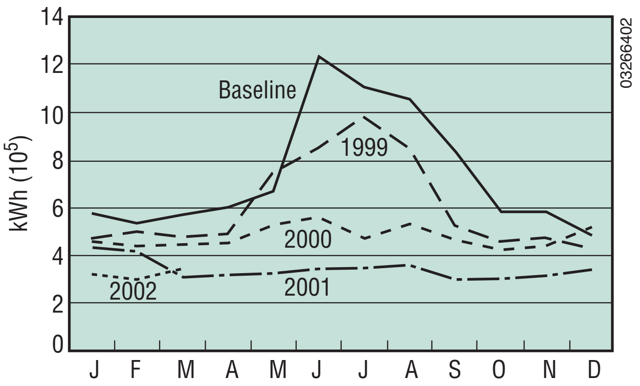

Figure 2. Electricity consumption

It was assumed that the use of direct-fired chillers would increase the natural gas usage in the summer months, but the overall usage fell for the winter and summer months. The total annual gas usage was reduced by 35%.

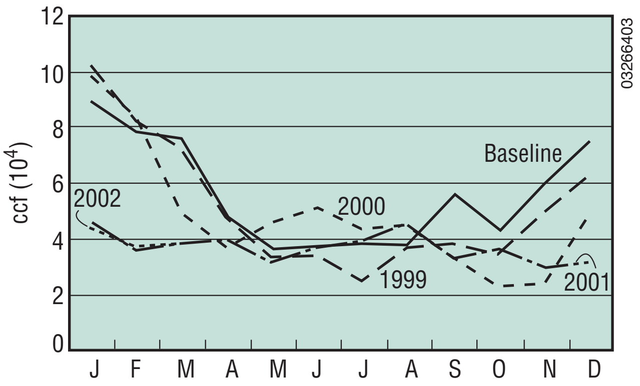

Figure 3. Gas consumption

Additional design considerations included the ability to recirculate air in many of the test laboratories (cells). These test cells are equipped to hold an engine or sometimes an entire automobile or full-size truck. Temperature and humidity tolerances are typically ±2°F and ±5 grains humidity (7000 grains/lb) based on operating range specifications of 68°–86°F and 40–80 grains per pound of dry air humidity (RH range of 21%–78% ±2% humidity). Handling the huge changes in heat load was a challenge, particularly during the typical summer design day. The test cell air handlers were designed with enthalpy energy recovery wheels to maximize heat and moisture transfer and, for the largest test cells, evaporative heat piping was added to provide an added degree of cooling capability. A typical high-duty test cell AHU is shown Figure 4.

The outdoor air supply and exhaust are shown on the left side of the diagram. Air first passes through the enthalpy wheel and through typical heating, cooling, and reheating coils before entering the test cell space. Although the heating, cooling, and reheating sequence is not the most energy efficient, the design engineers felt that the tight tolerances and potentially extreme changes in the test cell during a testing sequence required the conservative strength of this design.

Exhausted air can be channeled through any of three paths. If the return airflow meets the required specifications, it can be channeled directly back to the test cell through return path 1. If additional conditioning is required, it can be channeled

