GROUNDBREAKING SOLAR

CanmetENERGY, Natural Resources Canada

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At first glance, the tidy two-story houses lining two streets in a Canadian suburb look much like the thousands of other homes that surround them; but a district heating system that stores summer's abundant solar energy to heat the homes during winter makes this community a global pioneer in heat storage technologies for residential space heating. Drake Landing Solar Community proves that such a system can deliver a large fraction (over 90%) of space heating with solar energy in a cold climate. The builder designed the 52 detached single-family houses to appeal to mainstream home buyers who want energy efficiency without sacrificing aesthetic appeal.

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Above Drake Landing Solar Community's central solar district heating system continues to collect and store solar energy through the winter. The image illustrates how the garage-mounted solar collectors clear themselves of snow, while the house-mounted domestic hot water heating panels are a little slower to clear with their lower slope.

Top Drake Landing houses are designed to appeal to mainstream buyers while minimizing environmental impact. Rain barrels are used to provide water for lawns and gardens.

Drake Landing provides a real-world example of how conventional heating fuel consumption for space heating can be nearly eliminated, reducing greenhouse gas emissions by more than 5.5 tons per house annually. This is made possible in the harsh 9,027 heating degree day climate by using solar heat collectors with seasonal heat storage, energy-efficient house design and construction, and a low temperature district heating network to distribute the heat to the homes.

Inspiration for the project came from Natural Resources Canada's solar research group's exploration of innovative seasonal storage technologies that allow much greater use of solar energy for residential space heating.

Thermal Energy Storage

Some 24,700 ft^2 of hydronic flat-plate collectors cover the roofs of the houses' detached garages. Solar heat is captured via the collectors, is stored underground in soil and later is extracted and distributed through a district system to each home in the subdivision when needed for space heating.

BUILDING AT A GLANCE

Name Drake Landing Solar Community

Location Okotoks, Alberta, Canada (22 miles south of Calgary)

Owner Drake Landing Company

Principal Use Residential
Includes 52 single-family detached houses and Energy Centre (houses mechanical and control equipment to supply heat to the community)

Employees/Occupants 52 families occupy the homes

Expected (Design) Occupancy 52 families
Percent Occupied 100%

Gross Square Footage 122,000 (houses) + 3,000 (Energy Centre) = 125,000 ft^2
Conditioned Space 125,000 ft^2

Distinctions/Awards
Energy Globe World Award, 2011; International Energy Agency Solar Heating and Cooling Programme Solar Award, 2013; Canadian Solar Industries Association Solar Thermal Project of the Year, 2006; Federation of Canadian Municipalities Sustainable Communities Award for Energy/Renewable Energy, 2006; International Awards for Livable Communities Gold Award in the Environmentally Sustainable section, 2005

Total Cost
CAN$14 million (Houses) + CAN$560,000 (Energy Centre) = CAN$14.6 million
(includes CAN$3.4 million in funding from the Canadian Government, Alberta government and the Federation of Canadian Municipalities)
Cost per Square Foot
CAN$115 (Houses) and CAN$187 (Energy Centre)

Substantial Completion/Occupancy
2006 and 2007

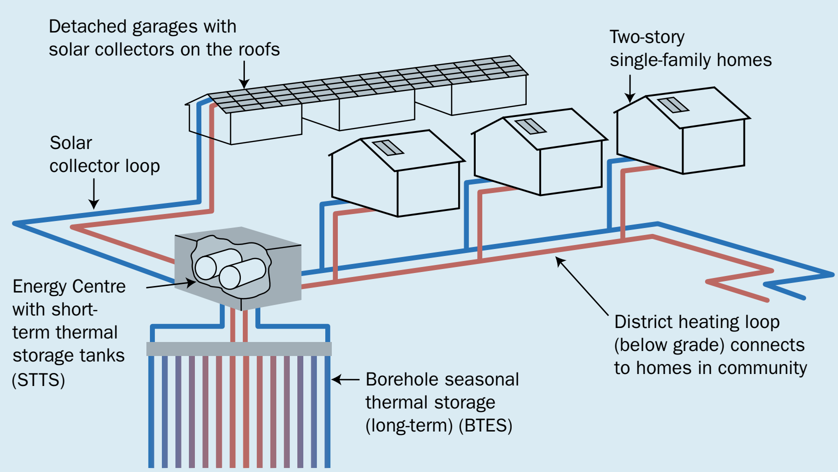
Figure 1 is a simplified schematic of the system. The seasonal borehole thermal energy storage (BTES) is comprised of a grid of 144 boreholes with single u-tube heat exchangers within approximately 44,500 yd^3 of earth. (See *Solar Seasonal Heat Storage System,* Page 40.) It is configured to maintain the center of the storage at the highest temperature to maximize heating capacity. The outer edges are maintained at the lowest temperature to minimize heat losses.

