

## LIVING OFF-GRID ON RENEWABLE ENERGY IN THE YUKON

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### ABSTRACT

NRCan is implementing a co-ordinated R&D program to foster the advancement of renewable energy technologies (RETs) and integrated systems in off-grid, remote communities. There are more than 200,000 Canadians living in 300+ remote communities throughout Canada. Energy supply to these communities is characterized by high costs, high degree of dependence on imported fuel, and usually a lack of local technical expertise to provide needed services. Many communities rely on diesel generators for producing electricity at costs that vary from \$0.15 to \$1.50 per kWh. At these rates, some RETs can be cost effective for electricity generation and for heating applications. The design *charrette* was the second activity in a 4year R&D project entitled "An Integrated Approach to Increasing the Use of Renewable Energy in Off-grid Residences in the North" with the aim of increasing the ratio of renewable energy to total energy use in off-grid residences by 10%. The first undertaking established baseline information on renewable energy use in off-grid residences North of the 60<sup>o</sup> north latitude. In conjunction with a survey questionnaire identifying the needs and preferences of residents in 30 off-grid dwellings in the Yukon, the Yukon Energy Solutions Centre (YESC) was able to identify potential participants for renewable energy and energy efficiency audits as well as consider home owners' preferences and likely possibility to implement retrofits based on the recommendations included in the energy audits. This paper will present the results of the baseline study and the design *charrette*.

### 1 INTRODUCTION

There are more 200,000 Canadians living in 300+ remote communities throughout Canada. These communities are typically fishing villages or small mining or logging towns. Energy supply to these communities is characterized by high costs, high degree of dependence on imported fossil fuel, and insufficient base of local technical expertise to provide needed services. Many communities rely on diesel generators for producing electricity at costs that vary from \$0.15 to \$1.50 per kWh. At these costs, some renewable energy technologies (RETs) can be cost effective for electricity generation and for heating applications. Consequently, there is much-needed demand by off-grid residences for affordable renewable energy systems that could supply power for heating and electricity. Advances in renewable energy systems and the building sciences now make it possible to build more economic and energy-efficient off-grid houses. To exploit this opportunity, there is a need to identify and address several obstacles to renewable energy use and to demonstrate more complete and practical energy solutions based on incorporating and using various combinations of RETs.

NRCan is mandated to foster the advancement of renewable energy technologies and integrated systems in off-grid, remote communities through its various programs in energy research and development. One such program<sup>1</sup> is funding a four-year project entitled "*An Integrated Approach to Increasing the Use of Renewable Energy in Off-grid Residences in the North*" which aims to increase the ratio of renewable energy to total energy use in off-grid residences by 10 percent. Although, initially, this project targets houses in latitudes north of the 60<sup>th</sup> parallel, its aim is to apply and disseminate the results of the research to off-grid residence developers and owners in all regions of Canada.

## 2 RESEARCH INTO INTEGRATED RETs IN OFF-GRID RESIDENCES IN CANADA

The purpose of this project is to increase and optimize the use of renewable energy sources, and to reduce fossil fuel use in off-grid houses in the Yukon. Using an integrated approach, the project looks at ways to get the most out of homeowner's investments in renewable energy systems, and provides an analysis of total energy use (including space and hot water heating) and electrical energy use in a sample of off-grid houses. Off-grid houses often have reduced electrical needs, yet still use large amounts of purchased fuel for space and water heating. An integral aspect of this project was to look at the renewable energy and overall energy efficiency of off-grid houses in the Yukon, and to suggest ways in which the overall energy use can be reduced.

There has been much study of renewable energy systems at lower latitudes, but not as much in high latitudes, such as the Yukon. So, we don't know as much about how these systems perform in extreme weather conditions. Getting the right mix of energy collectors (e.g. PV panels, wind turbines, micro-hydro systems), storage capacity (e.g. batteries), and load management (e.g. lights, appliances) is a real challenge anywhere, but especially so in Canada's north, where the seasons are extreme in the difference between available resources and the needs of a house. The most obvious example of this is the sun. The summer gives up to 10 hours of usable solar radiation on a clear day – this period coincides with a lower electricity use, a full hot water load and little or no space heating requirements. The winter gives 1 or 2 hours of usable solar radiation on a clear day – this period coincides with a higher need for electricity, a full hot water load and space heating requirements. Difficult to determine which is the best route to go for electricity and for hot water – a hybrid PV and wind system, solar hot water? Stick with a fuel-fired generator because the renewable energy system have a big price tag and does not seem to be as reliable as a generator? Therefore, Comparing the long-term costs (fuel, maintenance, and replacement equipment) to the up-front costs of any system is crucial to making the best decision for your household.

