Okotoks: Seasonal Storage of Solar Energy for Space Heat in a New Community

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ABSTRACT

A community of 52 houses now being built near Calgary, Alberta will be the first in North America to use seasonal storage of solar energy. 800 solar panels (2,313 m^2 or 24,897 ft^2) mounted on rows of garages behind the houses will produce up to 1.6 MW of thermal power. Energy will be stored in a seasonal borehole thermal energy storage (BTES) system during the summer. During the heating season, the collectors and BTES will heat the houses through a district heating system.

The garages with solar collectors will be constructed first, and individual house models will be built to the owners' choices. Each of the houses (10 of which are already built) will meet the R-2000 and Built Green™ Alberta Gold standards, and be 30% more energy efficient than conventional new houses. They will also feature low-impact landscaping, local materials, and water conserving fixtures and appliances. Each house will have its own solar domestic hot water system and high-efficiency water heater, which should save up to 65% of the natural gas for hot water.

The BTES will consist of 144 boreholes, each 35 m (115 ft) deep, under an area that will be part of a park. Heat will be extracted after the first summer, and within five years the system will be fully charged, operating at temperatures up to 80 °C (176 °F). Gas-fired boilers will provide supplementary space heat during charging, and as required near the end of heating seasons. When fully charged, solar energy should supply 90% of the space heat – a world first for a seasonal storage solar heating system.

Introduction

The Drake Landing Solar Community (DLSC) is a 52-house subdivision being built in Okotoks, Alberta, 15 minutes south of Calgary. It will be the first community in North America to use seasonal storage of solar energy. An array of 800 solar panels with a total area of 2,313 m^2 (24,897 ft^2) is predicted to supply 1.6 mega-watts (MW) of thermal power on a typical summer day. This energy will be stored in a seasonal borehole energy storage (BTES) system during the summer. During the heating season, a district heating system will deliver the stored energy, and energy directly from the collectors to the houses for space heating.

The solar panels will be mounted on four long rows of garages connected by breezeways. An insulated piping system carries a 50% propylene glycol solution from the collectors underground to the community's Energy Centre. There, a heat exchanger transfers the heat to the water in two short-term thermal storage (STTS) tanks from which it can be sent to either the BTES or the houses. The BTES consists of 144 boreholes each 150 mm (5.9 in) in diameter and

35 m (115 ft) deep, and spaced 2.25 m (7.4 ft) on center. The BTES field is 35 m in diameter, so it will occupy just under a quarter of an acre. The land on top of it will be part of a park.

Each of the houses will meet Natural Resources Canada's R-2000 Standard (NRCan 2005) and the highest (Gold) level of the Built Green™ Alberta (Alberta 2006**)** program, and will be 30% more energy efficient than conventionally built houses. Each will have a solar domestic hot water system, and a specially designed combination air handler and heat recovery ventilator. Other green features include low-impact landscaping, use of locally manufactured and recycled materials, use of certified lumber and engineered components, and the water conservation package required by the town. The garages and solar system will be built first, and homeowners will then be able to choose from six two-story, single-detached house models.

The BTES is predicted to supply some space heat after the first summer. It will take five years to fully charge, and from then on should reach 80 °C (176 °F) by the end of each summer, and supply 90% of the houses' space heat. Compared with conventionally built new houses, the energy efficient houses that get 90% of their heat from the sun should reduce natural gas use for space heat by 94%. The combination of solar hot water and efficient fixtures and appliances should save 65% of the gas used for hot water. Together, these savings should be 88% of the natural gas used by a conventional house, and should reduce greenhouse gas (GHG) emissions by six tonnes per house. Ground was broken in the spring of 2005. As of mid-February 2006, the BTES, the Energy Centre, the district heating system, and one row of collectors are complete, and ten houses have been built. Two more houses are scheduled to be completed in April 2006.

The Community

Drake Landing Solar Community (DLSC) is located in the Town of Okotoks, 36 km (22 miles) south of Calgary, Alberta, at 51.1° N, 114° W. The design heating temperature for this location is -31 °C (-24 °F). The design cooling temperatures are 29 °C dry bulb, and 17 °C wet bulb (84 and 63 °F). DLSC is North America's first major implementation of seasonal solar energy storage, in which solar thermal energy is collected in the summer, stored underground, and then delivered to the houses to heat them during the winter.

The DLSC project was conceived by Natural Resources Canada (NRCan), a department of the Government of Canada. The project is being implemented by NRCan in partnership with a number of innovative, environmentally conscious companies. The site plan for the community is shown in Figure 1. It consists of five main components: the solar collection, the Energy Centre, the borehole thermal energy storage system, the district heating system, and the houses. Each is described below.

