The Archetype Sustainable Houses: Overview of Design and Monitoring Systems

Living City Campus at Kortright, Vaughan

Toronto and Region Conservation
Ryerson University

Final Report 2011

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Prepared by:

Toronto and Region Conservation's Sustainable Technologies Evaluation Program

based on research reports and papers prepared by faculty and graduate students from Ryerson University's Department of Mechanical and Industrial Engineering, and Department of Architectural Science

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities for implementing technologies;
- develop supporting tools, guidelines and policies; and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

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A comprehensive list of the many generous sponsors who contributed to construction of the houses is available at www.sustainablehouse.ca.

EXECUTIVE SUMMARY

The Archetype Sustainable House is a semi-detached twin house designed to serve as a model or prototype for the next generation of "green" production homes. The two houses differ in that House A is intended to demonstrate technologies that are practical today while House B showcases those of the near future (Fig. 1). The goal of the project is to demonstrate and evaluate sustainable housing technologies, materials and practices as a means of influencing how production homes are designed, built and lived so that ecological footprints are minimized and quality of life is improved. This first report provides a summary of the green features and innovative technologies installed in the houses, and details the process of developing and installing a system of sensors and data acquisition hardware and software for monitoring of energy performance.

Figure 1: Archetype semi-detached twin Houses A (right) and B (left)

The project was initiated with a national competition conducted in partnership with the Design Exchange. The intent was to engage architects, engineers and graduate students from across Canada to design a mass production green home for new community development. Of 17 entries, the design submitted by the Building Blocks Partnership was selected as the winner by a blue ribbon panel of judges. The houses were constructed in the summer of 2008 at the Living City Campus at Kortright in Vaughan, roughly 15 km north of Toronto.

Unlike other sustainable house demonstration projects, the Archetype Sustainable House will remain open to the public indefinitely, serving as an ongoing education and training centre for builders, colleges, universities, and the public. Energy efficient features and equipment have been installed in a manner that facilitates removal and replacement to allow testing and evaluation of newer technologies and approaches as they become available. Monitoring of the various innovative technology component systems in the houses will provide valuable insight into their effectiveness in the local climate and serve as a basis for improving on technology designs where needed.

House Design

Architecture

The Building Blocks design of the twin houses allows stacks of blocks to be combined in pairs (semi-detached houses), rows (row houses or stacked townhouses) or slotted in between existing buildings (urban infill) to create diverse and interesting communities. The following are some of the most important features of this unique design concept.

- **Modularity**. Modular building blocks offer a range of design options without the high cost of customization. There are four different housing types to suit different lifestyles: detached, semi, row and townhouses from 2-7 bedrooms.
- **Adaptability/Affordability**. An attached garage and fully finished attic offers adaptable use with potential for rental income.
- **LEED and Energy Star Certified**. Third party environmental certification verifies best building practices. The house has been third party certified as a LEED-platinum building – the highest rating possible in the LEED green building rating system.
- **Superior Insulation and Air-Tightness**. The Sustainable Archetype House offers year-round comfort and low utility bills by means of high-grade insulation and a secure building envelope.
- **Interior Design**. The open concept design makes the most of natural light and air flow. A recycled wood staircase lets in daylight and creates natural stack effect ventilation. The kitchen features recycled material counters, energy-efficient appliances and low flow fixtures.

Heating, ventilation and air conditioning

Each of the two houses has their own HVAC and water systems. A central design feature of the twin houses is integration between its components. For example, House B uses a geothermal ground loop as both a heat source and sink. By integrating this system with the radiant floors and ventilation system, House B regulates its temperature efficiently without burning gas.

There are two major components of the ventilation system: (i) the Enthalpy Recovery Ventilator (or Heat Recovery Ventilator in House A) and (ii) the Air Handling Unit. The ERV captures heat from the exhaust air to pre-heat incoming fresh air, thereby reducing the energy consumption of the AHU. The ERV in House B differs from the HRV in House A in that it can transfer a certain amount of water vapour along with heat energy while the HRV only transfers heat. The AHU, which is integrated with an air-to-air heat pump, has a variable speed fan and supplies forced hot air to the zones above the basement for space heating.

Insulation features include super-insulated walls, floors and roof, super-efficient windows and doors, and passive solar features such as deciduous trees and an ivy trellis that shade the house during summer months but lose their leaves in the winter to let light through.

