



# Building Technologies Research and Integration Center

Breaking new ground  
in energy efficiency



OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY



To enjoy a sustainable energy and environmental future, America must continue to increase the energy efficiency of its buildings. For more than three decades, Oak Ridge National Laboratory (ORNL) has worked in tandem with government, industry, and academia to address these enormous challenges. Today, through the Building Technologies Research and Integration Center (BTRIC) and associated Centers of Excellence, ORNL applies its multidisciplinary science and technology expertise, state-of-the-art facilities, and partnership mechanisms to accelerate building energy efficiency solutions from concept to commercialization.

## National Impact of Buildings

- 40% of total primary energy consumption
- 74% of electricity consumption
- 56% of natural gas consumption (including gas-generated electricity used in buildings)
- 39% of US carbon emissions



\* Industrial building energy use is not included, because of the way the nation accounts for its energy consumption, making the energy savings potential even greater.

## Centers of Excellence

Residential, commercial, and industrial buildings are the nation's primary consumers of energy and offer tremendous energy savings potential. They also serve as deployment platforms for decentralized renewable energy technologies and create additional efficiencies through improved building-to-grid integration. To address the associated energy-efficiency and renewable energy integration opportunities and challenges, ORNL conducts research through BTRIC's Centers of Excellence focused on advancing (1) the building envelope, (2) building equipment, (3) system/building integration, and (4) building technologies deployment.



# Building Envelope

The building envelope (the materials that separate the indoor and outdoor environments ) primarily determines the amount of energy required to heat, cool, and ventilate a building. The envelope also can significantly influence energy needs in areas accessible to sunlight.

To cost-effectively improve the energy efficiency, moisture-durability, and environmental sustainability of building envelopes, the Building Envelope Center of Excellence is exploring new and emerging materials, components, and systems as well as the fundamentals of heat, air, and moisture transfer. The research group is also focused on multifunctional solutions in which the envelope serves as a filter that selectively accepts or rejects solar radiation and outdoor air, depending on the need for heating, cooling, ventilation, and lighting.

*Wall air and moisture penetration test chambers inside the MAXLAB (Building 4020)*



- Walls
- Roofs and attics
- Foundations
- Sheathings
- Membranes
- Coatings
- Materials

*Apparatus for low-sloped roof or roof/attic system performance characterization (Building 3144)*



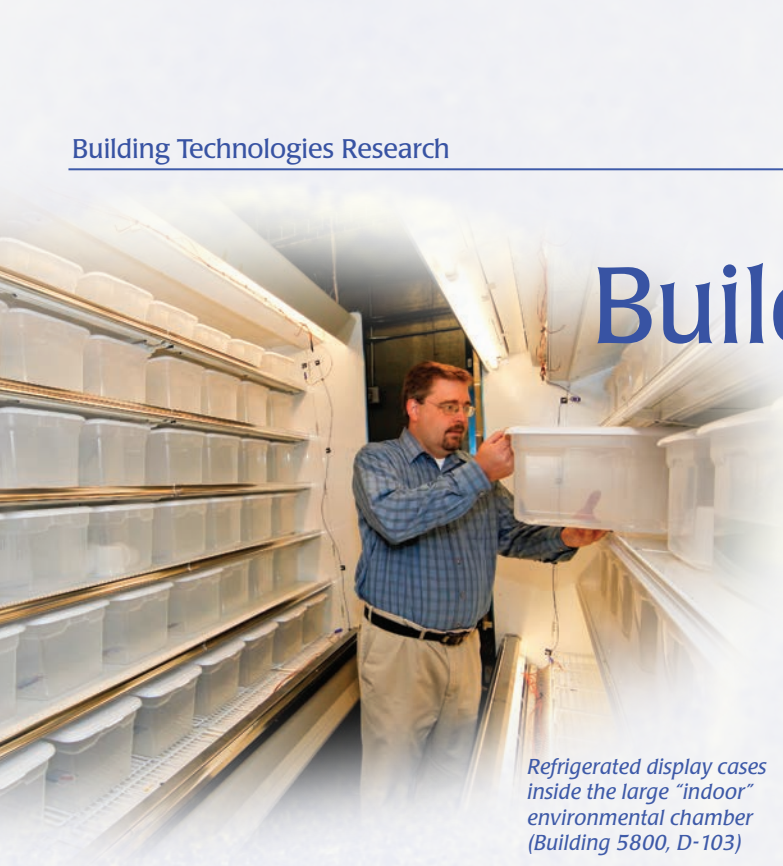
*Roof/attic system natural exposure test facility (Apparatus 3153)*





