Final Draft

SAND98-1200C
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IMPORTANCE OF ENERGY EFFICIENCY IN THE DESIGN OF THE PROCESS AND ENVIRONMENTAL TECHNOLOGY LABORATORY (PETL) AT SANDIA NATIONAL LABORATORIES, NEW MEXICO (NM)

CONF-980654--

(Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-ACD4-94AI85000)

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JUN 08 1998
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ABSTRACT:
As part of the design of the Process and Environmental Technology Laboratory (PETL) in FY97, an energy conservation report (ECR) was completed. The original energy baseline for the building, established in Title I design, was 595,000 BTU/ft.^{2}/yr, site energy use. Following the input of several reviewers and the incorporation of the various recommendations into the Title II design, the projected energy consumption was reduced to 341,000 BTU/ft.^{2}/yr. Of this reduction, it is estimated that about 150,000 BTU/ft.^{2}/yr resulted from inclusion of more energy efficient options into the design. The remaining reductions resulted from better accounting of energy consumption between Title I ECR and the final ECR.

The energy efficient features selected by the outcome of the ECR were:

- Energy Recovery system, with evaporative cooling assist, for the Exhaust/Make-up Air System
- Chilled Water Thermal Storage system
- Premium efficiency motors for large, year-round applications
- Variable frequency drives for all air handling fan motors
- Premium efficiency multiple boiler system
- Lighting control system

The annual energy cost savings due to these measures will be about $165,000. The estimated annual energy savings are two million kWhrs electric, and 168,000 therms natural gas, the total of which is equivalent to 23,000 million BTUs per year. Put into the perspective of a typical office/light lab at SNL/NM, the annual energy savings is equal the consumption of a 125,000 square foot building. The reduced air emissions are approximately 2500 tons annually.

KEYWORDS: energy efficiency, life-cycle costs, commissioning, premium efficiency, energy conservation, energy conservation report, DOE Order 430.2, 10 CFR 435, ASHRAE Standard 90.1, energy use benchmarking.

INTRODUCTION

The mission of the Process and Environmental Technology Laboratory (PETL) is to provide DOE with an improved analytical materials science facility to support SNL/NM's new production capability in non-nuclear weapons components. PETL will provide facilities to develop and apply environmentally conscious manufacturing processes that will reduce the use of toxic materials associated with the production and dismantlement of nuclear weapons. The construction of the PETL was awarded on a "best value" procurement method and is scheduled to begin in May 1998 and completed in two years. It is anticipated that the facility will be fully operational beginning in fiscal year 2001.

PETL was designed as a three-story building oriented in an east-west direction. It will consist of 130 offices and 60 laboratories with 150,640 gross square feet and house 250 persons. About 60,000 square feet of the net space will be allocated to laboratories, all of which is located in the interior of the building The mechanical equipment, including one large-capacity exhaust and make/up air system operating 8760 hours/year, is contained in the basement and penthouse. A portion of the lab had to meet the requirements of an H-6 (UBC) occupancy and ANSI Z-9 guideline. The energy use at the PETL will be driven primarily by lab equipment use and the exhaust requirements. The result is a building that is characteristically energy intensive.

As part of the design for PETL, an energy conservation report (ECR) was completed. The need to complete an ECR and include energy efficiency into the design of new buildings is based on Federal and Department of Energy (DOE) requirements. As a Government Owned, Contractor Operated (GOCO) Facility, SNL/NM is required to comply with the Department of Energy (DOE) Order 430.2 (In-House Energy Management). This order was entered into the SNL/NM Maintenance and Operations Contract baseline of directives. New designs must comply with 10 CFR 435, Energy Conservation Performance Standards for New Federal Buildings. This regulation incorporates similar requirements and guidelines found in the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 90.1, Energy Efficient Design of New Commercial Buildings. For buildings greater than 10,000 ft^2 DOE Order 430.2 requires that an ECR be prepared and that the building is commissioned to ensure construction meets the design intent before the facility is accepted into the federal inventory.

The SNL/NM Facilities Design Manual provides guidance based on design and construction experience to ensure compliance. The PETL Project Design Criteria incorporated the Design Manual by reference, and provided specific guidance. The prescribed design approaches included: variable air volume, variable frequency drives, economizers for air handling systems, heat exchangers for winter economizer chilled water

production, and energy efficient lighting. It also called for investigation of heat recovery from exhaust air and smart controllers for the lighting system.