Solar Collection

The solar collectors were manufactured by Enerworks, Inc. of Dorchester, Ontario. Each of the 800 flat-plate glazed collectors measures 2.45 m x 1.18 m (8 x 3.87 ft). All face true south, and have a tilt of 45°. The panels are mounted on four rows of garages connected by breezeways, and each row of garages has two rows of panels. Figure 2 is a photograph of one row of garages taken at approximately solar noon in late November, 2005. Note that the shadows of the seven houses end just short of the bottom of the collectors. A non-toxic antifreeze (50% propylene glycol) carries the collected heat through underground insulated pipes to the Energy Centre.

Figure 1. The Drake Landing Solar Community Site Plan

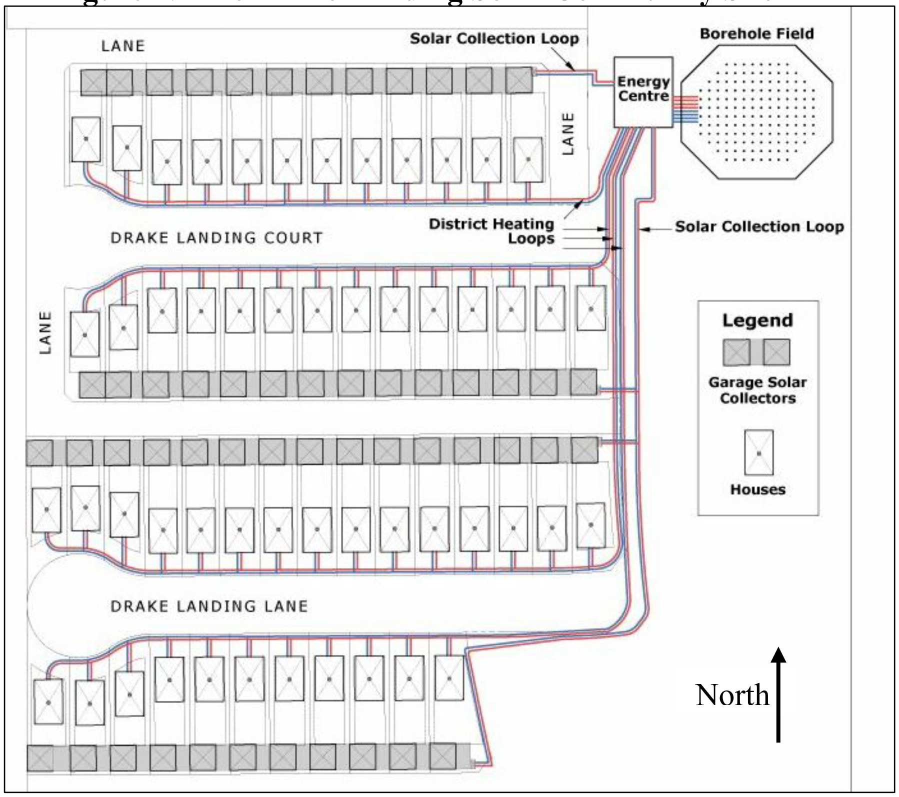


Figure 2. A Row of Garages with Solar Panels

Figure 3. The Energy Centre

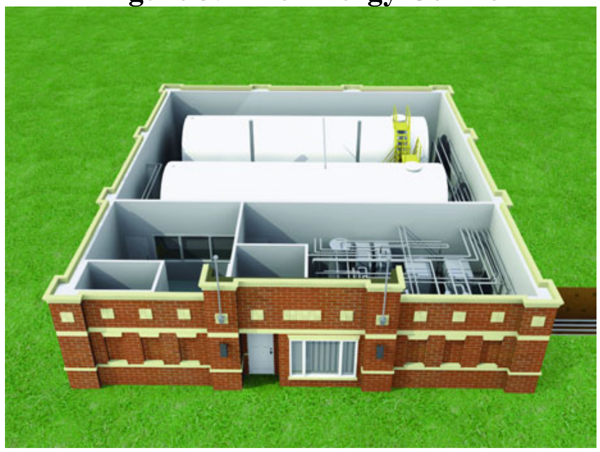


Figure 4. Schematic of the Solar Collectors, Heat Exchanger & STTS Tanks

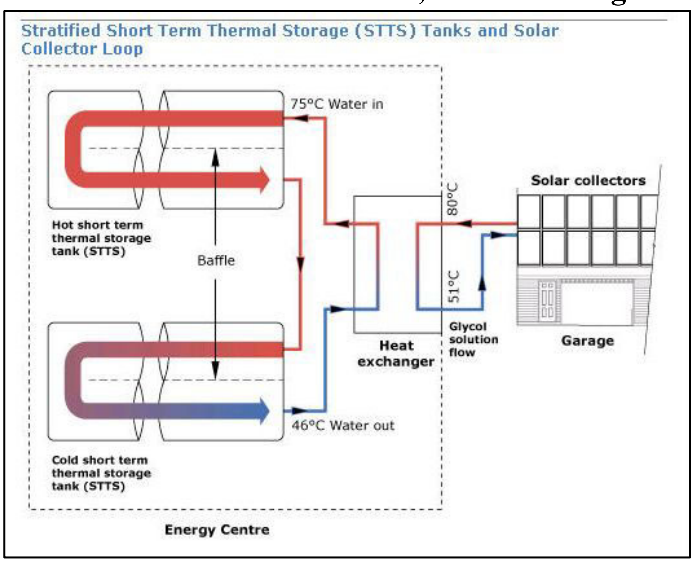
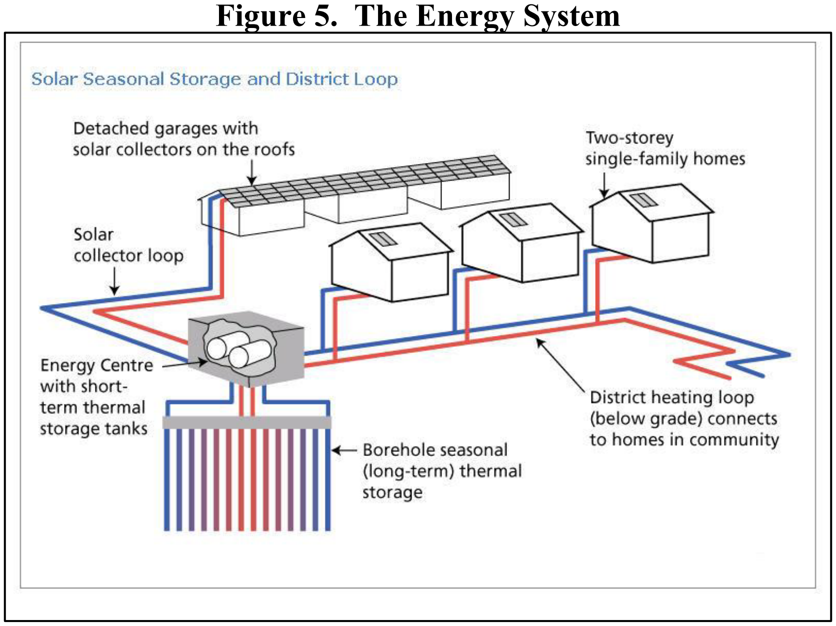


Figure 5. The Energy System



The Energy Centre

The 232 m^2 (2,500 ft^2) Energy Centre building is located in a corner of the community park. It houses the heat exchangers, the two short-term thermal storage tanks, back-up natural gas fired boilers, and the pumps, valves, expansion tanks and controls for the entire energy system. Heated propylene glycol from the collectors passes through the heat exchanger that transfers the heat to water in the short-term storage tanks. Flow through the collectors starts whenever the glycol is hot enough to heat the STTS tanks, and is automatically adjusted to give a desired temperature rise. The two short-term thermal storage (STTS) tanks are made of steel, insulated to RSI-4.23 (R-24) with polyurethane foam. Each