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A Study of Wind Energy Use for Space Heating in Prince Edward Island[1]

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Abstract

Prince Edward Island is Canada's smallest province, with a predominately rural economy based upon agriculture. It also happens to have an excellent wind resource, with a capacity factor in excess of 50 percent recorded in some locations. Since the province is almost entirely dependent upon imported energy (from oil for transportation and home heating to electricity for most other applications), the provincial government has proposed that 200 MW of wind capacity be installed by 2010. This paper considers the possibility of meeting some of the Island's residential space heating requirements with energy from the 200 MW of capacity using one of four methods: electric baseboard heating, off-peak ETS (Electric Thermal Storage), anytime ETS, and generator-supplied ETS. The cost of electricity and the potential greenhouse gas reductions are included in this paper.

1 Introduction

World energy prices are increasing and there is no indication that this rise will stop. Jurisdictions without major hydrocarbon resources (notably coal, oil, and natural gas), hydroelectric facilities, or other energy sources, are at the mercy of rapidly changing energy prices.

Prince Edward Island is an example of a jurisdiction without a significant source of any of the "traditional" fuel sources. As such, all electricity has been locally generated from imported fossil fuels or supplied from New Brunswick via an undersea cable. The cost of this electricity has resulted in most residential space heating and domestic hot water demand being met by imported fuel oil.

Throughout most of the 1990s, the price of crude oil remained relatively stable. This changed dramatically in late 1999 when prices began to increase. Today's high price of crude oil has pushed the cost of home heating fuel to near record levels, bringing the price of home heating fuel more in line with the cost of electricity. The effects of rising oil prices will be felt in other ways:

Social. The rising cost of energy is causing financial hardship for many families living on Prince Edward Island.

Environmental. As fuel oil prices increase, switching heating sources, from fuel oil to electricity, becomes more economically attractive. However, since most oil furnaces are more efficient than thermal power stations, switching from fuel oil to electricity results in a significant increase in greenhouse gas emissions.

Economic. Rising energy costs means that an increasing percentage of a family budget must be spent on energy, meaning that less is available for other activities.

These three issues alone suggest that those living on Prince Edward Island must find alternatives to existing methods of space and water heating. One approach could be the use of wind generated electricity, given its declining cost and the proposed plan to install 200MW of wind turbine capacity on Prince Edward Island by 2010.

This study examines the opportunities for using wind generated electricity for space and hot water heating on Prince Edward Island. Three residential electric heating system configurations are considered and simulated using hourly wind and temperature data collected on Prince Edward Island between January 1999 and December 2005.

2 Residential heating demand in Prince edward island

Residential energy demand encompasses five distinct areas: space heating, domestic hot water, appliances, lighting, and space cooling. Of these five, space heating and domestic hot water consume the most amount of energy, averaging between 75 and 80 percent of residential energy requirements (NRCan, 2004).

Prince Edward Island's housing stock consists mainly of single detached houses, followed by apartment units, semi-detached and row houses, and mobile homes (see Figure 1).

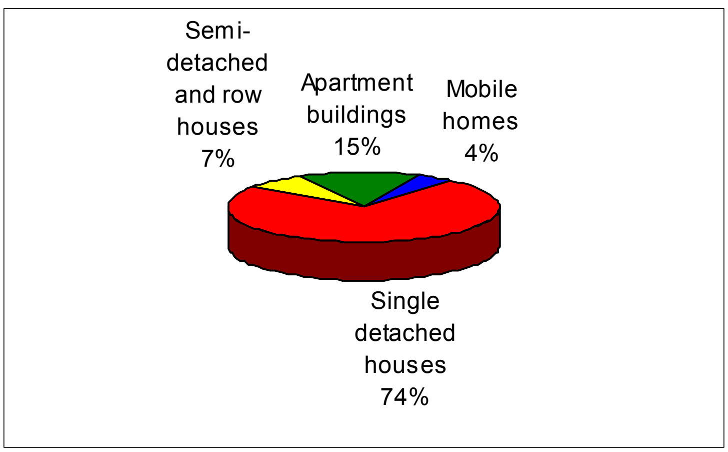

Figure 1: Residential housing stock on Prince Edward Island (PEI, 2004)

The remainder of this section explains how the space heating and domestic hot water requirements for an average residence on Prince Edward Island were found.

2.1 Space heating

Prince Edward Island, unlike most other Canadian provinces, relies almost exclusively on light fuel oil (typically #2 fuel oil) for residential space heating (see Figure 2). Given the rising cost of fuel oil and the high price of electricity, many residential consumers rely on wood for space heating, which is also unlike most other Canadian provinces.

