NSERC Solar Buildings Research Network

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Near Net-Zero Energy ÉcoTerra™ Home Demonstration Project

Summary

The ÉcoTerra™ house, built by Alouette Homes, is a 2,600 square foot (240 m^2) prefabricated home that was assembled in September 2007 in Eastman, Quebec – about 120 kilometres south east of Montreal. The NSERC Solar Buildings Research Network, and in particular a team headed by Dr. Andreas Athienitis at Concordia University, led the energy system design of the house. The approach that was followed integrates the passive and active solar systems into the house design and optimizes energy efficiency technologies. The house includes an innovative building-integrated photovoltaic/thermal (BIPV/T) roof linked to a hollow core thermal storage system that is based on research carried out at Concordia University. The BIPV/T demonstration was funded by Natural Resources Canada's (NRCan) Technology Early Action Measures (TEAM) program, championed by Josef Ayoub of NRCan's CanmetENERGY at the Varennes research centre. This is the first time that a BIPV/T roof has been built as a system in a factory.

ÉcoTerra™, one of twelve CMHC Equilibrium™ Demonstration Projects, uses energy collection and conservation features that are expected to enable it to consume less than 10% of the energy of a standard house of the same size on an annual basis. The major features include:

- Building-integrated photovoltaic/thermal (BIPV/T) system which covers one continuous south-facing roof surface and simultaneously generates renewable electricity and heat.
- Passive solar design featuring high-performance windows, thermal mass and a highly-insulated and airtight building envelope.
- Ground-source heat pump system
- Waste-water and ventilation-air heat recovery systems
- Energy-efficient appliances

The house demonstrates full architectural and envelope integration of an advanced solar energy system, as well as energy-saving measures, while maintaining occupants' interior comfort.

Figure 1: The Completed ÉcoTerra™ House

ÉcoTerra™ serves as an initial demonstration of solar building design concepts developed by the SBRN and its partners aimed toward achieving the SBRN's long term goal: The development of the solar-optimized building as an integrated advanced technological system that approaches net-zero energy consumption while being cost effective and comfortable.

Project Highlights

- The house is expected to be near net-zero energy, meaning that it produces nearly as much energy as it uses on an annual basis.
- One of the 12 CMHC Equilibrium™ demonstration houses.
- The entire upper section of the south-facing roof features a building-integrated photovoltaic-thermal system (BIPV/T).
  - 2.8 kWp electricity generation
  - 10 kWp of thermal energy.
- The solar-heated air from the BIPV/T system is used for space heating, domestic hot water pre-heating and clothes drying.

- A ground-source heat pump (GSHP) is used as the primary system for heating and cooling of the house.
- The house is optimized for passive solar performance.
    - High-performance south facing triple-glazed windows maximize the amount of solar radiation entering the house while minimizing heat loss.
    - Concrete slabs on the main and basement level absorb incoming solar radiation and slowly release it throughout the day and into the night.
- The house was built in a factory in modules and then assembled on-site.

Figure 2: Assembly of ÉcoTerra™ ™ house

Background

In Canada, buildings consume 30% of the total secondary energy and about 50% of total electricity[1]. The substantial energy consumption of the building sector presents a great opportunity for savings.

In an effort to encourage innovation, public knowledge, industry expertise, and public-private collaboration, the Canada Mortgage and Housing Corporation (CMHC) started the

[1] Natural Resources Canada: Office of Energy Efficiency (2007). Energy use data handbook tables, *Technical Report OEE 2952*.

EQuilibrium™ Sustainable Housing Project Initiative. The initiative was an open design competition for builder- or developer-led teams to submit house designs that were both healthy and sustainable. Of the seventy-entries, the top 12 teams were selected to build their design. Concordia University, and associated SBRN researchers, were involved in two of the projects that demonstrate BIPV/T systems. They were the Alstonvale and ÉcoTerra™ houses.