The PETL Design team submitted an ECR at the Title I complete phase; the ECR showed an energy baseline for the building of 595,000 BTU/ft^2/yr. This value exceeded by 20% the average annual energy use of SNL/NM's energy intensive facilities, and would have been a penalty in trying to meet the DOE Order 430.2 reduction goals for this class of building. It appeared that the design team was utilizing standard off-the-shelf approaches and had not really begun to fully analyze the alternative systems. It was at this point that the SNL/NM Energy manager became involved in evaluating the PETL design for energy efficiency.

Despite DOE requirements and the advantages of energy efficient design, the focus of a design team continues to be the production of a design that meets the structural and operational demands of the customer within the specified schedule and at the lowest cost. In the present paradigm, designing for energy efficiency often lengthens the schedule and frequently costs more. To realize the full worth of an energy efficient design, one must consider the life cycle costs of the building, as well as the overall conservation of resources, and the societal benefit. The challenge to the site Energy Manager, the design team, and ultimately the customer is not only to understand and meet the requirements, but, also to apply the correct accounting and analysis methods to the life of the design, and understand that an energy efficient design performs better and truly costs less. This requires thinking outside the traditional engineering box . Advantages of designing for energy efficiency include:

- Reduced Life Cycle Costs. Carefully considering cooling, heating, process and electrical loads can produce designs that yield significant annual savings. Examples of energy efficient design features include: right-sized and high or premium efficiency equipment; optimized systems; well-formulated sequence of operations; optimizing equipment run-time; good commissioning, including control systems and training. These savings can offset the initial costs that would have to be paid for tighter envelopes and premium efficiency equipment. These savings may be realized through reduced energy, maintenance, water, natural gas, waste disposal, and chemical costs.
- Reduced Pollution. Energy efficient designs result in reduced releases of pollutants to the environment. To account for the total benefit, one must consider both source and on-site reductions. Examples include:
  - Source. Of the electric mix provided by the Public Supply Company of New Mexico (PNM), the SNL/NM provider, 57% comes from coal-fired plants. A reduction in electrical demand results in reduced emissions of CO_2, SO_2, NO_x,
  - On-Site. Reductions in the use of natural gas used for heating and steam production directly reduce the emission of CO_2, SO_2, NO_x, CO and particulates.

  Attaching costs to pollutant releases is difficult, however, there have been attempts to do so. For instance, EPA estimates a societal cost of $8.40/ton of CO_2 emitted and $0.75/pound of SO_2 emitted.

- Conservation of Resources. Similar to reduced pollutants, both source and on-site resources are conserved. Examples include water and coal at the source.
  - The author previously worked at a coal-fired power plant, which burned over 700 tons of coal/hr at full load (over four million tons/yr) and used over 17,000 acre-feet annually of river water and ground water.
  - On-Site. Resources that may be conserved on-site include water and chemicals (cooling towers) and natural gas (boilers)
- Increased Awareness. Designing, constructing and operating an energy efficient building, and quantifying the benefits sets a good example for future designs.

PROCESS AND METHODS

The process for incorporating energy efficient measures into the Title II design for the PETL facility essentially followed the typical design sequence. The key point was having energy experts involved in the process. The SNL/NM Energy manager assumed this role, with support from the Energy Manager of the DOE/Albuquerque Office. As a consultant to the design team, the role of the energy manager included:

- Providing guidance on compiling the ECR and what alternatives should be studied .
- Dispelling "rules of thumb" engineering, in favor of more energy efficient designs.
- Providing recommendations on energy efficient considerations.
- Helping to ensure that the base case design meets the minimum requirements of 10 CFR 435.
- Helping to assure that an Energy Systems model is accurately completed for the base case design and each alternative. In this case, DOE 2.1E Energy Analysis Software was used.
- Ensuring that Life Cycle Costing (LCC), according to 10 CFR 436, is completed for the base case and each alternative considered.

For the ECR to serve as a value-added tool in the Design Decision process, the energy models must be as accurate as possible, i.e., very reflective of the design, system sizes, and all other building parameters. The LCC models must be very accurate, since final selection of systems hinges on the results. The analysis program, National Institute of Standards and Testing (NIST) BLCC version 4.3, is input with first cost, annual energy use, applicable energy rates, estimated maintenance costs for the base case and for each alternative, to arrive at the present value of the each system's life cycle costs. All other things being equal (e.g. needs of the building occupant being met), the system with lowest life cycle cost is selected. As needed, other economic evaluations like savings to investment ratio (also called benefit to cost ratio), and annual Return on Investment (ROI) are used to confirm the selection.