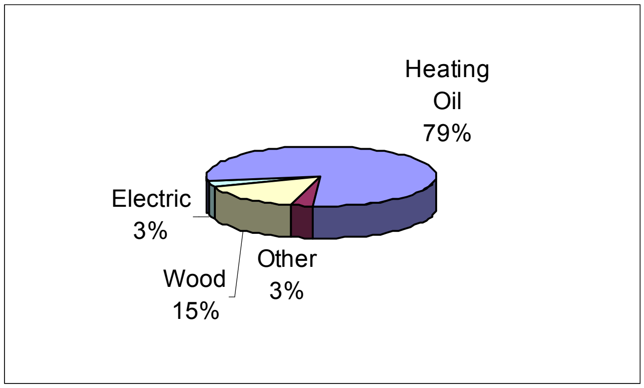

Figure 2: Residential space heating supply on Prince Edward Island for 2003 (NRCan, 2005)

The average annual residential space heating demand for the four different housing types are shown in Figure 3. As nearly 74 percent of houses on Prince Edward Island are single detached, the residential space heating demand for an average house is taken in this paper to be equal to the demand for a single detached house, or 75 gigajoules (GJ).

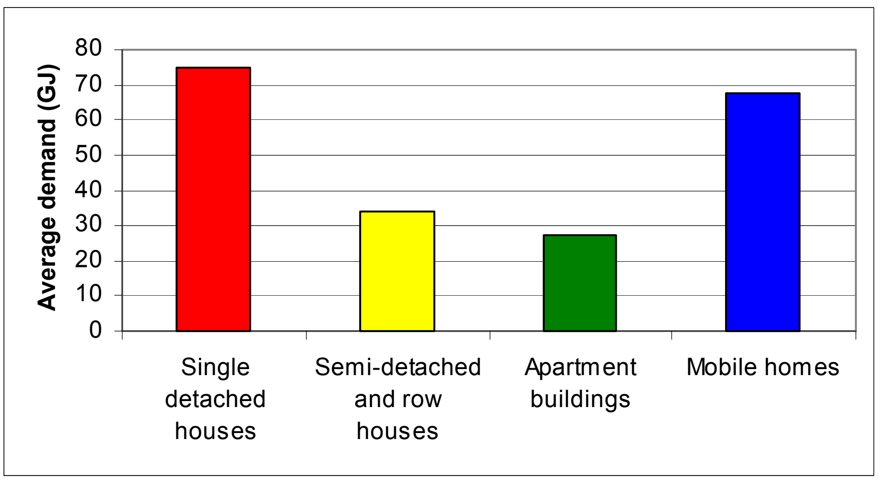

Figure 3: Annual average space heating demand for houses on Prince Edward Island

In order to determine the opportunities for wind generated electricity for space and hot water heating on Prince Edward Island, it is necessary to determine the space heating requirements for every hour of the year. This is done by calculating the Heating Degree Hour (similar to the Heating Degree Day, except done on an hourly basis) using temperature data from Environment Canada's online climate database for the town of Summerside, Prince Edward Island.

The Heating Degree Hours were calculated for seven years (1 January 1999 to 31 December 2005).

2.2 Domestic Hot Water

On Prince Edward Island, domestic hot water is supplied almost exclusively from two sources:

heating oil and electricity, as shown in Figure 4.

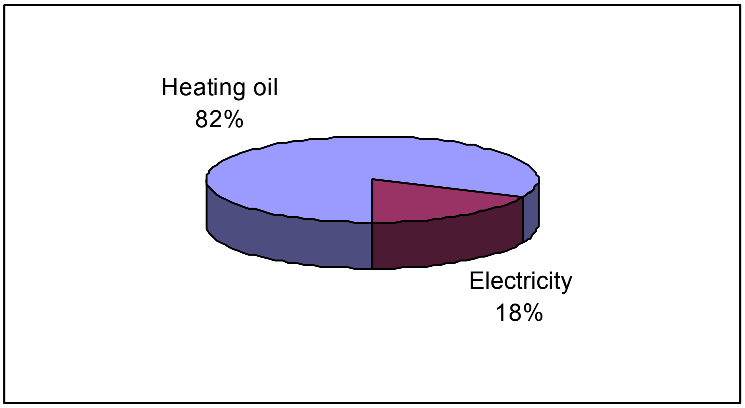

Figure 4: Domestic hot water supply sources on Prince Edward Island (NRCan, 2005)

Annual domestic hot water demand by housing stock is shown in Figure 5. The annual average demand for a house containing 2.6 persons is about 15.32 GJ. The hourly hot water usage pattern was found using the hot water draw profile developed by Perlman and Mills (Perlman and Mills, 1985).

