Sustainable buildings often feature photovoltaic applications. But, where does research and development of new photovoltaic technologies take place? Now, it occurs in a new light-filled, energy-efficient research facility on the Golden, Colo., campus of the U.S. Department of Energy’s (DOE) National Renewable Energy Laboratory (NREL). From within the lab, researchers can look outside to a scenic view surrounding the building. Completed in August 2006, NREL’s 71,347 ft² Science and Technology Facility (S&TF) houses nine laboratories for advanced materials synthesis, analysis, characterization, and support, as well as a 10,170 ft² process development and integration laboratory (PDIL).
**Surpassing Gold**

As a partner with the Laboratories for the 21st Century (Labs21®), NREL set aggressive goals for energy savings, daylighting, and achieving a USGBC LEED® for New Construction (NC) Gold rating. Through the Labs21 program, NREL staff worked with the design team to analyze, design, review, and implement the energy-saving features highlighted in this case study. Staff also coordinated documentation for the LEED submittal, oversaw an analysis to validate the project’s energy simulation, and prepared documentation to showcase the project through design awards and other venues.

The S&TF laboratories are designed to accelerate renewable energy process and manufacturing research for near-term technologies, such as thin-film solar cells, and next-generation technologies, such as organic and nanostructured solar cells. Energy costs for this building are estimated through computer simulation to be 41% lower than those of a comparable facility designed to ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, for an estimated savings of $96,000 per year. The estimated annual energy savings are 10,648 million Btu. The added cost for the energy savings features was $482,500. This represents a five-year simple payback.

The S&TF surpassed the LEED rating goal, receiving a LEED Platinum rating. The S&TF is using more

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**BUILDING AT A GLANCE**

**Building Name**
Science & Technology Facility

**Location**
NREL’s Golden, Colo., campus

**Size**
71,347 ft²

**Started**
February 2005

**Completed**
August 2006

**Use**
Research facility with laboratories

**Cost**
$29.8 million

**Building Distinctions**
LEED-NC Platinum; First Place, 2008 ASHRAE Region X Chapter Regional Conference; Recognized as trendsetter in laboratory design in R&D Magazine’s 2008 Laboratory of the Year competition; 2006 Federal Energy Saver Showcase Award; 2006 Design Excellence Award from Jefferson, Colo., County Board of Commissioners

**BUILDING TEAM**

**Owner**
NREL

**Architect and MEP Engineer**
SmithGroup

**Civil Engineer**
Martin-Martin

**Landscape Designer**
Wenk Landscape Architects

**Structural Engineer**
Paul Koehler Leffler

**General Contractor**
M.A. Mortenson
energy than the simulation predicted, but significantly less energy than a comparable facility designed to comply with Standard 90.1.

**S&TF: A Better Lab**
The S&TF is a two-story, 71,347 ft² laboratory building completed in 2006 at a total construction cost of $22.7 million ($318/ft²) and a total project cost of $29.8 million.

The ground floor includes laboratories, office space and a lobby. The second floor houses laboratories and includes the PDIL. An elevated bridge connects the second floor service corridor to the adjacent 117,000 ft² Solar Energy Research Facility (SERF). The third level houses the bulk of the S&TF’s mechanical support functions, including laboratory exhaust fans. The exterior consists primarily of precast concrete panels and metal panels at the entry that complement the exterior of the adjacent building.

Seven interaction spaces encourage informal discussions among researchers. Each space features seating, a whiteboard, access to a local area computer network, and views to open space outside.

The building’s centerpiece is the 10,170 ft² PDIL. It was designed to accommodate a new class of deposition, processing, analysis,
film photovoltaics, hydrogen nanostructures for production and storage, thin-film window coatings, and solid-state lighting. The intent is to reduce risk and cost to industry associated with these processes.

The PDIL allows researchers to move samples between large tools under vacuum, which prevents the samples from contacting airborne contaminants. Researchers bring samples under vacuum to the lab in mobile transport pods.

**Providing Flexibility**

Laboratory spaces were designed around a common module to provide flexibility and distribution of utilities and services. The selected planning module is 10 ft by 27 ft. Structural bays allow an appropriate span for the second floor to reduce vibrations. Designers arranged building spaces to reflect the relationship of labs to one another, to offices, and to support spaces. The need to use toxic and flammable materials in some labs also influenced the plan.
On the first level of the two-story laboratory portion of the building are labs that are more sensitive to vibration and noise and need to be darkened. Lab spaces were organized along a service corridor nearly identical to that of the second floor. The rectangular PDIL is centrally located on the second-floor ground level (because the site slopes) and along support laboratories to improve operational efficiency and make future expansions easier. Large second-floor labs required the largest available floor plate, a direct connection to the SERF for service, and proximity to the PDIL. Vibrations are controlled by a structural slab beneath the PDIL. Both floors feature daylighting and exterior views.