At the present time, there is no stated intent or requirement to report the decrease in pollutants or resources conserved, resulting from energy use reductions. However, it is clear that pollutant reductions and conserved resources are additional benefits of an energy efficient design. Following the completion of the ECR, estimates of the pollutants reduced and the resources conserved were calculated, based on the energy savings. It is hoped this will be a continuing practice.

RESULTS

The completed Title II design reduced the original energy baseline for PETL from 595,000 BTU/ft.^{2}/yr. to 341,000 BTU/ft.^{2}/yr. Of this reduction, it is estimated that about 150,000 BTU/ft.^{2}/yr resulted from inclusion of more energy efficient options into the design. The remaining reductions resulted from better accounting of energy consumption between Title I ECR and the final ECR. The measures resulting in these reductions fall into three categories, each of which is discussed below. A fourth category, Commissioning, is a new process employed to assure the energy performance modeled in the design is achieved or surpassed.

Envelope Improvements
The envelope that met the minimum requirements of 10 CFR 435 was selected. Additional insulation in the roof and wall was analyzed, but not selected. Window upgrades were analyzed (late in Title II), but not selected. Effective use of daylighting was designed for, with appropriate use of daylighting controls.

HVAC System Improvements
The base case, as cited above, included many energy efficient measures that are now commonplace, such as variable air volume, air side economizer, high efficiency motors, and primary/secondary water systems with variable volume pumping on secondary loop. All new SNL buildings are designed with a full DDC Energy Management and Control System (EMCS).
The LCC effective improvements included the Chilled Water Thermal Storage system, the Energy Recovery system and Variable Frequency Drives for all fan motors. The premium efficiency multiple boiler system and premium efficiency motors were selected based on a less rigorous economic analysis, since the additional cost was relatively small. The Energy Manager introduced the concept of Chilled Water Thermal Storage, matching it to project needs and SNL needs, to the Project Mechanical Engineer and aided in its justification.

Lighting System Improvements
The base case has the majority of all fluorescent fixtures with high frequency electronic ballasts and T-8 lamps, compact fluorescents instead of incandescents (with some exception), photoelectric control of exterior lighting. The upgrades include daylighting controls to effectively control the use of supplemental artificial lighting, occupancy sensor control of lighting in common use areas, and microprocessor-based timer control of laboratory lighting. Occupancy sensors for the office areas were considered, but not selected.

Building System Commissioning
The PETL project includes a detailed Commissioning Specification which the Contractor bid upon and hence is fully cognizant of the requirement to ensure that all installed systems

are tested in an integrated manner for full, functional performance. Integrated whole building systems commissioning is very important for new buildings, as well as being a new DOE requirement (DOE O 430.2). According to one SNL Project Manager, building commissioning is imperative to pass a Readiness Assessment and begin operations in a new laboratory building.

ENERGY AND COST SAVINGS

Table I provides a summary of the cost and energy savings associated with each of the improvements. Energy savings are presented as kilowatt hours (kWhr) for electrical savings, or therms (=100,000 BTUs) for natural gas savings. Two basic economic indicators, simple payback and annual ROI are presented for each improvement, where:

$$\text{Payback} = \frac{\text{Investment}}{\text{Annual Savings}}$$

$$\text{ROI} = \frac{(\text{Annual Savings}) - (\text{Investment/Useful life})}{\text{Investment}}$$

COST FOR BASELINE SYSTEM = $666,120

	Useful life (yrs)	Additional Cost	Electrical Savings (kWhr/yr)	Natural Gas Savings (therms)	Energy Savings ($/yr)	Simple Payback (yrs)	ROI (%)
1. Variable Frequency Drives instead of inlet vanes for fans' variable volume control	10	109,600	1,082,300	0	61,700	1.8	46.3
2. Energy Recovery System with Evaporative Cooling	25	329,600	249,400	90,400	31,800	10.4	5.6
3. Chilled Water Thermal Storage System	25	239,500	55,670	0	104,000	2.3	39.4
4. Premeium Efficiency motors	10	6,930	54,700	0	3,200	2.2	36.2
5. Premium efficiency multiple boiler system	25	8,750	14,500	29,500	8,200	1.1	89.7
6. Lighting Control system	10		130,000	0	7,400		
7. Validating lab equipment diversity			100,000	17,500	5,700		
8. Fundatmental improvements on duct design			300,000	30,000	17,100		
TOTAL		694,380	1,986,570	167,400	239,100	2.9	