# Building Equipment

Indoor amenities that improve consumer health and productivity—such as heating, cooling, hot water, and refrigeration—can be satisfied while consuming less energy through advances in building equipment. Since the 1970s, ORNL has executed numerous equipment technology research and development collaborations with industry and university partners. Through the use of extensive experimental facilities, advanced hardware-based design models, and emerging materials, the Building Equipment Center of Excellence has helped industry launch some of the most energy-efficient building equipment technologies on the market today.




*Refrigerated display cases inside the large “indoor” environmental chamber (Building 5800, D-103)*

- Vapor-compression cycles (including trans-critical, ejector, and other variations)
- Absorption/adsorption/desiccant cycles
- Magnetocaloric/electrocaloric cycles
- Working fluids, materials
- Heat pumps, air conditioners, dehumidifiers
- Packaged rooftop units
- Appliances
- Water heaters
- Supermarket refrigeration systems
- Ground-source space-conditioning and water heating systems
- Multi-zone heating, ventilation, and air-conditioning systems
- Wireless communications, sensors, controls, fault detection and diagnostics



*Engine-driven heat pump rooftop unit inside the large “outdoor” environmental chamber (Building 5800, D-103)*



*Heat pump water heater accelerated durability test facility (Building 3144)*



# System/Building Integration

The buildings industry encompasses numerous designers, builders, construction material and component manufacturers, distributors, dealers, and other vendors and service providers. Whether coming together for new construction or retrofitting established structures, these stakeholders often face research limitations and challenges when integrating components, equipment, and systems. This is especially true for anything that is new.

Through the System/Building Integration Center of Excellence, ORNL provides the means for our industry partners to work out the wrinkles in their new products in low-risk, realistic environments before market introduction. In ORNL's residential and light commercial research buildings, in addition to natural exposure to weather, an average occupant effect on energy use is imposed using process control so



*Vacant research house with simulated occupancy leased by ORNL*

that realistic loads, operating conditions, and interactive effects are provided for technology evaluation and physical validation of models. Some technologies, such as system- and building-level controls or fault detection and diagnostics systems, also benefit from the use of research buildings during the development process. The facilities and expertise in this center are also well suited to address renewable energy and building-to-grid integration challenges with our industry partners.

- Vacant research houses with simulated occupancy
- Owner-occupied houses
- Light commercial building flexible research platforms (FRPs)
- Computer modeling, visualization, analytics

*Research buildings on the 1-story and 2-story flexible research platforms (Apparatus 3170A and 3170B)*





# Building Technologies Deployment

Once building technologies emerge and become commercially available, only in exceptional cases does robust market uptake automatically follow. Additional efforts remain to ensure that emerging and under-utilized technologies are successfully deployed to the fullest extent possible. The Building Technologies Deployment Center of Excellence helps optimize the energy performance of buildings and industrial processes by moving technologies to full use in residential, commercial, and industrial sectors through applications research, technical assistance, and a variety of deployment strategies. The team's comprehensive knowledge of buildings and energy use spans multi-building sites, whole buildings, systems, components, and multi-level interactions. They also help federal and private sector building and plant owners reduce energy consumption through cost-effective energy-management best-practices tools and strategies.