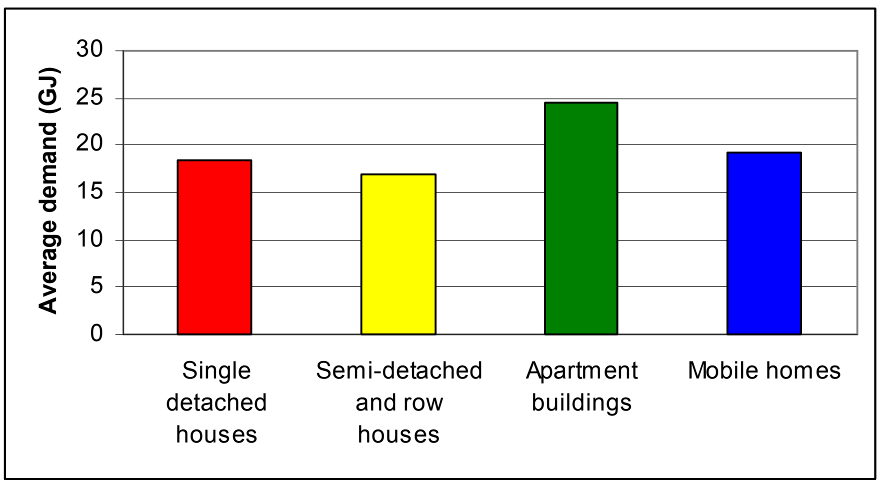

Figure 5: Average annual domestic hot water for houses on Prince Edward Island

2.3 Average residential heating load

The total heat required per hour was created by adding the hourly space heating requirement to the hourly domestic hot water requirement. The maximum hourly thermal demand calculated from the seven years of temperature data is 10 kW. The average annual heating requirement for both space heating and domestic hot water is 90.32 GJ/year.

3 Meeting the heating load from conventional sources

As shown above, the majority of the residential space heating and domestic hot water demand on Prince Edward Island is met from fuel oil and electricity. Fuel oil is burned in furnaces that either heat water that is circulated through radiators (hydronic system) or heat air that is blown through registers (forced hot air). Homes that are heated electrically typically use baseboards for heating; because of their simplicity, electric baseboard heaters are inexpensive to purchase and install.

Between January 1999 and December 2005, the typical single detached house on Prince Edward Island required an annual average of 25,089 kWh for space heating and domestic hot water. The annual cost to a consumer depends upon the type of heating system employed in the house and the cost of energy used in the heating system.

In 2005, the cost of space heating and domestic hot water for the typical house would have been $2,028 for oil heating and $2,647 for electric heating.

4 Electric Thermal Storage

Electric Thermal Storage (or ETS) is an alternative method of heating with electricity. In an ETS system, electricity is used to heat ceramic bricks that subsequently release the stored heat to the environment for space heating (typically a limited number of rooms or an entire house). With the addition of a heat exchanger, the ETS can also provide heat for domestic hot water.

Broadly speaking, there are two types of ETS system: room and central. A room ETS system is sized to heat a limited number of rooms in a house, whereas a central ETS system stores sufficient thermal energy to heat a house. There are two types of central-ETS: forced hot air and hydronic. Most ETS systems can run in a stand-alone fashion at maximum output for at least 16 hours between recharges.

An ETS system operates in one of four states:

Off. When the ETS system has heated the environment to the required temperature, it shuts off, saving its thermal energy until more heat is required. A fully charged ETS system can retain its heat for up to 10 days.

Charging. When electricity is available to heat the ceramic bricks, the ETS will supply heat to them. If the environment is at the required temperature, the ETS diverts all the electricity to heating the bricks.

Discharging. When there is no electricity available to heat the environment, the ETS releases some of its stored thermal energy. The discharging is done in a controlled manner to ensure that the environment does not exceed the maximum specified temperature; when the maximum is reached, the ETS system enters the "off" state.

Charging and discharging. When electricity is available to heat the ceramic bricks and the environment is in need of heat, the ETS system will both charge and discharge.

4.1 Time of Use pricing

One of the arguments for ETS is that it allows electricity suppliers a degree of demand side management, in that an ETS system can be charged during the "off-peak" hours during the heating season (typically 23:00 to 07:00 for winter week-nights, weekends and holidays). This is especially useful during the winter months because of the higher demand for electricity, notably during the early evening.

To encourage consumers to switch to ETS, electricity suppliers often offer low-cost electricity rates to make electric heating costs competitive with other fuel sources, such as fuel oil or natural gas. To discourage charging ETS systems outside the off-peak hours, rates are higher during the "peak" hours.

Electricity suppliers dictate when a consumer's ETS system enters the charging state by transmitting a simple on-off signal over the grid to each ETS system.

4.2 Sizing the ETS system

An ETS system is "sized" for the environment it is to heat; this is why it is necessary to know the maximum hourly space and water heating demand of the rooms or building that are to be heated and the length of time between charges. From this, a simple sizing of the system can be obtained: the product of the maximum hourly demand and the number of hours between charges.

