INTEGRATING 'NEGAWATTS' TO IMPROVE SOLAR PROJECT PERFORMANCE: ASSESSING POTENTIAL ENERGY SAVINGS IN THE RESIDENTIAL SECTOR

By: **Paul Parker[1], Ian H. Rowlands[2] and Daniel Scott[3]**

1. Department of Geography, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada
pparker@fes.uwaterloo.ca

2. Department of Environment and Resource Studies, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada
irowland@fes.uwaterloo.ca

3. Department of Geography, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada
dj2scott@fes.uwaterloo.ca

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ABSTRACT

The Ontario government has announced its intention to create a 'conservation culture' and to promote 'negawatts'. The recognition of opportunities to reduce demand through conservation instead of building new supply capacity has implications at the aggregate system level as well as the individual household level. The paper identifies the potential energy savings in the residential housing stock in Ontario and demonstrates that savings through investment in conservation can significantly reduce the cost of renewable energy projects (solar, wind, or heat pumps) designed to meet particular residential loads. Similarly, the inclusion of conservation investments along with solar investments reduces the average cost per unit of energy service provided. The estimation of potential savings through conservation is based on the detailed *EnerGuide for Houses* evaluation of 4565 houses in Waterloo Region, Ontario, undertaken by the Residential Energy Efficiency Project (REEP). Evaluation teams (one certified evaluator and one student intern) measured building envelope attributes and modelled the heat losses through the five main areas of attic, walls, foundation, doors and windows, and air leaks for a wide range of housing types. Recommended upgrades were identified for each individual house based on the attributes of the building envelope, its heating/cooling system, and discussions with the homeowner. Homeowners who report that they are interested in solar energy are found in a wide range of houses. Rather than simply estimating the investment in new solar technology required to meet their current needs, this paper identifies the potential reduction in demand through conservation and estimates the cost. The paper concludes that government programs designed to encourage investment in renewable energy in general, and residential solar energy systems in particular, would benefit from including the opportunities for conservation to improve overall performance and reduce unit costs. Similarly, the solar industry would reduce cost estimates for clients by integrating the assessment of gains from energy efficiency upgrades as part of the comprehensive solar project. The range of recommended upgrades varies with housing age and type, but opportunities for savings were found in all age categories.

NOMENCLATURE

CO_2: carbon dioxide

EGH: EnerGuide for Houses, Canadian Home Energy Rating System managed by the Office of Energy Efficiency, Natural Resources Canada

GHG: greenhouse gases

tCO_2: tonnes of carbon dioxide

INTRODUCTION

Solar technology has steadily improved its technical and cost performance over the last four decades (Strong 1987, RSMeans 2002). The range of economically viable specialized applications has grown, but entry into the general residential market remains marginal. Global photovoltaic production grew at an annual rate of 28 percent from 1993 to 2003, but the current use of 0.2 EJ/year from this source is dwarfed by total energy use of 422 EJ/year (Sawin 2004). Public concern over the environmental and health costs of conventional energy sources has increased interest in solar and other renewable sources of energy. Provincial governments have restructured energy markets and encouraged renewable supplies through a variety of policies and incentives. The Canadian federal government encourages renewable energy sources and conservation to reduce greenhouse gas (GHG) emissions as part of its climate plan to meet the national Kyoto Protocol target of emissions in 2012 being six percent below 1990 levels, or the personal challenge of a one tonne reduction. Despite these initiatives, adoption rates remain low.

This paper argues that the inclusion of conservation projects as part of a solar energy package serves two purposes. First, the size of the supply technology is reduced because of the system's increased efficiency. The term 'negawatts' has been used to refer to these reductions in demand through increased efficiency. Second, the cost per unit of energy supplied or avoided is reduced because conservation projects are typically lower in cost than new supply projects. Finally, the integration of conservation and generation projects enables a systematic examination and ranking to be made of the priorities for investment. For example, rather than seeing photovoltaic panels as an unusually high cost option that home buyers and renovators typically avoid because of its long payback period, the long payback periods on common renovation projects such as window upgrades demonstrate that homeowners are willing to make long term investments when they consider it an important feature of their home. Similarly the cost of meeting a household's one tonne challenge per person with solar technology is reduced when efficiency upgrades are included as part of the project.