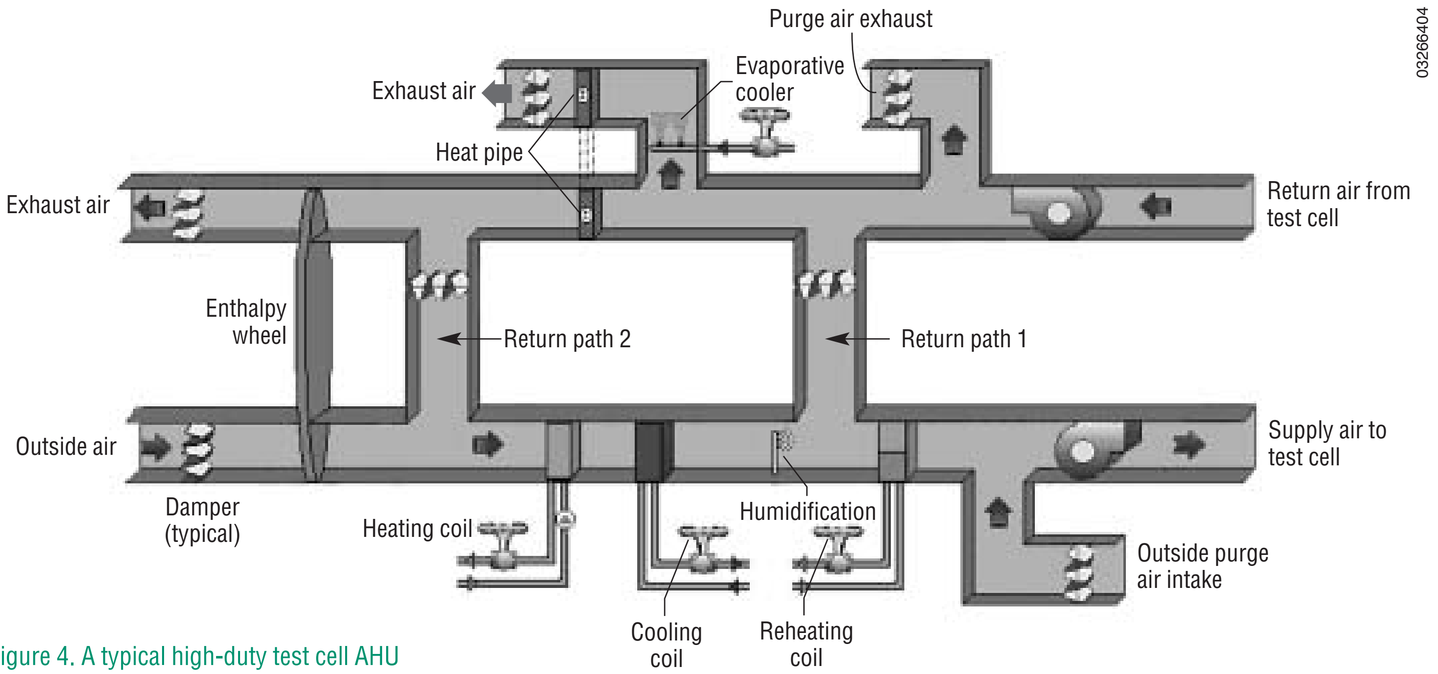

Figure 4. A typical high-duty test cell AHU

through return path 2. In both cases 20% of outside air is constantly introduced into the test cell. If the exhaust return air is too hot for the cooling coil to condition (based on outside air conditions), a portion of the air can be passed through an evaporative cooling section (shown on the top-middle of the diagram) and then through a heat pipe. The heat pipe cools the remainder of the exhaust return air stream, providing indirect evaporative cooling. The indirect evaporative cooling section is used only when ambient air moisture content is low and test cell heat load is high. In all cases the enthalpy wheel tempers the incoming air to more closely match the test cell conditions. The system also has the capability to quickly purge the test cell in an emergency, including some temperature control to prevent freezing conditions during the winter.

Overall, the entire AHU system is capable of delivering 354,000 cubic feet per minute (CFM) of supply air (reduced from the original system capacity of a constant volume of 410,470 CFM); however, the extensive use of variable frequency drives and a variable testing schedule have made accurate estimates of typical air flow difficult. The total 1015 tons of system cooling can meet all cooling requirements.

The 200-kW fuel cell was added during the initial design. The availability of clean power and the recovery of waste heat are beneficial. However, the high cost of natural gas during 2001 made cost-effective operation difficult. Gas prices have since decreased to historical normals. The fuel cell electrical and thermal outputs are connected to primary electrical and heating systems. The fuel cell serves part of the base load of the facility, reducing electrical demand by almost 200 kW. Even though it is grid connected, surplus energy will probably not be transmitted to the serving grid. The connection of the fuel cell waste heat loop is shown in Figure 5.

The gas to electricity base efficiency of the fuel cell averages 36.5%. Counting the recovered heat transferred to the heating loop the efficiency is increased to as high as 75%. One challenge of the recovered heat is the operating temperature of the primary hot water loop. Originally the fuel cell was to have been configured with the high heat output option that would have delivered hot water in excess of 250°F. Because of some procurement challenges, the low temperature option (maximum output temperature of 160°F) was installed. Even with this limitation, the system efficiency is affected little. The total efficiency averages 65%.

Commissioning Process and Measurement and Verification

The ESPC leaves much of the commissioning process in the hands of the contractor. The contractual requirements of the measurement and verification (M&V) plan and tracking of several system performance parameters ensure that the system is operated correctly and efficiently. The complex nature of the test cell tolerances does not allow the system operator to hide improper operation by making simple adjustments.

The system operation is measured through two sets of parameters to maintain the system at peak operating efficiency: The M&V plan calls for annual analysis; the system diagnostic programming provides real time feedback based on expected performance parameters. The M&V action provides system savings based on the measurement plan and a variety of baseline parameters.

As described in the M&V plan:

> To gather data for the M&V function, the EMS continuously logs appropriate variables and calculates energy usage by system

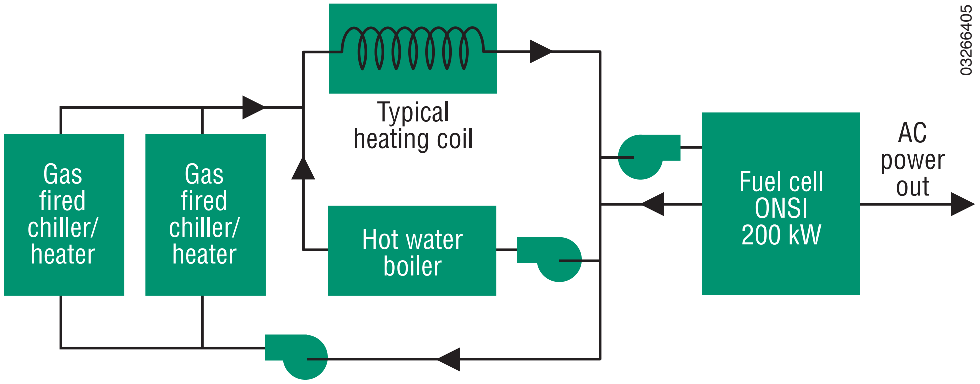

Figure 5. Fuel cell waste heat loop

and by measure, using a dedicated computer networked to the EMS. NORESCO on-site operations personnel have access to the stored data, and review it regularly to verify system performance. The stored data is downloaded monthly by the NORESCO on-site staff and sent to the NORESCO M&V group for processing.