The current phase of the project involved a survey of off-grid residents in the Yukon to increase understanding of the current use of renewable energy in off-grid residences and to identify obstacles and opportunities for encouraging the use of renewable energy in the Yukon. The survey was used to identify approximately 30 off-grid residences that currently use renewable energy technologies for a part of their energy supply and to provide information for the baseline study phase of the project. Each house underwent an extended energy audit conducted during the spring and summer of 2003 (Table 1).

A new renewable energy audit questionnaire was added to the standard EnerGuide for homes audit. The energy analyses were conducted using the HOT2000<sup>2</sup> software tool. EnerGuide audits for off-grid houses had never been conducted in Canada, and some adjustments were made to ensure off-grid energy use such as wood heating were well integrated into the global energy analysis. Subsequently, three of these houses (highlighted) were used as case studies for an integrated design *charrette*<sup>3</sup> that was held in December 2003 in Whitehorse, Yukon Territory. The results of the *charrette* are detailed in this paper.

## 3 YUKON DESIGN CHARRETTE: AN INTEGRATED APPROACH TO INCREASING RETs IN OFF-GRID RESIDENCES IN THE NORTH

Three case studies (House File # x986, x987 and x999) from the 30 off-grid residences identified in the initial survey phase of the project were the focus of an integrated design *charrette* in Whitehorse from December 4<sup>th</sup> to the 6<sup>th</sup>, 2003. Three criterion were the basis for their selection:

- they had to be occupied most of the year;
- the occupants would accept to have their energy use monitored (and in some cases to participate actively in the monitoring, e.g. recording monthly diesel fuel consumption); and
- the owners were planning to improve or optimize their RE systems within the following year of the design optimization process. Since no grant will be provided, preference was given to those participants who have already committed a budget for an eventual upgrade of their house energy system.

**Table 1: Fuel consumption estimates of off-grid residences in the Yukon<sup>4</sup>.**

File #	Occ. #	Vol. (ft <sup>3</sup> )	BTU (10 <sup>6</sup> )	GJ	Elect. (kWh)	Wood (ton)	LPG (gal)	LPG (L)	Oil (gal)	Oil (L)	kBTU / ft <sup>3</sup>
<b>x999</b>	<b>2</b>	<b>19471</b>	<b>59</b>	<b>62</b>	<b>2314</b>	<b>3,2</b>	<b>142</b>	<b>540</b>			<b>3,0</b>
x998	5	24346	129	136	510	6	585	2223			5,3
1039	4	13158	79	83	6019	4	120	456			6,0
5167	2	17587	107	113	1950	6	308	1170			6,1
1341	2	20258	128	135	1135	8	300	1140			6,3
<b>x986</b>	<b>2</b>	<b>23700</b>	<b>161</b>	<b>170</b>	<b>2946</b>		<b>95</b>	<b>361</b>	<b>1031</b>	<b>3918</b>	<b>6,8</b>
5357	2	11040	76	80	478	5,5	90	342			6,9
1203	5	24492	171	180	4048	10	395	1501			7,0
5261	4	20758	145	153	1894	8,5	395	1501			7,0
<b>x987</b>	<b>2</b>	<b>25564</b>	<b>185</b>	<b>195</b>	<b>4000</b>		<b>300</b>	<b>1140</b>	<b>1035</b>	<b>3933</b>	<b>7,2</b>
x988	5	25408	195	206	9340	2	750	2850	500	1900	7,7
x989	2	11932	92	97	1059	5	300	1140			7,7
1141	4	11165	87	92	237	6			100	380	7,8
1013	2	19158	155	164	6100	2	1200	4560			8,1
5677	1	16928	138	146	493	10	95	361	40	152	8,2
x985	2	10404	88	93	350	4	180	684	150	570	8,5
1479	2	4417	43	45	99	3,5					9,7
1291	4	12840	125	132	530	3	500	1900	300	1140	9,7
x993	4	11774	115	121	1680	8	142	540			9,8
x984	2	9640	98	103	730	7	121	460			10,2
x983	2	7500	85	90	570	5	250	950			11,3
1251	4	11604	133	140	496	5,5	500	1900	145	551	11,5
5190	2	7240	85	90	6709	1	390	1482	100	380	11,7
1449	2	6435	76	80	840		120	456	450	1710	11,8
x990	3	6912	83	88	1740	3,5	378	1436			12,0
5033	3	7122	90	95	2935		190	722	450	1710	12,6
x995	3	12545	170	179	5540	6	525	1995	220	836	13,6
1487	2	5550	78	82	336	5	142	540	26	99	14,1
1159	2	8580	132	139	688	10	102	388			15,4
1419	1	7632	161	170	763		142	540	1050	3990	21,1

The owners of the three houses were committed to the design process and their house were also amongst the top tier of the most energy efficient off-grid homes in the survey sample: house x999 (henceforth referred to as “Carcross”) was rated the most energy efficient at 3 kBTU/ft<sup>3</sup>; house x986 (henceforth referred to as “Long Lake”) was rated 6<sup>th</sup> overall at 6.8 kBTU/ft<sup>3</sup>; and house x987 (henceforth referred to as “Takhini”) was the least efficient of the three at 7.2 kBTU/ft<sup>3</sup> but rated 10<sup>th</sup> overall.