There are two key ways that a house can have a positive impact on energy use:

1. **Energy efficiency:** reduction of heat loss through the building envelope and energy efficient mechanical equipment, appliances and lighting. Heating represents about two-thirds of a home's energy use. By well insulating a house and reducing air leakage, the heat that is added to the house can be preserved for longer periods. Efficient appliances, such as refrigerators, laundry machines, and light bulbs can reduce plug-load electrical use by half or more at no sacrifice to comfort or convenience.
2. **On-site solar energy collection**: Ultimately energy efficiency measures can only reduce the energy use of the house by so much. At some point, for a house to approach net-zero, it must generate some of its own energy. ÉcoTerra™'s BIPV/T system can produce both electricity and thermal energy by exploiting the solar energy incident on a large roof surface area. The electricity generated by the photovoltaic (PV) system can be consumed immediately on site or exported to the electrical grid. This eliminates the need for electricity storage (i.e.: batteries). When the sun is shining, the passive solar gains of the house are usually adequate for providing the space heating. Thus, the thermal energy from the BIPV/T system is actively stored in a ventilated concrete slab and then released into the interior space passively, or it is used to heat water or dry clothes.

Besides providing the owners with substantially lower than average utility bills, the ÉcoTerra™ house also provides a home with high indoor air quality and ample daylighting. The following section describes each of the features that make the house unique.

Features in Detail

The ÉcoTerra™ house made use of an integrated design process (IDP) early in the project development to ensure that all components were optimized to work together. All of its systems and features help to contribute to energy conservation or production. This section describes each of the unique features in detail. The features are shown in the diagram below.

