COLD CHALLENGES

BY MOLLY RETTIG AND NATHAN WILTSE

Winter days with little to no sunlight, frigid temperatures and reliance on expensive fuel oil for heat might seem to be insurmountable obstacles to building sustainable, energy-efficient structures in Alaska. But the Cold Climate Housing Research Center (CCHRC) in Fairbanks, Alaska, proves otherwise. The Research and Testing Facility, housed in the farthest north LEED Platinum building in the world, is a living laboratory for arctic building science and energy research.

The 15,000 ft² Research and Testing Facility sits on the edge of the University of Alaska Fairbanks campus. Experiments are embedded throughout the building in the form of innovative wall assemblies, creative energy storage and multiple heating and distribution systems.

CCHRC was formed in 1999 by members of the Alaska home building community to address the challenges and costs of building in this climate. Its mission is to make housing more energy efficient, healthy, affordable and durable throughout Alaska and circumpolar regions. CCHRC is supported by the state-owned Alaska Housing Finance Corporation, which finances more than 40% of all new residential construction in Alaska, as well as other funding sources.

The team researches building techniques and materials, tests heating and energy systems and designs sustainable prototype houses for rural Alaska. This research is disseminated to building professionals, regulators, housing agencies, policymakers and homeowners through publications, education and outreach. For instance, CCHRC developed a wall system for Interior Alaska that saves homeowners thousands on energy costs and designed prototype homes for rural Alaska that cost far less than conventional homes and use one-tenth the energy.

The facility, built in 2006, integrates proven technologies—such as a super-tight thermal envelope and a highly efficient stone masonry heater—with innovative ideas—such as an adjustable foundation and experimental wall designs. The structure is laced with hundreds of sensors monitoring temperature, humidity, light, carbon dioxide and more. It is designed to prove that sustainable, affordable building is possible even in the world’s coldest places.

Energy Efficiency

Fairbanks swings from −50°F and three hours of daylight in the winter to 80°F and nearly 23 hours of sunlight in the summer. It has a six-month cold season and nearly 14,000 heating degree days, almost three times the national average. In addition, Interior Alaska has no access to low-cost natural gas or electric heat and therefore relies on oil (at roughly $4 a gallon) as its main heating fuel. The extreme climate and high cost of heating have pushed Alaska to the forefront of energy efficiency design and innovation.

The facility was built for $346/ft², less than the cost of typical
commercial construction in this region at $400/ft². It uses roughly half the energy resources of a typical commercial building its size in Fairbanks.

The building combines high-efficiency oil boilers, as well as experimental solar thermal and wood boiler systems into an integrated hydronic heating system. But the thermal envelope is the heavy lifter, delivering a majority of the energy savings. The building has a warm, airtight envelope with an R-60 roof, R-40 to R-45 walls, and 0.15 to 0.20 U-value triple-pane, argon gas-filled windows.

Wall assemblies are comprised of combinations of materials and insulation. The west wing, which houses the labs and design office, mimics commercial construction with a structural steel frame wrapped with 2 × 4 light gauge steel stud curtain walls, interior cellulose insulation (R-21) and layered EPS exterior foam insulation (R-26). The east administrative wing simulates residential construction with 2 × 6 wood framing, interior fiberglass insulation (R-19), and exterior foam (R-26).

Both systems use a construction method called REMOTE (Residential Exterior Membrane Outside-insulation TEchnique) that was developed to prevent moisture problems in the wall cavities, a widespread issue in the severe cold of Interior Alaska. The method moves the majority of the insulation and the air barrier to the outside of the wall sheathing, keeping dew point

The masonry heater is made of 12,000 local rocks that absorb heat from exhaust gases and radiate it slowly into the building. With a 2,000°F fire in the firebox, the heater produces an extremely hot, clean burn, exhausting 300°F gas out of the flue.

NET ENERGY USE FOR ELECTRICITY AND HEATING
JULY 2008–JUNE 2009*

*Net heating includes fuel oil, wood and solar thermal. Solar thermal accounts for less than 1.5% of space heating. Net electricity includes purchased electricity only. Gross annual electricity use (including electricity generated on site) is about 85,000 kWh (290,032 kBtu).

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condensation outside the cavity and allowing walls to dry to the inside. The REMOTE system also eliminates thermal bridging, another contributor to building heat loss. The REMOTE wall has become a popular new construction and retrofit method in the Interior, with an estimated one-half of new homes using this technique.

On a standard 2 x 6 wall in a 1,900 ft² home, adding 6 in. of EPS in materials cost and will pay back in energy savings in about 4.5 years. Energy savings over 10 years equal more than $5,000 (assuming heating oil prices of $5 a gallon).

Heating. The building absorbs all its heat for space heating and domestic hot water from passive solar and solar thermal from April through September. In the winter, it relies on two of its three oil-fired boilers (designed to be interchangeable for testing purposes).