The office area is a structurally separate one-story module east and south of the labs. Advantages of this design include lower cost; enhanced safety due to separation of staff from labs using hazardous materials; and allowing daylight to enter offices from the south and north sides.

Utility Servicing
Laboratories are organized along a central service corridor that supports them on each floor, like a spine supporting limbs. The service corridor is required to distribute hazardous production materials (HPM) to the labs because the S&TF is classified as high hazard occupancy 5 (H5) under the International Building Code (IBC). The service corridor accommodates gas lines, water lines, exhaust and supply ductwork, electrical, and signal system distribution to the back of the labs. The front of each lab includes access to an exit corridor that links to the rest of the building. The service corridor includes notched areas for heat- and noise-producing equipment. An in-floor utility trench allows this equipment to be connected to equipment inside the labs.

**Site**
The S&TF is oriented along an east-west axis so that windows on the north and south façades can provide natural lighting. A butterfly roof over the office module collects storm water and directs it to detention ponds with xeriscape landscaping. The construction contractor recycled more than 80% of the construction waste by weight. In addition, a portion of the excavation soils was retained and used to restore a previously disturbed portion of the site.

Per the Labs21 Environmental Performance Criteria (the basis for the LEED Application Guide for Laboratories, expected to be published in 2009), NREL contracted for an exhaust effluent study using wind tunnel modeling to define the impact of emissions from exhaust sources at the building intake and other sensitive locations. The study suggested minimum acceptable design

<table>
<thead>
<tr>
<th>Measure</th>
<th>Savings Per Year</th>
<th>Payback (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAV Only</td>
<td>$92,120</td>
<td>3.3</td>
</tr>
<tr>
<td>Energy Recovery</td>
<td>$36,487</td>
<td>2.2</td>
</tr>
<tr>
<td>Lab Supplementary Cooling &amp; Raised Primary Supply Air Temperature</td>
<td>$14,873</td>
<td>10.1</td>
</tr>
<tr>
<td>Overhangs &amp; Glazing</td>
<td>$4,400</td>
<td>N/A*</td>
</tr>
<tr>
<td>Lighting Power Density</td>
<td>$5,694</td>
<td>N/A*</td>
</tr>
<tr>
<td>Daylight Controls</td>
<td>$4,111</td>
<td>2.4</td>
</tr>
<tr>
<td>Office Underfloor Air &amp; Evaporative Cooling</td>
<td>$3,103</td>
<td>6.4</td>
</tr>
<tr>
<td>Chiller Plant Upgrades</td>
<td>$12,607</td>
<td>2.6</td>
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<tr>
<td>Tower-Free Cooling</td>
<td>$6,754</td>
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</tr>
<tr>
<td>Process Commercial Hot Water for Preheating</td>
<td>$4,752</td>
<td>10.1</td>
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<tr>
<td>Lab Air-Handling Unit Evaporative Section</td>
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<tr>
<td>Fan Pressure Drops</td>
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<tr>
<td>Fan Staging</td>
<td>$4,691</td>
<td>8.0</td>
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<tr>
<td>Boiler &amp; Domestic Hot Water Improvements</td>
<td>$8,972</td>
<td>2.7</td>
</tr>
</tbody>
</table>

*These measures are part of the building architecture, and incremental cost could not be broken out separately.
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parameters in terms of exhaust stack height, exit velocity, volume flow and exhaust, and location of intake air. The recommendations were used in designing the air intake location and exhaust system.

Energy Efficiency
The energy-efficiency features of the S&TF were designed to provide a 41% reduction in energy cost in comparison to a standard laboratory building. These features include a variable-air-volume (VAV) supply and exhaust system, variable-frequency motor drives, efficient fume hoods and fans, energy recovery, efficient heating and cooling equipment, and underfloor air distribution.

VAV Supply and Exhaust System Requirements
The minimum occupied airflow is 1 cfm/ft² as required by IBC H5 occupancy. The VAV system allows more supply air as needed for fume hoods and other exhaust devices.

The facility’s chemical fume hoods feature an automatic sash closer to ensure that the sash is open no
Fan Coils
Fan coil units provide heating and cooling directly to laboratory spaces, nearly eliminating the need for inefficient reheating systems. Fan coils allow the ventilation system to supply only the tempered air required for minimum ventilation (1 cfm/ft²) and makeup air for exhaust devices. Fan coils provide cooling for areas with high internal heat gain.

Energy Recovery
A runaround coil system with an estimated 63% sensible effectiveness reduces the heating and cooling requirements associated with conditioning ventilation air in labs. The system recovers energy from exhaust air to precondition supply air and uses waste heat from the process water loop to preheat ventilation air. This also provides free cooling for process cooling water when the outside temperature is below 60°F, for savings in chiller energy and cooling tower water.

