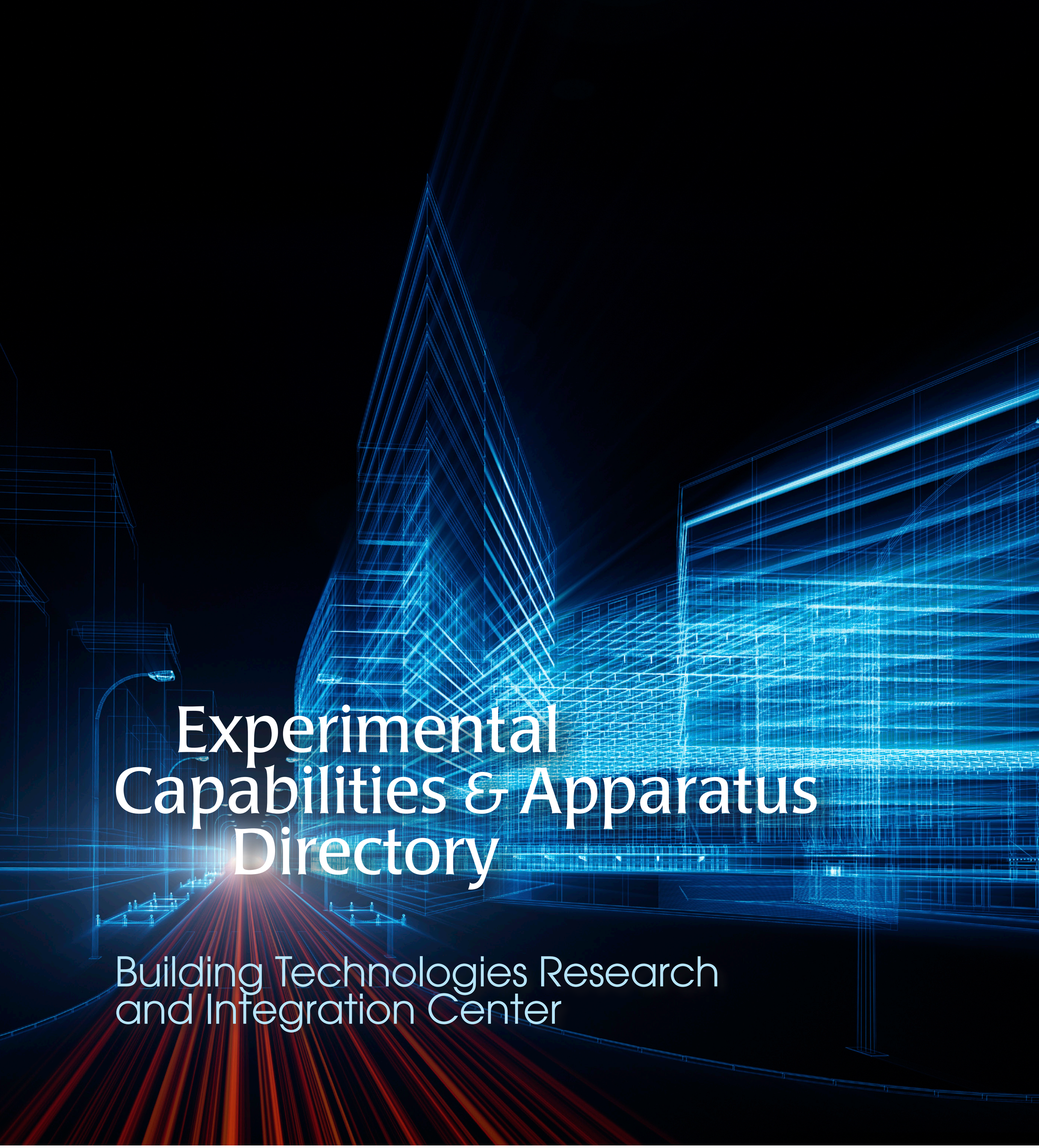


Experimental Capabilities & Apparatus Directory

Building Technologies Research and Integration Center

Oak Ridge National Laboratory

Managed by UT-Battelle for the Department of Energy

Building Technologies Research and Integration Center

Oak Ridge National Laboratory's (ORNL) Building Technologies Research and Integration Center (BTRIC) provides unique experimental capabilities needed to accelerate building energy efficiency solutions from concept to commercialization. This Directory details these capabilities, with descriptions of the laboratories, tools, and apparatuses accessible to industry, universities, and other ORNL collaborators. The capability descriptions are organized under the three BTRIC Centers of Excellence that are involved with experimental work – Building Envelope, Building Equipment, and System/Building Integration.

Benefitting Buildings Industry Stakeholders:

- Materials suppliers
- Product manufacturers and channel partners
- Service providers
- Architects
- Engineers
- Builders and contractors
- Consultants
- Building owners
- Code officials
- Utilities

Building Envelope Center of Excellence

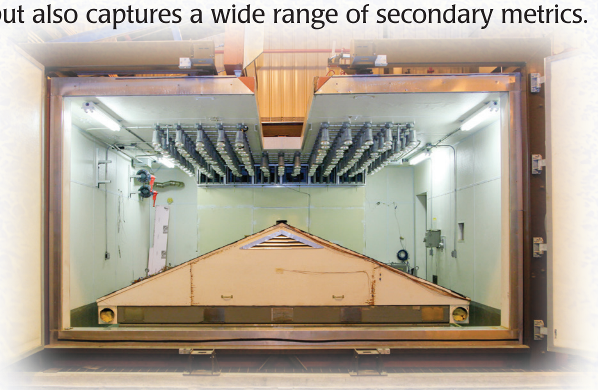
Developing component technologies that are more resistant to heat flow, airtight, and moisture-durable than existing technologies

Success Story:

Faced with rising fuel and electricity costs, building owners and homeowners demand improvements in energy efficiency. Through new and established partnerships, ORNL is helping industry improve the energy efficiency of building envelopes without creating