Canada's EQuilibrium™ Housing Demonstration Initiative: Net-Zero Energy Houses in Cold Climates

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ABSTRACT

The objective of the EQuilibrium™ Housing Demonstration Initiative is to design, construct and showcase healthy, resource efficient, affordable, net-zero energy houses. A net-zero energy house is one that produces as much energy as it uses for all purposes, with the produced energy coming from renewable sources on the house property.

The demonstration initiative was open to all builders in Canada who were willing to design and construct low-rise residential buildings that met several criteria including minimum envelope energy-efficiency, and onsite renewable energy generation. Eighty proposals were received in two rounds and a total of 15 were selected for construction. Designs did not have to achieve the net-zero energy target to qualify, but did have to be significantly more energy-efficient than current houses. The selection criteria were heavily weighted in favor of those that achieved modeled net-zero energy consumption, and two-thirds did.

Renewable energy sources include PV, PV-thermal, solar DHW, solar air heating, and solar-combi systems (space heat and hot water). Energy saving strategies include ground source heat pumps, drain water heat recovery, and super-insulated airtight building envelopes.

All EQuilibrium™ houses must go through one-year post-occupancy monitoring to determine whether they meet their energy targets, and many (will) have more detailed monitoring of individual systems, including real-time internet displays of PV generation.

This paper describes the design process, examples of the houses, initial energy usage results for three projects, and lessons learned.

Introduction

The EQuilibrium™ Housing Demonstration Initiative was launched by Canada Mortgage and Housing Corporation (CMHC) in 2006. The objective of the Initiative is to design, construct, showcase and monitor houses that are healthy, resource efficient and affordable while approaching or achieving net-zero energy consumption. CMHC asked Natural Resources Canada (NRCan) to become a partner in defining net-zero energy, writing the design procedures and evaluation methods, and defining the monitoring requirements. The Saskatchewan Research Council (SRC) was contracted to collect, analyze and report on the monitored data.

The EQuilibrium™ Housing initiative defines a net-zero energy house as one that produces as much energy as it uses for all purposes, with the produced energy coming from renewable sources on the house property. Renewable energy fuels such as wood pellets and alcohol were not considered as a renewable energy sources when balancing energy consumption with production.

Fifteen designs were selected for construction, seven are complete and four are under construction.

The Design Process

The Initiative began with a request for statements of interest, inviting interested parties to form design teams and to submit conceptual designs for low-rise residential buildings. Seventy-two statements were received, and twenty design teams were selected to develop detailed proposals. Each team received $10,000 to develop and refine their designs in CMHC-sponsored charrettes. In January, 2007, 18 teams submitted their final proposals, which were evaluated and ranked by an independent committee.

On February 13th, 2007, CMHC announced the 12 teams chosen to build and demonstrate their EQuilibrium™ projects in Quebec, Ontario, Manitoba, Saskatchewan and Alberta. A second call for proposals in 2008 resulted in three additional projects, two in British Columbia and one in Atlantic Canada. The winners each received an additional $50,000 from CMHC to help defray costs relating to the design and documentation of their projects, carrying out quality assurance, commissioning, and demonstrating the homes to the general public.

Final proposals had to show how the house would meet the criteria for health, resource efficiency, affordability, and energy-efficiency. Energy use was modeled with the HOT2000 building energy simulation software, and evaluated according to the Canadian EnerGuide Rating Service (ERS) ratings, and a modified version of these ratings (ERS*) developed for the EQuilibrium Housing Initiative.[1] Renewable energy production from PV and SDHW systems were modeled in RETScreen.[2] Some teams used other modeling software for systems and control strategies that were not available in HOT2000 or RETScreen.

The design for energy-efficiency required four steps, the first of which was to design an envelope that would achieve ERS 82 with an 80% efficient gas furnace and other standard equipment and conditions. For those not familiar with ERS ratings, an airtight, energy-efficient 210 m^2 (2,260 ft^2) house in Sault Ste. Marie, Michigan would be rated at an ERS 78 and use around 22,500 kWh/year for space heat, while an ERS 82 house would use only 12,000 kWh/year. The same ERS 82 house in San Francisco would need only 1,750 kWh/year for space heat. Efficient envelopes were required because the envelope is more permanent than lighting fixtures, appliance and heating equipment, and because envelope improvements are more cost-effective than renewable energy until a design gets close to net-zero energy.

The second step was to reduce energy use for lighting, appliances and hot water. Proponents had to justify how these reductions would be achieved, e.g., by specifying a set of major appliances that would come with the house and their EnerGuide annual energy uses. There were limits on these reductions. For example, hot water use could be reduced from the standard 225 L/day (59.5 US gal/day) to no lower than 150 L/day (40 US gal/day). Third, a HOT2000 model including the reduced "baseloads," and the actual heating, ventilation and water heating equipment to be installed, was used to determine whether air conditioning was required, and if so, then it was added to the model.