With the required sizing known, the heating system can be chosen. In most cases, the size of the system will not correspond to a specific model from a manufacturer, meaning that it is necessary to select the model that comes closest to meeting the system's heating requirements. Whether the model is oversized or undersized will depend upon factors such as the cost of the equipment and the type of backup heating available to the user.

In the typical Prince Edward Island house with an hourly maximum heat demand of 10 kW, the system was sized at 188 kWh. Steffes, a major manufacturer of ETS systems, has two units close to this size, 180 kWh and 240 kWh. While an ETS system can give an optimum economical performance at approximately 80 percent of the storage capacity required, using an oversized ETS is uneconomic; hence the 180 kWh ETS system was selected at a pre-tax price of $6,250 (Steffes, 2006).

5 Employing wind for space heating

As discussed in the Introduction, combining the output from wind turbines with electric heating may be a way to overcome the intermittency problems associated with wind energy. This section examines three ways in which homes on Prince Edward Island could be heated from the wind.

5.1 Wind turbine data

Electricity from the wind is obtained from wind turbines. By taking wind measurements from a site and combining it with a turbine manufacturer's power curve, the potential electrical energy from the turbine can be calculated. In this study, wind data from the Atlantic Wind Test Site at North Cape, Prince Edward Island was used; when scaled to a hub height of 80 metres, the capacity factor is 54 percent.

The Prince Edward Island government recently announced a plan to install 200MW of wind turbines. For the purposes of this study, it was assumed that the 200MW of wind energy would come from 134 GE 1,500kW turbines. The output from the turbines was assumed to be constant across all turbines.

If the turbines were located at North Cape, the annual generation would be 940,372,800 kWh. The seven year data set permits broad based conclusions, as wind energy consultants often correlate measurements to an average on the same timescale.

5.2 Wind baseboard

The simplest approach to wind-heating is to use radiant baseboard heaters. In this approach, the baseboards demand electricity when needed. The baseboard heaters were sized to meet a maximum heating load of 10kW, corresponding to the peak heating requirement. With the 10kW heating load, the maximum number of households that could use the wind-baseboard system is 20,000, given that there are 200MW of available wind energy.

The seven years of data show that backup from another heating source is required about one-quarter of the time (see Figure 6).

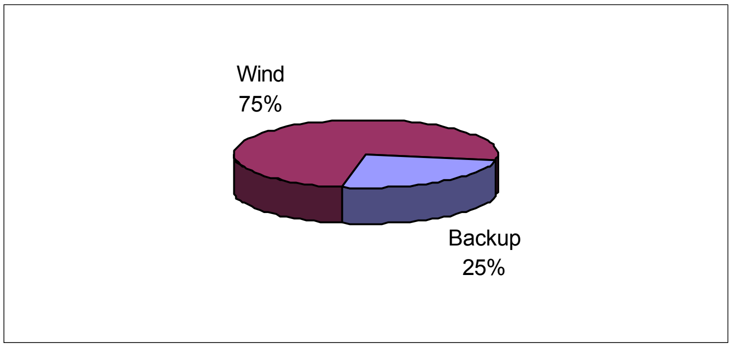

Figure 6: 10kW wind baseboard energy supply – January 1999 to December 2005

Of the available electricity generated from the wind, the wind-baseboard approach uses about 41 percent of the available electricity; the remainder is surplus. The surplus cannot be used by the baseboards because there are times during which electricity from the wind exceeds the demand.

5.3 Off-peak ETS

An alternative to radiant baseboard heating is to use ETS in an off-peak configuration, charging each unit from the wind between 23:00 and 07:00. The available wind energy that coincides with the ETS off-peak demand determines how well this approach performs. The ETS storage capacity is 180kWh, as explained above.

The off-peak ETS works as follows:

- If the load occurs during the charging hours (23:00 to 07:00), the ETS simultaneously discharges the required heat and recharges from the grid.
- If the load occurs during the on-peak hours, the storage is discharged to meet the heating demand.
- If the load exceeds the remaining ETS storage, the backup is accessed.

For this approach, the number of ETS systems that could be supported, 6,933, was determined from the maximum ETS recharge rate and the maximum output from the wind turbines (200MW).

Although this approach uses ETS, the fact that the off-peak ETS charging period and the available wind energy are not always coincident means there can be shortfalls requiring backup (see Figure 7). The need for backup is a result of the ETS trying to obtain a day’s worth of energy during eight rather than twenty-four hours.