moisture–durability issues. For example, ORNL in collaboration with the Fraunhofer Institute of Building Physics has developed the world's most respected hygrothermal models for understanding the flow of heat, air, and moisture through envelope assemblies, storage of heat and moisture in the assemblies, and thresholds for onset of failure modes. Known as WUFI (Wärme Und Feuchte Instationär), the model has been validated with data from natural exposure field test facilities in North America and Europe. Scaling envelope improvements in the market is now feasible without fear of unintended consequences. Recently WUFI was recognized with the "Moisture Safety 2011" award from the Moisture Research Center in Sweden and as a "2013 top-10 green building product" by BuildingGreen, Inc. at the US Green Building Council's annual GreenBuild conference.

Large-Scale Climate Simulator

The large-scale climate simulator tests low-slope roof or roof/attic assemblies weighing up to 9000 kg (10 tons) and with footprints as large as 3.8×3.8 m (12.5×12.5 ft) under any inhabited climatic condition in North America. The upper (outdoor) chamber can expose assemblies to a broad range of temperatures (–40 to 150°F, –40 to 65°C), and humidity, sunlight, and wind can also be simulated. The lower (indoor) chamber can control temperature and humidity within ranges typical for indoor conditions. Realistic static air pressure differences between the upper and lower chambers can also be maintained to simulate air leakage. The LSCS primarily measures heat flux between indoors and outdoors but also captures a wide range of secondary metrics.