The fourth step was to model the renewable energy systems to be included with the house. These could include on-site photovoltaic (PV), wind-electric, solar domestic hot water (SDHW), and solar combi (combined DHW and space heat) systems. The energy produced by the renewable systems was subtracted from the energy requirements of the house, to determine the final ERS* rating. The minimum to qualify was ERS* 90 (3,400 kWh/yr for space heat, and

[1] http://oee.rncan.gc.ca/residential/personal/new-homes/upgrade-packages/energuide-service.cfm?attr=0
[2] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools

reduced DHW energy, for the house in Sault Ste. Marie), and the goal was ERS* 100, which is net-zero energy. Scoring was heavily weighted toward designs that came close to, or achieved a predicted net-zero energy consumption.

The Designs

Table 1 summarizes the fifteen selected EQuilibrium™ House designs. All of the houses use grid-connected PV systems, as grid-interconnection is one of the technical requirements of the initiative. Only one of the proposals included battery storage for back-up electrical power. Eighty-seven percent have solar thermal, and most of these are solar-combis. More than half have ground source heat pumps (GSHP), and drain water heat recovery (DWHR) is used in 40 % of the designs. The minimum envelope ERS rating is 83, and the average is 85. The minimum ERS* is 94, which was achieved by the two renovations. The minimum ERS* for new houses is 98, and their average is 99.9, just short of net-zero energy. Four designs achieved ERS* 101, which means they are predicted to produce more energy than they use.

Table 1. Summary of the 15 EQuilibrium™ House Designs

House	Location	Status	PV	SDHW	Solar-Combi	GSHP	DWHR	Env ERS	ERS*
Aboundance Montreal	Montreal, QC	U	√		√	√		85	100
Alstonvale	Hudson, QC	U	*		√	√	√	84	100
Avalon Discovery III	Red Deer, AB	C	√		√			86	101
ÉcoTerra™	Eastman, QC	C	*			√	√	85	98
Echo Haven	Calgary, AB		√		√			86	100
Inspiration	Ottawa, ON	C	√		√		√	85	100
Laebon CHESS	Red Deer, AB	C	√		√	√		88	100
The NOW House™	Toronto, ON	C	√		√		√	84	94
Riverdale	Edmonton, AB	C	√		√			86	100
Top of the Annex	Toronto, ON		√			√		84	101
Urban Ecology	Winnipeg, MB		√	√		√		89	101
YIPI!	Saskatoon, SK		√		√		√	86	94
VISION Home	Moncton, NB		√	√		√	√	83	98
Green Dream Home	Kamloops, BC		√	√		√		84	99
Harmony House	Abbotsford, BC		√		√			83	101
Percent with			100%	20%	67%	53%	40%		
Minimum								83	94
Average								85.2	99.1
Maximum								89	101

"Env ERS" means Envelope ERS rating, "U" means Under construction, "C" means Complete, * under PV means PV/Thermal

All of the new houses are very airtight, with 0.5 to 1.5 or less air changes per hour at 50 Pascals of depressurization (ACH@50Pa), and all have heat recovery ventilators (HRVs). Table 2 compares the climates of the three houses in this report with cold locations in the US and Sweden.

Table 2. Climates of the EQ Houses, with Others for Comparison

City	Degree Days		Heating Design Temperature	
	base 18 ºC	base 64 ºF	ºC	ºF
Anchorage, Alaska	6,062	10,912	-35.1	-31.2
Edmonton, Alberta	**5,589**	**10,060**	**-32.0**	**-25.6**
Red Deer, Alberta	**5,550**	**9,900**	**-35.0**	**-31.0**
Eastman, Quebec	**5,242**	**9,436**	**-28.0**	**-18.4**
Fargo, North Dakota	5,126	9,227	-27.8	-18.0
Sault Ste Marie, Michigan	5,027	9,045	-22.2	-8.0
Stockholm, Sweden	4,589	8,260	-13.3	+8.1

Demonstration & Monitoring

Once an EQuilibrium™ house is complete, it is open to public and professional tours for at least six months, and monitoring of its performance may begin during this time. After the demonstration period, the house may be sold, and once occupied, its performance must be monitored for at least one year.

Minimum Requirement

All EQuilibrium™ houses will be monitored to determine whether they meet their energy target during the first year of occupancy. Each house will have the following meters, to be read once each month:

- Electricity from the grid to the house;
- Electricity from the house to the grid;
- Electricity generated by the PV system;
- Hot water volume and energy;
- Space heating energy (either electric or hydronic); and
- Heat recovery ventilator energy.

Houses that use a combustible fuel will have meters to record its use, and houses with solar-thermal systems will record the energy they deliver. One-time measurements of energy use by major appliances will also be done, with energy meters left on some select appliances to sample their energy use. Real-time and cumulative PV outputs for all of the houses will be posted on-line at http://www.cmhc-schl.gc.ca/en/inpr/su/eqho/eqho_019.cfm.

Analysis by SRC

The Saskatchewan Research Council (SRC) is conducting monthly analyses of the data as it is collected. Actual house energy use is compared with predictions from HOT2000, and actual outputs of renewable energy systems are compared with their models. The models were updated from those submitted by the design teams during the proposal stage to reflect the as-built houses. Heating degree day data for each house location is compared with the climatic averages and used to modify the space heating energy in the models before comparing recorded values with modeled energy consumption. Results are analyzed to determine whether the house is meeting, or is likely to meet, its energy target. The analyses to date for three houses are summarized in the results section of each example house.