This paper will briefly review provincial and federal policies designed to encourage investment in renewable energy. The residential sector is examined as an area where renewable energy alternatives are available for comparison to and integration with conservation projects. The substantial potential for negawatts in the residential sector is estimated using data from the *EnerGuide for Houses* (*EGH*) evaluation of 4565 houses in the Waterloo Region. The heat loss and potential savings are measured for five major areas: attic, walls, doors and windows, foundation and air leaks. Upgrades to the space and water heating systems are also considered. The estimated cost of various upgrades are converted into cost per annual kilowatt hour and cost per tonne of GHG for comparison to the cost of new energy sources such as photovoltaic panels. The overall result is a ranking and selection of energy projects that have a lower average cost than that of the new technology alone.

CONTEXT

> "We [the Ontario Government] are the first government ever to put conservation and new generation on an equal footing" (Duncan 2004)

In 2004 the Ontario Government announced its plans to create a 'culture of conservation' to reduce electricity demand by five percent and thereby reduce the need for investment in new generation capacity (McGuinty 2004). The limited life expectancy of Ontario's aging nuclear power plants and the election promise to shut down the province's largest coal-fired plant at Nanticoke in 2007 combined with growing demand to require the province to prepare for investment in electricity supply equal to 80% of current capacity. Given the magnitude of investments required, the opportunity exists for renewables and conservation to fill a significant part of that demand. A request for proposals for 300 MW capacity in renewable energy projects in early 2004 generated proposals totaling 4,400 MW in capacity. The June 2004 request for proposals for 2,500MW in new capacity or conservation projects is argued to be the first time that conservation was placed on an equal footing with new supply projects (Duncan 2004).

The Ontario government's approach represents the inclusion of negawatts or energy efficiency as a central part of government policy. This represents the adoption of ideas advocated by Amory Lovins in his 'Negawatt Revolution' for decades. Lovin's message about the potential of negawatts is simple yet powerful:

> "By increasing our energy efficiency we can "generate" large amounts of power without building any new power plants or buying any fuel for existing plants. … Think of a compact bulb, with 14 watts replacing 75, as **a 61 negawatt power plant**. By substituting 14 watts for 75 watts, you are sending 61 unused watts -- or negawatts -- back to Hydro, who can sell the electricity saved to someone else without having to make it all over again" (Lovins 1989)

At the federal level, the government's ratification of the Kyoto Protocol in 2002, signified its intention to address the global climate change issue by trying to reverse Canada's trend of growing energy consumption resulting in increased greenhouse gas emissions. The residential sector offers many opportunities for reducing emissions through improved efficiency (CREEDAC 1999, NRCan 1999) and the federal government launched the *EGH* program in 1998 to provide a standard ranking and evaluation tool for use across the country. The cost of evaluations was subsidized by the federal government purchasing each file at the cost of $150 and a range of public, private and not-for-profit green community organizations offered the service in their local areas (GCA 2004). Despite success in achieving high response rates in some communities (Kennedy et al., 2000), overall only 50,000 out of the 12 million households in Canada participated by 2003. A financial incentive program was announced in 2003 to encourage increased participation rates in the *EGH* program.

The one tonne challenge was also announced in 2003 with the Prime Mininster asking Canadians to reduce their personal GHG emissions by one tonne, or approximately 20 percent. Suggestions to achieve this reduction include changing modes of transportation (from private vehicles to walk, ride or public transport), turning off lights and appliances, improved residential efficiency or fuel substitution (OEE 2004a). In short both provincial and federal public policy objectives can be achieved through investment in new renewable energy sources or improved energy efficiency.