*A big box retail facility's roof with highly efficient and demand-responsive packaged rooftop equipment for heating and cooling, a cool roof surface, and daylight harvesting*

When it comes to technology deployment, sponsor and partner needs can be very diverse, so ORNL routinely customizes teams to satisfy these requirements. For example, for the DOE Office of Weatherization and Intergovernmental Programs (OWIP), ORNL has created an interdisciplinary team of building scientists, computer programmers, program evaluators, and social scientists to assist with the diverse aspects of OWIP operations.

- Planning
- Metering
- Benchmarking
- Audit tools
- Retro or ongoing commissioning
- Developing, implementing, and evaluating energy retrofit projects
- Alternative financing of retrofit projects when direct funding is not available



# Partnerships & Collaborations

In addition to supporting the US Department of Energy (DOE) Building Technologies Office, which is part of the department's Office of Energy Efficiency and Renewable Energy (EERE), ORNL through BTRIC provides research, demonstration, and deployment for EERE's Federal Energy Management Program, Advanced Manufacturing Office, and OWIP. BTRIC also supports other offices within DOE, federal agencies, state agencies, and the private sector through DOE's work-for-others program and as a DOE-designated National User Facility.

As a National User Facility, BTRIC provides external collaborators the resources and means to conduct research and development not possible in-house. Industry, universities, and others can enter into user agreements to access ORNL facilities, tools, and expertise. In most cases the user provides the test specimens (the materials or walls or roofs) and ORNL staff operates the apparatus, takes the data, and documents the results.

Almost all of the buildings-related research conducted by ORNL is done in collaboration with industry and international research institute partners. The funding enabling ORNL to participate in these collaborations may come from DOE via the annual operating plan process or through competitive funding opportunity announcements, or from our collaborators through cooperative research and development agreements (CRADAs), work for others agreements, or user agreements. Although partners can fund ORNL through CRADAs, by far the most common funding arrangement is for ORNL's costs within the CRADA to be sponsored by DOE, and for the industry partner's costs to be self-funded.

# Experimental Capabilities

ORNL buildings research is multidisciplinary in nature, with BTRIC providing unique experimental capabilities needed to accelerate building technology research, development, design, and commercialization. The Center provides scientists and engineers with unmatched access to a broad array of research laboratories, tools, and apparatuses designed to help industry partners accelerate products to market that will maximize cost-effective building energy efficiency.

*Maximum Building Energy Efficiency Research Laboratory or MAXLAB (Building 4020)*





Complementary to BTRIC resources, staff and partnering researchers engaged in advancing building energy efficiency technologies have access to several other highly sophisticated DOE National User Facilities located at ORNL. Tapping into these unique capabilities, researchers are able to accelerate searches for optimal materials, component designs, and manufacturing processes, and pinpoint energy efficiency opportunities.

- **Center for Nanophase Material Sciences**—synthesis of high-performance materials and nanostructures.

- **National Center for Computational Sciences**—the world’s most powerful computing resources for researching how the physical world works and using that knowledge to address pressing national and international concerns.
- **Spallation Neutron Source**—accelerator-based neutron source that provides the world’s most intense pulsed neutron beams for scientific research.
- **Manufacturing Demonstration Facility**—advanced manufacturing technologies and materials research and characterization to foster cost reduction and domestic production of next-generation building energy efficiency products.



*BTRIC offices and experimental facilities are on the ORNL main campus near the intersection of Bethel Valley Road and Fifth Street as highlighted in orange, with the exception of the largest building equipment research laboratory, which is in Building 5800, D-103.*

## Strong Foundation in Science, Technology, and Impactful Application

- Mid-1970s ORNL developed the first version of the Heat Pump Design Model, a hardware-based steady-state vapor-compression equipment design tool that continues to be an essential contributor to industry collaborations leading to next-generation products.
- 1975 ORNL and partners built the first research houses; since then, more than 20 have been constructed as test beds for emerging building energy efficiency technologies.
- 1980s ORNL worked with the Consumer Products Safety Commission and industry to develop testing standards associated with cellulosic insulation materials.
- Late 1980s ORNL became a major player in developing and evaluating the alternative refrigerants that enabled an orderly transition from and replacement of stratospheric-ozone-depleting chlorofluorocarbons (CFCs) with hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs).
- 1988 ORNL collaboration with industry led to commercial introduction of the first refrigerator compressor in history rated at 5 Energy Efficiency Ratio (EER), a 44% improvement in efficiency relative to existing compressors of the same size.