This process is completely automated so site staff always have access to the data and can review past performance to continuously improve system response and performance. During the first year of system operation, quarterly M&V reports were prepared to closely track system savings and performance. Now that the stability of these reports has been verified, the reporting is done annually.

The system diagnostic programming constantly monitors the operation of the electronic control modules to detect inefficient operation and notify the plant operator. Monthly reports of system diagnostics ensure the EPA that the system is being operated at optimum efficiency. The system diagnostic report is prepared each month. The ongoing system diagnostics are designed to look at key system performance factors to ensure efficient everyday operation. Examples of these diagnostics include:

1. Position of AHU bypass damper when the test cell is within specifications.
2. Position of AHU hot and chilled water valves when the test cell is not being used.
3. Low chilled water system temperature differential.
4. Chiller/heater Btu input versus Btu output.

Whenever the measured parameters fall out of expected ranges, the system operator is alarmed. The monthly alarms and operator follow-up are reported to the EPA.

A challenge of this approach was how to define allowable tolerances to avoid alarms during normal dynamic operation of the AHU system. The test cell operation allows the space conditions to move from normal building temperatures and loads to heat output from a 500 horsepower engine completing a high load emission test. This test may last only 10 minutes, then the system will revert to normal building loads. Currently the system examines operation at 15-minute intervals when the system is in steady state mode. The alarm parameters are reviewed monthly to determine whether any modifications are necessary.

Summary

EPA used an ESPC to upgrade the entire mechanical system at NVFEL at no initial cost. The annual energy cost was reduced by 60%; domestic water use was reduced by 60%. The ESPC contractor also provides the operation and maintenance services. The ongoing attention to energy use and system efficiency through the ESPC contract provides comfortable assurances that the laboratory will be able to meet its programmatic mission for many years in an environmentally responsible manner.

Acknowledgments

Thanks are due to Phil Wirdzek and Steven Dorer of EPA, Timothy Kehrli of TLK Consulting, and Otto Van Geet of NREL for their contributions to this Laboratories for the 21st Century case study.

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Building Metrics for the NVFEL

System	Key Metrics	Annual Energy Use (based on design data)	Annual Energy Use (based on measured data)
Ventilation	Exhaust = 0.52 W/cfm Supply = 0.87 W/cfm(2) Total = 0.73 W/cfm(1) (2.6 cfm/gross ft^2)(2)	33.2 kWh/gross ft^2(3)	Not separately analyzed (NA)
Cooling Plant	1015 ton peak gas fired absorption chillers	NA	Included in heating plant use
Lighting	2.0 W/gross ft^2	9 kWh/gross ft^2(4)	NA
Process/Plug	1 W/gross ft^2	5.3 kWh/gross ft^2(5)	NA
Heating Plant	3200 MBH + chillers + 200 kW fuel cell	NA	236,640 Btu/gross ft^2 Central plant, 335,240 Btu/gross ft^2 including fuel cell use
Total		47.5 kWh/gross ft^2 for electricity 162,118 Btu/gross ft^2 for electricity	28.9 kWh/gross ft^2 for electricity(6) 98,636 Btu/gross ft^2 for electricity 335,276 Btu/gross ft^2 combined site for electricity and central plant gas(7) 433,880 Btu/gross ft^2 combined site for electricity and total gas(7)

Notes:

1. W/cfm for the supply/exhaust air handlers represents the fan nameplate horsepower. Ventilation is for test chambers that have short runs of ductwork.
2. 354,000 CFM/135,000 gross ft^2 = 2.6 CFM/gross ft^2
3. 0.73 W/cfm x 2.6 cfm/gross ft^2 x 8760 h x 2/1000 = 33.2 kWh/gross ft^2
4. 2.0 W/gross ft^2 (assumed) x 4534 h/1000 = 9 kWh/gross ft^2 (assumes lights are on 87.2 h/wk)
5. 1.0 W/gross ft^2 (assumed) x 5256 h/1000 = 5.3 kWh/gross (assumes equipment is operating 60% of the time. Most of the heat load is produced by running engines, not electricity.
6. Part of the electricity is generated on site by the fuel cell and used on site, the 28.9 kWh/gross ft^2 is purchased electricity.
7. Presented in site Btu (from actual energy bills for 9/00–8/01). To convert to source Btu, multiply site Btu for electricity by 3. Ann Arbor has 6,569 heating degree days and 626 cooling degree days.

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U.S. Department of Energy
Office of Federal Energy Management Programs
www.eren.doe.gov/femp/

Prepared at the
National Renewable Energy Laboratory
A DOE national laboratory

DOE/GO-102002-1630
December 2002

Printed with a renewable-source ink on paper containing at least
50% wastepaper, including 20% postconsumer waste