Avalon Discovery III

Project Description

Figure 1. The Avalon Discovery III House

The Avalon Discovery III house (Figure 1) is located in Red Deer, Alberta, about 151 km (94 miles) south of Edmonton. As indicated in Table 2, northern Alberta is colder than any major city in the US outside of Alaska, so it presents a major challenge to net-zero energy housing. The house is 1½ stories, with a slab-on-grade foundation, 243.8 m^2 (2624 ft^2) of floor area, and a heated volume of 451.9 m^3 (15,960 ft^3). As modeled by the design team, it's envelope ERS is 86, and it's ERS* is 101. The PV system includes 244 roof-integrated tiles with a peak output of 8.3 kW, and a predicted annual output of 8437 kWh.[3]

The solar-combi system includes 15.3 m^2 (165 ft^2) of flat-plate panels mounted vertically on south-facing walls, and 908 L (240 US gal) of storage in two insulated tanks. It is predicted to produce 3420 kWh/yr, or 29% of the combined space heat and DHW energy consumption.

The triple-glazed argon-filled windows have manually operated external roller shutters. The shutters can be closed so as to allow a small amount of light and view, or completely closed. The shutters can prevent overheating in a house with a very high proportion of solar heating, and also add approximately RSI-0.5 (R-3) to the windows when closed.

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[3] Information on the EQuilibrium House Designs is from the CMHC Project Profiles and EQuilibrium Housing InSights available from: www.cmhc-schl.gc.ca/en/inpr/su/eqho/eqho_007.cfm. Predicted energy balances are from HOT2000 and RETScreen models revised by SRC to reflect the houses and systems as built and installed.

The exterior walls are composed of a double layer of pre-fabricated structural insulated panels (SIPs). The inside layer is installed as a standard 165 mm (6 ½") thick SIP wall rated at RSI 7.7 (R 44). The second 102 mm (4") SIP panel is rated at RSI 4.9 (R-28) and is fastened to the outside of the main SIP wall using cantilever screws.

The thermal characteristics of the envelope are:

Component	RSI	R
Roof	15.3	87
Walls	12.29	70
Slab-on-grade	10.6	60
Windows	0.85	4.8

As shown in Table 3, the house has a predicted net consumption of 2086 kWh/year based on revised SRC models using as built construction details and results. The initial proposal called for an airtightness 0.5 ACH@50Pa, whereas the house only achieved 1.5 due to problems with ceiling penetrations and with the control mechanism of the exterior roller shutters, which penetrate the envelope.

Table 3. Modeled and Measured Energy Use, Avalon Discovery III

		Energy Consumption					Produced Energy				Energy Balance
		Space Heating (kWh)	Domestic Water Heating (kWh)	Appliances Lighting (kWh)	Mech Ventilation (kWh)	Total Energy Use (kWh)	Solar Electricity (kWh)	Solar Domestic Water Heating (kWh)	Active Solar Space Heat (kWh)	Total Production (kWh)	('-' export) (kWh)
Jan	*Modelled*	*1815*	*250*	*320*	*71*	*2455*	*635*	*118*	*57*	*810*	***1645***
	Measured	1404	253	515	24	2196	202	21	117	340	**1856**
Feb	*Modelled*	*1331*	*227*	*289*	*59*	*1907*	*794*	*150*	*220*	*1164*	***743***
	Measured	1152	140	415	22	1728	472	26	213	711	**1017**
Mar	*Modelled*	*801*	*250*	*320*	*59*	*1430*	*1065*	*213*	*354*	*1632*	***-202***
	Measured	390	221	581	25	1217	862	133	235	1230	**-13**
Apr	*Modelled*	*545*	*238*	*310*	*52*	*1144*	*1062*	*228*	*159*	*1449*	***-305***
	Measured	197	233	523	27	980	1058	141	119	1318	**-338**
May	*Modelled*	*221*	*240*	*320*	*50*	*830*	*1070*	*233*	*88*	*1391*	***-560***
	Measured										
Jun	*Modelled*	*54*	*226*	*310*	*46*	*636*	*1066*	*223*	*54*	*1344*	***-707***
	Measured										
Jul	*Modelled*	*9*	*230*	*320*	*47*	*606*	*1111*	*229*	*9*	*1350*	***-743***
	Measured	1	246	561	36	844	1205	211	0	1417	**-573**
Aug	*Modelled*	*23*	*228*	*320*	*47*	*619*	*1015*	*228*	*23*	*1266*	***-648***
	Measured	0	176	474	31	681	876	155	0	1032	**-351**
Sep	*Modelled*	*103*	*222*	*310*	*48*	*683*	*850*	*200*	*98*	*1148*	***-465***
	Measured		234	548	36	818	1078	228		1306	**-488**
Oct	*Modelled*	*731*	*234*	*320*	*54*	*1339*	*783*	*162*	*108*	*1053*	***286***
	Measured	579	299	607	34	1520	451	44	85	579	**941**
Nov	*Modelled*	*1010*	*232*	*310*	*60*	*1612*	*596*	*113*	*35*	*744*	***868***
	Measured	721	297	509	26	1553	421	81	195	697	**856**
Dec	*Modelled*	*2183*	*245*	*320*	*69*	*2817*	*526*	*118*		*644*	***2174***
	Measured	1708	290	473	25	2495	74	12	70	155	**2340**
Year	*Modelled*	*8826*	*2821*	*3770*	*662*	*16079*	*10573*	*2215*	*1205*	*13993*	***2086***
To Date	*Modelled*	*8550*	*2355*	*3140*	*566*	*14612*	*8437*	*1759*	*1063*	*11259*	***3353***
	Measured	6152	2389	5207	285	14033	6699	1052	1035	8786	**5247**

