The Oak Ridge National Laboratory and the New Technology Demonstration Program

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ABSTRACT

The Oak Ridge National Laboratory is one of four National Labs implementing the Federal Energy Management Program's New Technology Demonstration Program for the Department of Energy. The Oak Ridge National Laboratory has an extensive history of working on energy-related projects in both the public and private domain. Work on this program is intended to bring the strength of the Oak Ridge National Laboratory technology development abilities and unique facilities to bear on the technical challenges associated with evaluating energy efficient technologies.

This paper describes some energy-related experiences at the Oak Ridge National Laboratory and the New Technology Demonstration Program at the Lab. The five technologies that the Lab is supporting in this Program are introduced. One of the technologies being evaluated, a retrofit system for rooftop units, is described in detail.

OAK RIDGE NATIONAL LABORATORY

The Oak Ridge National Laboratory (ORNL) is managed by Lockheed Martin Energy Systems, Inc., for the U.S. Department of Energy (DOE). The primary mission of the Laboratory is to perform leading edge Research and Development (R&D) in support of the nonweapons roles of DOE and to work in partnership with manufacturers and industry to strengthen the nation's competitive edge. Especially important elements of ORNL's mission are to perform basic and applied research, to provide the scientific and technical community technical expertise in the areas of research and development integration, technology development and transfer, and, through contributions to the national initiative, to improve science and math education.

Laboratory Missions

ORNL's programs are roughly divided between applied energy technologies and basic sciences. The Laboratory accomplishes its missions by utilizing a staff of 5000 personnel, including some 1500 scientists and engineers. Every year, ORNL hosts more than 27,000 visitors, including 4400 guest researchers and students.

A common theme uniting the Laboratory's diverse disciplines is energy: better ways to produce it, conserve it, efficiently use it, harness it, and measure its effect on life and the environment.

<u>Energy Technologies</u>

The Laboratory conducts applied R&D in several key technologies. The user facilities and various research laboratories provide a platform, in partnership with scientists and engineers from universities and industry, to conduct sophisticated research, analysis, and evaluation. *Energy efficiency R& D* seeks more efficient ways to use energy: better building "envelopes," advanced heating and cooling systems, more efficient electrical distribution equipment, strong new ceramics for high-temperature engines, and other energy-related developments. *Renewable energy* sources include fast-growing biomass, or energy crops, which can be converted to liquid or gaseous fuels. The *fission program* concentrates on improving nuclear power plants through better control systems, tougher materials, and inherently safe designs and fuels for a new generation of modular reactors. *Magnetic fusion* seeks to harness the power of the stars to supply clean, unlimited power for the future. Finally, *fossil energy research* explores way to tap coal, our most abundant fossil energy source, in ways that are efficient and environmentally sound.

Life Sciences and Waste R&D

ORNL researchers probe the processes, both microscopic and planetary in scale, that sustain the balance of life, (from unlocking the mysteries of DNA to modeling global climate change). ORNL researchers are also devising high-tech ways to manage the world's growing wastes; one innovative technique uses bacteria to digest contaminants in groundwater.

Basic Research

Underpinning the Laboratory's applied R& D in these and other fields is a strong tradition of fundamental science. Areas of experimental and theoretical research include physics (nuclear, atomic, and solid-state), chemistry, materials science, mathematics, and computer science.

ENERGY DIVISION

One of 17 research divisions at ORNL, the Energy Division's mission is to provide innovative solutions to energy and related issues of national and global importance through interdisciplinary R&D. The Energy Division is committed to:

- developing and transferring energy-efficient technologies,
- understanding the mechanisms by which societies make choices in energy use,
- improving society's understanding of the environmental, social, and economic implications of technology change,
- improving transportation policy and planning,
- enhancing basic knowledge in the social sciences as related to energy and associated issues, and
- providing a unique climate that allows engineers, physicists, environmental scientists, and social scientists to address major societal problems and to develop professionally in their respective disciplines.