- 1990 The compressor efficiency breakthrough noted above strongly influenced the minimum efficiency level set by the first National Appliance Energy Conservation Act (NAECA) standard for refrigerators and freezers.
- 1990 ORNL helped guide the insulation industry through the transition from foam production using CFC-11 to use of non-ozone-depleting HCFC blowing agents while retaining insulating performance levels.
- 1990s ORNL developed the National Energy Audit Tool (NEAT), the first approved computerized residential energy audit instrument to provide engineering estimates of cost-effective measures to be installed under the Weatherization Assistance Program. Subsequent versions, known as the Weatherization Assistant, address both single-family and mobile homes; they received major updates in 2003, 2006, and 2012.
- 1992 R&D 100 Award presented for CFC/HFC Ratiometer, which is capable of identifying the refrigerants present in a given sample and determining the concentration of each component when mixtures are used.
- 1992 ORNL research on convective heat loss through loose-fill fiberglass attic insulation was selected as “one of the year’s 100 Greatest Achievements in Science and Technology” by Popular Science magazine.
- 1993 ORNL published the results of the first comprehensive national evaluation of the DOE Weatherization Assistance Program, the nation’s largest residential energy efficiency program.
- 1993 ORNL collaboration with six large refrigerator/freezer manufacturers provided the technical underpinnings for DOE to raise the NAECA minimum efficiency level for refrigerator/freezers by 25% relative to 1990, even with the imminent mandatory transition away from CFC refrigerants.
- 1996 ORNL provided a comprehensive analysis of the efficacy of residential energy efficiency measures for warm climates to support the Weatherization Assistance Program’s Hot Climate Initiative.
- 1997 ORNL introduced the Zipcode Calculator, a Web-based calculator to help consumers determine the optimal amount of insulation to use in new or existing homes.
- 1998 ORNL played a lead role in establishing DOE’s umbrella energy savings performance contracts (Super ESPCs) in the Southeast Region, and training and technical assistance nationwide.
- 1998 ORNL completed its evaluation of the 4,000-home ground-source heat pump retrofit project at Fort Polk, LA, and subsequently led establishment of DOE’s technology-specific Super ESPC program and widespread use of this technology in federally owned buildings.
- 1999 R&D 100 Award presented for the Frostless Heat Pump, which provides space heating and cooling and features a new design that greatly reduces frost formation on the outdoor coil and eliminates the need for most energy-wasting defrosting sequences.
- 1999 ORNL and Fraunhofer Institute of Building Physics developed the first version of WUFI, a hygrothermal modeling system for envelope assemblies that considers heat, air, and moisture flow; storage of heat and moisture; and moisture thresholds for onset of failure modes.
- 1999 The Environmental Protection Agency released its first Energy Star whole-building energy performance rating tool based on the benchmarking methodology pioneered at ORNL.
- 2000 ORNL began using advanced building energy benchmarking capabilities to develop creative, leading-edge benchmarking tools targeted to specific commercial and residential building populations.
- 2001 ORNL collaboration with the Appliance Research Consortium (eight large refrigerator/freezer manufacturers) in the 1990s led to development of a 1 kWh/day refrigerator/freezer, enabling DOE to raise the NAECA minimum efficiency level 30% relative to 1993.
- 2001 R&D 100 Award presented for Drop-in Residential Heat Pump Water Heater, a 50-gallon water heater that uses half the electricity of a conventional electric storage water heater and has the same footprint, making it suitable not only for the new construction market, but also for replacements (or drop-ins).
- 2001 The conclusion of the National Academy of Sciences report Energy Research at DOE: Was It Worth It? was an emphatic “yes,” and among the underpinning building energy efficiency case studies, ORNL’s advanced refrigerator/freezer compressor project had the highest benefit/cost ratio at 4,375.