Results

The Avalon Discovery III house in Red Deer, AB has been occupied and monitored since July, 2009. Figure 2 shows a graph of the modeled energy consumption (updated to reflect the as-built house and actual climate) in the wider, striped bars. The measured energy consumption from July 2009 through April, 2010 is shown in the narrow, solid bars. The energy balance line for the modeled data is shown in dark blue and the measured data in light blue. The same data is shown in Table 3, above.

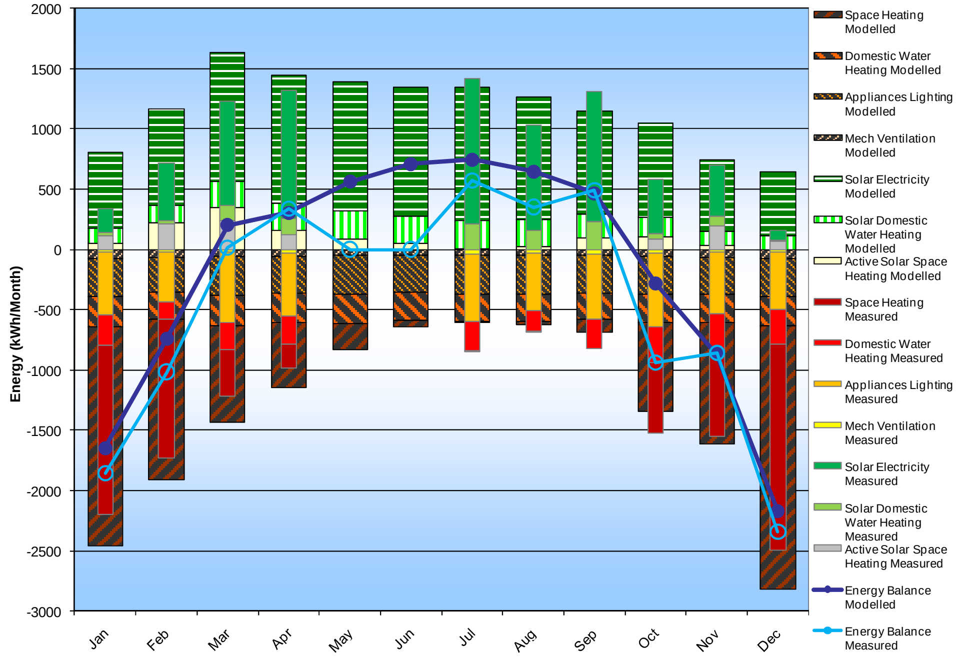
The house is using less energy than the models predict, but the energy produced by the renewable energy equipment is also less than predicted by the models. Table 4 shows the monthly heating degree days for the measurement period and a comparison with the climate normals. October was a particularly cold and cloudy month (compared with the long term average for the region), which is reflected in the relatively large energy consumption and small energy production. The space heating energy makes up less than half of the total energy used in the house, so an annual deviation from normal heating requirements of 5% will cause a variation of only 2.5% in house energy use due to weather deviations from normal.

Table 4. Normal and Measured Heating Degree Days, Red Deer, AB

Month	Climate Normal Heating Degree Days (base 18 ºC)	Heating Degree Days over Measurement Period (base 18 ºC)	Difference from Normal (%)
Jul	85.8	81.8	-4.7%
Aug	104.7	97	-7.4%
Sep	243.8	125.1	-48.7%
Oct	431.4	559.9	29.8%
Nov	702.4	565	-19.6%
Dec	895	1046.6	16.9%
Jan	962.7	868	-9.8%
Feb	790.8	736.5	-6.9%
Mar	677.6	539.2	-20.4%
Apr	414.9	412.6	-0.6%
Total	**5309.1**	**5037.1**	**-5.2%**

The occupants of this house are very cognizant of the energy they use. They were involved in the design of the project from the beginning and therefore have a good understanding of the way the house works. These facts are reflected in how closely the house performance matches the modeled performance. This house has the potential to reach net zero energy.

Figure 2. Modeled and Measured Energy Consumption, Avalon Discovery III



Riverdale

Project Description

Figure 3. The Riverdale NetZero Project

The Riverdale NetZero Project (Figure 3) is located in Edmonton, Alberta. It is a semi-detached duplex. Each of the two units has 234 m^2 (2519 ft^2) of heated floor area, and a volume of 634 m^3 (22,425 ft^3). Its envelope ERS is 86, and its ERS* is 100. Each side of the duplex has a PV system with a peak output of 5.5 kW, and a predicted production of 7149 kWh per year. Each solar-combi system has 22 m^2 (237 ft^2) of collectors, and water storage tanks of 300 L (79 US gal) and 17,000 L (4,497 US gal).