Large scale climate simulator

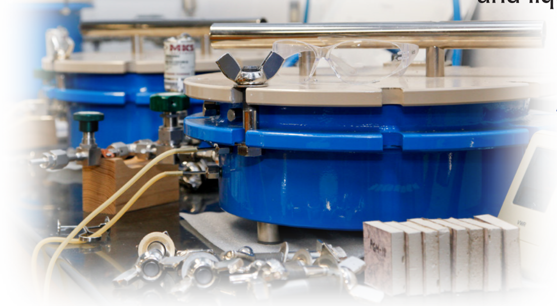
Rotatable Guarded Hot Box

Rotatable guarded hot box

The rotatable guarded hot box measures heat flux across large-scale wall/fenestration assemblies. It accommodates systems as large as 4×3 m (13×10 ft) and as thick as 0.6 m (2 ft). Chambers on both sides can maintain a range of temperatures; low-side (39 to 140°F, 4 to 60°C) and high-side (75 to 140°F, 24 to 60°C).

Hygrothermal Material Properties Laboratory

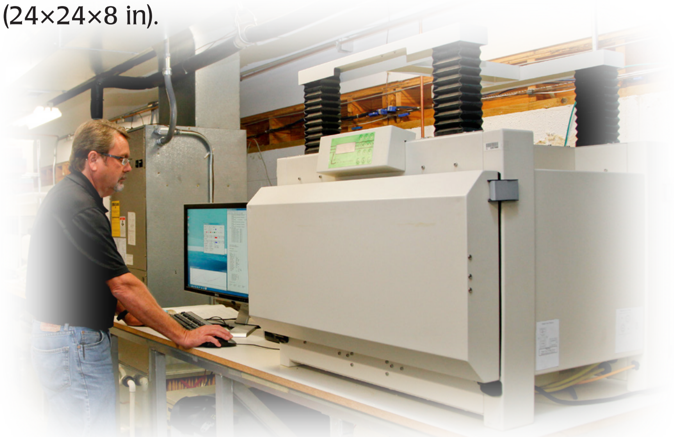
ORNL is developing hygrothermal models of building envelope assemblies and validating them against experimental data to advance understanding of heat, air, and moisture flow and how moisture accumulates in building components. Properties necessary for hygrothermal modeling are not readily available for construction materials, so facilities are available for measuring water vapor permeance, sorption and desorption isotherms, and liquid diffusivity.



Pressure plate apparatus for sorption isotherm measurement at very high relative humidity

Insulation and Air Barrier Materials Laboratory

ORNL supports industry collaborations to develop advanced insulation and air barrier systems and testing methods. The insulation and air barrier materials laboratory enables precise measurements of properties using tools such as a heat flux meter apparatus, air flow meters, precision slicers to prepare thin slices of foam insulation for accelerated aging experiments, 13 temperature-controlled chambers for long-term aging, and air-tight chambers for aging in various gases to estimate air permeance. The heat flux meter apparatus accommodates specimens of up to 60×60×20 cm (24×24×8 in).



Heat flux meter apparatus used to measure the thermal conductivity of materials

Roof Thermal Research Apparatus

The roof thermal research apparatus measures effects of long-term natural weather exposure on small, low-slope roof specimens. The interior is heated and cooled to constant typical indoor conditions and houses a continuous data acquisition system. The apparatus handles up to four instrumented 1.2×2.4 m (4×8 ft) test specimens. The roof thermal research apparatus wall panels and foundation slab edges are used to evaluate wall- and slab-insulation systems under long-term weather exposure.

Duct Blaster

A duct blaster measures air flow in a duct system and helps locate air leaks. It typically connects to the duct system at an air return while other grills are temporarily sealed. As it exerts a standard test pressure on the duct system, airflow and pressure gauges measure air leakage. ORNL's Minneapolis Blower Door Company Duct Blaster provides air flow rates up to 1350 cfm and sustained pressures up to 50 Pa. It can be used for testing in most residential and light commercial buildings.