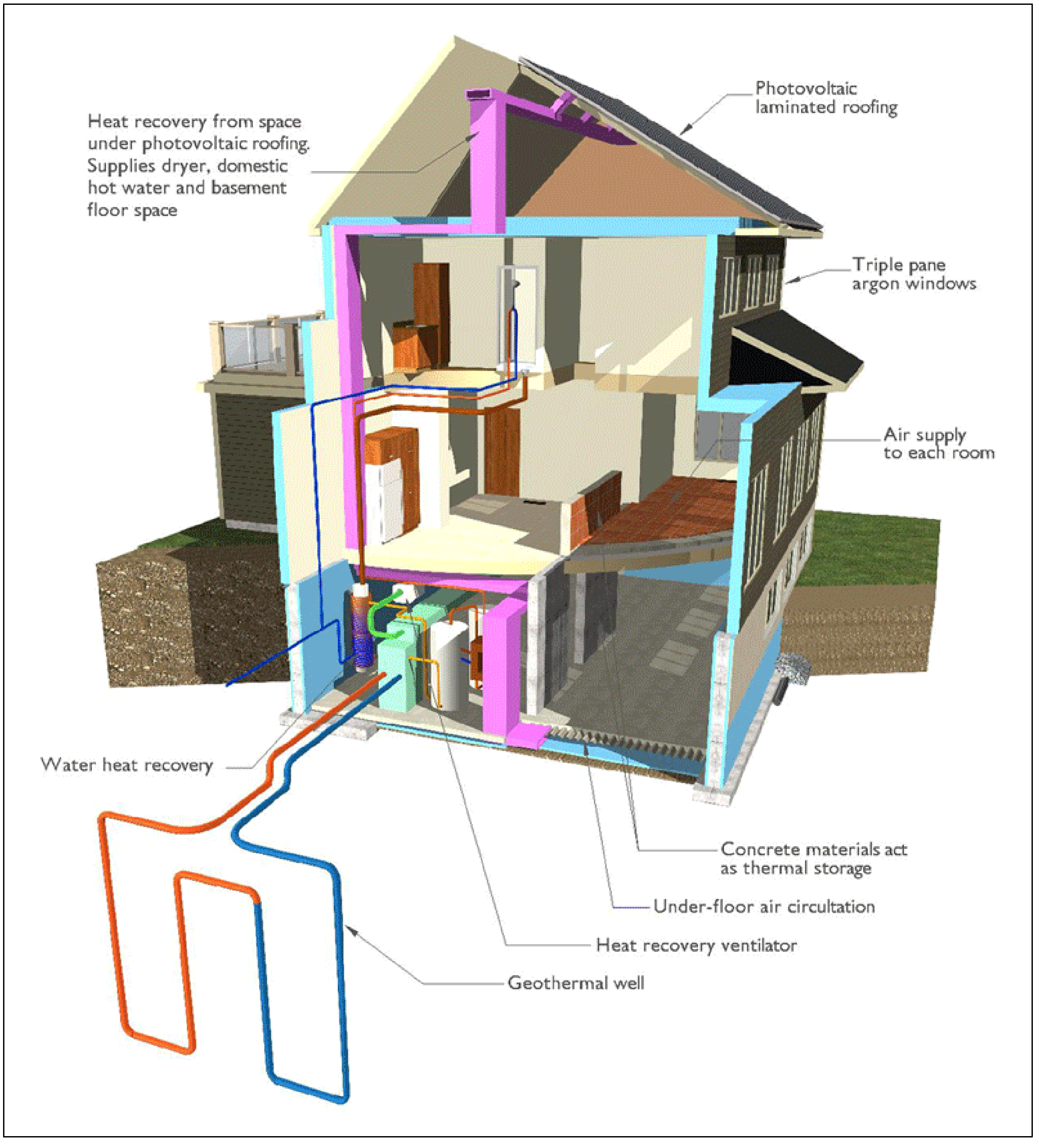

Figure 3: ÉcoTerra™ Energy System Layout

Building-Integrated Photovoltaic/Thermal (BIPV/T) System

The south-facing upper roof area is covered by PV panels. These panels can produce as much as 2.8 kW of electricity. The electrical utility (Hydro-Quebec) allows net-metering for residential customers. When the ÉcoTerra™ home is producing more electricity than it is consuming, the meter runs backwards.

The PV modules that were selected are amorphous silicon (a-Si). These flexible PV laminates were integrated on the metal standing-seam roof in order to enhance the aesthetic appeal of the house. In typical installations, a small quantity of the incident solar energy is reflected or irradiated back to the surroundings. For a-Si modules, approximately 6-8% of the absorbed solar radiation is converted into electricity. The remaining absorbed energy heats up the PV modules. The innovative design proposed by Concordia University and SBRN researchers cools the PV modules and also puts this otherwise wasted thermal energy to good use.

Outdoor air is passed under the panels, from the eaves to the peak, and then this heated air is sent into the house through insulated ducting where it can be used. The solar-heated air leaves the roof approximately 35°C warmer than the outdoor temperature. This air can be used in three ways:

1. Space heating though thermal storage in a ventilated concrete slab.
2. Pre-heating domestic hot water through an air-to-water heat exchanger.
3. Supplying warm air to the clothes dryer.

Solar-heated air is delivered by ductwork to the intended location. A variable speed fan is used to ensure proper flow and control.

The energy balance equation for the BIPV/T roof is shown below:

$$\alpha \cdot I = E_{PV} + E_{Thermal} + E_o$$

where α is the solar absorptance of the roof, **I** is the incident solar radiation, $\mathbf{E_{PV}}$ is the electrical energy produced by the PV cells, $\mathbf{E_{Thermal}}$ is the thermal energy output of the roof, and $\mathbf{E_o}$ is the heat lost to the surroundings.