Exhaust Fans
The building’s six exhaust stacks are on the southeast side. Each is connected to a dedicated direct-drive 20,000 cfm exhaust fan. Fans are staged on and off to maintain an exhaust plenum negative static pressure setpoint of approximately 1.5 in. w.c. The fans are started in sequence until they exceed the setpoint; then, the bypass damper in the exhaust plenum modulates open to maintain the setpoint pressure as the system reacts to varying lab conditions. When the bypass damper modulates to 80% fully open, an exhaust fan shuts down and the bypass damper modulates toward closed to maintain the negative setpoint pressure. This saves considerable energy in comparison to running a full-capacity fan and large bypass damper in part-load conditions.

Labs21®
Prior to the inception of Laboratories for the 21st Century (Labs21) in 1999, laboratories were an underserved market in the area of sustainable design. In general, laboratories used five to 10 times the energy of standard office buildings due to health and safety concerns such as intensive ventilation requirements. The Labs21 program recognizes the great potential to save energy in laboratories. Through the program, dedicated voluntary partners improve the environmental performance of U.S. laboratories.
Labs21 examines the entire facility from a whole building perspective to improve efficiency. Areas of improved efficiency include reducing ventilation energy, moving air efficiently, using energy recovery where applicable and installing energy-efficient equipment. Labs21 is supported by DOE and EPA. Visit www.labs21century.gov for more information.
**Efficient Heating and Cooling**

The S&TF uses a high-efficiency condensing boiler and variable-speed chiller, indirect evaporative cooling, and a heat exchanger that allows cooling water to bypass chillers and be cooled directly by the cooling tower. Direct evaporative cooling cools offices and provides cooling and humidity control in labs. Modulating indirect gas-fired heating sections in the makeup air units heat makeup air for labs and reduce hot water piping needs. The condensing boiler provides heat for offices and fan coil units in labs.

**Underfloor Air Distribution**

The offices are conditioned by a VAV underfloor air-distribution system. It provides fan energy savings and increases the number of hours when the economizer and evaporative cooling can be used by raising the supply air temperature. It also minimizes overhead ductwork.

**Water Efficiency**

In addition to using a storm water detention system for irrigation water, the building contains low-water-consuming fixtures, such as ultra-low-flow (0.5 gallon per flush) urinals. The cooling towers operate at six cycles of concentration, reducing makeup water requirements in comparison to those of a tower operating at more conventional cycles of concentration (e.g., two or three). The cycles of concentration represent the relationship between the concentration of dissolved solids in the bleed-off to the concentration in makeup water. Increasing the cycles of concentration of the tower from three to six reduces makeup water consumption by a factor of four.
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Commissioning
NREL contracted directly with a third-party commissioning authority to work with the A/E project manager, construction contractor team, and NREL project manager to commission the building during each of these phases: schematic design and design development, construction documents, construction and acceptance, and warranty. Commissioning at the construction and acceptance phase includes startup and testing of selected equipment. For the warranty phase, it includes coordinating required seasonal or deferred testing and performance evaluations and reviewing the building 10 months after occupancy. The commissioning authority evaluated the central automation systems; laboratory air supply and exhaust systems and controls; life-safety systems; the toxic gas monitoring system; central plant systems; process and specialty gas systems, including hazardous production materials; all HVAC equipment; process cooling water systems; deionized water; backup power systems; lighting control systems; and domestic hot water systems.

Indoor Environmental Quality
The goal was to provide 100% daylighting in first-floor office spaces between 10 a.m. and 2 p.m. and for daylighting to meet 50% of the labs’ lighting needs. The daylighting system includes north- and south-facing windows and clerestories coupled with automated lighting controls, which dim or turn off electric lights as needed. The performance of the daylighting system was simulated to verify that the performance objectives would be met.
This cost approximately 0.5% of the total construction budget, or about $1.60/ft² of building area.

**Measurement and Evaluation**
Continuous metering and monitoring equipment measure various systems. Mechanical systems monitored include constant and variable motor loads, variable-frequency drive operations, chiller efficiency at variable loads, cooling load, air and water economizer and heat recovery cycles, air-distribution static pressures, ventilation air volumes, heating load and boiler efficiency.

Electrical systems are measured by nine electric submeters. The meters identify four types of loads in the S&Tf, including lighting, lab process load, office load and building load. Domestic water and natural gas use are also metered.

The central building automation system (BAS) provides measured or calculated values for mechanical systems. It can monitor some equipment and show trends over time. Advanced performance metrics are necessary to find and solve these types of problems.