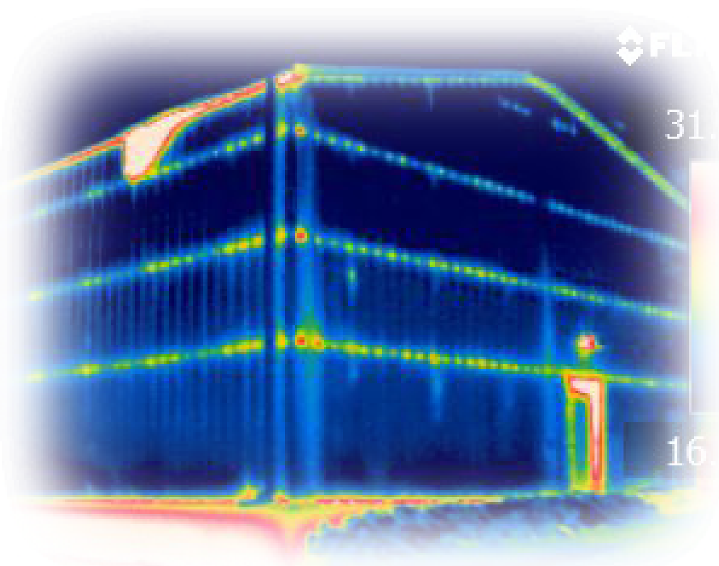
Wall Air and Moisture Penetration Test Chambers

The wall air and moisture penetration test chambers subject 2.4×3 m (8×10 ft) wall assemblies to simulated indoor and outdoor temperatures of 15.6 to 32.2°C (60 to 90°F) and –17.8 to 43.3°C (0 to 110°F), respectively, and 10 to 90% relative humidity. Other simulated outdoor conditions are positive and negative wind/gust pressures, rain, and solar radiation.

Wall air and moisture penetration test chambers

Infrared Cameras

Three infrared cameras are available for nondestructive thermograpic imaging of building envelopes and equipment. The FLIR Thermacam™ S65 HS has a spectral range of 7.5 to 13 µm and accuracy of ±2°C (±3.6°F) or 2% of reading. Its measurement range is –40 to 1500°C (–40 to 2732°F) and operating temperature range is –15 to 50°C (5 to 122°F). Two older models, the FLIR PM 280 and PM 295, have spectral ranges of 3.4 to 5 µm and 7.6 to 13.5 µm and measurement temperature ranges of –10 to 450°C (14 to 842°F) and –40 to 500°C (–40 to 932°F), respectively.



Solar Reflectometer

A portable solar spectrum reflectometer is used to measure the total hemispherical solar reflectance of exterior surfaces of building envelopes. The device uses a tungsten halogen lamp to diffusely illuminate a sample. Four detectors, each fitted with differently colored filters, measure reflected light in different wavelength ranges. The four signals are weighted in appropriate proportions to yield the total hemispherical solar reflectance.

Thermal Emissometer

A portable emissometer measures the total hemispherical emissivity of building envelope surfaces. Its thermopile radiation detector is heated to 82.2°C (180°F). The detector has two high-e and two low-e elements and responds only to radiation heat transfer between itself and the sample. It must be calibrated in situ using two known standards.

Blower Door Apparatus

A blower door consists of a calibrated fan temporarily sealed into an exterior doorway. It forces air through gaps in the building envelope to measure envelope airtightness and locate air leaks. ORNL's Minneapolis Blower Door Company model 3/110V is capable of air flow rates up to 6000 cfm in free air and 4900 cfm at 75 Pa of building interior pressure. Attachment flow rings allow measurements as low as 12 cfm. It can be used for testing in most residential and light commercial buildings.

Natural Exposure Test Facilities

ORNL's natural exposure test facilities expose side-by-side roof/attic and wall assemblies to natural weathering in four different humid US climates. The data gathered at these facilities assists industry in developing products that make envelopes more energy efficient yet avoid adverse moisture-related impacts, and are essential in validating hygrothermal and energy models. Natural exposure test structures are located at ORNL and at Charleston, SC; Tacoma, WA; and Syracuse, NY. Each is temperature and humidity controlled and instrumented to measure parameters such as moisture content in materials, vapor pressure, temperature, heat flux, humidity, and condensation.