Short-term thermal storage (STTS) consisting of 63,000 gallons of water is used to interconnect the collection, distribution and seasonal heat storage subsystems and to act as a buffer to accept and release heat at rates considerably higher than are available through the BTES (*Figure 1*).

STTS tanks, pumps, controls, auxiliary boilers and other mechanical equipment are housed in the Energy Centre located at one corner of the community, and the BTES is located under an adjacent park. Heat pumps have not been used in this design.

A 22 kW photovoltaic system mounted on the Energy Centre's roof provides emergency power for critical Energy Centre loads and generates enough electricity annually to supply the solar energy collection and storage pumps.

FIGURE 1 **SOLAR SEASONAL STORAGE AND DISTRICT LOOP**



System Operation

A propylene glycol-water mixture is circulated through the collectors whenever their temperature is high enough to raise the temperature of the short term thermal storage (STTS). The antifreeze mixture in the pressurized collector loop is separated from the atmospheric pressure water in STTS and borehole thermal energy storage (BTES) by a heat exchanger. A second heat exchanger separates the water in the pressurized district loop from that in the STTS and BTES.

The control system anticipates the amount of heat that will be needed for space heating based on the outdoor ambient temperature. If the STTS contains surplus heat, it is used to charge the BTES, and when insufficient heat exists in STTS for the anticipated load, heat is moved from the BTES to charge the STTS.

Heat is delivered to the houses through the two-pipe district heating system whenever it is required, and the temperature of the water supplied to the loop is increased as the ambient temperature drops below 27.5°F.

The STTS tanks are critical to the proper operation of the system, because they can accept and dispense heat at a much higher rate than the BTES can.

During periods of intense summer sunshine, the BTES field cannot accept energy as quickly as it can be collected; so heat is temporarily stored in the STTS tanks, with transfer to the BTES continuing through the night. This situation is reversed in the winter, when heat cannot be extracted from the BTES field quickly enough to meet peak heat demands, typically in the early morning.

Sustainable Design

All of the Drake Landing houses are located along two streets running east-west. Buyers could select one of six two-story models. The resulting mix gave a site average above-grade floor area of 1,565 ft^2. Each house also has a full heated basement.

Detached garages at the back of each lot face onto a back alley. A continuous roof connects the adjacent garages, creating large, uninterrupted roof surfaces to mount solar heat collectors. The covered walkways between garages provide shelter for a vehicle or trailer, or a play area for children. The absence of garages at the front also contributes to an attractive streetscape.

The houses are certified to meet Canada's R-2000 standard, which promotes the use of cost-effective, energy-efficient building practices and technologies, and the Built Green Alberta program, which focuses on sustainable building standards. The houses' envelopes are upgraded with higher insulation values, low-e argon-filled windows and improved airtightness and construction details, reducing the space heating load by an expected

Sterling Homes

Six different model homes, which have an above-grade floor area between 1,492 ft^2 and 1,664 ft^2, helped showcase the solar and other sustainable features. Drake Landing houses are designed to conserve energy with envelopes that use higher insulation values, low-e argon-filled windows and improved airtightness.