CANMET Energy Technology Centre-Varenes organized the three-day long forum in collaboration with The Yukon Energy Solutions Centre (YESC). Over 32 participants (federal departments<sup>5</sup>, Canadian and American research institutions, local energy service providers and local energy industry) with expertise in computer simulations (HOT2000<sup>®</sup>, RETScreen<sup>®</sup> <sup>6</sup>) renewable energy technologies, energy efficiency, architecture, home building, construction as well as manufacturing and systems installations were divided evenly into three teams (Fig. 1). Each team was assigned a different case study with the goal of developing design changes or adjustments to the

energy supply system and building envelope that would increase the renewable energy portion of the home's total energy supply by 30% -50%<sup>7</sup>. The teams were asked to consider the homeowners' preferences and likely possibility to implement retrofits based on the recommendations included in the energy audits. The following design principles guided the teams' work:

- (i) energy efficiency;
- (ii) cost effectiveness (affordability);
- (iii) maximization and optimization of RET use (consider quality, stability, variety, other);
- (iv) integrated system design (matching supply with demand);
- (v) long-term time horizon (reliability and flexibility to adapt to residents' changing needs);
- (vi) simplicity of design and technology (easy to understand, implement and transfer);
- (vii) proven technology (robust under extreme Yukon climate conditions and easily repairable); and,
- (viii) maintain or improve the liveability of the home in terms of indoor air quality and comfort level.



Figure 1. Team discussion at the Yukon off-grid charrette.

### Guidelines of the Charrette

Two of the design teams looked at low-cost options for upgrading the energy performance of their houses (x987 and x999) in order to provide some current options that are feasible for the greatest number of people. The third team (x986) was, in addition, tasked with coming up with a more ideal energy producing and consuming house.

The two low-cost option teams operated under the following guidelines:

- (i) work with the existing footprint (minor addition such as a northern entrance/mudroom allowed).
- (ii) use the existing orientation and footprint of the house on the lot.
- (iii) the interior layout of the house may be rearranged.
- (iv) minor landscaping such as the planting or removal of trees is allowed. Major terrain features (hill, ravine) cannot be changed.
- (v) the existing lifestyle of the occupants is a given.
- (vi) no net cost incurred by the homeowner after 5 years. Savings from using less fossil fuels and firewood should offset the cost of the proposed changes amortized over a 5-year period.

The third team (house x986) had an additional goal as they were charged with coming up with an optimal renewable energy scenario assuming that future off-grid houses would be newly built with energy efficiency and energy independence in mind. Their guidelines were to:

- (i) work with the existing interior footage of the house  $\pm$  a maximum of 10% of the heated floor space.
- (ii) consider house reorientation;
- (iii) rearrange the interior layout of the house;
- (iv) allow minor landscaping such as the planting or removal of trees. Major terrain features (hill, ravine) could be changed.
- (v) consider the existing lifestyle of the occupants as a given;
- (vi) incur no net cost by the homeowner after 10 years. Savings from using less fossil fuels and firewood should offset the cost of the proposed changes amortized over a 10-year period. The return on investment should be greater than the lowest cost option; and
- (vii) propose only RETs that are currently on the market and suitable for home application.

## 4 ENERGY CONSUMPTION PROFILES OF THE OFF-GRID HOUSES

### 4.1 Carcross House

#### *Baseline Energy Analysis*

The Carcross house<sup>8</sup> (Fig. 2) was designed and constructed by its owners to have a minimum impact on the environment and their pocketbook. The result is a very energy efficient home that is completely powered by renewable energy for eight months of the year. The base energy scenario for the Carcross house is presented in Table 2. In this energy mix, renewable energy sources (wood and PV) supply 71.11% of the total annual fuel consumption. The house cost approximately \$100,000 in material related expenses to build – the homeowners undertook the construction and associated labour, and \$13,000 for the renewable energy system. The house sits on a flat lot, surrounded by aspen forest.

The design is a two-story plus loft timber frame house, rectangular in shape to maximize southerly exposure for passive solar heating. It is an open concept floor plan, which simplifies heating and cooling systems and would be easy to modify to accommodate future lifestyle changes of the homeowners. The house is constructed with locally grown and milled timber. The primary heat source is locally harvested wood burned in masonry *Tulikivi* Soapstone mass wood heater (Fig.3). The backup heat source is a *Rinnai*, direct vent propane space heater. The house is equipped with a Bosch instantaneous propane hot water heater. Electricity is primarily generated by an eight-panel 685 Watt PV array. It provides 100% of the load from February through September. A gasoline genset provides back up power and is only required from October through January. Insulation is blown cellulose to R38 in the walls, and R45 in the ceiling. The windows are all hard coat low-e; 1/2” argon filled and are a combination of triple and double-glazed. There are a minimum number of windows on the north side of the house.