Natural exposure test facility located at ORNL

Atlas Ci-3000+ Weathering Chamber

The Ci-3000+ provides a testing environment with precise control of solar irradiance, temperature, and relative humidity for up to 22 samples. It tests the impact of dew formation on surfaces and generates solar irradiation equivalent to that of two Suns. Users can program a weathering cycle through a digital control panel, save the data to an SD disc, and display test parameters on a screen for monitoring. Multiple test cycles can be stored in the system's memory.

Building Equipment Center of Excellence

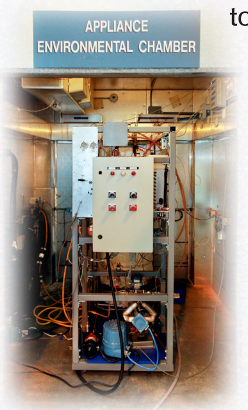
Success Story:

Industry and consumers want improved equipment efficiency to counteract rising costs, scarce resources, and climate change. For decades, ORNL research has addressed these challenges and enabled successful collaborative development of more energy-efficient building equipment, marketplace acceptance, and job creation. For example, GE Appliances launched its GeoSpring™ heat pump water heater only 20 months after its collaboration with ORNL began. This technology saves 62% on energy use and pays for itself in a few years when compared with standard models. In 2012, the product created 100 GE manufacturing jobs in Louisville, Kentucky, and more than 1000 estimated total US jobs.

GE GeoSpring™ heat pump water heater

Small Appliance Environmental Chamber

This 3.3×3.3×2.6 m (10×10×8 ft) chamber is used to characterize the performance of appliances such as residential water heaters and refrigerators. It controls dry-bulb temperature from –17.8 to 48.9°C (0 to 120°F) and relative humidity from 40 to 80% at a cooling load of about 4000 Btu/h. Utilities include 480 V, 3-phase power at 40 A with step-down transformers to provide 240, 208, and 120 V.



Small appliance chamber

Mid-Size Environmental Chambers

These chambers support performance characterization of gas and electric space-conditioning and combined heat and power components and systems (up to 10 tons). Gas and electricity are supplied, with 480 V, 3-phase power at 225 A and step-down to 240, 208, and 120 V. The "outdoor" chamber is 4.6×5.5 m (15×18 ft) and "indoor" chamber 4.6×3.7 m (15×12 ft). Dry bulb temperature is controlled at –23 to 54°C (–10 to 130°F) and relative humidity at 30 to 90%.

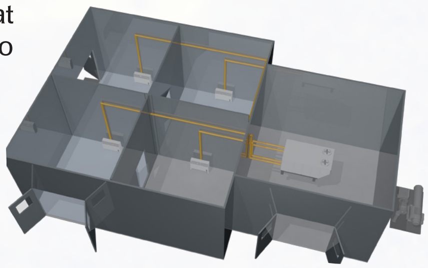
Large Environmental Chambers

Characterizing the performance of commercial heating/ventilation/air-conditioning (HVAC), supermarket refrigeration, and combined heat and power systems (up to 20 tons) is accomplished using "outdoor" and "indoor" chambers of the same size at 6.1×6.1 m (20×20 ft) with a 4.3 m (14 ft) ceiling. Gas and electricity are supplied, with 480 V, 3-phase power at 225 A and step-down to 240, 208, and 120 V. Dry bulb temperature is controlled at –29 to 54°C (–20 to 130°F) and relative humidity at 30 to 90%.

Large environmental chambers (outdoor shown)

Multi-Zone Environmental Chambers

This facility characterizes the performance of multi-zone electric or gas HVAC systems (up to 10 tons) for residential and small commercial use. The "outdoor" chamber is 6.1×4.6 m (20×15 ft); the 8.5 m (28 ft) square "indoor" chamber can be divided into up to four spaces controlled at different conditions to represent separate zones. Dry-bulb temperature is controlled at –23 to 54°C (–10 to 130°F) and relative humidity at 30 to 90%. Utilities include 480 V, 3-phase power at 225 A with step-down to 240, 208, and 120 V.