The house has a double-stud wall system with a 406 mm (16 in) cavity filled with blown-in cellulose insulation. The north windows are argon filled, quadruple-glazed, with three soft low-e coatings. To enhance solar heat gain, the south windows are triple-glazed, argon filled, with two soft low-e coatings. The east and west windows are similar, but with a lower solar heat gain coefficient to reduce excess heating in the summer. Overhangs above the south windows also reduce summer heat gain.

The thermal characteristics of the envelope are:

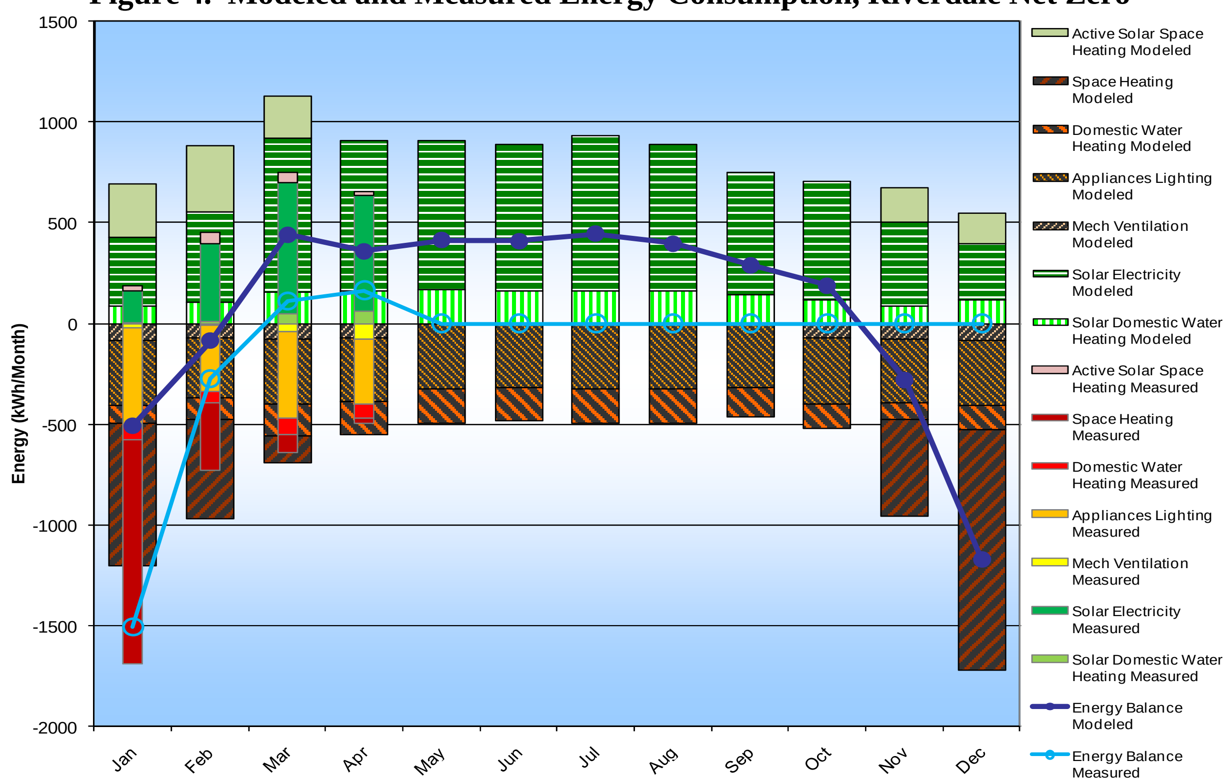
Component	RSI	R
Roof	17.6	100
Main wall	9.96	56
Basement walls	9.51	54
Basement floor	4.2	24
South windows	1.3	7.3
East & west windows	1.5	8.3
North windows	1.8	10

As shown in Table 5 each unit has a predicted net production of 905 kWh/year.