Water heating

Integrated space-water heating systems in each of the houses combine the functions of space and water heating to reduce the capital cost of equipment and increase operating efficiency.
In House A, a solar combi-system[1] with an active flat plate solar collector is used for domestic hot water heating, along with auxiliary gas heating. A wall-mounted mini boiler is used for auxiliary heating when the solar collector alone is not sufficient. The mini boiler also aids in space heating by supplying water for the radiant heating system in the basement. The hot water system of House A is a one-tank system, which serves as both a solar hot water and time-of-use tank.

Like House A, House B has a solar combi-system with an auxiliary heat source, which in this case is electricity rather than gas. The solar combi-system uses an evacuated tube for space and water heating. The house uses a two-tank rather than one-tank system; one tank is the solar hot water preheat tank and the other is the time-of-use based electric hot water tank which receives additional heat from a ground source heat pump.

A micro cogeneration system has also been installed in House B and can simultaneously produce electricity and heat water for household use or space heating. Hot water used in the radiant heating system of House B is stored in a buffer tank. During the summer, the buffer tank also supplies cold water to the AHU to cool down the incoming fresh air in the ventilation system.

An important system installed in both houses is the drain water heat recovery system, in which a power pipe coils around the main drain pipe to recover drain water heat (e.g. shower, laundry).

Electricity generation and conservation

Both Houses have various measures installed for conserving electricity, including Energy Star® appliances which consume 15 to 50% less energy and water than standard models (NRCan, 2009c) and compact florescent bulbs, which consume less power and have a longer rated life. Of the two houses, only House B has systems for generating electricity. There are three electricity generating systems connected to House B:

Solar photovoltaic array. The PV system on House B has a total of 48 modules, each with an 85 watt capacity. The total array area is 31 m^2 and the generation capacity is 4.08 kWp.

Household-sized wind turbine. Connected to the main electrical panel in House B is a 1.8 kW grid-tied wind turbine. The horizontal axis turbine has non-furling blades and is mounted on a 50 ft tilting monopole. It is net-metered, offsetting House B’s electrical bill by slowing down the electrical meter, and even turning the meter backwards during periods of low electricity demand.

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[1] A solar combi-system is a solar heating system that provides space heating and cooling, and hot water. It is often linked to an auxiliary heat source, such as gas or geothermal.

Micro cogenerator. Installed in the basement of House B, the system uses a Whispergen Stirling engine powered by natural gas to generate electricity, while capturing waste heat from the generator for water heating.

Stormwater management and water conservation

The Archetype Sustainable House contains several technologies to maximize efficient use of water, and minimize both stormwater runoff and the demand for municipal water supply. While the houses have different technologies installed, some systems are connected so that excess water supply in one house supplements the supply in the other.

A green roof installed above the garage in House A provides an opportunity for significant retention of rainfall incident upon the roof. Downspouts draining water from the roof of House A are extended out to the garden away from the foundation, to demonstrate the proper method for disconnecting a downspout from the storm sewer system. A Brac™ system installed in House A is an important water conservation measure. It allows for the collection of grey water from the showers in House A. The water is collected in a 150 litre barrel, filtered, chlorinated and pumped out to supply water for toilet flushing.

In House B, rainwater is collected for re-use in two ways: a rainwater harvesting cistern and a simple rain barrel. All stormwater draining from the south side of the roof of House B and the roof of the in-law suite is conveyed to a 10,000 litre underground concrete cistern. Water collected is filtered and pumped into House B for use in toilets, and to the hose bibs of both houses. It also serves as a back-up supply of water for the grey water system in House A. House B's 170 litre rain barrel collects all runoff from north side of the roof and overflows to the garden when full.

Systems common to both houses are the permeable pavement driveways, wetland wastewater treatment system, xeriscaping and water efficient appliances and fixtures. Both houses have individual permeable pavement driveways, which allow for full infiltration of rainfall through the pavement and base course and into the native soil. The wetland wastewater treatment system is a single system that treats wastewater from all sinks and toilets in both houses. It consists of a septic tank, two wetlands, and tile bed in which the treated effluent is infiltrated into the ground.

Monitoring Program

Monitoring of the technologies at the Archetype Sustainable House was initiated in 2008 and is being carried out to track and evaluate the performance of the energy, water, and ventilation systems of the twin houses. To date, the houses have been instrumented with over 300 sensors and a state-of-the-art National Instruments data acquisition system to allow the buildings and their component systems to be monitored continuously for research and educational purposes.