METHOD

To illustrate the opportunities for conservation to increase the appeal and financial feasibility of renewable energy projects, alternative means to achieve the one tonne challenge are compared. In the first case, the installation of a residential photovoltaic system is priced for a residence in Waterloo Region, Ontario. This case is then modified to note the reduced cost if the homeowner joined NRCan's TEAM project to subsidize the cost for houses in a new subdivision in Waterloo. The conversion to GHG emission reductions is based on the assumption that coal is the marginal fuel for electricity generation and that the coefficient is 0.75 kg CO_2 / kWh electricity. Other studies have used coefficients ranging from the Ontario Power Generation average of 0.3 kg CO_2 / kWh to 1.0 kg CO_2 / kWh for less efficient coal systems.

The second option is to consider the potential for energy upgrades or retrofits that reduce emissions through conservation instead of substitution. Data were collected from 4565 houses in Waterloo Region between May 1999 and December 2003 by the Residential Energy Efficiency Project (REEP), a partnership between the Faculty of Environmental Studies at the University of Waterloo and the Elora Centre for Environmental Excellence. *EGH* evaluations were completed using the current *HOT 2XP* model provided by the Office of Energy Efficiency, Natural Resources Canada (OEE 2004b). Single detached houses, duplexes and row houses were included in the study while multi-storey apartments were excluded. Each evaluation consisted of a detailed measurement of all doors, windows, components of the building envelope and an inspection of the space and water heating systems. Heat loss was calculated for five major areas: air leaks, attic, exterior walls, foundations, doors and windows. An overall rating on the standardized scale (100 = zero net commercial energy requirement, 80 = R2000 residential standard, 0 = energy consumption five times that in an R2000 house) was calculated and an *EGH* label printed for the homeowner. The range in *EGH* values among the houses studied is –6 to 87. The average rating was 65 initially and 73 if the recommended upgrades were implemented.

Technical opportunities to upgrade the house are identified and the difference in heat loss and energy consumption between initial conditions and upgrades calculated. The approach differs from studies where it is simply assumed that the technical upgrades can be undertaken (for example that upgrades can be made to insulation levels even if there is insufficient space in the wall or roof cavity and the installation would be substantially more expensive). Instead, a dialogue is conducted with the homeowner to identify upgrades that are more likely to be acted upon. The resulting *socio-technical potential* for upgrades is lower than the technical potential found in studies focusing on technical opportunities (CREEDAC 1999, ERG 1998). A four-page report is provided to the homeowner that serves as an energy plan to upgrade the house and its energy systems. This enables the homeowner to rank the projects and make better decisions on the sequence and likely improvements from various actions. For example, the energy efficiency and economic benefits from upgrading to a high efficiency furnace are much greater than typical window upgrades. The dialogue with homeowners also reveals that implementation rates will not be universal as a series of perceived and actual barriers prevent many people from taking the actions. In some cases, action is not taken for financial or cost reasons, in others, the barrier is a lack of trust, or not knowing who to hire, or a busy lifestyle, or a desire to avoid mess and interruptions, etc. This paper adds the relative cost of a solar photovoltaic installation for comparison to standard conservation upgrades.

SOLAR SCENARIO

The solar scenario envisions a homeowner deciding to meet their one tonne challenge and to contribute to Canada achieving its national Kyoto Protocol target by installing a photovoltaic system on the roof. The estimated costs are shown in Table 1. In the first example, a one kilowatt system is installed and results in the homeowner saving the first tonne of GHG emissions at a cost of approximately $15,000 per tonne. If the family decides to invest in a larger 5kW system to save the GHG emissions for the whole family, the average cost per tonne is reduced to $10,000 through the economies of scale in the installation. A third option is to participate in a subsidized solar home program such as the ARISE Solar Homes in a Waterloo subdivision sponsored by NRCan in Waterloo. In this case the cost per annual tonne is reduced to $7000 (ARISE 2003).