Sterling Homes

SOLAR SEASONAL HEAT STORAGE SYSTEM

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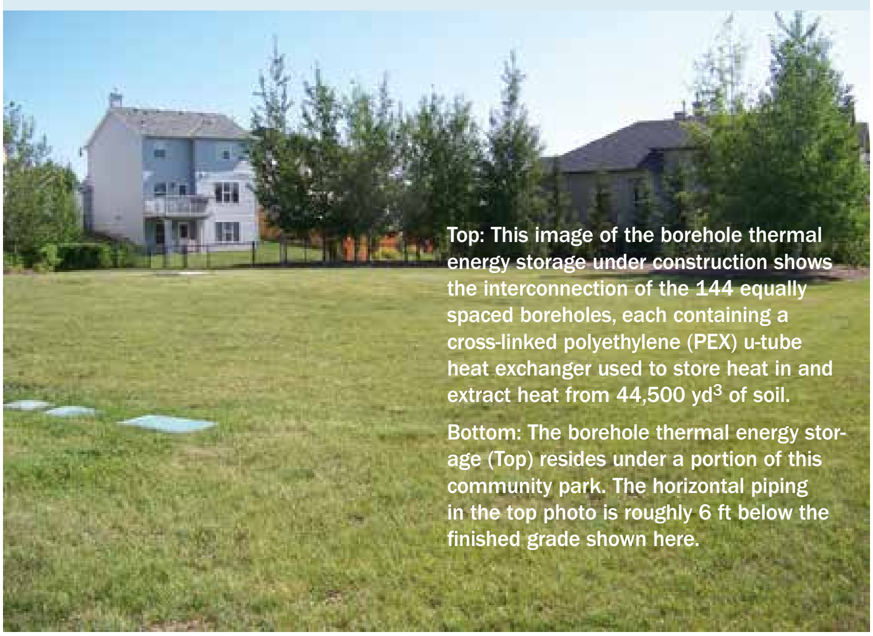
The borehole thermal energy storage (BTES) is used to save surplus solar heat collected in the spring, summer and fall for use the following winter. The heat is stored in a large volume of earth that is cylindrical in shape (approximately 115 ft in diameter by 115 ft deep), located under a corner of a neighborhood park and covered with a layer of R-40 insulation beneath the topsoil and grass.

Some 144 evenly spaced boreholes, each 115 ft deep, are plumbed in 24 parallel circuits, each made up of a string of six boreholes in series. Each series string is connected in such a way that the water flows from the center to the outer edge of the BTES when storing heat, and from the edge toward the center when recovering heat, so the highest temperatures will always be at the center.

Since the BTES soil is undisturbed, aside from the drilling of boreholes into it, the sides and bottom of the storage are uninsulated. As a result, it is essential to have a large storage volume to surface area ratio and significant radial stratification to minimize losses and deliver acceptable annual BTES efficiencies.



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Top: This image of the borehole thermal energy storage under construction shows the interconnection of the 144 equally spaced boreholes, each containing a cross-linked polyethylene (PEX) u-tube heat exchanger used to store heat in and extract heat from 44,500 yd^3 of soil.

Bottom: The borehole thermal energy storage (Top) resides under a portion of this community park. The horizontal piping in the top photo is roughly 6 ft below the finished grade shown here.

ENERGY AT A GLANCE

Annual Site Energy Use Intensity (EUI) 42.8 kBtu/ft^2
- Natural Gas 9.1 kBtu/ft^2
- Electricity (From Grid) 11.8 kBtu/ft^2*

Renewable Energy (Solar) 21.9 kBtu/ft^2
- Solar District Heat 18.4 kBtu/ft^2
- Solar Domestic Hot Water 3.1 kBtu/ft^2
- Solar Electricity Used on Site for Emergency Power Battery Charging and Other Energy Centre Loads 0.36 kBtu/ft^2

Annual Net Energy Use Intensity 20.7 kBtu/ft^2

Annual Source (Primary) Energy 55 kBtu/ft^2

Annual Energy Cost Index (ECI) CAN$0.70/$ft^2$

Annual On-Site Renewable Energy Exported 0.17 kBtu/ft^2

Carbon Footprint 7.8 lb $CO_2e/ft^2 \cdot yr$

Heating Degree Days (Base 65˚F) 9,027 HDD

Cooling Degree Days (Base 65˚F) 671 CDD

Annual Hours Occupied 8,760

Note: Data represent houses and Energy Centre from July 1, 2012, to June 30, 2013. All central and household energy uses are included, e.g., heating, cooling, distribution, cooking, lighting, appliances, computers, fireplaces, block heaters, barbecues, etc. Passive solar gains and metabolic heat inputs were not quantified.

Water at a Glance: The local utility provides the individual homeowners with their own water use data. Permission from each owner is required to obtain their information from the utility. However, the permissions and water use data have not been requested by the authors.

*Electricity data for all 52 houses was extrapolated from available electricity use data for 29 houses.

30% compared to baseline houses. Each home is also equipped with a stand-alone solar domestic hot water heater designed to supply 40% to 60% of the service water heating load by using two collectors mounted on each house roof. A conventional high-efficiency natural gas water heater backs up the solar water heater.

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Top Interconnected garage roofs provide large surfaces for solar collector mounting and provide homeowners with an additional covered space. Snow-covered Rocky Mountain peaks are visible in the background.

Above An aerial view of the Drake Landing Solar Community in summer. Fifty-two houses receive almost all of their space heating from solar energy through a central solar district heating system with seasonal storage.