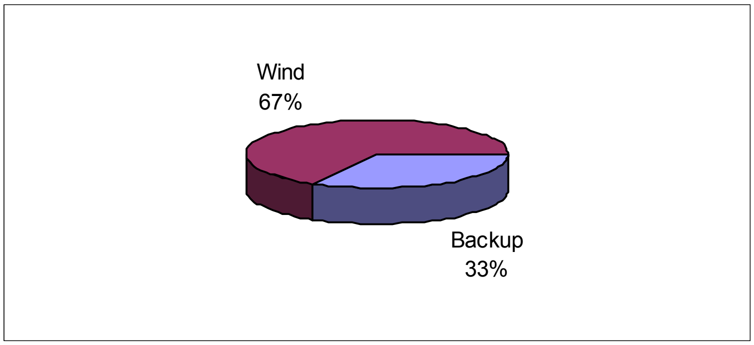

Figure 7: 180kWh off-peak ETS energy supply – January 1999 to December 2005

The off-peak ETS uses only 13 percent of the available electricity from the wind.

5.4 Anytime ETS

The third approach considered allows the ETS systems to be charged at anytime throughout the day as long as the volume of electricity generated from the wind exceeds the heating demand from the ETS systems.

As with the other approaches examined, the anytime ETS approach was simulated over the seven year period. Since the ETS systems were the same size as those used in the off-peak ETS simulation, the total number of customers remained at 6,933.

The seven year simulations show that the anytime ETS has two distinct advantages over the other wind-heating approaches:

- Backup was required for the least number of hours (see Figure 8). In the worst case, a total of 140 hours of backup were required during February 2005.
- There was always a surplus of electrical energy during each heating month.

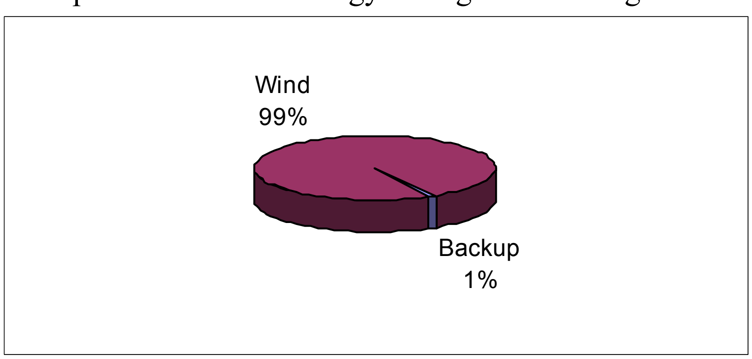

Figure 8: 180kWh anytime ETS energy supply – January 1999 to December 2005

The anytime ETS approach uses 20 percent of the available energy from the wind; the remainder is surplus.

6 Greenhouse Gas Emissions

One of the benefits associated with wind energy is that it has the potential to reduce greenhouse gas emissions by displacing carbon intensive generation, such as the burning of fossil fuels for the generation of electricity or the combustion of fuel oil for home heating.

As discussed above, the average annual heating requirements for both space heating and domestic hot water for a single detached house on Prince Edward Island is 90 GJ per year. Figure 9 shows the different levels of greenhouse gas emission associated with each of the five heating methods.