Table 1: Solar scenarios to reduce GHG emissions

	1kW	5kW	2.6 kW
pv panels ($)	7500	36000	
charge controller ($)	300	300	
roof rack ($)	900	4500	
Inverter ($)	5000	6000	
disconnect/wiring	500	500	
Equipment cost ($)	14200	47300	
installation ($)	2500	7500	
total cost ($)	16700	54800	20,000
sun (hrs/day)	4	4	4
kWh/year	1460	7300	3800
$/kWh	11.40	7.50	5.30
tCO_2/yr avoided	1.1	5.5	2.9
$/$tCO_2$ avoided	15000	10000	7000

POTENTIAL ENERGY SAVINGS

Substantial energy savings potential is found in the residential sector. The detailed evaluation and modeling of 4558 houses in Waterloo Region found potential savings of 42 Gj per house or 23 percent of total energy consumption (Table 2). These energy savings translate into average GHG emission reductions of 2.7 tonnes CO_2 or 18 percent. However, the savings are not equal across all fuel categories. The largest savings are in oil consumption where many houses could easily convert to natural gas or propane as a less carbon-intensive fuel. In contrast, electricity consumption is reduced the least because the evaluation focuses on the building envelop and the heating fuel while most of the electricity consumption is based on a set of standard assumptions about appliances and household usage rates.

Table 2: Average residential fuel consumption and potential savings

	initial	upgraded	Savings	% change
Electricity (kWh)	11095	10317	778	-7
Natural Gas (m^3)	3478	2630	848	-24
Oil (l)	297	95	202	-68
Total (GJ)	181	139	42	-23
CO_2 (t/yr)	15.7	13.0	2.7	-18

N=4558, Source: REEP HOT 2XP files

Differences in potential fuel savings are better understood by separating households according to their primary heating fuel (Table 3). Overall, houses heated with electricity or oil have the largest potential reductions in GHG emissions with an average 30 percent reduction or 7 tonnes of CO_2 per year identified. In both of these cases, the largest portion of the savings were gained by switching to natural gas as a less carbon-intensive fuel. Although electrically heated houses use carbon intensive fossil fuels (indirectly through coal-fired power stations), they typically are better insulated and use less total energy than average houses using natural gas or oil. Houses using propane as the heating fuel (n=7) have similar attributes to the natural gas fueled houses. The lowest reductions in GHG emissions were found in houses heated with natural gas where the average savings are only 2.4 tonnes per year. The typical household of four persons would have to make all of the recommended efficiency upgrades and then take further steps to achieve a one tonne reduction per person. The houses fueled by natural gas are thus selected for further consideration as to how solar projects could be included along with efficiency upgrades to meet a family's one tonne challenge.

The 4029 houses heated primarily with natural gas were then examined to determine the influence of their date of construction on energy consumption and potential savings (Figure 1.). Residential construction techniques have improved with houses built in the 1990s being three times as efficient for space heating as those built 100 years earlier. Average space heating requirements declined from 239 GJ in houses built prior to 1900 to 73 GJ for those built after 1990. However, the potential for energy savings remained substantial for most houses.

Energy consumption for space heating could be reduced by 40-45 percent for houses built between 1900 and 1949 (Figure 2). Average savings of 34 percent were identified in houses built in the 1950s, 1960s, 1970s and prior to 1900. Even houses built in the 1980s offered savings equal to 29 percent of their space energy. Houses built in the 1990s have less potential savings (18 percent), but these should still be included in a systematic assessment of areas to reduce GHG emissions. Although the potential for savings is larger in older houses, a recent study (Parker et al. 2004) found that the age and size of house did not differ between households who reduced consumption following an EGH evaluation and those who increased consumption. Instead, differences in demographics and knowledge helped identify those most likely to reduce consumption by over 10 percent.