Instead of a natural gas-fired, forced-air furnace, the norm in this market, each house uses with an air handler, which combines the space heating function with that of continuous ventilation using a heat recovery ventilator (HRV).

Designed to provide high levels of comfort with low district heating water temperatures (99°F to 131°F, depending on ambient temperature), the houses are equipped with oversized ducts to maintain low

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Above During construction, pre-insulated PEX pipes were placed in trenches running the length of both streets. This image depicts two of the branch trenches and pipes that carry space-heating water to each house.

Right The Energy Centre houses the system's mechanical equipment, including two short-term thermal storage (STTS) tanks with a volume of 63,000 gallons, district heating and storage pumps, heat exchangers, auxiliary boilers and system controls.

air delivery velocities. Fans with electronically commutated motors allow the airflow rate to vary with the heat load and minimize electricity consumption.

Given the low demand for cooling in this climate, the houses were not originally equipped with mechanical cooling systems. However, a significant fraction of the homeowners have subsequently added central air conditioners.

Good indoor air quality is provided through continuous forced ventilation using the HRV. The predominantly north- and south-oriented windows offer pleasant, occupant-controlled daylighting.

Water conservation measures are extensive with low consumption toilets; low-flow showerheads and faucets in bathrooms and kitchens; Energy Star low-water-consumption clothes washer and dishwasher; and a hot water recirculation pump equipped with timer control. Outdoor water conservation is also encouraged with eaves trough-connected rain barrels, timer controlled outdoor tap and increased topsoil depth.

Lumber certified and produced by sustainably harvested sources was used for construction, and the engineered joist and load bearing components were produced using sustainable manufacturing practices. The site was also designed with low-impact landscaping, and house construction used locally manufactured materials.

BUILDING TEAM

Building Owner/Representative Drake Landing Company (Atco Gas, Sterling Homes, United Communities and the Town of Okotoks)

Project Leader CanmetENERGY, Natural Resources Canada

Project Coordinator Leidos Canada

General Contractor Sterling Homes (Houses) and Hurst Construction (Energy Centre)

Mechanical Engineer Enermodal Engineering

Energy Modeler Thermal Energy Systems Specialists (TESS)

Land Developer United Communities

Borehole Storage Design IF Tech International

Performance

The system has been monitored in detail to document its performance and to refine the model used in its design since being brought into service in July 2007. Refinements have included adjustments to the design assumptions for borehole thermal energy storage soil properties, short-term thermal storage stratification and heat loss and pumping energy.

Besides controlling the system, the automated control system also

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Each of these houses is responsible for approximately 5.5 tons less greenhouse gas annually than a typical home. The roof-mounted solar collector for domestic water heating is the only obvious difference from neighboring homes.

is used to record over 100 temperatures, flow rates, pressures and other operating parameters every 10 minutes. These data combined with monthly readings from utility meters and the high accuracy heat meters that are installed in each house provide a comprehensive picture of system operation and energy flows.

The recorded data are checked and used to produce monthly and annual performance reports. The system's "Current Conditions," including key operating temperature, power and energy values, are displayed on a public dashboard at the Drake Landing Solar Community website (www.dlsc.ca) and updated every 10 minutes.

Simulations predicted that the district heating system would reach a solar fraction (the fraction of heat load provided by solar heat) of 90% in the fifth year of operation. The measured solar fraction has been within the range of predicted performance, given the expected variability resulting from year-to-year differences in the weather.

During the first four years of operation, the amount of solar energy delivered to the load was limited by the heat needed to charge the seasonal storage (BTES) to its normal operating temperature range. *Table 1* provides an overview of the system performance since start-up and *Table 2* gives additional detail for the sixth year of operation.

Year six performance is being highlighted since that winter was notably colder than year five but not as cold as year seven. The first four years were excluded from consideration since system performance was atypical before quasi-steady operation was achieved in year five.

In year six, a total of 2,308 million Btu (MBtu), or 98%, of the heat delivered by the district loop was from solar and the remaining 2%, (40 MBtu), was from natural gas. Purchased electricity to operate the pumps, fans, lights and controls, was 68 MBtu, and 21 MBtu of site generated electricity was exported to the grid.

Domestic consumption in the 52 homes for all uses was 1,098 MBtu in natural gas and 1,408 MBtu in electricity (extrapolated based on

KEY SUSTAINABLE FEATURES

Water Conservation Energy Star low-water-consumption clothes washer and dishwasher; 1.4 gallon/flush toilets; low-flow showerheads and faucets; hot water recirculation with timer; timer on exterior taps; rainwater barrels; and extra topsoil depth.