Figure 2: Two -storey post and beam house (x999).

**Table 2: Annual Energy Supply by Fuel Source**

Base Performance (Carcross)					
Source	Units	Total	MJ	kWh	%
Wood	kg	3200	48000	13333,3	68,47
LPG (Propane)	litres	540	13770	3825	19,64
Electricity (PV)	kW	0,685	1849,5	514	2,64
Generator (gas)	kW	3,5	6480	1800	9,24
<b>Total</b>			<b>70100</b>	<b>19472,3</b>	<b>100,00</b>

This house was the most efficient of the three modelled in design optimization process and was ranked the highest of the 30 houses surveyed in terms of energy consumed per volume of spa (3.0 kBTU/ft<sup>3</sup>). It uses exclusively the *Tulikivi* mass wood heater for all space heating requirements.



Figure 3: Masonry *Tulikivi* Soapstone mass wood heater.

#### *Renewable Energy Design Optimization Process*

The Carcross House is very energy efficient with a high use of renewable energy. The design team assigned to this house proposed several improvements to increase efficiency and comfort, but very few of these have a payback of less than five years<sup>9</sup>. These measures are factored into the optimized energy profile of the house presented in Table 3.

**Table 3: Annual Energy Supply by Fuel Source**

Recommended performance (preferred by owner)						Annual Energy Supply				
Source	Units	Total	MJ	kWh	%		Base	Recom.	Improvement	
Wood (1)	kg	3040	45600	12000	70,71	Total	MJ	70100	64487	8% reduction
LPG (Propane) (2)	litres	405	10327,5	2868,8	16,01	RE/Total	%	71,11	76,45	5,34% increase
Electricity (PV) (3)	kW	1,37	3699	1027,5	5,74					
Generator (4)	kW		4860	1350	7,54					
<b>Total</b>			<b>64486,5</b>	<b>17246</b>	<b>100,00</b>					

- (1) Keep efficient *Tulikivi* masonry mass heater, insulation measures reduce amount of wood used by 5%.
- (2) Equipment switching EE measures reduce LPG by 25% (e.g. switch propane fridge to electric for better utilisation factor of solar electric).
- (3) Double PV capacity to offset summer use of propane for refrigeration.
- (4) Switch 3.5 kW gas Honda that is underutilized to propane only generator. 254L propane delivers same MJ as base scenario for generator. Reduce use by 25% because of EE measures (e.g. double battery bank for optimal storage).

By employing only those suggested measures that have a payback of five years or less - primarily related to better insulating and separating the ground floor living space from nonliving spaces such as the garage, switching to a better sized generator and greater utilization of electrical appliances during the summer months to take advantage of excess solar capacity – the annual renewable energy supply can be reduced by 8% and the renewable content can be increased by 5.34% to 76,45% in the owner-preferred scenario with an additional cost of about \$6,000. The increase is primarily due to doubling capacity of the PV system to offset summer loads associated with propane use for refrigeration. Suggested improvements in insulation reduced total annual energy consumption by 8% from the base scenario. The decision to implement upgrades on the house will be based a combination of affordability and owner preference.

## 4.2 Takhini House

### Baseline Energy Analysis

The Takhini house<sup>10</sup> (Fig. 4) is representative of many off-grid houses in the Yukon. It is a 10 to 15 year old log home that has been constructed over an extended period of time as permitted by resources. The current owner is interested in updating its renewable energy systems and making the home more energy efficient. The baseline scenario for the Takhini house is presented in Table 4. The base scenario includes 4.67% renewable energy sources from PV and wind electricity generation. While the log walls are a primary source of heat loss from the building envelope they are aesthetically very appealing and the owner is not interested in building modifications that would compromise their aesthetic value



Figure 4: Single storey log house (x987).

The house is a single story log construction with a 2.4 m high basement (PTW foundation wall). Logs are naturally leaky and have an estimated insulation value of R11.5. The ceiling is cathedral type insulated to R38 with 12”sprayed on insulation. Large, double glazed, south facing windows result in substantial solar gain. This is an issue for occupant comfort from March through September. The windows are also a major source of heat loss during the winter months but are a major component of the house’s aesthetic attraction.

The houses heating needs are supplied by oil fired, mid-efficiency boiler (Fig.5), which account for about 76% of total annual energy consumption of the base energy profile. A combination of a sixteen-panel 1.2 kW PV array, a 1 kW wind turbine, and a 7kW diesel generator generate the electricity needs of the house. The

generator is used throughout the year for three hours/day from November through March and two hours/day from April through October. Hot water supplied by a conventional propane fired tank located in the unheated water tank room outside the building is used for heating water. There is a significant wood on the house lot that the owner would like to utilize for heating the home. His request to the design team is to propose options that would make good use of this renewable fuel stock.