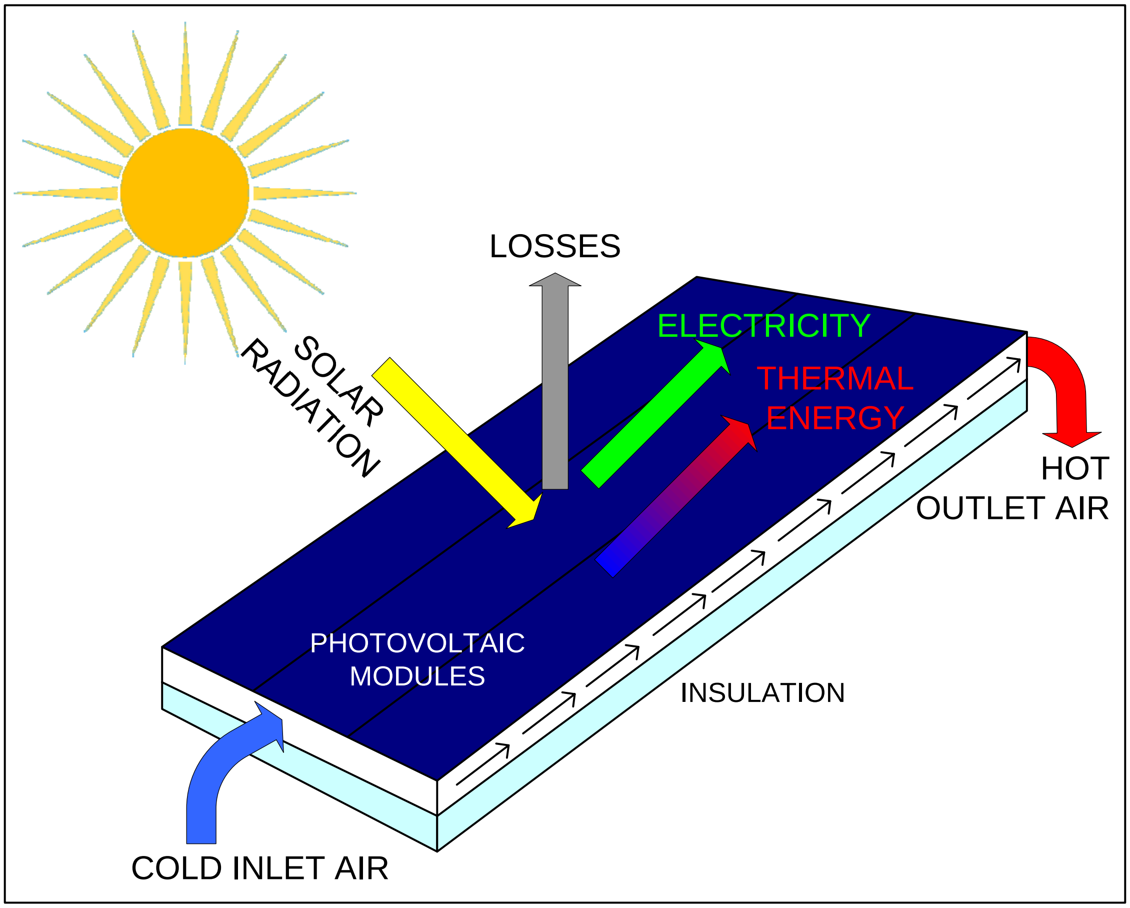

Figure 4: Energy Balance of BIPV/T Roof

As an example, at solar noon on a sunny day the roof receives about 1,000 W/m^2 of solar radiation. Considering that the entire 60 m^2 roof collects solar energy, this means that 60 kW are available from the sun. The PV modules, which cover about 80% of the roof, convert 6% of this of this to electricity, or about 3 kW. At the same time, the air flowing behind the

PV panels on the roof can recover up to 20%, or about 12 kW. The effect of the heat recovery reduces the temperature of the PV modules and thus also increases their electricity output. The remaining 45 kW is lost to the surrounding environment – the improvement of the technology for heat recovery will further reduce this amount.

These numbers can be shown in the energy balance equation as:

$$60kW(\alpha \cdot I) = 3kW(E_{PV}) + 12kW(E_{Thermal}) + 45kW(E_o)$$

Operating data from the ÉcoTerra™ home shows that on a sunny day, with the outdoor air temperature at 0°C, the BIPV/T roof is able to raise the temperature of 400 cfm (188 l/s) of air by about 35°C. Performance at this level can last for about 4 hours a day, from 10:00AM to 2:00PM. This example demonstrates that during the winter the roof can produce warm air and electricity that helps reduce purchased energy.