Multi-zone environmental chambers

Water Temperature Control Loop

This apparatus tests heat-pump–based water heating systems (e.g., heat pump water heaters and integrated heat pumps for both space conditioning and water heating) in the mid-size chambers and small appliance chamber. Supply water is provided to test systems at 4.4–43.3°C (40 to 110°F). The plant for the loop includes a 2 ton nominal capacity variable-speed refrigeration system and an 18 kW electric resistance immersion heater for precise water temperature control.

Water Heater Accelerated Durability Test Facility

This facility tests up to 10 residential heat pump water heaters simultaneously, simulating 10 years of residential operation in 10 months, to support statistical service life estimates. Electricity and gas are supplied. Total rated input power is 50 kW; supply voltage is variable from 190 to 240 V to simulate grid voltage droop. Supply water is provided over a 4.4 to 24°C (40 to 75°F) range.

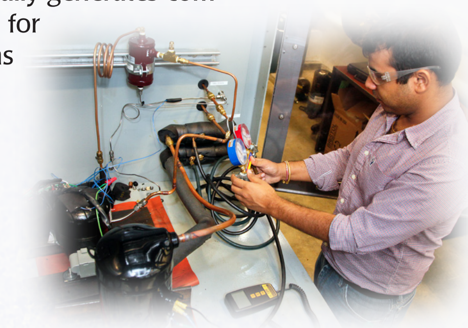
Heat pump water heater accelerated durability testing

Small Compressor Calorimeter Test Stand

The small compressor calorimeter test stand experimentally generates compressor performance maps for fractional-ton compressors (300 to 3600 Btu/h) used in refrigerators and other small appliances and equipment. It is equipped to safely test compressors using alternative refrigerants with some level of flammability (e.g., isobutene, propane) and nonflammable refrigerants such as hydrofluorocarbons (HFCs) and low-global warming potential (GWP) hydrofluoroolefin alternatives.

Large Compressor Calorimeter Test Stand

This apparatus experimentally generates compressor performance maps for compressors of up to 3 tons (3,000 to 36,000 Btu/h) like those in air conditioners and heat pumps. It can safely test compressors at very high pressures using transcritical CO_2 as the refrigerant and nonflammable refrigerants such as HFCs and low-GWP hydrofluoroolefin alternatives.



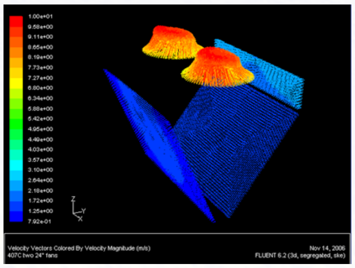
Large compressor calorimeter test stand

High Temperature Heat Exchanger Test Loop

This loop tests air-to-water heat exchangers (HXs) at high air-side temperatures like those encountered in recovering heat from turbine exhaust in combined heat and power applications. It features variable air flow from 10 to 1500 cfm, entering air temperatures from room temperature up to 593°C (1100°F), and entering water temperatures from 10 to 93.3°C (50 to 200°F).

Computational Fluid Dynamics Modeling

Computational fluid dynamics modeling is conducted using a 65 inch LCD screen for visualization, four work stations, computers with quad processors, and FLUENT and SolidWorks modeling packages.