Table 3: Residential fuel consumption and potential savings by fuel type

Electrically heated houses, n=233

	initial	upgraded	savings	% change
Electricity (kWh)	31800	20400	11400	-36
Natural Gas (m^3)	218	878	-660	303
Oil (l)	3	16	-13	433

	initial	upgraded	savings	% change
Total (GJ)	123	108	15	-12
CO_2 (t/yr)	24.3	17.0	7.3	-30

Houses heated with natural gas, n=4029

	initial	upgraded	savings	% change
Electricity (kWh)	9763	9577	186	-2
Natural Gas (m^3)	4030	2823	1207	-30
Oil (l)	0	0	0	0
Total (GJ)	181	140	41	-23
CO_2 (t/yr)	14.9	12.5	2.4	-16

Houses heated with oil, n=305

	initial	upgraded	savings	% change
Electricity (kWh)	13531	12602	929	-7
Natural Gas (m^3)	305	1412	-1107	363
Oil (l)	4432	1413	3019	-68
Total (GJ)	223	154	69	-31
CO_2 (t/yr)	23.3	16.1	7.2	-31

Source: REEP HOT 2XP files

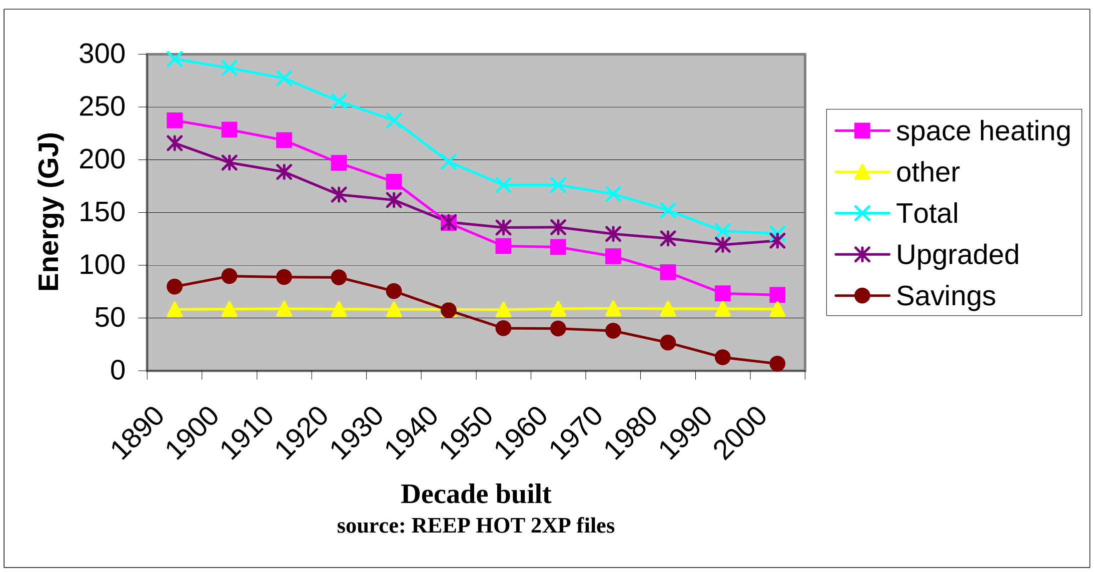

Figure 1: Residential energy consumption by decade built

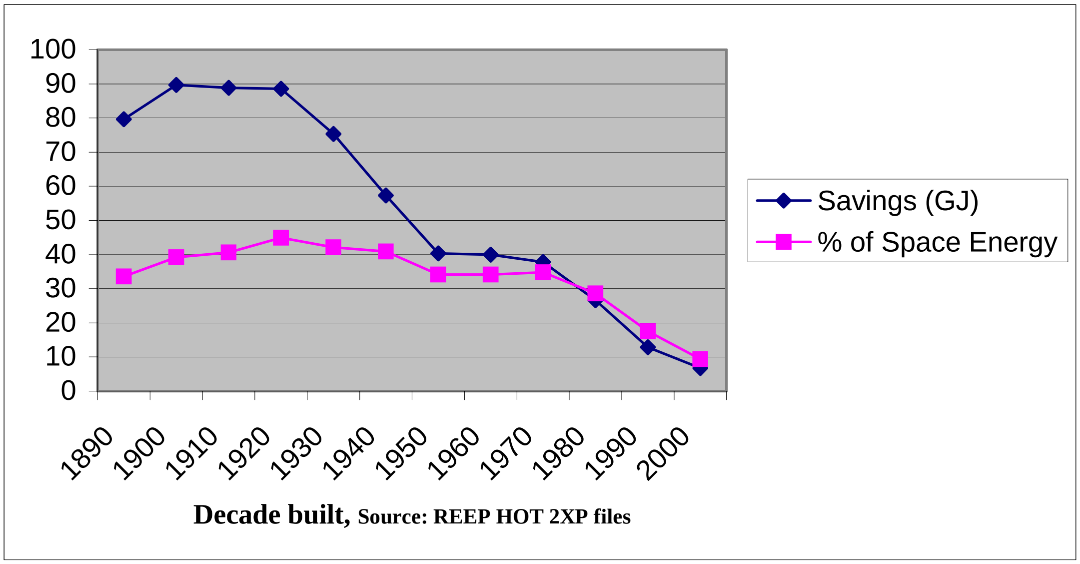

Figure 2: Potential residential energy savings by decade built

Each section of the building envelope can be examined for its contribution to heat loss (Table 4). The attic is often the first area examined and it was the primary target for upgrades by previous programs such as the Canadian Home Insulation Program (CHIP) of the 1970s and 1980s. Average heat loss has been reduced to 9 GJ per year, but this can be improved by a further 32% to 6 GJ. The open structure of most attics makes this an easy area to blow in cellulose or other forms of insulation for cost effective savings. In other cases, there may be no additional space and the addition of extra insulation needs to be completed in conjunction with roof or ceiling replacement.

Table 4: Annual heat loss by section of the building envelop (GJ)

	Initial (mean)	Initial (sd)	Upgrade	Savings	% Change
Attic	9	6	6	2.8	-32
Foundation	33	14	24	8.1	-25
Air leaks	33	19	26	7.5	-23
Walls	34	25	30	4.6	-14
Windows/Doors	33	14	30	2.6	-8
Total	142		116	25.7	-18

N=4029, Source: REEP HOT2XP files from houses heated with natural gas