In total, the BIPV/T system is predicted to produce about 3,200 kWh of electricity and 6,000-8,000 kWh of useful thermal energy, annually. The advantage of this design concept is that it allows for a large surface area to be utilized that can actively recover solar energy throughout the year, at a lower cost per unit of energy than other methods. It is also architecturally, functionally and aesthetically integrated into the roof design.

Ventilated Concrete Slab Storage

Due to the efficient passive solar design employed in the ÉcoTerra™ house, on a sunny and cold day there is no need for mechanical heating. In fact, there is an excess amount of heat that is recovered from the roof that can be stored for later use.

The heated air from the BIPV/T collector is ducted to the basement slab for storage. The slab is unique in that it contains air channels that allow the slab to absorb heat as the air passes through them. Once the slab is heated, it radiates heat to the basement. This process happens gradually through the night and potentially into the next day due to the slab's large thermal inertia. Apart from allowing solar energy to warm the house well into the night, occupant comfort is also improved as the basement slab can be maintained at warmer temperatures than normal.

Ground-Source Heat Pump and HVAC System

During the heating season and if the BIPV/T system is not producing heated air, a ground-source heat pump (GSHP) is used. A GSHP exchanges heat between the house and the vertical wells drilled into the ground. GSHPs work on the principle that the ground, deeper than several meters, remains at a fairly constant temperature of about 6 to 10°C year-round. Obviously, this is much warmer than Quebec's cold winter air. To exploit the mild underground temperatures, a heat-transfer fluid is circulated in a closed-loop between the house and the wells. As the fluid is passed through the wells, it absorbs heat from the ground. ÉcoTerra™'s heat pump uses this heat and concentrates it to bring it to a temperature suitable for forced-air heating.

The reason GSHPs are gaining in popularity today is that they use energy very effectively. For every unit of electricity that is used, they can produce about three to four units of heat. While the GSHPs cost more than traditional systems, their savings can pay for themselves within several years and, perhaps more importantly, protect the home owner's from increases in utility prices.

The efficient building envelope of the ÉcoTerra™ house is both well-insulated and air tight. Test results with a blower door showed about 0.8 air-changes per hour at 50 Pascal. To ensure indoor air quality for occupants, a heat recovery ventilator (HRV) is used to provide fresh air to the building in an efficient manner. The HRV captures heat from the exhaust air that would otherwise be lost and transfers it to the incoming outside air. This way, the air does not have to be heated as much before being supplied to the space.

Passive Solar Heating

The ÉcoTerra™ house is optimized for passive solar heating. About 40% of the south-facing façade area consists of windows. Thus, on cold sunny days, much of the heating required to keep the house warm is from solar gains. Normally, a significant portion of heat loss in houses occurs through windows which are fairly conductive. To combat this problem, the ÉcoTerra™ house uses high-performance, triple-glazed, low-e, argon-filled windows.

The second part of good passive solar design is to have adequate thermal mass. The ÉcoTerra™ house has concrete floor slabs and walls in the basement and on the main floors. These slabs and walls act as thermal mass which provides a way to store solar gains during the daytime, while preventing room temperature swings, and releasing the stored heat slowly at night.

In order to keep the heat from the solar gains inside the building envelope, the house is very well insulated. The walls are RSI 6.6 (R-37.5) and the ceiling is RSI 9.5 (R-54.2), both of which are well above the minimum prescribed by the building code, R-2000 and Novoclimat guidelines. Insulation plays an essential role in minimizing heat loss. Furthermore, its simplicity and lack of moving parts means that it will last for the life of the house.