has a volume of 120 m^3 (31,700 US gal), and contains a horizontal baffle to promote stratification and plug flow through the upper and lower chambers. A fluid cooler on the roof will prevent possible overheating of the collectors. Figure 3 is a rendering of the Energy Centre, with the two tanks in the back, and the heat exchangers, pumps, etc. at the right front. Figure 4 is a schematic of the solar collectors, heat exchanger and STTS tanks, with typical operating temperatures. Figure 5 shows the relationships among the Energy Centre and the other components of the energy system.

The Borehole Thermal Energy Storage (BTES) System

During the summer, heat from the STTS tanks is stored in the BTES. This system is an array of 144 boreholes, each 150 mm (5.9 in) in diameter by 35 m (115 ft) deep, and spaced 2.25 m (7.38 ft) on center. Each borehole resembles a standard drilled well. A single 25 mm (1 in) PEX U-tube and a 40 mm (1.6 in) grout tube is inserted in each borehole, and the borehole is then filled with a high thermal conductivity grouting material to provide good thermal contact with the surrounding soil. There are 24 strings and each string has six boreholes in series. The borehole field is divided into four circuits that are distributed through the four quadrants, so that the loss of any single string or circuit will have a minimal impact on the heat capacity of the entire BTES. During the storage of solar energy, heated water flows from the center of the BTES field, and passes through successive boreholes to the outside. This provides maximum horizontal stratification. When heat is extracted, the flow is reversed, taking the highest temperature heat from the center of the BTES. Figure 6 is a plan of the BTES, and Figure 7 shows a single borehole with its tubes.