The division's programmatic activities are embodied in three key areas: 1) energy use and delivery technologies, 2) energy and environmental analysis, and 3) transportation systems. *Energy use and delivery technologies* focus on electric power systems, building equipment, building envelopes (walls, foundations, roofs, attics, and materials), and methods to improve energy efficiency in existing buildings. *Analysis activities* involve energy and resource analysis, preparation of environmental assessment and impact statements, research on emergency preparedness, transportation analysis, and analysis of energy and environmental needs in developing countries. *Transportation system research* is conducted both to improve the quality of civilian transportation and for sponsors within the U.S. military to improve the efficiency of deployment, scheduling, and transportation coordination.

Energy Division's Buildings Technology Center

In 1993, the Energy Division established the Buildings Technology Center (BTC), a DOE national user facility, to more aggressively promote integration of building technologies and industry partnerships. The Buildings Technology Center provides the U.S. buildings industry with broad access to a unique collection of testing and analysis capabilities at ORNL. The special focus of these capabilities is building energy efficiency improvements. The BTC makes available ORNL expertise on building envelopes; heating, cooling, and refrigeration equipment; and existing buildings performance monitoring and analysis. The BTC consists of the Envelope Research Center, the Heating and Cooling Technology Center, and the Existing Buildings Center.

The Energy Division has demonstrated experience related to each of the three centers within the BTC:

The Envelope Research Center:

- Identified the *in situ* thermal performance of different types of attic, wall, and foundation insulation.
- Developed decision guides for roof construction, including cost effectiveness of roof color and slope.
- Determined the performance characteristics of foam insulation with chlorofluorocarbon (CFC) alternatives.
- Found significant heat losses from convection in low-density loose-fill insulation in attics during the heating season and identified cures.

The Heating and Cooling Technology Center

- Performed laboratory and field evaluations of high-efficiency electric and gas heat pumps.
- Designed and tested modifications to refrigerator-freezers that improve energy efficiency and eliminate CFC refrigerants.
- Conducted technical assessments for cogeneration and central heating plant options to improve energy efficiency.
- Assessed the global warming impact of CFC alternatives.

The Existing Buildings Center

- Developed and field tested energy diagnostic procedures for residential and small commercial buildings.
- Developed and field tested PC-based energy audits for single-family homes.
- Provided field training on diagnostic inspection methods for weatherization and rehabilitation agencies.

Industry can access the BTC in several ways. User Agreements allow users to work on their projects alongside BTC staff. Cooperative Research and Development Agreements (CRADAs) give companies the opportunity to seek DOE co-funding for their projects. Work For Others Agreements allow the BTC to carry out proprietary research for full cost recovery. The most appropriate arrangement for a project can be determined by contacting the BTC facility manager. All projects are subject to the condition that they be consistent with or give priority to the BTC's primary mission: to support DOE research on energy-efficient buildings.

NEW TECHNOLOGY DEMONSTRATION PROGRAM AT ORNL

The DOE has utilized personnel that work in the BTC User Facility to support the National Technology Demonstration Program (NTDP) for the Federal Energy Management Program (FEMP). The mission of the DOE's FEMP is to work with the National Laboratories, industry, utilities, and federal facilities to reduce the cost of government by advancing energy efficiency, renewable energy, and water conservation. It does this by creating partnerships, leveraging resources, transferring technology, and providing training and support. The FEMP provides assistance to federal facilities in meeting the goal of using 30% less energy in Federal Facilities in 2005 than used in 1985.

The NTDP is a mechanism by which the FEMP can:

- provide technical assistance for identifying projects,
- provide means of leveraging Federal and private sector investments,
- provide the technical support necessary to successfully implement the projects, and
- assist in the transfer of knowledge about successful projects to encourage others to achieve additional progress toward the goals.

Through the FEMP NTDP, a technology is applied at a federal site and its performance evaluated. Technologies that demonstrate energy and environmental benefits in a cost effective manner are then showcased and emphasized for additional wide-spread federal applications. Another aspect of the FEMP involves technologies for which extensive private-sector and some federal sector performance data are available. These technologies are more likely to be featured in a Federal Technology Alert (FTA), a FEMP publication on the energy and cost savings potential for products by technology type.