Recycled Materials Recycled materials used in drywall.

Daylighting Windows mainly facing north and south.

Individual Controls Light switches and curtains or blinds.

Carbon Reduction Strategies High solar fraction solar district heating system, each house equipped with solar domestic hot water system.

Transportation Mitigation Strategies Sidewalks and walking trails.

Other Major Sustainable Features Electronically commutated motor fans, variable frequency drive pumps, continuous heat recovery ventilation, lumber produced by sustainable harvested sources.

BUILDING ENVELOPE

Roof
Type Glass fiber
Overall R-value R-50
Reflectivity Low

Walls
Type Glass fiber
Overall R-value R-20
Glazing Percentage 8%

Basement/Foundation
Basement Wall Insulation R-value R-20

Windows
Effective U-factor for Assembly R-4.3

Location
Latitude 50.73 N
Orientation Streets are oriented east-west; most windows face north and south; garage roofs face due south

electricity use data for 29 houses). The resulting annual net site energy use intensity was 20.7 kBtu/ft^2 for all site energy uses.

As a result of the large solar contribution, the annual net site energy use intensity for space heating was 0.87 kBtu/ft^2. When all household energy consumption is included, the total site energy intensity is 42.8 kBtu/ft^2 (renewable + conventional energy). For competing homes (those that use no renewable energy), the corresponding total site energy intensity is estimated to be 59 kBtu/ft^2.

Finance

While each of the homes in the Drake Landing Solar Community is independently owned, the Energy Centre and all of the solar heating equipment used to deliver space heating to the homes is owned by the Drake Landing Company.

TABLE 1 ANNUAL SOLAR DISTRICT HEATING SYSTEM PERFORMANCE SUMMARY (JULY – JUNE)

Year	1 2007–2008	2 2008–2009	3 2009–2010	4 2010–2011	5 2011–2012	6 2012–2013	7 2013–2014
Heating Degree Days (°F)	9,085	9,309	8,913	10,059	8,240	9,027	9,738
Incident Solar (kBtu/ft^2)[1]	512	534	488	479	498	488	488
Collector Efficiency (%)[2]	33.5	31.6	33.6	32.5	34.1	34.0	34.0
Total Heat Delivered (MBtu)[3]	2,877	2,809	2,412	2,710	2,008	2,363	2,875
Solar Fraction (%)[4]	55.0	60.4	79.6	85.9	96.7	97.6	91.7
Purchased Electricity (MBtu)[5]	187	187	177	155	91	68	82
PV Generated Electricity (MBtu)[6]	10	13	12	28	73	66	63
Purchased Gas (MBtu)[7]	1,491	1,132	515	413	62	40	220

1. Based on gross collector area and radiation on the 45° collector slope. **2.** Collected energy divided by incident energy. **3.** Heat delivered to the district heating loop. **4.** Fraction of heat load provided by solar heat. **5.** Purchased electricity used to operate the solar collection, storage and central heating system. **6.** Generated electricity from the 22 kW solar array on the Energy Centre roof. **7.** Purchased gas used to supplement the solar heat delivered by the central heating system.

TABLE 2 MONTHLY SITE ENERGY SUMMARY FOR YEAR SIX (JULY 2012 TO JUNE 2013)

	Solar District Heating System (Energy Centre)				Distributed Consumption (52 Houses)			Combined	
	Solar Energy Delivered	Natural Gas Purchased	Electricity Purchased	PV Electricity Generated[8]	Solar to Domestic Hot Water Estimated	Natural Gas Purchased	Electricity Purchased[9]	Total Renewable	Total Purchased
	MBtu								
July	7.9	0	3.3	10	34.2	38.1	102.4	52.1	143.9
August	10.6	0	3.6	9.5	30.2	59.8	103	50.3	166.3
September	20.5	0	4	7	23.2	53.9	94.8	50.8	152.7
October	211.8	0	4.9	3.8	26.6	121	121.3	242.2	247.1
November	332.1	0	7.4	0.6	21.5	103.5	129.8	354.2	240.8
December	386.2	13.2	9.7	0.5	26.5	126.4	151.7	413.2	301
January	401.9	16.2	9.5	1.1	28.9	143.4	140.6	431.9	309.7
February	298.1	6.3	6.9	2.5	35	77.9	116.3	335.6	207.5
March	328.8	3.9	6.6	4.5	44	109.4	124.9	377.3	244.8
April	238.4	0.5	5.1	7.7	42.6	88.4	114.2	288.7	208.2
May	50	0	4.2	9.4	39.6	94.9	107.6	99.1	206.6
June	21.4	0	3.2	9.5	32.8	81.5	101.3	63.7	186.1
Annual Total	**2,308**	**40**	**68**	**66**	**385**	**1,098**	**1,408**	**2,759**	**2,615**