- 2001 ORNL building energy efficiency research received 5 of the DOE Energy 100 Awards, including refrigeration research that ranked second among greatest achievements in the department's history.
- 2002 ORNL developed the first comprehensive ESPC training for federal agencies. By 2013, both basic and advanced versions of this course are available, providing training for over 300 federal ESPC acquisition team members per year.
- 2003 ORNL's comparison of the life cycle costs of ESPC and appropriations-funded energy conservation projects showed that, given the delays and overhead costs associated with many appropriations-funded energy conservation programs, ESPC is a more cost-effective method for the federal government to meet energy efficiency goals.
- 2004 ORNL's evaluation of financing costs in federal ESPCs led to incorporation of a requirement for increased financing competition in Super ESPC contracts. As a result, finance premiums over Treasuries are reduced by more than 50% in subsequent Task Order awards.
- 2004 Emerson Climate Technologies, Inc., the largest manufacturer of scroll compressors (Copeland), adopted ORNL's Heat Pump Design Model as the engine for its Windows-based tool for customers for vapor compression system application design.
- 2004 ORNL collaborated with multiple industry partners to integrate infrared reflective pigments into roofing materials for sloped roofs in multiple colors, resulting in significantly higher total solar reflectance than conventional roofing materials of the same color
- 2005 R&D 100 Award presented for SEMCO Revolution, a hybrid vapor compression and desiccant packaged rooftop air conditioner that can independently control humidity and temperature while delivering any specified percentage of fresh outdoor air mixed with return air from the conditioned space, up to 100 percent, with aid of a heat source.
- 2005 ORNL published the first national evaluation of the State Energy Program, focusing on program accomplishments in Program Year 2002.
- 2005 ORNL partnered with the Department of Housing and Urban Development and the Environmental Protection Agency to demonstrate building energy performance benchmarking as a method to improve the determination of energy budgets for federally-assisted housing.
- 2006 R&D 100 Award presented for Trane CDQ, a hybrid vapor compression and desiccant packaged rooftop air conditioner that can independently control humidity and temperature while delivering up to 40 percent fresh outdoor air mixed with return air from the conditioned space, using only condenser waste heat as the heat source.
- 2006 NORDYNE launched the iQ Drive inverter-driven rotary compressor air conditioner, the highest-efficiency product on market at 23 SEER; the design process relied extensively on ORNL's Heat Pump Design Model.
- 2006 By the late 1990s ORNL's Heat Pump Design Model was used by companies representing about 30% of the market for new air conditioner and heat pump design; in the early 2000s Allied Signal (now Honeywell) established HFC R-410A as the leading replacement for HCFC R-22 in air conditioners and heat pumps in part by demonstrating, through use of the model, that efficiency could also increase; these ORNL model contributions contributed to DOE's raising the NAECA minimum efficiency level 30% to 13 SEER in 2006, even with the imminent mandatory transition away from HCFC R-22.
- 2006 R&D 100 Award presented for Hybrid Solar Lighting System, which delivers natural sunlight to the interior spaces of buildings.
- 2007 ORNL's hygrothermal research collaboration with the exterior insulation and finish system (EIFS) industry irrefutably demonstrated that EIFS cladding with drainage is moisture-durable.
- 2007 ORNL partnered with New York State Energy Research and Development Authority and the State of California to develop building energy performance rating tools customized for multi-family and state commercial building needs.
- 2007 At DOE and Office of Management and Budget (OMB) request, ORNL designed new comprehensive national impact and process evaluations of the Weatherization Assistance Program.
- 2007 ORNL's evaluation of DOE's Super ESPC program showed that the 100 projects awarded up to that time are delivering 108% of their guaranteed energy cost savings.
- 2008 ORNL added new research houses; partnered with Schaad Companies to develop four ZEBRAAlliance research houses, with the Tennessee Valley Authority to develop three Campbell Creek research houses.