While ceilings offer the easiest potential for savings, the area with the largest potential reduction in heat loss is the foundation. An estimated 8 GJ per year (25%) could be saved by upgrading foundation insulation. Basement walls are often only partially insulated as even the 1997 Ontario building code does not require full insulation below ground level. Headers are another area where heat loss can be reduced substantially.

Heat losses through air leaks are similar in size and savings potential to heat loss through the foundation. A pressurized blower door test is administered to measure the rate of infiltration. Air leaks correlate with the age of the house as old houses are often considered very ‘drafty’ and new houses ‘too tight’. Air quality is considered very important so heat recovery ventilators are recommended for houses that are too tight. If a ventilator is not present, the HOT2XP program assumes that bathroom and other fans are used to achieve sufficient air changes and electricity consumption is adjusted accordingly. Air leaks are found in all parts of the building envelop, but the potential for substantial savings in the foundation and air leaks provides an example where two problems can be solved at once. The installation of additional basement wall and header insulation should be combined with the installation of an air or vapor barrier so that both problems are addressed.

The main walls of an average house lose a similar amount of heat as the foundation or air leaks, however, the savings identified are less (14%) because of the high cost involved in addressing the problem. The standard deviation in values is highest for this type of heat loss because some old houses have minimal insulation in the wall while some new or renovated houses have much higher insulation levels that result in lower heat losses. Some old houses can have insulation blown into the wall cavity, but in other cases the addition of insulation requires an extra layer to be added to either the inside or outside of the wall. These upgrades should be included as part of major renovation projects, but are less likely to be undertaken for energy savings alone. Wall upgrades should include a new air barrier that reduces air leaks as well.