ORNL supports the NTDP through work on 5 technologies: a Small Commercial Hydronic Boiler/Water Heater, a Large Industrial Steam Boiler, Insulating Liquid Coatings, Commercial Size Heat Pump Water Heaters, and a Retrofit System for Rooftop Units.

Hydronic Boiler/ Water Heater

This Hydronic Boiler/ Water Heater marries a condensing heat exchanger design with a modulating combustion system that incorporates proportional integral derivative temperature controls. This technology was submitted to the NTDP by AERCO International, Inc. The electronic control system matches the firing rate to the system load, to achieve a 14 to 1 turndown ratio (from 1,000,000 BTU to 70,000 BTU). This virtually eliminates cycling losses. The hydronic boiler/water heaters incorporate the features of condensing, modulation, and tight temperature control to maximize performance. The modulating/condensing design gives the unit an inverse efficiency curve. As the load decreases, the efficiency increases. Thermal efficiencies of the hydronic boiler/water heaters are similar to conventional units at full load, however offer the added benefit of increased efficiencies at lower loads because of increased condensation due to more heat exchanger surface available relative to load. The hydronic boiler/water heater is the only one in its size range that modulates heat input to match the load. ORNL is working with industry to prepare an FTA on this technology.

Industrial Steam Boiler

This Industrial Steam Boiler is an advanced natural-gas-fired boiler for industrial use. The boiler is a combination watertube/firetube design and incorporates a unique cyclonic burner concept developed with funding by the Gas Research Institute. This technology was submitted to the NTDP by Donlee Technologies, Inc. The boiler is suitable for applications in the range of 750 to 2500 hp, or up to 90,000 lb/hr of steam, and pressures up to 850 psig. The high fuel efficiency and high steam capacity are achieved in a compact boiler that has a reduced space requirement and lower installation costs. The cyclonic operation of the burner causes excellent mixing of combustion air and fuel gas and high convective heat transfer. As a result, the unit offers quick start-up (30 minutes from a cold start compared to 3 hours for a conventional unit), good response to load changes, and low emissions of carbon monoxide and nitrogen oxides (15 to 40 ppm compared to 40 to 100 ppm for a conventional unit). The operating efficiency of this unit is high (80% minimum at high fire and an increased efficiency with turndown, compared to 78% at high fire and decreased efficiency with turndown for a conventional unit). ORNL is coordinating a demonstration project on this technology.

Commercial Heat Pump Water Heaters

Heat pump water heaters have been successfully applied to commercial facilities such as laundries, restaurants, hospitals, hotels, apartment buildings, and health clubs, for a number of years in some areas of the United States. This technology was submitted to the NTDP by Hawaiian Electric Company, Inc. Heat pump water heaters can be located outdoors or indoors. When operated indoors, the heat pump provides the added benefit of air-conditioning (cooling) the surrounding air. Energy savings are achieved by heat pump refrigeration technology: low grade heat extracted from air is boosted in temperature by a compressor and transferred to water. Colmac, a vendor referred to in the NTDP solicitation, produces heat pump water heaters that achieve a Coefficient of Performance (COP) of approximately 3 to 4. COPs for electric resistance heaters are typically between 0.85 and 0.95, while natural gas heating COPs are typically between 0.5 and 0.75. Applied correctly, this efficiency advantage when using heat pump water heaters means a good economic return by reducing energy operating costs, and a good environmental return by conserving fossil fuels, and reducing Global Warming. ORNL is working with industry to prepare an FTA on this technology.

Insulating Liquid Coatings

This technology is an insulation which comes in liquid form, available in regular and fireproof formulation. It is widely used as a rooftop insulation, but performs extremely well on piping, air distribution systems, exposed water pipes, oxygen and steam lines, water tanks, and so on. This technology was submitted to the NTDP by ThermShield International, Ltd. This insulation is a mixture of various silicas and ceramic beads immersed in a high quality latex base with acrylic binders. This combination of materials makes the product lightweight and pliable, so that it expands and contracts with the surface to which it is applied. One benefit of reflective roof/pipe coatings is to increase the reflectance of existing surfaces, thereby decreasing the radiation heat exchange between the surface and its surroundings. A secondary effect is the ability to insulate the underlying surface somewhat from convective heat transfer with its surroundings. Additional benefits can be that the reflective coatings can waterproof the surface against leaks, prevent corrosion or rusting of metals and protect surfaces from atmospheric contamination. In an effort to quantify these benefits, ORNL is coordinating a demonstration project on this technology.