**Plan Implementation**
Even with a detailed monitoring plan, determining actual annual energy use and energy metrics has been challenging. Some BAS and electrical meter data was lost. Part of the challenge is that a central plant that also serves other buildings provides the chilled water and heating water. Btu meters measure the energy use of the chilled water and heating water for the S&Tf. However, to determine actual energy use, cooling system and boiler energy use in the central plant must be measured. This is complicated because much of the chilled water is provided by the tower-free cooling system. The actual cooling energy use is determined by multiplying the Btu meter reading by the tower-free cooling system energy use (about 0.1 kW/ton) or the chiller system energy use (about 0.45 kW/ton), depending on the mode of operation. This calculation needed to be done for every hour of operation for the year.

A measurement and evaluation plan was in place. However, implementation of the plan did not go as expected. Even with submeters to break out energy use by appropriate categories, obtaining useful information from the readings proved harder than expected. The team needed a better understanding of who, how and when to execute the measurement and evaluation plan.

**Performance Metrics**
Despite commissioning and a talented building operator, the HVAC systems operations have not been optimized. The supply air to the laboratories is being overheated and then recooled by the fan coils. In addition, the operation of the evaporative coolers (supplying cooling and humidification to the laboratories and cooling to the offices) has not been optimized, resulting in excessive heating and cooling energy use. While collecting performance data for this article, calculation of annual energy use identified these control issues. The control sequences have been modified, and energy use and energy metrics will be monitored. Good performance metrics are necessary to find and solve these types of problems.

**Process Loads**
The measured process loads in the laboratories are lower than design. The process load will increase in the future as more process equipment is added. The measured combined lighting and plug/process loads are 15.7 kWh/ft². The combined design lighting and plug/process loads were estimated between 22 and 23.6 kWh/ft². Typically, process loads are lower than estimated during design. Even when using a similar building to calculate design process loads, the actual process load numbers come out lower than the design numbers.

Researchers receive only a small percentage of the energy-efficient lab equipment they expect, and the equipment is not run as often as anticipated.

**Conclusion**
The measured annual energy use is 17% higher than predicted by the simulation. This result is not unusual because the simulation assumes optimized operation of HVAC systems, and the HVAC systems actual operation has not been optimized. Collecting energy use data identified control issues. The control sequences have been modified, and NREL believes the energy use will be reduced.

The S&Tf saves significant amounts of energy compared to a standard lab building. A Standard 90.1-2004, Appendix G, Performance Rating Method, building located in Golden, Colo., would be expected to have an annual energy consumption of 361 kBtu/ft². The actual annual energy use of the S&Tf is 24% less, 269 kBtu/ft². (See the Annual Energy Use Table on page 21.)

Most importantly, the S&Tf provides a superior work environment for employees to conduct state-of-the-art research. NREL will continue to monitor and document the building’s performance so others can learn from this experience.

**Acknowledgments**
This article is based on a case study of the S&Tf written by NREL for the Labs21 Program. For the case study, see www.labs21century.gov/pdf/cs_nrel_508.pdf.

**Lessons Learned**

| Plan Implementation | Even with a detailed monitoring plan, determining actual annual energy use and energy metrics has been challenging. Some BAS and electrical meter data was lost. Part of the challenge is that a central plant that also serves other buildings provides the chilled water and heating water. Btu meters measure the energy use of the chilled water and heating water for the S&Tf. However, to determine actual energy use, cooling system and boiler energy use in the central plant must be measured. This is complicated because much of the chilled water is provided by the tower-free cooling system. The actual cooling energy use is determined by multiplying the Btu meter reading by the tower-free cooling system energy use (about 0.1 kW/ton) or the chiller system energy use (about 0.45 kW/ton), depending on the mode of operation. This calculation needed to be done for every hour of operation for the year. A measurement and evaluation plan was in place. However, implementation of the plan did not go as expected. Even with submeters to break out energy use by appropriate categories, obtaining useful information from the readings proved harder than expected. The team needed a better understanding of who, how and when to execute the measurement and evaluation plan. |
| Performance Metrics | Despite commissioning and a talented building operator, the HVAC systems operations have not been optimized. The supply air to the laboratories is being overheated and then recooled by the fan coils. In addition, the operation of the evaporative coolers (supplying cooling and humidification to the laboratories and cooling to the offices) has not been optimized, resulting in excessive heating and cooling energy use. While collecting performance data for this article, calculation of annual energy use identified these control issues. The control sequences have been modified, and energy use and energy metrics will be monitored. Good performance metrics are necessary to find and solve these types of problems. |

**About the Authors**

Anna Hoenmans, P.E., is a senior mechanical engineer in the Site Operations Group and Otto Van Geet, P.E., is a senior mechanical engineer in the Strategic Energy Analysis and Applications Center at NREL in Golden, Colo. The authors were involved in the design, construction and operation of the S&Tf.