Windows and doors are the final area of heat loss. The magnitude of average heat loss is similar to that of the foundation, walls, or air leaks, however, the potential savings are smaller (8%). Windows have improved substantially in terms of their heat loss performance and low-E, argon-filled doubled paned windows have become the standard in the Ontario renovation industry. However, less efficient double paned sliding panels remain common in general construction. Single pane windows remain a feature of some older houses and internal or external storm windows can be used to improve performance. In addition to the characteristics of the window, the quality of installation is important to control air leaks, or drafts, around windows. An area that is often overlooked is the type of door and its insulation characteristics. In many newer houses, the replacement of the uninsulated interior door to the cold room with an insulated exterior door can result in the same energy savings as the upgrading of windows, but at a much lower cost.

Overall, EGH evaluations are able to identify areas to reduce heat losses through the building envelope by 18% on average. Further savings are achieved through the investment in high efficiency furnaces or water heaters. Given the known size of potential energy savings through efficiency upgrades, the cost of these upgrades is considered next.

COST ESTIMATES

The estimated energy savings and standard cost of residential upgrades for the Canadian housing stock has been reported by CREEDAC (1999). Their results have been adjusted to general values based on typical upgrades recommended during an EGH evaluation (Table 5). The conversion to CO_2 reduction is based on the assumption that natural gas is the primary heating fuel. Similar tables could be calculated for houses using electricity or oil as their primary heating fuel and the potential CO_2 reduction would be larger.

The first area considered for upgrading is the furnace. By converting to a high efficiency furnace, the CREEDAC study estimated savings of 9 MJ/yr/$. This converts to a cost of $2300 per tonne of CO_2 emissions avoided annually for the life of the equipment. In the average natural gas fueled house in the study this would result in an annual reduction of 1.2 tonnes of CO_2. The actual reduction varies from house to house and can be calculated for the particular dwelling with the HOT 2XP data generated during an evaluation.

The attic is the lowest cost area for energy savings from increased insulation. These costs are based on the assumed ability to blow more insulation into the attic. If more elaborate measures are required, the cost would increase accordingly. The foundation is the next area for attention. The cost estimate includes studding, insulation and vapor barrier, but excludes the wall surface as costs vary widely according to the type of material chosen. In practice, the total cost of the renovation project will be higher than the energy component identified here. Increasing the insulation in the main walls is more expensive with an estimate of $10,000 per annual tonne of CO2 saved. The cost for window upgrades varies with the types of windows considered and the example given represents upgrading from single pane windows with storms to double glazing or going from double to low-E double glazing.

Table 5: Estimated cost of upgrades and potential CO_2 reduction

	MJ/yr/$	$/kWh	$/tCO$_2$*	tCO$_2$*
Furnace	9.0	0.40	2300	1.16
Attic	8.0	0.45	2600	0.14
Foundation	6.5	0.55	3200	0.39
Walls	2.0	1.80	10000	0.22
Windows/Doo rs	1.2	3.00	17000	0.13

Note *: assumes natural gas fuel, average savings attributes
Source: CREEDAC 1999, REEP HOT2XP files

The solar and conservation projects considered above can now be compared directly (Figure 3). The homeowner can then use the information to decide which projects to include in their plan to reduce CO2 emissions and thereby meet the federal government's one tonne challenge, or to reduce their demand on the electricity system and put into practice the provincial government's desire to consider conservation on an equal footing to new sources of energy. The lowest cost options are to upgrade to a high efficiency furnace, or increase insulation in the attic and foundation. However when greater improvements are desired, solar projects offer similar returns as the more expensive conservation upgrades. The cost of improving the performance of exterior walls is similar to that of a large solar photovoltaic system. Even a small 1kW system offers greater carbon reductions that typical window upgrades. These results highlight the importance of considering conservation or negawatts along with renewable energysources when planning to reduce GHG emissions or move away from conventional energy sources.