The BTES field has an area of 962 m^2, or just less than a quarter of an acre, and will be underneath part of a landscaped park. It is covered with a layer of sand, 200 mm (7.9 in) of extruded polystyrene insulation (RSI-7 or R-40), a waterproof membrane, and soil. There is no insulation on the sides or bottom of the BTES. Heat losses are reduced by the large volume-to-surface-area ratio, and by the horizontal stratification. In a typical year, 2100 GJ (1990 million Btu) should be sent to the BTES, and 1000 GJ (948 million Btu) should be recovered, giving it an efficiency of 48%. It will supply some space heat in the 2006-2007 heating season, but will take approximately five years to fully charge. When fully charged, it should reach 80 °C (176 °F) by the end of each summer, and should supply 90% of the space heat needs of the houses. Until it is fully charged, and at the end of particularly cold heating seasons, the back-up natural gas boiler will supply the necessary supplemental heat. The BTES was designed by IFTech International of Arnhem, The Netherlands with input from the Climate Change Division, Atlantic Region of Environment Canada. Enermodal Engineering Limited of Kitchener, Ontario advised on North American construction standards, and are the engineers of record.

Figure 6. Plan of the Borehole Thermal Energy Storage System

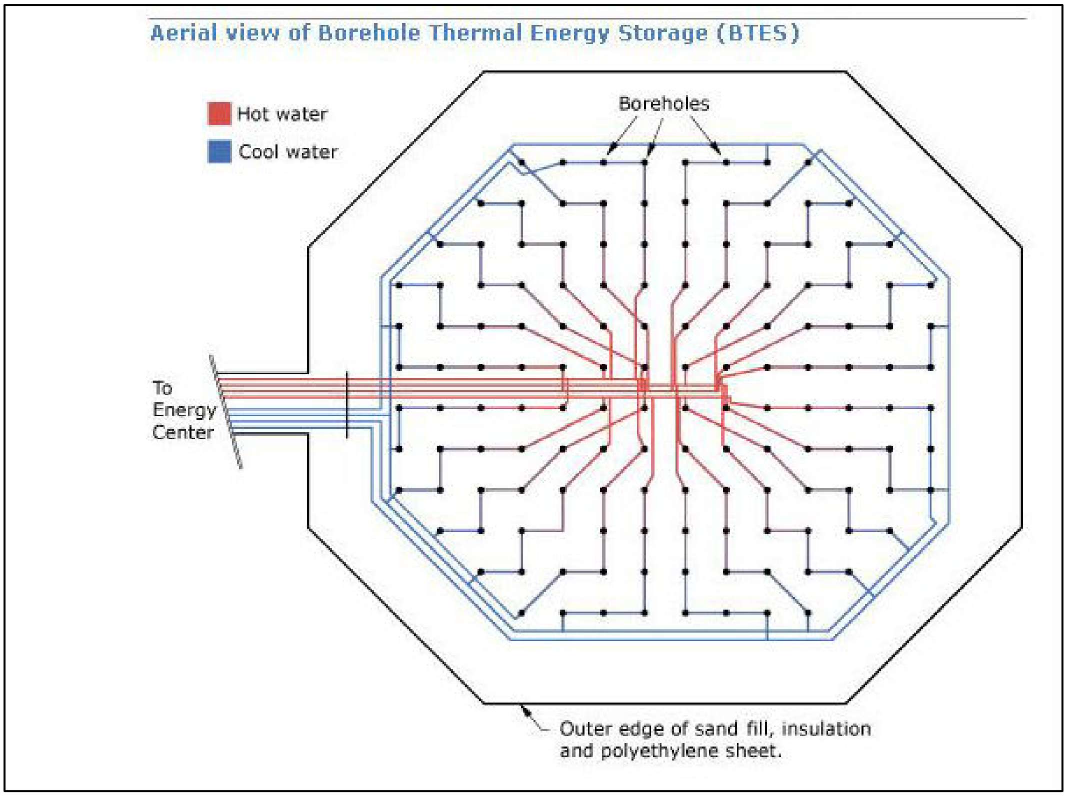
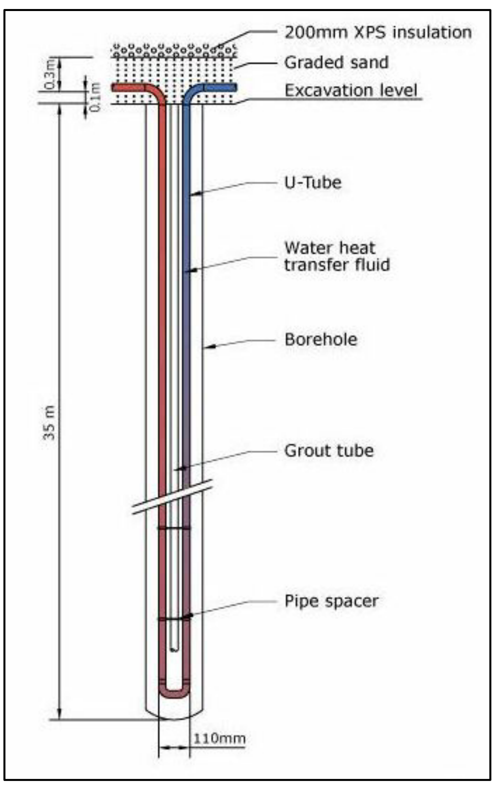