Table 5. Modeled and Measured Energy Use, Riverdale NetZero Project

		Energy Consumption					Produced Energy				Energy Balance
		Space Heating (kWh)	Domestic Water Heating (kWh)	Appliances Lighting (kWh)	Mech Ventilation (kWh)	Total Energy Use (kWh)	Solar Electricity (kWh)	Solar Domestic Water Heating (kWh)	Active Solar Space Heat (kWh)	Total Production (kWh)	('-' export) (kWh)
Jan	*Modeled*	*709*	*86*	*326*	*80*	*1201*	*343*	*86*	*266*	*695*	***506***
	Measured	1112	80	479	20	1691	162	2	24	187	**1504**
Feb	*Modeled*	*496*	*109*	*294*	*70*	*968*	*445*	*109*	*330*	*883*	***85***
	Measured	334	57	333	6	730	389	9	56	454	**276**
Mar	*Modeled*	*132*	*155*	*326*	*74*	*687*	*770*	*155*	*203*	*1127*	***-441***
	Measured	90	79	429	43	640	650	48	54	752	**-111**
Apr	*Modeled*		*165*	*315*	*70*	*551*	*744*	*165*		*910*	***-359***
	Measured	26	68	320	79	493	576	59	23	657	**-164**
May	*Modeled*		*169*	*326*		*495*	*739*	*169*		*908*	***-413***
	Measured										
Jun	*Modeled*		*162*	*315*		*478*	*726*	*162*		*889*	***-411***
	Measured										
Jul	*Modeled*		*166*	*326*		*492*	*769*	*166*		*935*	***-443***
	Measured										
Aug	*Modeled*		*166*	*326*		*492*	*724*	*166*		*890*	***-398***
	Measured										
Sep	*Modeled*		*145*	*315*		*460*	*605*	*145*		*750*	***-290***
	Measured										
Oct	*Modeled*		*117*	*326*	*73*	*516*	*588*	*117*		*706*	***-190***
	Measured										
Nov	*Modeled*	*481*	*85*	*315*	*75*	*956*	*419*	*85*	*173*	*678*	***279***
	Measured										
Dec	*Modeled*	*1193*	*118*	*326*	*80*	*1716*	*277*	*118*	*152*	*547*	***1169***
	Measured										
Year	*Modeled*	*3011*	*1643*	*3836*	*522*	*9012*	*7149*	*1643*	*1125*	*9917*	***-905***
To Date	*Modeled*	*1337*	*515*	*1261*	*294*	*3408*	*2302*	*515*	*799*	*3616*	***-208***
	Measured	1561	283	1561	148	3554	1775	118	156	2049	**1505**

Figure 4. Modeled and Measured Energy Consumption, Riverdale Net Zero



Results

Modeled and measured energy consumption data for the Riverdale Net Zero house is shown in Figure 4 and Table 5. The house in Edmonton, AB contains some complicated active solar systems designed to take advantage of as much renewable energy as possible. These systems took considerable time to get working properly, resulting in a delay in the commencement of monitoring for the house to the beginning of January, 2010. Despite high space heating consumption in January, the February to April values are more in line with predictions. The electric space and domestic hot water heating energy of the house for March and April was 78 kWh, or 30% of the load. During these two months 1200 kWh was captured by the active solar system and stored in the large thermal storage tanks.

ÉcoTerra™

Project Description

Figure 5. The ÉcoTerra™ House

The ÉcoTerra™ house (Figure 5) is located on a 1.1 ha (2.7 acre) rural lot in Eastman, Quebec, about 110 km (68 miles) east of Montreal. The climate is not as severe as northern Alberta, but is still colder than most places in the coterminous US. The house was assembled from seven factory-built modules, including the building-integrated PV/thermal system. It has two stories and a full basement, 234 m^2 (2519 ft^2) of heated floor area, and a volume of 671 m^3 (23,710 ft^3). Its modeled envelope ERS is 85 and its ERS* is 98.

The building-integrated photovoltaic system combined with thermal recovery (BIPV/T) includes 21 PV film sheets laminated to a standing-seam metal roof. Its peak electrical output is

3 kW, and it is predicted to produce 3178 kWh per year. Air drawn beneath the metal roof cools the PV sheets, thus increasing their efficiency. The heated air is used to preheat hot water, fed into the clothes dryer, or used to heat the basement ventilated concrete slab. A 10.6 kW (3 ton) two-stage GSHP is used for both space heat and hot water. There is also a drain water heat recovery device for preheating hot water.

The house has a sophisticated home automation system with real-time graphic display and touch screen user interface that displays current indoor and outdoor conditions, and the operation of the various systems (PV electrical generation and supply to or from the grid, PV/T heat, and GSHP). The windows are triple-glazed, low-e and argon filled. The south-facing windows on the ground and second floors have awnings that can be operated automatically to prevent overheating.

The thermal characteristics of the envelope are:

Component	RSI	R
Roof	6.3	36
Walls	6.6	38
Basement floor	1.3	7.5
Windows	0.7	4.0

As shown in Table 6, the house has a predicted net consumption of 4546 kWh/year.