Notes

- though energy recovery system has a long simple payback, it was shown to have a lower life cycle cost and a savings to investment ratio (SIR) > 1 (was 1.36)
- No analysis was included in the ECR to support the selection of the additional lighting control elements (lighting control cabinet(s) for laboratory lighting, occupancy sensors for common use areas, daylighting control for daylit common areas) – this was an oversight, but probably due to the fact that the ECR focused heavily on the mechanical systems analysis.
- The savings for the Chilled Water Thermal Storage system include documented maintenance savings of $35,000 per year. Note there are little energy savings, but very substantial energy cost savings; that's because the benefit of chilled water storage is shifting load from peak times to off peak times, avoiding electric demand charges.
- The improvements more than double the First Cost of the baseline system, but the simple payback for the improvements to the mechanical system is about three years

LCCA (life cycle cost analysis) is used when comparing mutually exclusive alternatives (where choosing one alternative precludes selection of the other). All costs (first cost + lifetime energy costs + lifetime maintenance costs) are brought to present value.
Ex: Baseline system LCC compared to LCC for Chilled Water Thermal Storage System

LCC (baseline) = $13,647,960; first cost is less than 5% of LCC
LCC (ChW storage) = $12,580,010: first cost is 7.2% of LCC, and the life cycle (25 years) savings are over 1 million dollars.

So, indeed, the design cost more and it took longer, and the capital cost is more (by 50%), but the system will better serve the owner over its life cycle.

POLLUTION PREVENTED

The energy savings resulting from the energy efficient design changes to PETL result in significant source and on-site pollutant reductions. Table 2 summarizes these results. Because SNL/NM purchases its electricity from PNM, the electrical savings are quantified as pollutant source reductions. These reductions are based on emission factors, established by EPA's Energy Star program, based on the percentage of the source electric power generating plant with the region. The reduction in natural gas usage can be quantified as an on-site pollutant reduction. Energy efficient features included in the PETL design will reduce the natural gas SNL/NM burns on site.

Note that reductions in carbon dioxide (CO_2) emissions are listed, even though CO_2 is not a regulated emission at this time. However, anthropogenic CO_2 emissions were addressed at the December 1997 Kyoto Climate Change conference and a treaty was signed. The treaty still needs to be ratified by the U.S. Senate until the target reductions become law, but Directors of 11 DOE laboratories, including Sandia National Laboratories, recommend developing a wide range of technologies for reducing greenhouse gas emissions over the next several decades. In a study ("Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions") released April 22, almost 50 "technology pathways" are described that could eliminate the emissions of hundreds of millions of tons of carbon per year, including near-term ones such as high-efficiency lighting, super-insulating windows, passive solar heating and cooling and electric hybrid vehicles. The report concluded, "developing solutions sooner rather than later will be more effective in reducing greenhouse gas emissions. Postponing action could increase future costs and risks." Therefore, designing energy efficient buildings now, utilizing the best available, cost-effective technologies, is a positive step in the effort to reduce CO_2 emissions.

ELECTRICAL SAVINGS = 2 MILLION kWH
(EMISSION FACTORS FROM ENERGY STAR FOR REGION 6)

Pollutant	emission factor	Unit	pollutant reduction (lbs)	pollutant reduction (tons)
Carbon Dioxide	1.7	lb/kWh	3400000	1700
Sulfur oxides	2.2	g/kWh	9692	5
Nitrous oxides	2.5	g/kWh	11013	6

TOTAL (ELECTRIC) REDUCTION	3420705	1710

NATURAL GAS SAVINGS = 168,000 THERMS = 19.6 MMscf
(EMISSIONS FACTORS FROM AP-42,
UNCONTROLLED COMMERCIAL BOILER, <10MMBTU/hr)
(ASSUME AVERAGE GROSS HEATING VALUE = 850 BTU/scf)

Pollutant	emission factor lb/1MMscf	Unit	pollutant reduction (lbs)	pollutant reduction (tons)
Carbon Monoxide	21	lb/MMscf	412	0
Sulfur Oxides	0.6	lb/MMscf	12	0
Nitrous Oxides	100	lb/MMscf	1960	1
PM (10)	4.5	lb/MMscf	88	0
Carbon Dioxide	120000	lb/MMscf	2352000	1176
TOC	5.8	lb/MMscf	114	0