Computational fluid dynamics modeling of heat exchanger

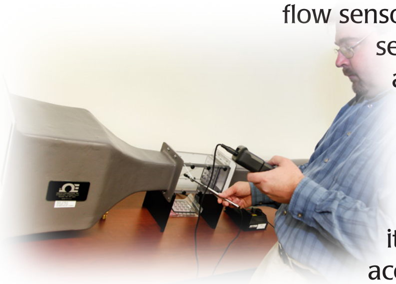
Pumped Liquid Refrigerant Test Loop

This loop for testing refrigerant-to-air HXs precisely controls entering refrigerant temperature and pressure. It accommodates evaporators with capacities up to 2 tons (24,000 Btu/h) and evaporating temperatures of 4.4 to 10°C (40 to 50°F), and condensers up to 3 tons (36,000 Btu/h) and condensing temperature of 48.9°C (120°F). Alternative pure refrigerants can be tested without lubricating oil. The air-side loop moves up to 7000 cfm of air against a 4 inch (water gauge) HX pressure drop. Thermal imaging can determine flow maldistribution through the HX.

Pumped liquid refrigerant test loop

Bench Top Wind Tunnel

The Omega WT4401-D wind tunnel tests novel HX concepts and features such as fin performance. It is also used to calibrate hot wire anemometers and other less precise air flow sensors. The test chamber has a cross-section area of 10×10 cm (4×4 in.) and induces a flow rate from 25 to 9,000 cfm. It is fully instrumented with high-accuracy barometric pressure, differential pressure, temperature, and relative humidity sensors. Flow rate measurement accuracy ranges from 1 to 2%. All instruments are provided with National Institute of Standards and Technology (NIST)-traceable calibration.



Bench top wind tunnel

Additive Manufacturing Plastic Heat Exchanger 3-Dimensional Printer

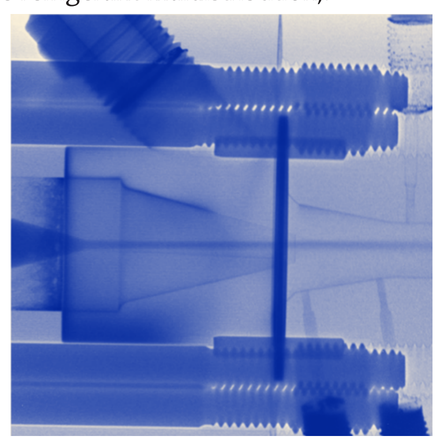
The Objet30™ 3D printer is used for rapid prototyping of functional HXs from plastics. HXs manufactured must fit within a 3D envelope size of 295×190×150 mm (11.6 by 7.6 by 5.9 in.). Dimensional HX accuracy is within ± 0.1 mm (± 0.004 in.). HXs can be manufactured from different materials, but each build must be with a single material. Several build materials are available.

Fluid Physical Properties Laboratory

This lab contains precision instruments for measuring density, viscosity, thermal conductivity, thermal diffusivity, and specific heat of fluids. They can be programmed to perform a temperature scan of a sample and measure properties over a broad temperature range while unattended. Instruments include an Anton Paar DMA 4100 M (density), an Anton Paar AMVn automated microviscometer, and a Thermtest THW (thermal conductivity and diffusivity and specific heat).

Two-Phase Flow Neutron Imaging Test Stand

ORNL's High Flux Isotope Reactor uses neutron imaging to simultaneously measure refrigerant 2-phase flow void fraction, pressure drop, and heat transfer in single- and multi-channel HXs. Images and other information generated guide HX redesign (e.g., to eliminate refrigerant maldistribution). The test apparatus accommodates flow channels of various sizes and materials and operates over a range of operating conditions and with several low-GWP refrigerants. It consists of a refrigerant flow loop and a test section that allows microchannel HXs to be interchanged.



Neutron imaging of heat pump internal ejector nozzle

System/Building Integration Center of Excellence

Success Story:

ORNL has developed an innovative means for our industry partners to work out the wrinkles in their new products in low-risk, realistic residential and light commercial building test beds before market introduction. For example, through alliances with utilities and private partners, ORNL has access to a fleet of research houses. Several of the houses were used to conduct the necessary field performance characterization of prototypes leading to ClimateMaster's Trilogy™ 40 Q-Mode™ ground-source integrated heat pump, which was introduced in 2012. The technology reduces annual residential space conditioning and water heating energy use by up to 65% compared with conventional systems.