Table 6. Modeled and Measured Energy Use, ÉcoTerra™

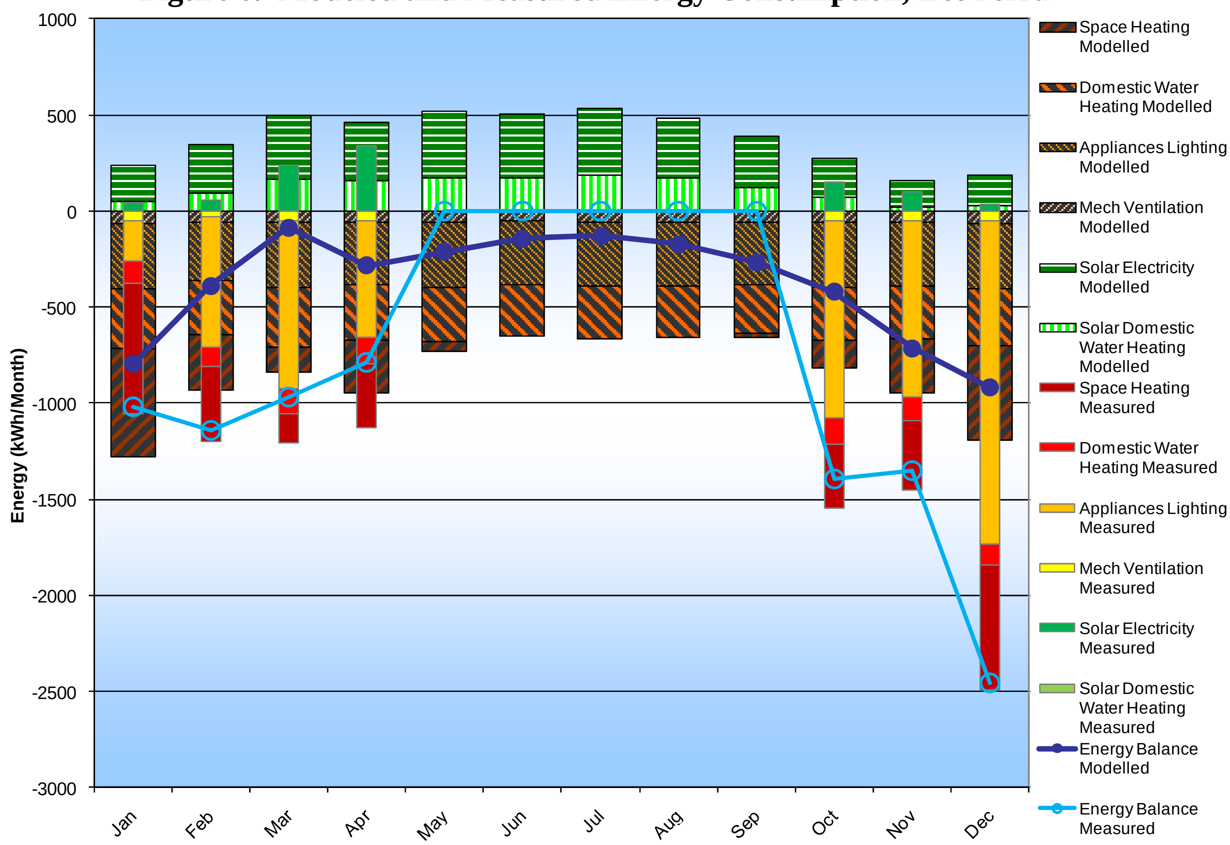
		Energy Consumption					Produced Energy				Energy Balance
		Space Heating (kWh)	Domestic Water Heating (kWh)	Appliances Lighting (kWh)	Mech Ventilation (kWh)	Total Energy Use (kWh)	Solar Electricity (kWh)	Solar Domestic Water Heating (kWh)	Solar Air Heating (kWh)	Total Production (kWh)	('-' export) (kWh)
Jan	Modelled	562	308	338	67	1275	190	49	237	476	799
	Measured	681	110	209	55	1056	38			38	1018
Feb	Modelled	288	281	305	58	932	247	97	199	543	389
	Measured	389	97	682	30	1198	54			54	1145
Mar	Modelled	132	308	338	61	839	337	164	250	751	88
	Measured	149	129	877	51	1206	237			237	970
Apr	Modelled	274	290	327	58	948	308	156	201	664	284
	Measured	332	141	601	54	1128	339			339	789
May	Modelled	49	287	338	57	731	343	175		518	213
	Measured										
Jun	Modelled		269	327	54	650	332	172		504	145
	Measured										
Jul	Modelled		269	338	56	662	349	185		534	128
	Measured										
Aug	Modelled		266	338	56	659	316	170		486	173
	Measured										
Sep	Modelled	17	257	327	54	655	261	126		387	269
	Measured										
Oct	Modelled	148	275	338	58	819	202	70	125	398	421
	Measured	332	138	1021	55	1546	151			151	1395
Nov	Modelled	282	278	327	60	947	139	22	71	232	715
	Measured	358	123	914	55	1450	100			100	1350
Dec	Modelled	488	299	338	66	1191	154	32	85	271	921
	Measured	647	109	1681	55	2493	34			34	2458
Year	Modelled	2241	3388	3975	706	10310	3178	1417	1168	5763	4546
To Date	Modelled	2175	2040	2309	429	6952	1577	589	1168	3334	3618
	Measured	2889	846	5986	355	10077	952			952	9125

Results

Figure 6 and Table 6 show modeled and measured energy consumption for the ÉcoTerra™ house. Like the other projects, the renewable energy production is lower than anticipated by the models, especially in the winter months.