A RETROFIT SYSTEM FOR ROOFTOP UNITS

A significant fraction of the floorspace in commercial and Federal buildings is cooled by single-package rooftop air conditioning units. These units, typically located on flat roofs, usually operate during the day under hot conditions. Consequently, their energy efficiency, as compared with a chiller system for building cooling, is generally much lower. A retrofit system has been developed whereby inefficient rooftop units can be retrofitted with an ice storage/chiller system for improved performance and minimal use of on-peak electricity. Since the system substitutes an efficient chiller operating at night (off-peak) for rooftop units, the overall efficiency of the retrofit system is higher than for a packaged, conventional rooftop system. This technology was submitted to the NTDP by Calmac Manufacturing Corporation.

In this retrofit system, existing rooftop evaporator coils are adapted to use ethylene glycol from a chiller. The chiller operates at night to make ice in the tank, and during the day, building cooling may be provided by melting ice alone, or in a partial storage mode, to supplement cooling from the chiller. The flexibility in the system makes it particularly attractive as an efficient means for reducing on-peak electric demand. An additional benefit includes the reduction in maintenance costs associated with the retrofit system when compared to the old rooftop units.

The Rooftop Retrofit Demonstration Project

Based on significant manufacturer participation and the potential for energy savings by retrofitting rooftop units, ORNL is conducting an evaluation/demonstration of this technology. The retrofit system consists of a chiller, an ice storage tank, and one or more rooftop units which have been retrofitted appropriately. Figure 1 is a photo of the retrofit system installed outside of Building 2518 at ORNL. The ice storage tank contains a number of coils of heat exchanger tubing through which a solution of ethylene glycol passes. Water fills the tank and surrounds the tubing so that as cold ethylene glycol from the chiller