The current top performer is a 92% AFUE (annual fuel utilization efficiency) condensing boiler because it’s able to squeeze more BTUs out of the flue gas than standard non-condensing boilers. The boiler feeds water through the radiant in-floor slab, which is separated into 16 control zones throughout the facility. A large central air handler could possibly be more efficient if it were as sophisticated as the current zoned system; it would need a damper control system and pressure feedback system to respond to ventilation needs throughout the building.

Ventilation. Instead of one central air-handling system, the building has six highly efficient residential heat-recovery ventilators (HRVs) throughout the building. The system tests the three most popular brands of HRVs in the region and improves whole building efficiency by ventilating specific zones on demand. The HRV’s operate based on outdoor air temperature and interior carbon dioxide concentrations and can be manually activated. They also redistribute heat through ducting from warm areas, like near the masonry heater, to cooler areas. A large central air handler could possibly be more efficient if it were as sophisticated as the current zoned system; it would need a damper control system and pressure feedback system to respond to ventilation needs throughout the building.

Lighting. The building is lit with a mix of sunlight, T-8 fluorescent lamps and LEDs. Lights are controlled by motion sensors and ambient light sensors that gauge the amount of light coming in the windows. The controls reduce artificial lighting levels based on the availability of natural light and turn off lights when a zone is vacant. Few interior lights are needed from May through August.

Resources and Renewables

Researchers are studying solar, biomass and thermal storage to see how the resources perform in this climate and whether they can provide 100% of the facility’s energy in the future. Currently, approximately 25% of the energy use is offset by on-site renewable sources.

Two types of solar thermal panels—flat plate and evacuated tube collectors—are mounted on the roof to study which technology works best with the low-angle sun and heavy frost accumulation. The collectors provide heat for the labs’ radiant floor system during low heat demand periods, saving oil consumption for colder and darker times of the year.

While the evacuated tube collectors have produced more total BTUs over the past five years, they tend to work best in the spring and fall shoulder seasons, while flat plate collectors outperform them in the summer.

Another key energy source is the masonry heater, an old-world technology designed to hold and emit heat for long periods of time. Masonry heaters are one of the cleanest ways to burn wood, which is still a significant heating fuel in Alaska.

The heater is made from stone with a refractory brick combustion chamber and flue passage. Each morning during the heating season, it is loaded with about 60 lb of wood and burns as a hot, fast fire, which is a far cleaner combustion than a long, smoldering fire.

As hot flue gases meander through the heater’s 30 ft of winding flue passage, the heat is absorbed by 12,000 lb of mass and radiates...
One wall section of the Research and Testing Facility demonstrates the REMOTE technique with 2 x 6 studs filled with R-11 batt insulation and 6 in. of expanded polystyrene (EPS) foam board on the outside of the sheathing.

The gallery in the west wing of the building is impacted by the tracking arrays’ ability to collect the high level of diffuse light and reflected solar gains from snow cover, which amounts to one-third of collected solar energy in March, April, and May.

Solar PV CCHRC also taps the sun for electricity with a 12-kW photovoltaic array. A fickle resource at this latitude, the sun shines excessively in summer months (providing 30% of the building’s power) and scantily in winter months (kicking out just 2 kWh in January). When the building is not demanding power, the panels feed power into the local electric grid or charge the on-site 24-hour battery bank. The system includes three panel technologies arranged in three arrays that track the sun and one fixed array.

The greater output from the tracking arrays resulted in the same nine-year payback as the fixed array, despite a nearly 40% higher installation cost. The payback equation also is impacted by the tracking arrays’ ability to collect the high level of diffuse light and reflected solar gains from snow cover, which amounts to one-third of collected solar energy in March, April, and May.

Brownfield Redevelopment. The facility is located on a 2.5-acre brownfield site with a history of groundwater contamination and poor soils that is still being monitored by state environmental regulators. The site was previously cleared and was being used as an experimental farm by the University of Alaska Fairbanks until 30 years ago.

The location was selected to demonstrate how to design and build successfully on a lower quality site rather than develop additional land. The site is near an old gas station that is thought to have leaked gasoline, solvents, and waste oil into the groundwater, creating a benzene plume one-quarter mile from the facility.
To avoid the contaminated groundwater, CCHRC uses a system of delivered water, rainwater harvesting and remediation. Designers revegetated the land, preserved open space, developed a wetland habitat and restored native grassy fields.

Water. Half of the water consumed within the building (about 15,000 gallons a year) comes from the sky. This rainwater is collected during nonwinter months from the roof and stored in two 2,500 gallon cisterns in the basement. It is used to flush toilets and supply the sprinkler system.

Seasonally harvested rainwater also irrigates vegetable and flower gardens around the building and on the roof. The facility reduces water use with dual-flush toilets, waterless urinals and low-flow showerheads.