**Table 4: Annual Energy Supply by Fuel Source.**

<b>Base Performance (Takhini)</b>					
Source	Units	Total	MJ	kWh	%
Wood	kg	0	0	0	0,00
LPG (Propane)	litres	1140	29070	8075	15,71
Fuel Oil	litres	3933	141588	39330	76,51
<b>Electricity (PV)</b>	<b>kW</b>	<b>1,2</b>	<b>3240</b>	<b>900</b>	<b>1,75</b>
<b>Electricity (wind)</b>	<b>kW</b>	<b>1</b>	<b>5400</b>	<b>1500</b>	<b>2,92</b>
Generator (diesel)	kW	7	5760	1600	3,11
<b>Total</b>		<b>185058</b>	<b>51405</b>	<b>100,00</b>	



Figure 5: Forced air oil furnace.

### **Renewable Energy Design Optimization Process**

The design team assigned to the Takhini house came up with several measures to improve its energy efficiency and to be more reliant on renewable energy<sup>11</sup>. It was the express desire of the homeowner to switch his reliance from fuel oil for space heating to using the significant resource of wood from his lot. This request is factored into the optimized energy profile of the house presented in Table 5.

**Table 5: Annual Energy Supply by Fuel Source.**

<b>Recommended Performance (preferred by owner)</b>						<b>Annual Energy Supply</b>			
Source	Units	Total	MJ	kWh	%	Total	Base	Recom.	Improvement
<b>Wood (1)</b>	<b>kg</b>	<b>7200</b>	<b>108000</b>	<b>30000</b>	<b>73,80</b>	MJ	185058	133405,5	<b>28% reduction</b>
LPG (Propane) (2)	litres	988	25194	6998	17,22	RE/Total	4,67	80,57	<b>76% increase</b>
Fuel Oil (3)	litres	0	0	0	0,00				
<b>Electricity (PV) (4)</b>	<b>kW</b>	<b>1,2</b>	<b>3240</b>	<b>900</b>	<b>2,21</b>				
<b>Electricity (wind) (5)</b>	<b>kW</b>	<b>1</b>	<b>6660</b>	<b>1850</b>	<b>4,55</b>				
Generator (diesel) (6)	kW	7	3240	900	2,21				
<b>Total</b>		<b>146334</b>	<b>40648</b>	<b>100,00</b>					

- (1) Install masonry heater to replace 3000 litres oil. Equivalent to 7200 kg wood for space heating. Owner wants it.
- (2) Inline DHW saves 152 Lit LPG.
- (3) Owner preferred complete independence from fuel oil. Address air leakage; insulate exposed slab; add glazing.
- (4) Install PV tracker and relocate panels that will result in 25% more efficiency on annual basis. Add battery bank.
- (5) Increase elevation of wind turbine 10 metres above tree top; increase efficiency by 25%.
- (6) Reduction in diesel generated electricity for back-up power.

The simplest way to improve energy efficiency of the house is by increasing the air tightness of the building envelope and adding insulation. Minor upgrades include addressing obvious air leakage through installing weather stripping (Fig. 6), caulking logs and insulating the exposed basement slab. Major upgrades include chinking the logs and insulating the interior of the outside walls.

To reduce heat loss from the large southern exposure windows the installation of a third layer of glazing was recommended. Optimizing solar gain involved several options: install shutters between the existing and proposed

third layer of glazing; install a combined sun shading device and natural light shelf; and, explore the potential of growing seasonal shading plants. Two different heating system options were proposed: replace the existing oil fired furnace and conventional propane hot water tank with a combo system that would consist of a direct-vented oil fired hot water tank and a fan coil unit that would integrate into the existing ducting; and to install a masonry fireplace, which would include a foundation and chimney. Proposed changes to the electrical supply and storage system include increasing the height of the wind turbine, doubling the battery storage supply and installing a PV tracking system.



Figure 6: Air leakage of logs, frost build up on interior.

These suggested improvements with an estimated price tag of \$20,000 that have a payback period of about 5 years or less, if implemented, could result in a 28% reduction of annual fuel consumption - attributed mainly to lower fuel consumption for space heating. The switch to renewable wood fuel increased the renewable energy content of the total annual energy consumption from 4.57% in baseline energy profile to 80.57% in the owner-preferred energy profile. Renewable energy for electricity generation remained essentially unchanged from the base energy profile.

### 4.3 Long Lake House

As the newest building in the off-grid survey, the Long Lake house<sup>12</sup> (Fig. 7) was in the final stages of completion with systems installation still in progress during the site-visit. This house is a bungalow with detached double garage, which has all the appearance and convenience of an on-grid residence. The house is located a few kilometres downstream (north) of Whitehorse overlooking the Yukon River (Fig. 8). The house sits on a small ridge surrounded by open mixed boreal forest.