Prototype of ClimateMaster's Trilogy™ 40 Q-Mode™ while installed in ORNL research house

Unoccupied Research Houses

ORNL uses a fleet of instrumented research houses built by industry partners to evaluate prototypes of residential energy efficiency technologies under realistic conditions. An average occupancy effect on energy consumption is imposed for each house in addition to natural exposure to weather so that realistic loads, operating conditions, and interactive effects are provided for evaluating technologies and validating models. Generally each house is used to characterize the performance of one envelope configuration, but several generations of advanced equipment, appliances, and controls can be investigated over the term of the leases.

Unoccupied research house

Owner-Occupied Research Houses

ORNL evaluates residential energy-saving retrofit technologies experimentally in occupied homes by collecting energy performance data before and after retrofits. Under agreements with homeowners, ORNL and its partners conduct energy audits and recommend and provide technical advice about improvements. Homeowners pay for the improvements. When it is agreed that improvements will be implemented, ORNL collects before/after data and evaluates energy savings. The goal is to develop affordable retrofit packages with energy savings of 30–50%. Typical energy conservation measures implemented include air sealing and insulating the envelope, upgrading the existing HVAC systems, water heaters, appliances, and lighting.

Owner-occupied research house

Light Commercial Building Flexible Research Platforms

Flexible research platforms (FRPs) include one-story 40×60 ft (2400 gsf) and two-story 40×40 (3200 gsf) units, each consisting of foundation slabs, structural frames, and utility and IT infrastructure to support a variety of test building configurations. Both FRPs have slab-on-grade "active foundations" that thermally isolate buildings from the ground when desired. Through collaboration with industry, test buildings are designed, installed onto the FRPs, and instrumented for evaluation. The same system executes process control and acquires performance data in a building. Process control can control the active foundations, simulate occupant effects on energy use, support development and evaluation of fault detection and diagnostics (FDD) or continuous commissioning schemes by forcing faults, and rotate among multiple HVAC systems. Secure, web-accessible data analysis and visualization are provided. Collaborations typically address envelope, equipment, commissioning/FDD/controls, and modeling/analytics.

One-story light commercial building flexible research platform

Two-story light commercial building flexible research platform

Computer Modeling, Visualization, and Analytics

ORNL's building energy efficiency researchers have access to some of the most powerful supercomputing, visualization, and analytics tools in the world. ORNL hosts a 20 petaflop, 299K core, 710 terabyte memory Cray supercomputer (Titan, the world's fastest nonclassified system), as well as several others. Researchers can analyze and visualize their data using EVEREST, a 35 million pixel, 30×10 ft visualization wall at ORNL or the 16 million pixel display wall within the Transportation Research and Visualization Laboratory (TRAVL) at ORNL's National Transportation Research Center.

ORNL Roof Savings Calculator visualization using the TRAVL display

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, Office of Weatherization and Intergovernmental Programs, and Advanced Manufacturing Office. 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 a user agreement 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.

Diverse Facilities for Accelerating Buildings Research

ORNL buildings research is multidisciplinary in nature, with BTRIC providing unique experimental capabilities needed to accelerate building energy efficiency solutions from concept to commercialization. With facilities strategically located throughout the ORNL campus, the Center provides scientists and engineers with unmatched access to a broad array of laboratories, tools, and apparatuses described in this brochure that are designed to help industry partners accelerate products to market that will maximize cost-effective building energy efficiency.

MAXLAB, the Maximum Building Energy Efficiency Research Laboratory, is the newest BTRIC facility. Competitively funded through the American Recovery and Reinvestment Act, it houses a high-bay area for envelope research and a low-bay area for equipment research.

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 numbered above, with the exception of the largest building equipment research laboratory, which is in Building 5800, D-103.

Contact Information

For more information on ORNL partnership opportunities to advance building energy efficiency technologies, please contact:

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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.