This rainwater harvesting system had an increased up-front cost, roughly $7,000 including tanks, plumbing and pumps. Half the water is delivered at a cost of 6 cents per gallon. But the rainwater collection and water delivery are the best long-term options, as drilling a well was not possible (because of the site’s history) and hooking up to municipal water would have been cost prohibitive.

The frozen soils of the site are not compatible with a standard wastewater system—an underground septic tank and leach field. Instead, the building uses a locally made self-contained sewage treatment plant, rated for –50°F. At about $15,000, the sewage treatment plant cost approximately 40% more than a standard leach field system, but was required to build on this site.

It contains three chambers that separate the solid waste, break down the sewage through an aerobic process, disinfect the liquid effluent with a UV lamp and ultimately discharge the treated effluent. The treated water flows through a swale to a storm water pond that provides wetland habitat for ducks and other wildlife. Through adjusting the system’s fan, lights and sensors, researchers have cut its original energy use nearly in half. CCHRC researchers have adapted the sewage treatment plant to building projects in rural Alaska with equally challenging soils.

Foundation. CCHRC has a one-of-a-kind adjustable foundation that allows it to respond to possible movements in the frozen soils (or permafrost) that lay 15 to 30 ft.
beneath the building. The foundation includes concrete footings that can be pushed into the ground to help level the building in the event that permafrost melts or shifts.

The foundation contains more than 50 concrete jacking points. If the building experiences differential settling, hydraulic jacks can be installed to lift the structure.

LESSONs LEARNED

More Low-Temperature Radiant Heat, Less Radiant Baseboard Heat: CCHRC has a mixed heat distribution system with about one-third radiant floor slab and two-thirds baseboard heat. In floor heating is much more efficient because it requires lower-grade heat, allowing the building to take greater advantage of low-temperature sources such as solar thermal or a ground source heat pump. The addition to the CCHRC Research and Testing Facility planned for 2012 will incorporate more in-floor radiant heat as well as radiant panels in the walls and ceiling.

More Solar Thermal, More Thermal Mass: Researchers and builders are still exploring the vast potential of solar thermal in this climate, where many underestimate the sun’s potential to provide reliable heat. Our research shows that usable solar thermal can be harvested in Fairbanks as early in the year as March, improving the viability of the resource. Key to this approach is thermal storage, using mass to capture and hold heat from the sun, biomass and other sources. CCHRC will add greater thermal mass to the building addition in 2012.

Ventilation System: The idea of zonal ventilation was successful; installing six HRVs was more cost-effective upfront and uses less energy than a central air-handling system. However, monitoring has indicated that controlling the HRVs by carbon dioxide sensors has resulted in over-ventilation and lower humidity levels. Alternate indicators are being considered while adjustments to raise indoor humidity are ongoing.

Heating Load Evaluation: When designers focus on electric loads and heating loads as separate components rather than as a system, the heating contribution from large electric appliances can often be overlooked. Such is the case with the server room in the basement, which provides more than enough heat for that zone. Monitoring of the building’s zone demands has shown that no call has ever been needed for this zone, even at -50°F.

About the Authors

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Upcoming Innovations. A 7,500 ft² addition to the Research and Testing Facility planned for 2012 will incorporate a ground source heat pump, greater thermal storage and more radiant heat. By adapting today’s technologies to a cold climate and pushing toward net-zero energy, CCHRC is striving to transform the future of housing in Alaska.

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Materials: The building is made from local resources (63% regionally extracted, 22% regionally manufactured) that minimize its footprint. The heart of the building is the masonry heater that sits inside the entrance. Made from a half ton of local river rocks, the heater exudes cozy radiant heat all day.

Doors and windows are trimmed in milled Alaskan birch, logged 20 miles away. The walls are constructed with Forest Stewardship Council-certified plywood and the entire structure contains 16% recycled material, including steel columns and beams, asphalt paving, fly ash concrete, cellulose insulation, carpeting, cork flooring and stone.

An open floor plan and strategically placed windows ensure that every workspace receives natural light, either direct or reflected, and views. Argon-filled, double low-e coated triple-pane windows minimize heat loss while providing benefits of passive solar and daylight—especially nice during long, dark winters.

Green Roof. The green roof provides outdoor meeting space as well as an employee garden. The roof and surrounding landscape, covered in native vegetation, were designed to reduce heat-island effect and protect permafrost.

The energy and electricity use of the building ranges from more than 19,000 kBtu in January to fewer than 130,000 kBtu in June. Right: The energy and electricity use of this building every morning in the cold season, burning hot and fast for a few hours and warming stones to about 100°F. The stones slowly emit radiant heat over 16–24 hours. Above: A fire is built in the masonry heater beneath the site. After three years and beneath the building foundation that would accelerate thawing of permafrost.