The owner's interest in and commitment to renewable energy are prompted by the practical reality of living off-grid, as well as his philosophical conviction "that we are all called to be careful stewards of creation". The base scenario of the annual energy supply is presented in Table 6. The base renewable energy from wind for electricity generation represented only 2.71% of the baseline energy profile, while fuel for space heating represented 87.2% of the baseline energy profile.



Figure 7: Single storey wood frame house (x986).

The house is intended to serve as a quiet retreat for long-term guests, without the inconvenience of living off-grid. As well, the owner is frequently away from home for extended periods and expects the house to remain warm and comfortable during his absence. These lifestyle factors played a significant role in influencing the design of the home. In an effort to ensure that household systems function smoothly at all times, all systems have at least one back-up energy source. A Solarwall has been installed on the south-facing wall, but directly below a deck that shades it from direct insolation, thereby nullifying its contribution to space heating loads.

**Table 6: Annual Energy Supply by Fuel Source**

Base Performance (Long Lake)					
Source	Units	Total	MJ	kWh	%
Wood	kg	0	0	0	0,00
LPG (Propane)	litres	361	9205,5	2557,08	5,69
Fuel Oil	litres	3918	141048	39180	87,26
Electricity (PV)	kW	0	0	0	0,00
<b>Electricity (wind)</b>	<b>kW</b>	<b>2,5</b>	<b>4375</b>	<b>1750</b>	<b>2,71</b>
Generator (diesel)	kW	8	7020	1950	4,34
<b>Total</b>		<b>161649</b>	<b>45437,1</b>	<b>100,00</b>	



Figure 8: It costs approximately \$250,000 to get grid power to the Long Lake house (homeowners driveway on left).

The house design incorporated a living space separate from main area to offer privacy for guests. There were also redundancies in heating systems to ensure the house does not freeze up during winter. The frame walls are insulated to R-32. All windows are double-pane, double-hung. These windows increase heat loss over more energy efficient windows by 35-40%, resulting in a larger boiler, and in turn a larger garage. Boiler systems include a 500-gallon thermal storage tank (Fig. 9). Other house features include: crawlspace walls R-20 PTW on un-insulated slab floor; ceiling insulated with blown cellulose to R-50; solo-40 wood-fired boiler with a mid-efficiency oil-fired boiler (53,000 BTU/hr) for back up; and, hot water provided by tank-less coil from boiler.

### Renewable Energy Design Optimization Process

For this dwelling, the design team was asked to develop two scenarios. The first scenario was to identify measures that could be undertaken to improve renewable energy utilization with a ten-year payback period against the cost of implementing the measure, based on the existing footprint of the house. The second scenario was a fresh-start version, which involved re-designing structures and systems on the property to take maximum advantage of renewable and energy efficiency opportunities.

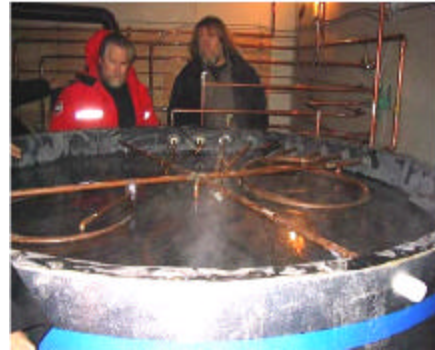


Figure 9: 500-gallon heat sink tank for space and DHW.

### 10-year Payback Scenario

The Long Lake example illustrates the importance of calculating realistic energy demand and supply needs prior to designing and sizing energy systems. The high cost of doubling up supply systems combined with significant inefficient features (e.g. windows) resulting in disappointing performance of renewable energy supply. With better planning, renewable systems could have successfully met the energy needs of the home at a lower and acceptable capital cost. There are several cost-effective opportunities to improve energy efficiency and to reduce the electrical load, to lower space heating requirements and maximize the use of the existing wind energy supply<sup>13</sup>. These measures are factored into the optimized energy profile of the house in Table 7.

Table 7: Annual Energy Supply by Fuel Source

Recommended 10-year Payback						Annual Energy Supply				
Source	Units	Total	MJ	kWh	%		Base	Recom.	Improvement	
Wood (1)	kg	0	0	0	0,00	Total	MJ	161649	143377	11,3% reduction
LPG (Propane) (2)	litres	361	9205,5	2557	6,42	RE/Total	%	2,71	20,60	18% increase
Fuel Oil (3)	litres	2887	103932	28870	72,49					
<b>Solar DHW</b>			<b>16487</b>	<b>4590</b>	<b>11,50</b>					
<b>Electricity (PV) (4)</b>	<b>kW</b>	<b>2,5</b>	<b>6750</b>	<b>1875</b>	<b>4,71</b>					
<b>Electricity (wind) (5)</b>	<b>kW</b>	<b>2,5</b>	<b>6300</b>	<b>1750</b>	<b>4,39</b>					
Generator (diesel) (6)	kW	6	702	195	0,49					
<b>Total</b>			<b>143377</b>	<b>39837</b>	<b>100,00</b>					