Figure 7. A BTES Borehole



The District Heating System

The district heating loop is a two-pipe system for delivering heat to the 52 houses. Heat from the STTS tanks goes through a heat exchanger and manifold to four loops of pre-insulated, buried pipe. A water-to-water heat exchanger is used because the district loops are pressurized, while the STTS is open to the atmosphere. The flow of water will be modulated based on the number of houses calling for heat at a given time. The water temperature will be modulated based on the outdoor temperature, and will generally be between 35 and 55 °C (95 and 131 °F). These relatively low temperatures will reduce losses from the pipes, and are more compatible with solar energy collection, allowing the collectors to operate more efficiently and produce more heat. Each house has an energy meter. Occupants are charged Can$60 per month, and receive a discount or extra charge depending on whether they use less or more than the community average. The system should deliver energy at about Can$25/GJ (US$23/million Btu).

Figure 8. The Six DLSC Show Houses

The Houses

When completed, DLSC will have 52 single-detached, two-story houses. Homeowners can choose from six distinct designs ranging from 139 to 155 m^2 (1,492 to 1,664 ft^2) of floor area. Figure 8 is a photograph of the six show houses. Each will be certified to Natural Resources Canada's (NRCan) R-2000 Standard, which specifies a minimum airtightness (1.5 air changes per hour at 50 Pascals of depressurization), and a maximum energy use for space heat and domestic hot water, based on the house volume and the heating degree-days of its location. Each house will also be certified by the Built Green™ Alberta program, which is modeled on both the R-2000 program and NRCan's EnerGuide for New Houses Program. Built Green™ Alberta has three levels of certification, bronze, silver and gold. All DLSC houses will be certified at the gold (highest) level. They will be built by Sterling Homes of Calgary, Alberta.

The houses will be 30% more energy-efficient than conventional houses being built in the area, and have a range of additional environmental benefits in the areas of envelope components and appliances, building materials, exterior and interior finishes, indoor air quality, waste management and water conservation. Energy-efficient and green features of these houses include:

- upgraded insulation and vapor barrier systems to eliminate drafts and allow even heating throughout;
- certified lumber from sustainably harvested sources;
- engineered joists and trusses that are stronger, more structurally stable, and were produced by sustainable manufacturing processes;
- a structurally integrated panel (SIP) system at joist header areas that provides consistent insulation and airtightness in these difficult areas;
- drywall with a recycled content of about 25%;

- double-pane, low-e, argon filled windows with insulated spacers and vinyl frames;
- a basement air gap wrap that will drain water away from the foundation to prevent moisture build-up; and
- upgraded roofing material with longer warranties.

The houses will also meet the Town of Okotoks' water stewardship measures, which include:

- low consumption toilets using 6 liters (1.6 US gal) per flush;
- ultra low flow showerheads (7.5 L/min or 2 US gal/min), bathroom faucets (4 L/min or 1 US gal/min), and kitchen faucets (6 L/min or 1.6 US gal/min);
- insulation on all hot, and most cold water lines; and
- an Energy Star®, low water consumption clothes washer and dishwasher supplied with each house.