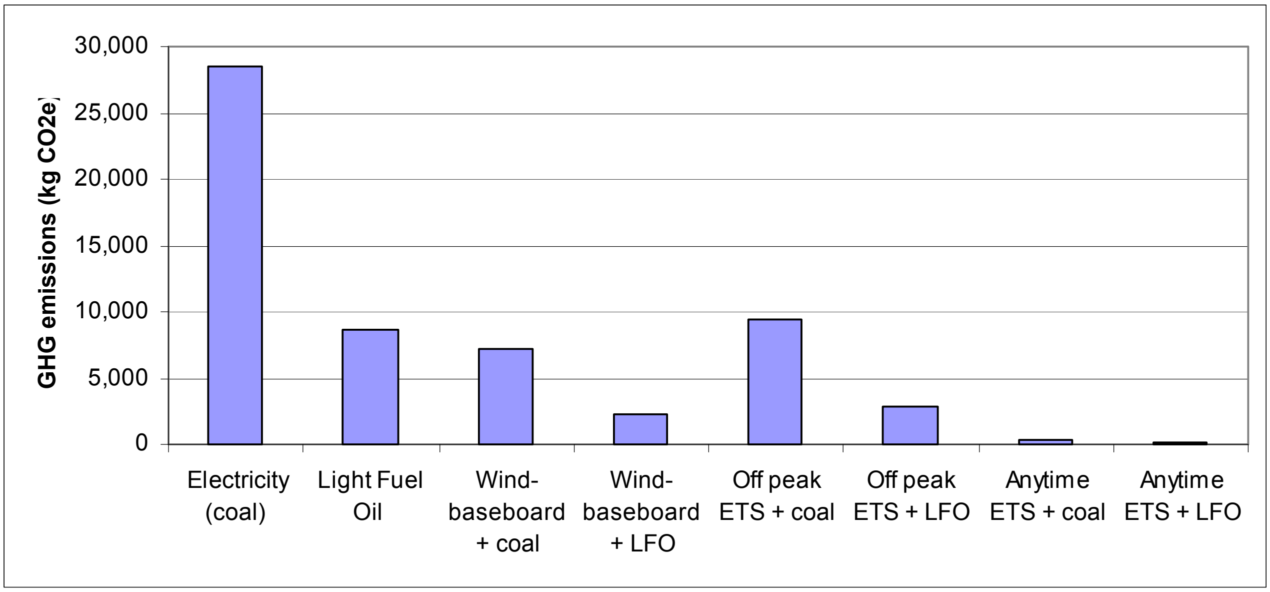

Figure 9: Greenhouse gas emissions by heating method

Homes heated electrically have the highest level of emissions if the electricity is generated from coal-fired thermal plants. Oil furnaces are more efficient, therefore contribute less. Since a large portion of their heating comes from emissions-free wind energy, each of the wind-heating systems is associated with smaller quantities of greenhouse gases, although the type of backup dictates the quantity.

7 Economics

The cost to the homeowner of running the heating system will help determine which system should be selected. This section considers two different costing methods for a wind-heating system: net present value and generator-supplied systems.

7.1 Net present value

Five different heating systems are compared: oil, electric-baseboard (residential rate electricity), wind-baseboard (with residential rate electricity or light-fuel oil as backup), off-peak ETS (with backup), and anytime ETS (with backup). The net present value of each system is calculated from the system's capital costs and the fuel costs; in the case of systems requiring backup, the cost of the wind-generated electricity is added to the cost of the backup. Systems based exclusively on oil do not include capital costs as the data is not readily available.

Figure 10 shows the net present value of the five different heating systems. The cost of oil is $0.70 per litre; coal generated electricity, $0.1055 per kilowatt-hour; and wind-generated electricity, $0.0528 per kilowatt-hour (half that of coal generated electricity). Of the wind-heating systems, wind baseboard has the lowest NPV and off-peak ETS is the highest NPV, while anytime ETS fall in between.

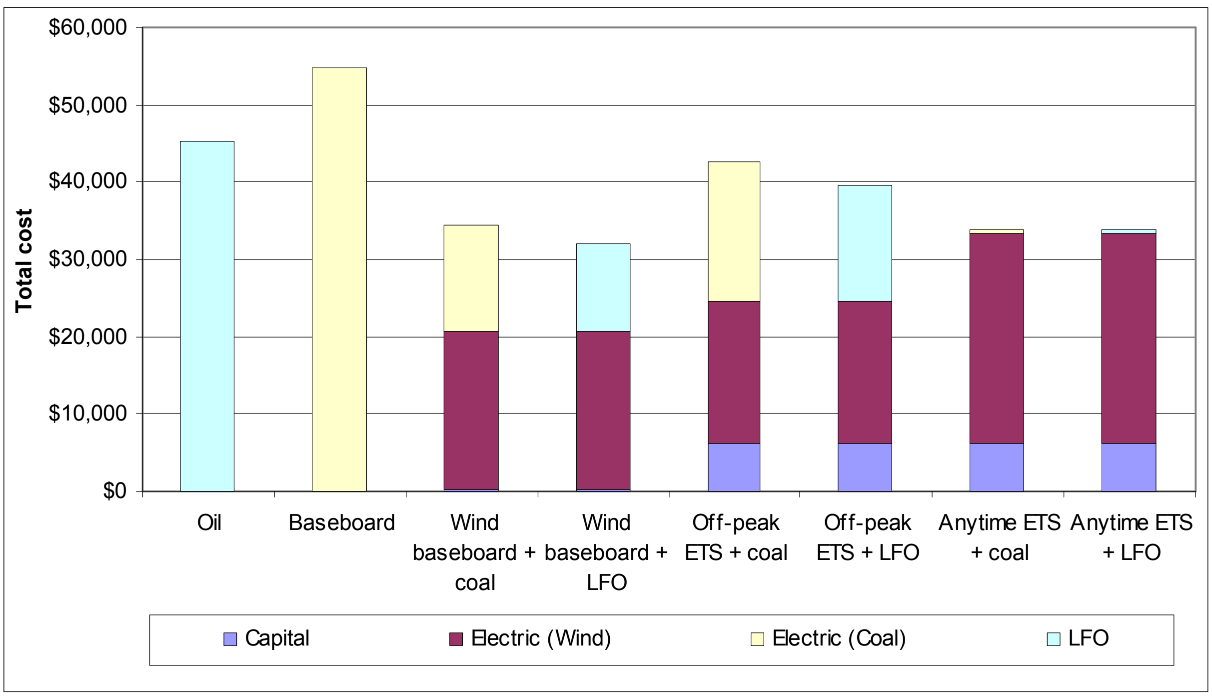

Figure 10: Net present value of the different heating systems

Although the capital cost of the wind-baseboard system is negligible compared to that of the anytime ETS system, the wind-baseboard's reliance on expensive backup fuels gives the anytime ETS a net present value that is competitive with wind-baseboard.