- (1) No recommendation, assume same value as Base.
- (2) No recommendations, assume same value as Base.
- (3) Install solar hot water from April - Oct; assume displaces 50% (or 413 Litres) fuel oil for DHW. Addressing building envelope (windows, crawl space) retrofits and insulation reduce space heating by 20% (assume from fuel oil for space heating which is recorded at 3092 litres; displace 618 litres).
- (4) Recommendation to supply estimated 2000 kWh/yr electrical load with PV. Assume 2.5 kW systems.
- (5) 2.5 kW "Proven" wind turbine providing 1750 kWh/yr as recorded.
- (6) Replace 8 kW Lester Pister genset with 6 kW. Use generator for back up only. Assume 10% fuel use of Base scenario.

These measures include: re-installing the south facing Solarwall with an appropriate airspace behind it and replacing mechanical with passive ventilation; adding a winter storm to existing windows and doors (lexan with magnetite);

blower door test and subsequent air-sealing; insulating inside perimeter footings of crawlspace and installing occupancy sensors on all lighting. Additional annual savings could be realized through installing a thermal solar collection system for domestic hot water and installing a grey-water heat recovery system. In this scenario, implementing the recommendations at an approximate cost of \$22,000 that have a payback period of 10 years or less could result in about 11% reduction of total annual energy consumption, due mainly to reductions in fossil fuel use (diesel for the power generator and fuel oil for home heating offset by a 2.5 kW PV and solar hot water collectors), and an increase in the renewable energy content of the total energy supply from 2.71% to 20.60 percent.

### **RE Optimal Fresh Start Scenario**

The Long Lake team, with the blessing of the homeowner, decided to redesign the house with slightly different design criteria. Instead of creating a modern house which relies solely on renewable energy supply systems, the team developed a more energy-driven house, taking advantage of its location to maximize energy efficiency options and providing an “energy sipping” living space relying on the renewable energy available at the site (Fig. 10). In addition to location considerations these concepts were guided by the design principles established for the *Charrette*. These measures are factored into the “ideal” energy profile of the house presented in Table 8. In this optimal fresh start scenario, taking into consideration the suggested energy efficiency and site planning improvements below, the total annual energy consumption of the house is reduced by 25% and where the renewable energy content is estimated at slightly below 95% of the annual total at the same approximate cost of \$22,000. The remaining 5% of the energy is attributed to back-up diesel power generation and propane fired hot water heaters.



Figure 10: Re-orienting the Long Lake House to maximize solar gain.

**Table 8: Annual Energy Supply by Fuel Source**

<b>Optimal RE Scenario</b>					
Source	Units	Total	MJ	kWh	%
Wood (1)	kg	5938	89064	24740	73,55
LPG (Propane) (2)	litres	236	6018	1672	4,97
Fuel Oil (3)	litres	0	0	0	0,00
Solar DHW			16487	4590	13,62
Electricity (PV)	kW	1	2700	750	2,23
Electricity (wind)	kW	1	6120	1500	5,05
Generator (diesel)	kW	6	702	195	0,58
<b>Total</b>			<b>121091</b>	<b>33447</b>	<b>100,00</b>

<b>Annual Energy Supply</b>				
		Base	Optimal	Improvement
Total	MJ	161649	121091	25,1 % reduction
RE/Total	%	2,71	94,45	91,74% increase

Masonry heater recommended for "fresh start" scenario. Displaces fuel oil for space heating.

Hot water heating loads cut by 50% (about 1600MJ). Propane for backup at 25% of base load (944 L)

2474 litres of fuel oil for space heating replaced with 5938 kg wood.

The team focused on reducing loads and employing passive means to reduce demand. Initially, the form was compacted by adjoining the garage, lowering the north wall of the main floor below grade into the hill to provide earth tempering and relocating guest room and storage into a loft accessible from the upper grade on the north. The south side penetrates the hill with extensive glazing. The lofted space has operable upper glazing for summer venting and year round day-lighting. All walls and roof are well insulated above and below grade. Windows are state of the art glazing technology. Air sealing is exceptionally tight. Other design considerations include:

- **Heating, Ventilation and Air Conditioning:** heating is supplied by passive solar and a central masonry heater, also used for cooking/baking and as a thermo-siphon for domestic hot water; a backup propane hot water heater provides ceiling convection heating; rooms have low and high grilles to provide convective air exchange; ventilation is mainly passive; supply air comes in through earth tubes from the south side Solarwall; exhaust air

is from compost toilet vaults and kitchen to roof peak with adjustable dampers; and no active cooling is provided, relying instead on earth tempering, solar control and night venting. This strategy eliminates parasitic electrical loads and firing schedule.