- 2009 ORNL received an R&D 100 Award for Fire Resistive Phase Change Material, which generates heating and cooling energy savings of up to 25% in small buildings.
- 2009 WUFI's influence on development of codes, standards, and industry designs for new envelope assemblies and retrofits grew; for example, the first moisture-control envelope design standard (ASHRAE 160) was issued and adopted by a federal agency (GSA P100).
- 2009 At DOE and OMB request, ORNL designed new comprehensive national evaluations of the State Energy Program (SEP) and the Energy Efficiency and Conservation Block Grant (EECBG) under pre-Recovery Act and Recovery Act conditions.
- 2009–2012 ORNL designed and supervised the technical assistance program for more than 3000 SEP and EECBG grantees.
- 2009 GE Appliances launched GeoSpring™ electric heat pump water heater; in 2012 domestic production began in Louisville, KY, creating 100 GE manufacturing jobs and approximately 1000 total US jobs; the unit uses 62% less energy than standard equipment and pays for itself in a few years.
- 2010 The GE Appliances heat pump water heater initiative motivated several competitors to also introduce products, enabling DOE to raise the NAECA minimum efficiency level for electric storage water heaters, 55 gallons and larger, by 120% relative to the previous level, effective April 16, 2015.
- 2010 ORNL projections of the impact of the American Recovery and Reinvestment Act (ARRA) on the Weatherization Assistance Program became the basis of DOE estimates of energy savings, expenditure reductions, and environmental impacts under the \$5 billion ARRA expansion of the program.
- 2010 ORNL introduced an industry-consensus Web-based calculator that today has evolved into the Roof Savings Calculator to help residential and light commercial building owners and contractors determine the energy savings performance and value of roof and attic technologies for new construction or retrofit applications.
- 2011 R&D 100 Award presented for an engine-driven rooftop unit, featuring heat recovery for space conditioning and 85% less demand during electric utility peak load periods, and launched by Southwest Gas under the NextAire brand.
- 2011 ORNL's hygrothermal research collaborations with industry (cool roofs, air barriers, insulation systems) became widespread and resulted in affordable, moisture-durable products in the market.
- 2012 ORNL's report on mixing appropriations and private financing revealed that contrary to current policy in many federal agencies, the most cost-effective way to meet energy and water goals is for agencies either to use their appropriations as one-time payments in comprehensive ESPC projects, or to fund long-payback measures that cannot be implemented through ESPC.
- 2012 ClimateMaster launched the Trilogy 40™ Q-Mode™, a variable-speed, ground-source integrated heat pump that reduces annual energy use as much as 65% compared with standard equipment.
- 2013 WUFI recognized as a "2013 top-10 green building product" by BuildingGreen, Inc. at the US Green Building Council's annual GreenBuild conference.
- 2013 ORNL released the first web-based version of the Weatherization Assistant energy audits with residential energy efficiency modules for single-family, mobile home, and small multifamily, and with a health and safety module.
- 2013 ORNL completed the field study of the impact of the Weatherization Assistance Program on indoor air quality, the largest study of its kind ever conducted.



## Contact Information

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ORNL building energy efficiency research activities are directed and funded primarily by the US Department of Energy (DOE) Building Technologies Office, which is part of the department's Office of Energy Efficiency and Renewable Energy (EERE). ORNL through BTRIC also provides research, demonstration, and deployment for EERE's Federal Energy Management Program, Office of Weatherization and Intergovernmental Programs, and Advanced Manufacturing Office. In addition, BTRIC supports other offices within DOE, federal agencies, state agencies, and the private sector through DOE's work-for-others program and as a DOE-designated National User Facility.