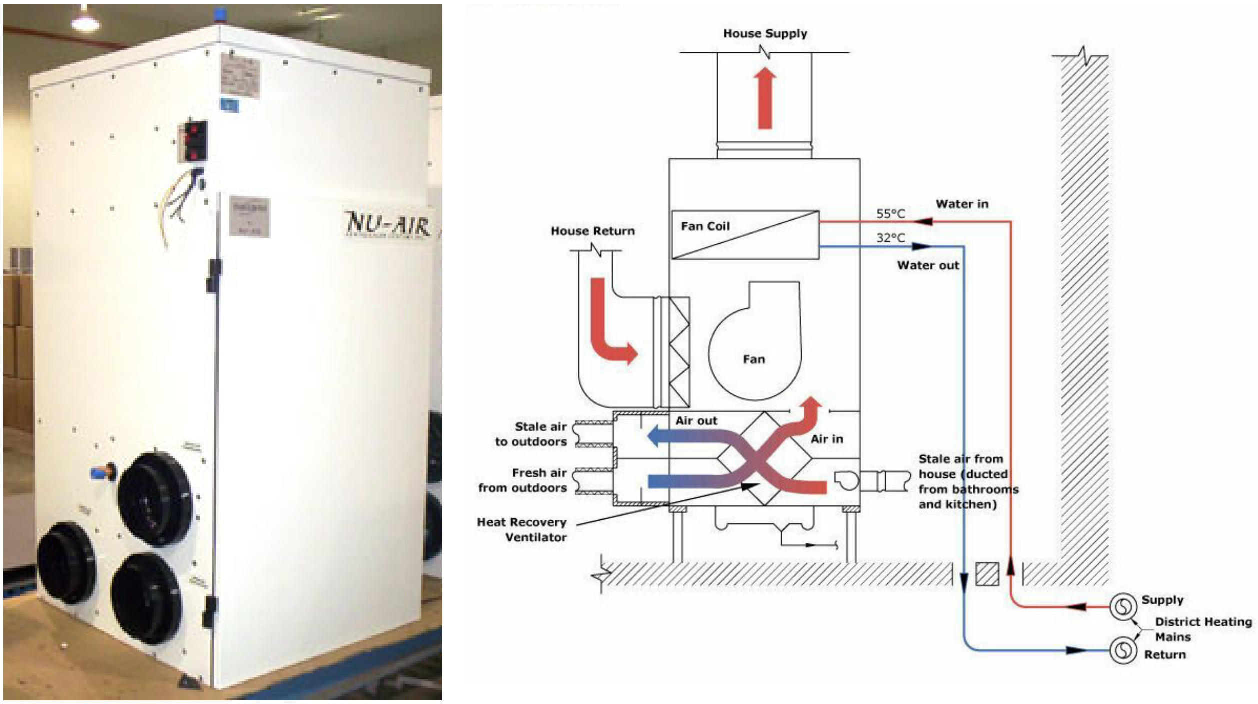
The low-impact landscaping will include extra topsoil to maintain moisture. Each house will have a rain barrel supplied by the eaves trough downspout, and an outdoor tap timer.

The garages & breezeways. Interconnecting the garages with breezeways provides a very large sloped area for the solar collectors, and leaves the builder free to design houses in several styles as owners select and purchase them. In the typical Canadian development method, the builder offers a range of models, and buyers can independently select their lots and models, so houses are built in a random order over a period of a year or more. This type of scheduling would not allow for the construction of a solar energy system if the collectors were mounted on the houses. Putting the collectors on the garages and breezeways allowed the energy system to be built and operated independently of when any house is completed, and allows the houses to be marketed and built in the normal way.

The air-handler. Because the district heating system operates at a relatively low temperature, an air-handler unit with a large counter-flow fan coil was specially modified for the DLSC houses. The main fan is driven by a high-efficiency, electronically commutated motor (ECM). It blows air through the fan coil at three speeds depending on the temperature of the water supplied by the district heating system. At lower water temperatures the air flow is reduced so occupants will not feel drafts when the heating system is delivering cooler air. A conventional thermostat is used to open an automatic valve that allows hot water from the district heating system to flow through the fan coil in the air-handler.

The air-handler serves as both a furnace and a heat recovery ventilator (HRV). As shown in Figure 9, the main fan circulates air from the house return duct across the fan coil, and draws fresh outside air through the HRV's heat exchanger core. A smaller motor powers the exhaust fan that draws stale inside air from the kitchen and bathrooms, and blows it through the HRV to the outside. In the air-handlers for DLSC, this motor is also an ECM. Thus, integrating the space heating and HRV functions allows one of the HRV motors to be eliminated, and using ECMs minimizes the use of electricity for both space heat and ventilation. The air-handlers are made by Nu-Air Ventilation Systems Incorporated of Windsor, Nova Scotia.