- Domestic Water Heating: hot water heating loads are cut in half using ambient air preheat, grey water heat recovery, and water efficient appliances; solar thermal absorbers under greenhouse glazing, thermo-siphon to a tank in the loft providing the majority of hot water loads at short payback costs; wood heating provides the remainder when solar is insufficient for space or water heating; and the propane heater is employed for convenience.
- Electrical Loads and Supply: in addition to eliminating mechanical loads, appliance and lighting loads are minimized through equipment selection and passive means; estimated load 2000 KWH/year; a 1kw PV tracking array and a 1KW wind turbine provide electrical supply with one-week storage capacity.

## CONCLUSION

The three-day integrated design *charrette* aimed at increasing the renewable energy component of the total annual energy consumed by three selected off-grid residences in the Yukon, by targeting improvements in energy efficiency of these homes and optimising for renewable energy generations systems. The EnerGuide audits were adapted to integrate off-grid energy use such as wood heating into the global energy analysis, and were performed for the very first time in this study on off-grid houses.

The three houses of this study were amongst the top ten most energy efficient homes in the energy survey of off-grid residences undertaken prior to the *charrette*. At the end of deliberations on design changes or adjustments to the energy supply systems and building envelope, the design teams came up with several recommendations with a payback period of five years or less that, if implemented by the homeowners, could increase the renewable energy portion of the total energy supply from as low as 5% for the Carcross house (the most energy efficient home) to as high as 76% for the Takhini house (the least energy efficient of the three in the *charrette*). The recommendations, costing \$6,000 for the Carcross and about \$20,000 for the Takhini, could also result in noticeable reductions in total annual fuel consumption from the base energy profiles of these homes by 8% and 28% respectively. Recommendations to the Long Lake house with a payback period of 10 years or less costing about \$22,000 may result in an 18% increase in the RE portion of the total energy, and an 11% reduction in fuel use. Under the optimal RE scenario for the Long Lake house, suggested improvements and design recommendations resulted in an off-grid residence supplied totally by renewable energy sources with only 5% by fossil-fuel for back-up and auxiliary power.

For the houses modelled in this *charrette*, homeowners were presented with a variety of means for improving the energy efficiency and the renewable energy components of their homes. Cost-effective measures may not be the only reason whether these owners implement partially or fully these recommendations, their motivational values (e.g. affordability, security, energy independence) could be the deciding factors.

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## ENDNOTES

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<sup>1</sup> Program of Energy Research and Development, "Application of Renewable Energy Technologies and Integrated Systems in Off-Grid/Remote Communities", Program at the Objective Level (POL) 3.2.2, Office of Energy Research and Development, NRCan. POL Leader Dr. Lisa Dignard-Bailey ([ldignard@nrcan.gc.ca](mailto:ldignard@nrcan.gc.ca)).

<sup>2</sup> Software can be downloaded from [http://www.buildingsgroup.nrcan.gc.ca/software/hot2000\\_e.html](http://www.buildingsgroup.nrcan.gc.ca/software/hot2000_e.html).

<sup>3</sup> A design charrette is an intensive, time-limited, collaborative workshop that provides "a forum for diverse groups of participants to explore, understand, create and evaluate possible and preferred options" (Socio-economic series 103, CMHC). By allowing for face-to-face discussion and design among an expanded range of stakeholders and experts, many of the barriers to optimizing design solutions are overcome.

<sup>4</sup> Draft Report to NRCan (#2004-116 (TR)), "Renewable Energy and Off-Grid Housing in the North" by Shawna Henderson, Abri Sustainable Design & Consulting, April 5, 2004.

<sup>5</sup> Natural Resources Canada (NRCan) Photovoltaic and Building experts and energy modellers from CANMET Energy Technology Centres in Varennes and Ottawa; housing experts from Canadian Mortgage and Housing Corporation (CMHC).

<sup>6</sup> RETScreen software can be downloaded from <http://www.retscreen.net/>

<sup>7</sup> The long-term target of the 4-year R&D project "entitled "An Integrated Approach to Increasing the Use of Renewable Energy in Off-grid Residences in the North" is an increased ratio of renewable energy to total energy use in off-grid residences by 10%.

<sup>8</sup> Information compiled by YESC. Details on the energy use in the house are provided in the report noted in endnote #4.

<sup>9</sup> Results of the design process for the Carcross House are posted at the web site: <http://www.nrgsc.yk.ca/offGrid/index.php>.

<sup>10</sup> Information compiled by YESC. Details on the energy use in the house are provided in the report noted in endnote #4.

<sup>11</sup> Complete details for the Takhini House are posted at the web site: <http://www.nrgsc.yk.ca/offGrid/index.php>.

<sup>12</sup> Information compiled by YESC. Details on the energy use in the house are provided in the report noted in endnote #4.

<sup>13</sup> Complete details for the Long Lake House are posted at the web site: <http://www.nrgsc.yk.ca/offGrid/index.php>.