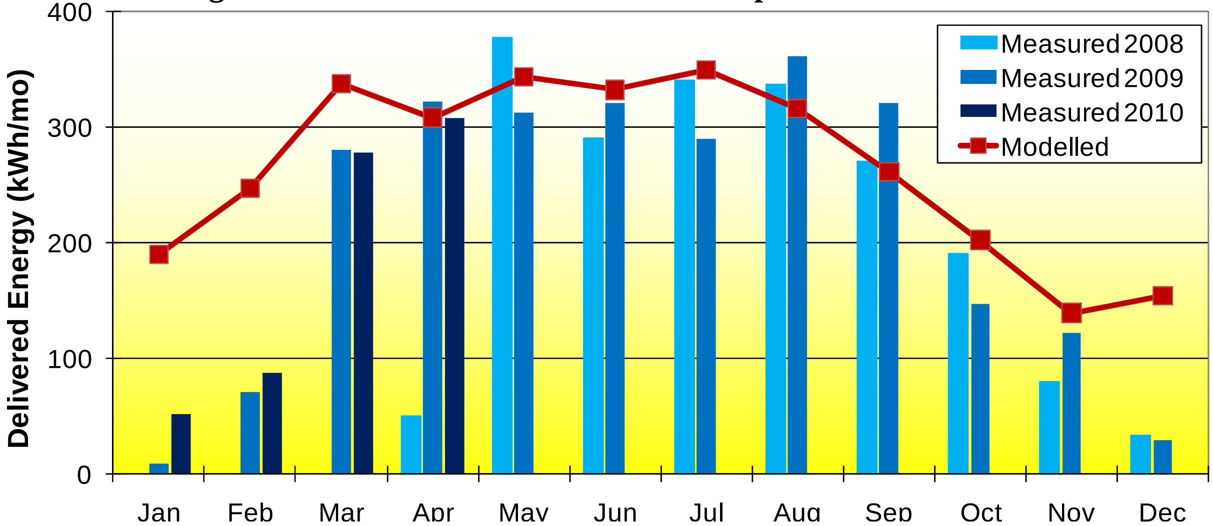
The appliances and lighting category includes all electrical energy not accounted for by the water heater and geoexchange heating system. The early readings from this house show a large energy consumption in this category. It was discovered in December that the occupants had installed an electric heater in the garage. An energy meter has been placed on the garage heater to determine the energy associated with this appliance, and investigation continues to uncover additional energy uses. Other issues identified include over 2,000 kWh per year of electricity consumed for third party monitoring equipment. The auxiliary heater on the GSHP had been set to turn on when the set-point temperature was more than 4 ºC above the room temperature. However, the occupants used a night setback from 22.5 ºC to 18 ºC, so if the temperature fell to 18 ºC overnight, then the auxiliary heater would start in the morning.

Figure 6. Modeled and Measured Energy Consumption, ÉcoTerra™



The renewable energy system output on each of the houses is less than predicted by the models, especially in the winter. Figure 7 shows the PV system output from ÉcoTerra™ since it came online in April 2008. Most of the poor performance of the PV systems in winter is probably due to snow cover. Another possible factor is RETScreen's default values for PV system efficiencies, which may be too high.

Figure 7. Measured and Modeled PV Output for ÉcoTerra™



Lessons Learned

Large, Complex Solar Combi-Systems May Not be Practical

The Avalon team found that an oversized solar thermal system brought additional expenses in operating the equipment, in addition to the increased costs of solar thermal equipment, labor, extra costs incurred due to system complexity, and the added space requirement of the equipment. If redesigning the system, the Avalon team would opt for a smaller solar thermal collection and storage system, which they feel would be more cost and energy efficient. The Riverdale house has an even larger and more complex solar-combi, and its designers decided that solar thermal systems should be eliminated in future projects.

Should PV Displace All Other Renewable Energy Sources?

Habitat Studio and Workshop Ltd. has built three net-zero energy houses in Edmonton. The first was the Riverdale EQuilibrium™ house. The second two, Mill Creek and Belgravia were built for private clients. The lessons learned from each were applied to the next, so they can be considered first, second and third generation net-zero energy houses. The main lesson seems to be "Simple is cheaper and faster," and simple seems to mean reducing or eliminating solar thermal systems, while increasing the size of the PV system. A brief comparison of the three houses is shown in Table 7. No doubt, there will be many who disagree with the idea that solar thermal systems don't belong in very energy-efficient houses, but that idea does seem to have worked in these cases.

Table 7. Comparison of Three Net-Zero Energy Houses in Edmonton

	Riverdale EQuilibrium™	**Mill Creek**	**Belgravia**
Net-Zero House Generation	1st	2nd	3rd
Solar Thermal Collector Area (m^2)	22	9.9	0
Storage Tank Volume (L)	17,300	1,500	0
PV System Size (kW_p)	5.6	6.0	7.38
Incremental Cost to Net-Zero (CAD$)			
Envelope	$20,000	$16,000	$15,000
Solar Thermal	$45,000	$9,000	$0
PV	$45,000	$50,000	$55,000
TOTAL	$110,000	$75,000	$70,000

Achieving Net-Zero Energy Depends on Occupants as Well as Design

Of the three houses, Avalon Discovery III has come closest to meeting its energy targets, and heating energy is somewhat less than modeled. As noted, its occupants were involved in the design process, and are very interested in minimizing energy use. The occupants of ÉcoTerra™ were not involved in its design, and may have selected the house more for location than energy-efficiency. They installed a garage heater that causes the house to consume more than predicted. It is reasonable to conclude that, although the envelope, appliances, and renewable energy systems of a house may be designed to allow the house to achieve net-zero energy, it is still up to the occupants to live in such a manner as to allow net-zero energy to be achieved.

Summary & Conclusions

CMHC's EQuilibrium™ Housing Demonstration Initiative has resulted in the design and construction of some of the most energy-efficient houses ever built in Canada. It is too soon to tell whether any of them will achieve true net-zero energy when occupied over a year, but there is no doubt that they will bring that goal significantly closer, and that the lessons learned from their design, construction, commissioning and operation will provide valuable information for future energy-efficient houses.