Figure 9. The Air-Handler, Photo & Schematic



Solar domestic hot water. Each of the 52 houses will have a stand-alone solar domestic hot water system. Each of these Enerworks systems uses two solar panels similar to those used in the DLSC energy system collectors. The panels on the houses have a stagnation prevention system that works by opening flaps in the back of the panels to allow air flow that prevents overheating. The south-facing panels on the roof of each house heat a glycol solution that is pumped at a low flow rate through a flat-plate heat exchanger attached to a solar storage tank. Water flows through the heat exchanger by natural convection (thermosiphoning). Water in the solar storage tank is heated before flowing to the natural gas fired, power vented hot water tank that provides back-up heat when required.

Heat Transfer through the System

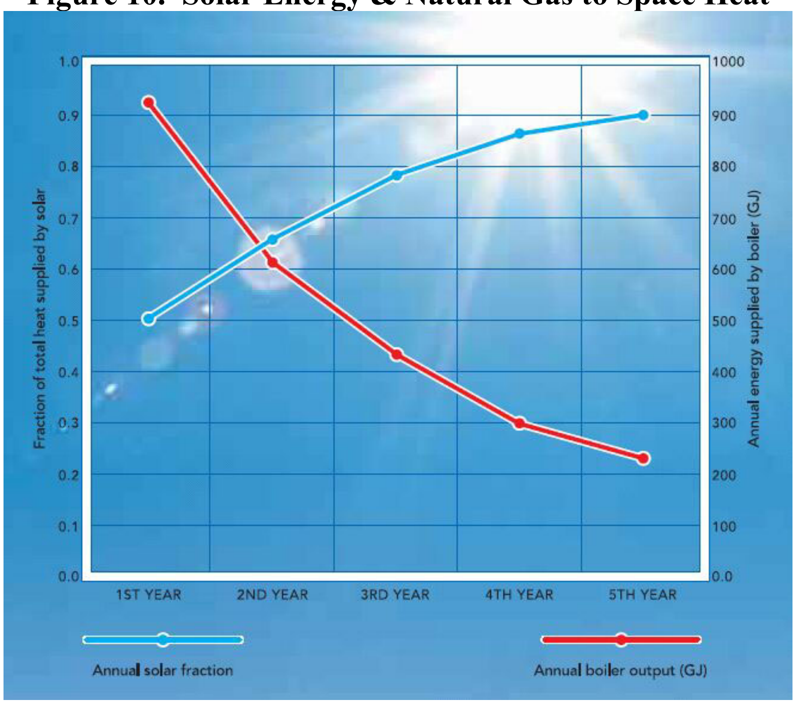
Solar collection can occur throughout the year. Whenever the sun heats the water in the collectors above the temperature of the water in the STTS tanks, then heat is transferred from the collectors to the STTS. If space heat is not required, then heat from the STTS will be transferred to the BTES whenever the STTS is hotter than the BTES. The collectors can produce heat much faster than the BTES can accept it, so after a sunny day, the collector pump will shut down while the BTES pump will run most of the night.

When space heat is required, it is supplied directly to the district heating system from the collectors and STTS as long as they can meet the demand. Any excess is sent to the BTES. When the collectors and STTS cannot supply the entire space heat load, then heat is transferred back from the BTES to the STTS. Toward the end of the winter, the collectors and BTES may not be able to supply all of the community's heating needs, and then the natural gas boilers will provide the required back-up. The fully automatic control system responds flexibly to changing conditions of weather, demand and storage. Piping distances were determined by the community layout, and the location of the Energy Centre and BTES in the park. The pumping energy for the complete system is modeled at 12,778 kWh/year, or 246 kWh/year for each of the houses.

The 52 houses are expected to require a total of some 2250 GJ (2133 million Btu) of heat annually. About 45% of this will be delivered directly from the collectors (through the STTS), about 45% from the BTES, and the final 10% by the back-up boilers. During the first winter of operation (2006-2007) the solar energy should be able to supply about 50% of the houses' space heat requirements, while the natural gas boiler should supply the remaining 930 GJ (881 million Btu). Over the next four years, as the BTES is fully charged, and as more houses are built, the solar energy fraction should rise to 90%, and space heat from natural gas should drop to 230 GJ (218 million Btu), or 4.4 GJ (4.2 million Btu) per house. These projections are based on extensive modeling including ESP-r models of the houses, a Swedish ground storage model, and a TRNSYS model of the entire system. Figure 10 shows the increase in solar fraction and corresponding decline in energy supplied by natural gas.

Enermodal Engineering Limited designed the energy systems (except the BTES). Thermal Energy System Specialists of Madison, Wisconsin performed computer modeling and simulations.