8. PV Electricity Generated includes approximately 21 MBtu of electricity exported to the grid and not used in the Energy Centre. Total purchased energy has not been reduced by the quantity of exported electricity. **9.** House electricity consumption is based on complete utility meter readings for 29 of 52 houses; their average consumption was used to extrapolate to the reported 52 house consumption; 23 owners did not provide the signed consent form needed to access their data.

LESSONS LEARNED

Successful Operation. Initial concerns about reliability issues with the solar heat collection and storage systems have not materialized. In almost eight years of operation, only two of 798 solar heat collectors have been replaced, and regular testing of the propylene glycol-water heat transfer fluid shows barely perceptible deterioration, indicating many more years of service can be expected.

Monitoring Has Proven the Design Simulations To Be Generally Accurate.

Include Builder and Developer Early. The Drake Landing builder and land developer were included in the project planning process from the beginning. It helped build confidence in the project regarding the market acceptance of the unfamiliar technologies being applied.

Homeowner Satisfaction. The Drake Landing homes were all sold in a reasonable time period. People who live in the community have opened their homes to people from over 20 countries around the world as far away as South Korea, China and Chile.

Drake Landing house values have increased in step with conventional homes in the area. The builder, the utility, the land developer and the municipality have all expressed interest in participating in the implementation of similar projects in the future.

Installation of District Heating Loop Piping. As with the other utilities, district heating loop piping needs be installed before the houses are built. Shut-off valves in the utility easement near the street should be considered for subsequent projects to simplify the line installation and connection process for the builder.

It Is Essential To Have Committed Partners. In significant projects, unexpected issues will almost certainly arise. However, with high levels of dedication and commitment, teams can identify acceptable paths forward. Some of the unexpected issues the Drake Landing team faced included severe construction site flooding, lower than expected reliability for some conventional equipment and some components that didn't perform to specification.

Access to Operating Data is Crucial. The ability to easily access and view relatively detailed system operating data combined with the ability to compare actual operation against predicted is extremely valuable for the successful commissioning and the efficient operation of energy systems such as that used at Drake Landing. Going well beyond the obvious benefits of fine-tuning control setpoints and identifying failed sensors and mechanical components, the availability of these data has identified inoperative control logic, inadvertent use of "temporary" setpoints, instances where plumbing modifications were warranted, and opportunities to reduce electricity consumption with improved control logic. The performance and financial implications can be significant.

Verifying Accuracy of Design Simulation. Using the system data in conjunction with the design simulation has raised confidence in the ability to predict the energy performance of similar systems and through refinements to the models improved the predictions as well. The refined simulations have been subsequently used to perform feasibility studies for follow-on projects using similar designs. The simulation model has also been used to look for evidence of soil drying within the borehole field and led to the conclusion that no significant change has taken place in the bulk properties of the soil or in the performance of the seasonal storage.

Its directors are from ATCO Gas (the utility), Sterling Homes (the builder), United Communities (the developer) and the Town of Okotoks (the municipality).

The incremental cost for design, purchase and installation of the entire solar heating system, CAN$3.4 million, was paid for with contributions from the Canadian Government, Alberta government and the Federation of Canadian Municipalities. As a result, the original selling price for the homes was competitive with conventionally heated energy-efficient homes in the same market.

The homeowners pay for their heating at a rate roughly equivalent to the cost of natural gas heating. That revenue pays for ongoing operating expenses, and Natural Resources Canada has been covering the cost of ongoing monitoring and analysis as part of a larger research project on seasonal heat storage.

Future Outlook

The project development team understood from the outset that the Drake Landing system was too small to be economically competitive with the extremely low cost of natural gas. However, subsequent feasibility studies show that larger systems of similar design can deliver solar energy at about half of the cost compared to Drake Landing, and additional work is underway to improve cost performance further. The purchase and installation of future systems of this kind in Canada will also qualify for accelerated depreciation under Canadian income tax regulations. ●

ABOUT THE AUTHORS

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