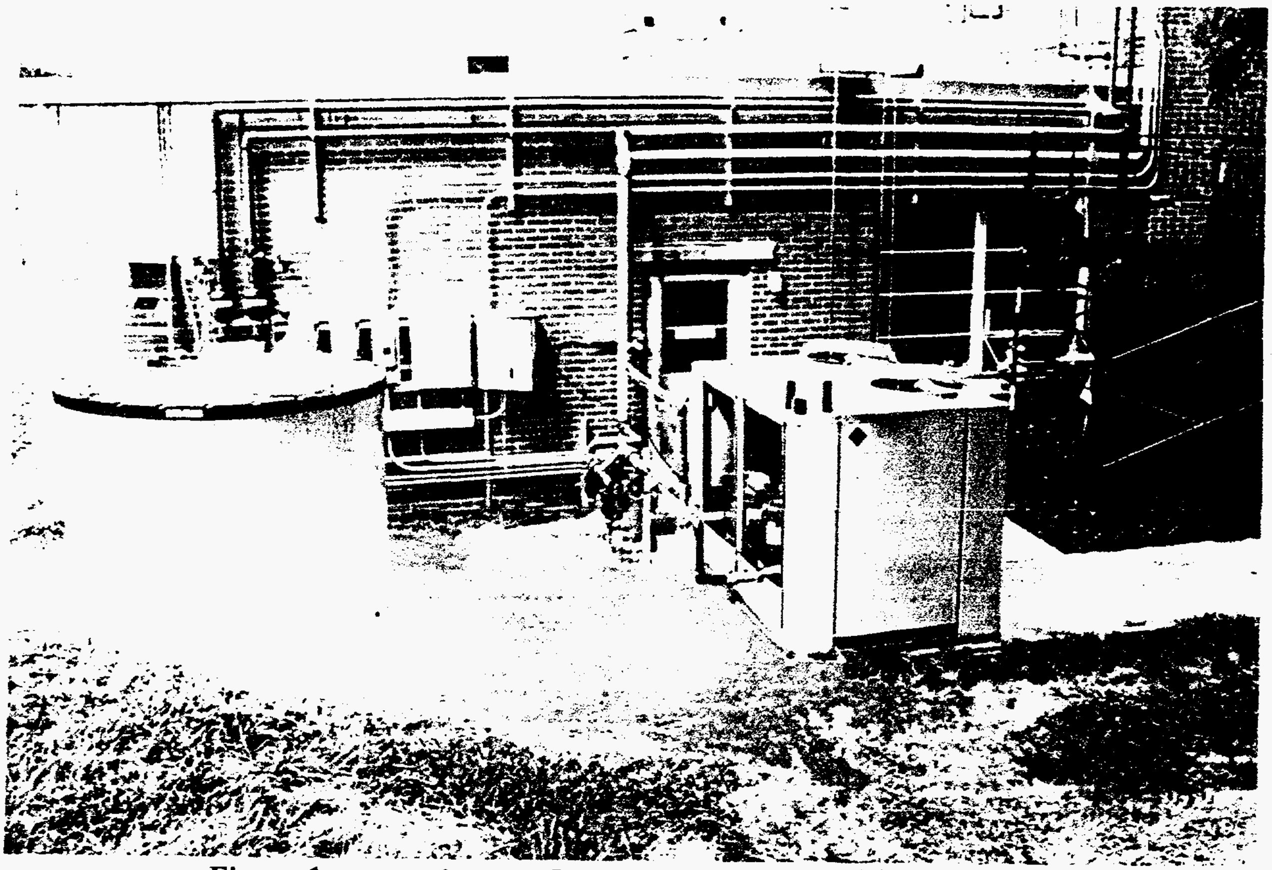

Figure 1. The Rooftop Retrofit System Installed Near Building 2518 at ORNL.

passes through the coils, ice is formed around the tubing. The ice storage process continues until most of the water in the tank has frozen at which point the chiller is turned off and the tank is considered fully "charged." About 190 ton-hours (about 16,000 lbs of ice) of cooling will have been stored ready to meet the cooling demand of the building. During the discharge process, warm ethylene glycol is circulated through the coils in the tank where it is cooled by the melting ice, and then the cooled ethylene glycol is circulated to the coils inside the rooftop units to provide cooling to the building. The ice storage component decouples the cooling demand of the building from the operation of the chiller. In this way, the chiller can operate at night (cooler, more efficient condensing temperatures) to meet a daytime cooling demand. This flexibility permits a smaller chiller to satisfy a larger peak cooling load. Further, the system can be operated to shift the cooling demand to off-peak hours when electricity from the utility is generated more efficiently and at lower cost.

As part of the retrofit, the existing packaged rooftop units remain in place, and the following changes are made:

1. The refrigerant and oil are removed from the system;
2. The rooftop evaporators are repiped to accept a low temperature ethylene glycol solution as the coolant;
3. An air-cooled chiller and ice storage tank is located on a pad adjacent to the building (or on the roof if conditions permit);
4. The existing, altered evaporators are connected to a common manifold which is located along the roof;
5. The manifold is connected to the new chiller and ice storage tank; and
6. Controls are added to operate the chiller at night to make ice, and to control chiller operation during the day to provide building cooling.

By retrofitting rather than replacing the existing packaged rooftop coils, no new building penetrations are needed, and no modifications to the fans or ducts are required. Zoning capabilities—a key feature of rooftop units—are preserved as well.

Until the system retrofit, Building 2518 was cooled by five packaged rooftop units which range in age from 25 years to about 3 years. The rooftop units vary in size from 22 nominal tons to 5 tons, and the total installed capacity is 44 tons. The oldest units are the 22-ton, a 10-ton, and a 7.5-ton, and under the demonstration program, these units have been retrofitted.