Figure 10. Solar Energy & Natural Gas to Space Heat



Benefits

The DLSC houses should get 90% of their space heat from solar energy. This is a significantly higher level than has been achieved by any other community in the world. European systems to date are achieving in the range of 50 to 70% solar fraction, according to discussions with designers and operators of various systems visited in September 2003 at five installations in Germany, Sweden and Holland. Combined with the fact that these houses are 30% more energy efficient than typical new houses in the Calgary area, they should use 94% less natural gas for space heat. A typical new house will use 126 GJ (119 x 10^6 Btu) of natural gas per year, and emit 6.3 tonnes of greenhouse gases (GHG, CO_2 equivalent). This includes 100 GJ (94.8 x 10^6 Btu) per year for space heat, and 26 GJ (24.6 x 10^6 Btu) for domestic hot water (DHW). It will also use about 8,760 kWh per year of electricity. In Alberta, where most electricity is coal-fired, generating that much electricity emits 6.8 tonnes of GHGs, so the total emissions due to energy use in a typical new house are 13.6 tonnes per year.

In the DLSC houses natural gas for space heat should be reduced to 6.1 GJ (5.8 x 10^6 Btu). The combination of water saving fixtures and appliances, and the solar DHW system on each house should reduce natural gas use for DHW to 9.1 GJ (8.6 x 10^6 Btu). The energy-efficient motors in the air handler, and the Energy Star® clothes washer and dishwasher in each house should reduce electricity use by about 10%. Altogether, each DLSC house should save 110.8 GJ (105.0 x 10^6 Btu) of natural gas, and 876 kWh of electricity each year. Subtracting the 246 kWh per house of system pumping energy, the net electrical savings should be 630 kWh/year. The gas and electrical savings for each house amount to a GHG reduction of 5.8 tonnes per year, or 43%. Thus, when all 52 houses are built and occupied, and the BTES is fully charged, the GHG reductions for the community should be 300 tonnes per year.

Longer-term benefits will depend on how quickly similar projects will be built. A major barrier to the use of solar energy, especially for space heating, in cold climates has been the problem of low solar radiation and temperatures in the winter. Short cold days, cloudy skies, and snow-covered collectors reduce or eliminate solar gains. The DLSC should demonstrate how the integration of energy-efficient technologies and seasonal storage of solar thermal energy can overcome this barrier. Thus, the DLSC project could significantly encourage the use of solar energy in future neighborhoods and communities.

Partners

In addition to the international team of companies and government agencies mentioned above, the following made significant contributions to this project:

- The Program of Energy Research and Development (PERD), and Technology Early Action Measures (TEAM), Government of Canada, funding;
- The Green Municipal Fund of the Federation of Canadian Municipalities, funding;
- Climate Change Central, a public-private partnership, Calgary, funding;
- ATCO Gas, an Alberta natural gas utility, funding and eventual ownership and operation of the energy system;
- the Innovation Program of the Government of Alberta, funding;
- Sustainable Development Technology Canada, a not-for-profit foundation, funding;
- SAIC Canada, Mississauga, Ontario, project coordinator;
- United Communities, Calgary, developer;
- Town of Okotoks, project facilitator;
- Bodycote Materials Testing Canada Inc., Mississauga, Ontario, design support and solar equipment testing;
- Sunbow Consulting Ltd., Calgary, subdivision design;
- Hurst Construction Management Inc., Calgary, energy centre building and system construction; and
- Howell-Mayhew Engineering Inc., Edmonton, Alberta, performance monitoring.

Summary

An international team lead by Natural Resources Canada has designed, and is now constructing, the Drake Landing Solar Community (DLSC) in the Town of Okotoks, Alberta. The DLSC will be the first community in North America to use seasonal storage of solar energy, and should overcome some of the longstanding obstacles in the use of solar energy. Seasonal storage overcomes the major obstacle to the use of solar energy for space heat in cold climates – the cold temperatures and lack of sun during the winter. Mounting the solar collectors on rows of garages allowed the energy system to be constructed first, leaving homeowners free to choose their preferred lots and house models over the next year or so. This made the construction of a solar community compatible with the normal way that new houses are marketed and constructed.

When the seasonal storage system is fully charged, 90% of the houses' space heat will be supplied by solar energy, a higher percentage than has been achieved by any other community in the world. Each house should save 111 GJ of natural gas per year, and reduce emissions of greenhouse gases by5.8 tonnes/year. Thus, the community of 52 houses should save 300 tonnes per year of GHGs, and should serve as a model for similar future communities.

References

Alberta. 2006. Built Green™ Alberta Checklist at www.builtgreenalberta.com/checklist.htm

[NRCan] Natural Resources Canada. 2005. *R-2000 Standard – 2005 Edition*. Ottawa, Ontario: Natural Resources Canada, Office of Energy Efficiency.