7.2 Generator-supplied ETS

An alternative to having the consumer purchase the ETS is to have the energy supplier purchase the ETS and be responsible for covering the cost of any backup. The consumer would be responsible for paying the cost of the electricity used by the ETS. Consumers participating in such an arrangement would see a constant price for the wind electricity purchased for heating use. The benefit of this scenario is that the wind energy supplier is responsible for managing the system during times of surplus and deficit electricity. Permitting the supplier to sell the surplus energy reduces the payback period and lowers the price of electricity to the consumer.

Figure 11 shows an example of the cost of the surplus wind energy (i.e., that not used for home heating), based upon a constant price of $0.04 per kWh for space heating purposes.

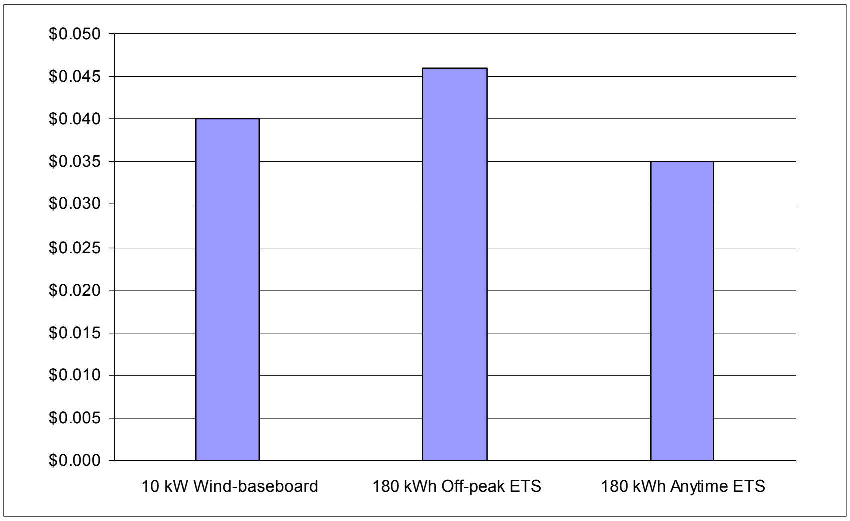

Figure 11: Required selling price of surplus to recover capital in 15 years

8 Implications for the grid

On Prince Edward Island, electricity is distributed through Maritime Electric's transmission grid, which is designed to carry about 200MW. Electricity is supplied by undersea cable from New Brunswick, a small generation station in Charlottetown, and several wind turbines. This picture could change dramatically should the envisaged 200 MW of wind capacity be installed by 2010.

Unlike most other generation technologies, wind is variable and non-dispatchable, meaning that integrating wind into the energy mix can be problematic. In the most extreme case, if demand is being met from wind turbines (displacing other sources of generation) and the wind output unexpectedly falls, the demand can exceed supply, leading to a "system collapse". A collapse on part of the grid can trigger a domino effect, tripping generators and transmission lines, leading to shutdown of the wider network, causing a blackout. Restoring the grid can take hours.

The wind-heating proposal assumes a maximum demand of about 200MW. Should the maximum demand from the wind-heating systems coincide with Prince Edward Island's peak demand, the total electrical demand could exceed the supply, potentially leading to a system collapse. Such a collapse could occur even if the wind output was at its peak of 200MW.

Fortunately, the likelihood of such events occurring is reduced with the use of ETS. If the individual systems are sized properly, there can be sufficient thermal storage to bridge the periods of peak electrical demand.

9 Summary

Energy costs are increasing and can be expected to continue increasing as demand for energy grows around the world. Anyone living in a northern climate must have space heating in order to survive the winter months; as fossil fuels become harder to obtain, alternatives must be considered. This paper has considered an alternative, electric thermal storage using electricity from the wind.

The paper has shown that:

- Operating an off-peak ETS system coincident with the wind requires the greatest amount of backup, more than a wind-baseboard system. This can be attributed to the fact that the off-peak ETS operates for one-third of the day, whereas the wind-baseboard operates for the full day.
- Allowing ETS to charge throughout the day almost eliminates the need for backup, reducing the cost of energy to homeowners and minimizing the output of greenhouse gases for residential space heating.
- Wind-baseboard heating may appear a more attractive option than anytime ETS; however, it contributes significantly more greenhouse gas emissions and does not free the consumer from the increasing cost of fossil fuel. This approach puts the greatest demand on the electrical grid.
- Although there are more consumers associated with baseboard heating (20,000) than with ETS (6,933), the anytime ETS approach:
  - runs with minimal backup and can span periods of peak demand, thereby increasing the stability and viability of the grid
  - has the lowest operating costs, given that it requires the least amount of backup capacity
  - generates negligible quantities of greenhouse gases
- The anytime ETS helps address the problem of wind variability.