While Building 2518 is typical of a small office building, it is also unique. This building has been monitored by ORNL for more than two years to characterize its thermal performance so that the effects of any retrofit system to improve the thermal performance of the envelope itself, or the performance of HVAC components could be measured from a well-defined baseline. Further, the building has been modelled using DOE-2.1E. An intensive model calibration effort backed by measurements of building electrical energy consumption have produced close agreement (within 5%) between predicted and actual building energy consumption during the summer. These modelling efforts have supported evaluation of lighting and roof recovering retrofits which were recently completed in Building 2518 under a separate project. The fact that Building 2518 has been so carefully characterized will make evaluation of the performance of the retrofit system and prediction of similar retrofit's potential in other buildings easier to accomplish and will produce results of greater precision and confidence.

Proposed Energy Savings

The energy savings of the retrofit system depends on the building cooling load and the change in efficiency between the old rooftop units and the new chiller/ice tank configuration. Energy savings will come from three areas: cooling load reduction by operating at night (cooler, more efficient condensing temperatures), off-peak energy usage, and maintenance.

The retrofit system replaces the three oldest rooftop units on the building (32-ton peak cooing load). The weighted average efficiency of the three units is approximately an EER of 4.9. Therefore, the new chiller is a nominal 20-ton unit. Based on the vendor data, this chiller has an EER of 8.0 under ice making conditions (EER = 10.9 as a conventional chiller). The new chiller is approximately 63% more efficient than the old rooftop units. The anticipated annual energy savings is 40,500 kWh. In areas where low off-peak electric rates are available, further operating cost savings accrue. In addition, with the retrofit system, it is anticipated that there will be approximately a 70% savings in maintenance costs.

The predicted lifetime of a properly-maintained retrofit system is 20 years, the same as the lifetime of a chiller. The ice tank components are made of PVC; all components in contact with liquid are thermally insulated which protects them from UV degradation.

The Demonstration Partnership

Several groups have agreed to collaborate under this demonstration. Calmac has donated the ice storage tank to the project. In addition, Calmac provided the expertise and labor to retrofit the coils on three of the existing rooftop units on Building 2518. The Trane Company has donated a new, 20-ton chiller to be used on the demonstration. This air-cooled unit is comprised of dual scroll compressors which operate on refrigerant HCFC-22, and the unit has been fitted with an ice-making option (lower leaving water temperature control). Pre-installation characterization of Building 2518 was part of another demonstration project funded by the DOE Office of Building Technologies. Finally, the engineering, installation, operation and evaluation of the retrofit system is being done by ORNL under the FEMP. Through this collaboration, each partner is able to leverage their resources to gain information on the performance of the system and to demonstrate the technology. The performance of the system will be determined during the 1995 cooling system; however, the system will continue to operate to provide building cooling beyond that time.

Market Potential

At the present time, cool storage in commercial buildings is a $25 million industry annually. Aided by electric utility incentive programs and/or high electric demand charges, ice storage installed in larger buildings with chillers has been found to be an economic option for reducing building operating costs. Particularly in smaller buildings, rooftops offer installation simplicity, zoning ease and low first cost. However, compared with chiller systems, rooftop systems have lower efficiencies with high operating costs.

Estimates show that more than half of all commercial floorspace in the Federal sector is currently cooled by rooftops. Since these buildings tend to be smaller than buildings containing chillers, the number of buildings cooled by rooftops significantly exceeds the number of buildings cooled by chillers. Under this retrofit concept, high efficiency chillers become an option to replace inefficient rooftop units for this large set of building types. By moving to chiller-based cooling, additional technologies such as gas absorption chillers, non-HCFC or non-fluorocarbon electric chillers (e.g. ammonia) can be considered. The ice storage component provides an additional advantage by allowing one to reduce the size of the chiller required (in this demo, a 20-ton chiller system can meet a peak load about twice as large), and/or to move the peak cooling load to off-peak hours.

This system retrofit demonstration is an important step toward making federal and non-federal customers aware of this particularly opportunity for improved energy efficiency and flexibility.

POTENTIAL PROJECTS FOR NEW TECHNOLOGY DEMONSTRATION PROGRAM

ORNL is currently working on several other technologies (including gas-fired heat pumps for heating and cooling, and advanced gas-fired commercial chillers) the NTDP may choose to highlight as their development progresses towards commercialization.

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