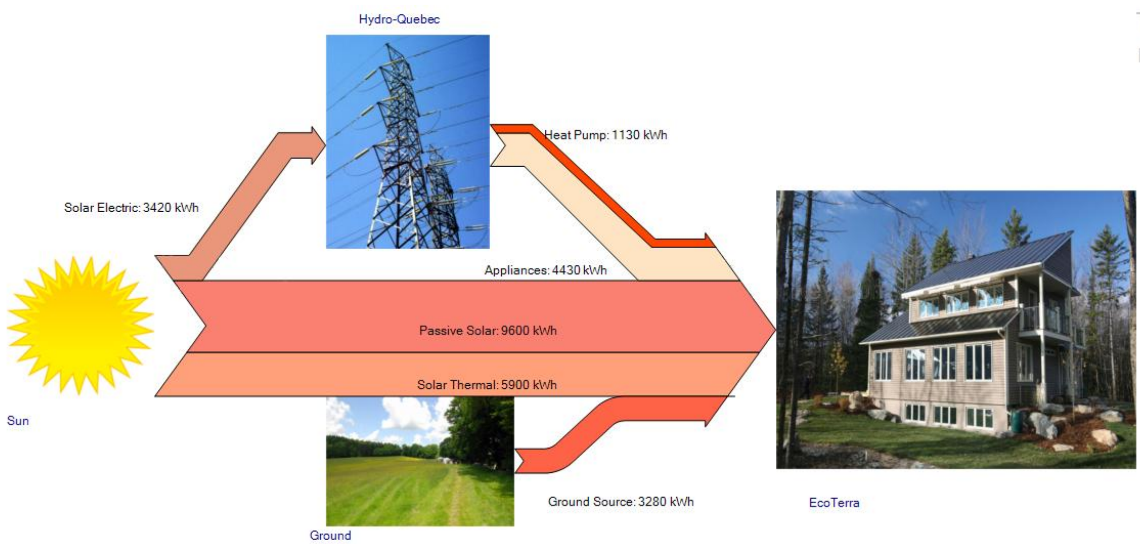

Figure 5: Estimated Energy Flow Diagram

Domestic Hot Water System

Domestic hot water (DHW) heating consumes about a quarter of the energy in Canadian households, making it the second largest consumer after space heating. Furthermore, much of the hot water is used only briefly before literally going down the drain.

The ÉcoTerra™ house addresses this problem in three ways. First, heat is recovered from the warm drain water (grey water) and is transferred to the incoming cool water from the mains. Secondly, the water is efficiently heated using the waste heat from the heat pump. Finally, DHW heating can be supplemented by the BIPV/T solar collector. The solar heated air can be passed through a heat exchanger to pre-heat the water.

Research

The systems of the ÉcoTerra™ home are being monitored by a research team at Concordia University, headed by Dr. Andreas Athienitis, Scientific Director of SBRN, and by Hydro-Quebec. Natural Resources Canada's CanmetENERGY research centre at Varennes is also participating in the evaluation of energy performance. Monitoring allows the design team to assess how the house is performing relative to the original simulated models. This research will allow for a better understanding of passive and net-zero solar homes, and the development of improved design and modelling tools and processes. Data is collected from hundreds of sensors located throughout the house

About the Solar Buildings Research Network

The NSERC Solar Buildings Research Network (SBRN), based at Concordia University, collaborated with Alouette Homes on the design and implementation of integrated active and passive solar design strategies. SBRN is currently the major Canadian research effort focused on solar energy and buildings. It brings together 26 Canadian researchers from 12 universities to develop the solar-optimized homes and commercial buildings of the future. The Network also includes researchers and experts from Natural Resources Canada (NRCan), the Canada Housing and Mortgage Corporation (CMHC) and Hydro-Quebec. The budget of the Network between 2005 and 2010 is about $7 million, with $5.1 million from NSERC; about $1.6 million from NRCan; $250,000 from CMHC; $75,000 from Hydro-Quebec; and more than $1.5 million in-kind support from more than 20 industrial partners. Industrial partners from the energy and construction sectors, including Alouette Homes, are involved in most projects, developing the know-how that will help them compete in the global market.

For more information, visit the SBRN's website:
www.solarbuildings.ca