As part of the energy monitoring program sensors have been installed throughout the houses to measure and record: (i) thermal energy flow, (ii) air flow and humidity, (iii) water flow, and (iv) electricity. Outdoor meteorological conditions are measured simultaneously at a nearby meteorological station. All sensor data collected are logged and analyzed by the data acquisition system, which collects raw data from all sensors, and uses a software platform called LabVIEW to convert sensor output signals into the corresponding units and carry out other data analyses and calculations. All data are stored directly in a local SQL server database.

Energy Audit

An energy audit was conducted on the twin houses on December 16, 2009. The audit involved a depressurization test, a building energy simulation, and thermal images taken to identify potential locations of infiltrations, leakages, and thermal anomalies within the building envelope.

The depressurization test results (Table 1) showed that air changes per hour (a measure of air tightness, with a lower value indicating a more airtight building) were under 1.5 for both houses, which is considered very airtight, making the houses eligible for R-2000[2] certification. As a comparison, and Energy Star home can have an air tightness value as high as 2.5 ACH@50pa, and the 2012 Ontario Building Code standard is 3.1 ACH@50pa.

Table 1: Air Tightness results for individual testing of Houses A and B

Parameter	House A	House B
Net floor area (m^2)	345	350
Internal volume (m^3)	986	1036
Volumetric Flow rate (CFM)	698.5	665.0
Air changes/hour @50 Pa (ACH)	1.204	1.091

In the building energy simulation, Natural Resources Canada's HOT2000 version 10.50 software was used to evaluate the energy performance of the twin houses. The simulation revealed that House B performed better than House A, which is largely a result of more efficient mechanical equipment and a better insulated building envelope in House B. It was also determined that both houses were more energy efficient than the R-2000 building standard, which has significantly higher efficiency requirements than the current Ontario Building Code.

Next steps

The Archetype Sustainable Houses have been designed as a living laboratory for green building technologies. As evaluations of the systems originally installed in the houses are completed, the information obtained and lessons learned will provide valuable information on the effectiveness of the existing technologies, and potential areas of improvement. The following options are currently being considered for evaluation in the twin houses:

[2] The R-2000 Standard – administered by Natural Resources Canada – is an industry-endorsed technical performance standard for energy efficiency, indoor air tightness quality, and environmental responsibility in home construction.

- Addition of ClimateWell® thermal cooling to the cogeneration system in House B, making it a trigeneration system, which is capable of harnessing the waste heat to simultaneously generate electricity, heat and cooling.
- Installation of a Heart™ Transverter, an electrical power conversion device capable of combining electrical power from various sources and converting power between different voltages and AC or DC. The transverter would allow the house to go temporarily off-grid in the event of a power outage and also help to improve power factor[3] on site so that electrical power is being used more effectively and transmission losses to the grid are reduced.
- Installation of a Building Integrated Photovoltaic/Thermal (BIPV/T) collector to be coupled with a two-stage variable capacity air source heat pump (ASHP). Heat energy taken from the back of the BIPV/T collector will be used to pre-heat air and thereby improve the efficiency of the ASHP while keeping the PV cool so that it operates more efficiently.
- Improving landscape-based stormwater management by adding measures to optimize absorbency and minimize stormwater runoff from the site, including a rock garden, rain gardens, and herb and vegetable gardens. Recommendations will be developed based upon monitoring data collected from this site and others, as well as community scale implementation and demonstration projects in Brampton, Richmond Hill and Toronto through TRCA's Sustainable Neighbourhood Retrofit Action Plan.

Monitoring of the houses and the individual systems within them will continue with an emphasis on generating realistic energy and water consumption patterns. This will be achieved in two ways: (i) develop and apply established load profiles with automated switch features to simulate a family's energy and water consumption, and (ii) allow the twin houses to be occupied by residents for a fixed period of time. Data collected during occupancy, or when load profiles are applied, will provide insight into how well the systems perform when subject to real life consumption patterns and also form a basis for comparison to other conventional or energy efficient homes.

Also planned in the near future is the posting of monitoring data (from the data acquisition system's LabVIEW software) on the web. The display data will be near real-time and available for viewing on in-house televisions by touring visitors as well as on existing websites affiliated with the Archetype Houses.

[3] The ratio of actual power being used in a circuit (in units of watts or kilowatts) to that of the power being drawn from the power source, usually the power grid (in volt-amperes or kilovolt-amperes). The difference between the actual power being used and the power drawn from the source represents the amount of power that is lost and does no useful work. Power factor is typically expressed as a ratio between 0 and 1.