TOTAL (NATURAL GAS) REDUCTION	2354585	1177
TOTAL POLLUTANT REDUCTION	5775290	2888

RESOURCES CONSERVED

Recalling that about 57% of the PNM electric mix is coal-fired, 2 million kWhr savings is equal to about 1,140,000 kWhrs less coal-fired electricity use at SNL. Assuming a 5% electrical transmission loss, that is equal to 1.2 million kWhr savings at the coal-fired plant. Assuming a coal plant heat rate of 11,000 BTU/kWhr and coal heating value of 12,000 BTU/lb, the coal resource conserved is 550 tons/yr. Based on the annual water consumption and annual tons coal burned information cited earlier, that results in an annual water conservation of 750,000 gallons.

CONCLUSION

Lessons Learned

- Establish commitment early - Achieving reductions in energy use by design was a hard sell at times. Establishing a commitment early in the process would have been very beneficial. If all or most of the project team had been "on board" at the outset of the design process with the importance of designing for energy efficiency, the value of preparing an effective ECR would have been recognized and it would not have seemed like a burden. Over the final month of designs, there seemed to be a growing acceptance by members of the design team that this was a worthwhile endeavor.
- Consistency in calculations and documentation - It was difficult to determine in the ECRs where improvements had been made from Title I (October 1996) to Title IIA (July 1997) to Title II final (September 1997) because of lack of consistency in the energy analysis (DOE 2.1E) runs. This is in part attributable to refinements in the design which yield small changes in system selections, etc., but the ECR did not document whether the changes were due to accounting improvements or to system efficiency improvements.
- The ECR document excluded the 10 CFR 435 compliance forms, so it was not possible to determine the energy use for the compliant design. These forms were required by the Facilities Design Manual. However, the ECRs did state that all systems considered, including the base case, complied with the DOE Energy Conservation Manual, which incorporates the requirements of 10 CFR 435.

In the final analysis, the building was designed with a multitude of cost-effective energy efficiency measures. The projected energy intensity of the building is now much less than the average for the category of building to which PETL will most likely be assigned. Most of the annual energy use is attributable to the laboratory space, which must conform to code requirements. At the request of the Energy Manager, a separate energy analysis was run just for laboratory space (equipment and lighting) and the mechanical systems dedicated to that space. The results showed that over 80% of the annual building energy use is due to the laboratory space.

As long as the building is commissioned well, i.e., according to the Commissioning Specification and the resulting Commissioning Plan, the building will function properly at "ribbon-cutting", should meet the designed energy performance and will likely use less energy than predicted, which, of course, will prevent even more pollution.

The process should continue from here. The Energy Manager intends to have a "lessons learned" session regarding development and effectiveness of the PETL ECR document, to improve the process for future buildings. The intent of the Energy Manager is to institutionalize energy efficiency into the Facilities' Building process, from the planning/programming phase, through design to the construction and commissioning phase and including the operations and maintenance of the building mechanical, electrical and control systems.

Near term objectives include a comprehensive review and update of the Facilities Design Manual for energy efficiency considerations, just now underway. The intent is to make the effort followed in the development of the PETL Energy Conservation Report fairly routine when SNL Facilities constructs new or renovates existing buildings greater than 10,000 square feet. Resources that will be consulted in this effort include the Design Guide for Energy Efficient Laboratories by Lawrence Berkeley National Laboratories "A Team", the Technology Atlases (Space Cooling, Space Heating, Drivepower and Lighting) by E Source and Energy Use Benchmarking data compiled by the SNL Energy Manager.

Another planned initiative is to seek acceptance by Facilities Management of the Green Building concept, whereby Buildings are designed and constructed to have reduced impact on the environment and more favorable impact on employee health and productivity. The Sustainable Building Technical Manual, produced by Public Technology Inc. and the U.S. Green Building Technical Manual with funding by DOE and EPA, will be the principal resource consulted.

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2. Personal phone conversation with Bob Jarrett, Public Service Company of New Mexico, January 1997.
3. EPA Ann Arbor Laboratory Energy Savings Performance Contract RFQ (Request for Quote), viewed at "Laboratories for 21st Century" workshop, May 1998.
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Report Number (14) SAND--98-1200C
CONF-980654

Publ. Date (11) 199806
Sponsor Code (18) DOE/EM, XF
UC Category (19) UC-2000, DOE/ER