This paper has raised a number of interesting possibilities regarding wind-heating in Prince Edward Island (or anywhere else for that matter). However, there are several issues that must still be addressed:

- There is an underlying assumption that all 200MW of wind does not take into account the maximum capacity of the grid, nor does it take into account Maritime Electric's hourly demand. A more detailed analysis of the anytime ETS could be performed with Maritime Electric's hourly demand data.
- In the present design, when there is sufficient wind generated electricity, each ETS system obtains as much electricity as is available, regardless of the state of its thermal storage. In certain circumstances, completely discharged ETS systems may be competing for electricity with nearly full ETS systems. It would appear that intelligent ETS controllers, given access to the state of the grid, could overcome the problem of ETS "starvation". The design of heating system controllers and the supporting communication system is necessary to further the benefits associated with the anytime ETS system.
- What are the "best" prices for ETS systems? If they can be reduced, the anytime ETS system becomes even more attractive.
- How dependent on capacity factor is the wind-heating model discussed in this paper? Could the model be applied elsewhere?

10 Acknowledgements

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References

Bedouani, 2001. Bedouani, B.Y., et al; *Central Electric Thermal Storage (ETS) feasibility for residential applications: Part 2. Techno-economic study*, International Journal of Energy Research, vol 25, pp. 73-83, 2001.

CANMET (n.d.). *Hot2000 V 7.00 (interactive) user manual*, CANMET, Ottawa,Canada

CanREN, 2003. Canadian Renewable Energy Network. *Commercial Earth Energy Systems: A Buyer's Guide. Sizing Heat Pumps and Ground Heat Exchangers*, Retrieved March 15, 2006 from http://www.canren.gc.ca/prod_serv/index.asp?CaId=169&PgId=1004

EIA, 2005 Energy Information Agency. *International Energy Annual 2003*, Retrieved March 15, 2006 from http://www.eia.doe.gov/pub/international/iealf/tablec6.xls

EnvCan, 2005 . Environment Canada, Greenhouse gas division. *Canada's Greenhouse Gas Inventory, 1990-2003, Annex 13*, Retrieved March 15, 2006 from http://www.ec.gc.ca/pdb/ghg/inventory_report/2003_report/toc_e.cfm

Fairey, P. and Parker, D., 2004. *A Review of Hot Water Draw Profiles Used in Performance Analysis of Residential Domestic Hot Water Systems*, Florida Solar Energy Center. Retrieved

March 15, 2006, from http://www.fsec.ucf.edu/Bldg/pubs/review/HW_DrawProfiles_RR.pdf

Harris and Roome, 2006. Personal communication. March.

Newman Electric Ltd., 2006. Personal communication. March.

NRCan, 2006. Natural Resources Canada. *Geographical Names of Canada.* Retrieved March 26,2006 from http://geonames2.nrcan.gc.ca/cgi-bin/v9/sima_unique_v9?english?BACBM?C

NRCan, 2005. Natural Resources Canada, *The National energy use database.* Retrieved Feb 28, 2006 from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/trends_res_pei.cfm

NRCan, 2004. *Energy Use Data Handbook, 1990 and 1996 to 2002*, Office of Energy Efficiency, Natural Resources Canada, June.

NRCan (n.d.) Retrieved date March 18, 2006 http://ntserv.gis.nrcan.gc.ca/cocoon/ngwd/services/ngwd-wrapper/debug-temperature.xls?BBOX=-64,45,-62,47 from National Ground Water Database

PEI, 2004a. Economics, Statistics and Federal Fiscal Relations Division (Department of The Provincial Treasury). *Province of Prince Edward Island , 31st Annual statistical review 2004,* Table 11 , Page 40 . Retrieved Feb 28, 2006 from http://www.gov.pe.ca/photos/original/31annualreview.pdf

PEI, 2005b. Economics, Statistics and Federal Fiscal Relations Division (Department of The Provincial Treasury). *Province of Prince Edward Island , 31st Annual statistical review 2004*, Table 14 , Page 43 . Retrieved March 15 , 2006 from http://www.gov.pe.ca/photos/original/31annualreview.pdf

Perlman and Mills B.E., 1985. *Development of residential hot water use patterns*, ASHRAE transactions – 1985, part 2 A, volume 91

StatCan, 2004b. Statistics Canada, *Household size, by provinces and territories* (2001 Census) . Retrieved Feb 28, 2006 from http://www40.statcan.ca/l01/cst01/famil53a.htm

StatCan, 2004. Statistics Canada. *Private households by structural type of dwelling, by provinces and territories (2001 census).* Retrieved Feb 28, 2006 from http://www40.statcan.ca/l01/cst01/famil55a.htm

Steffes, 2006. *Comfort Plus Hydronic Brochure*. Retrieved on February 17, 2006 from http://www.steffes.com/downloads/pdf/hydronic_brochure.pdf