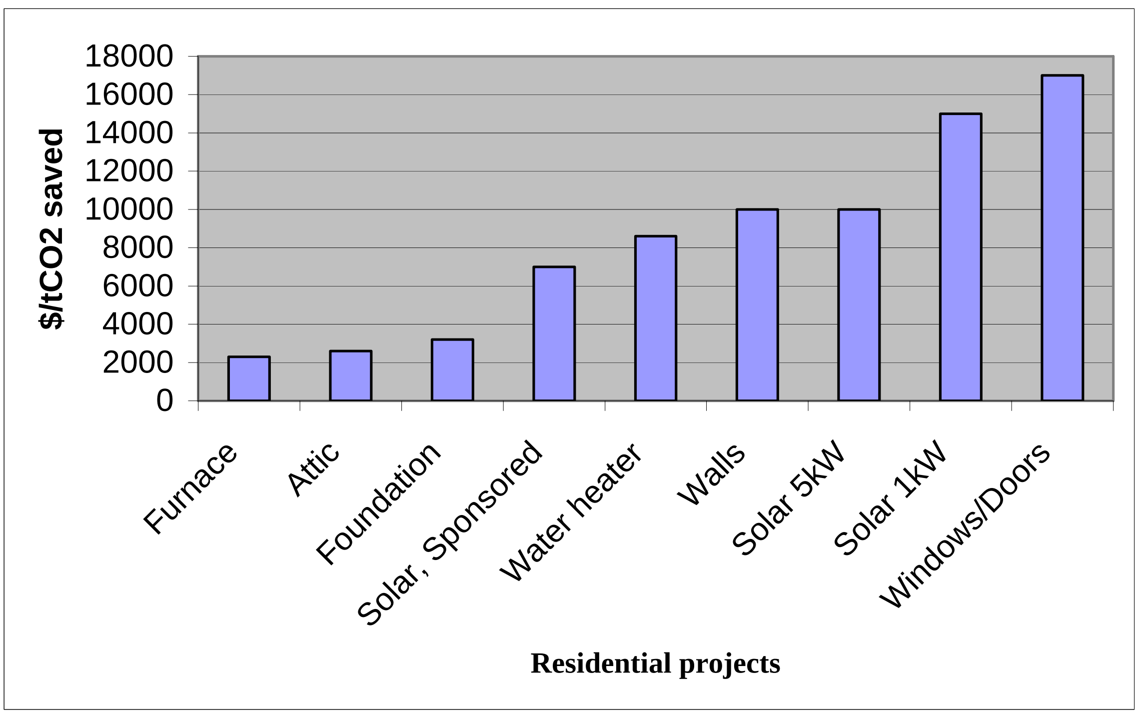

Figure 3: Cost comparison of solar and conservation projects

The direct comparison of negawatt or conservation projects alongside renewable energy projects enables homeowners to make informed choices about improving the performance of their homes. For example, if a family of four that lived in house with natural gas as their primary fuel decided that they wanted to achieve their one tonne challenge through changes to their home, they could select projects based on the costs shown above (Figure 3). Upgrading to a high efficiency furnace and adding insulation to the attic and foundation are the lowest cost actions. In the average home these projects would reduce annual CO2 emissions by 1.7 tonnes. If a subsidized solar program is available, it would provide the next lowest cost choice. If not, a full cost solar installation would be similar in price to adding insulation to the main walls or upgrading windows. Unless a major renovation project is already planned, many households may prefer a discreet solar array on the roof to opening the walls of their home. A large window installation industry thrives on people's decisions to upgrade their windows and current solar technology offers a similar environmental return on investment. The challenge is to grow the solar industry by linking directly to the energy retrofits being undertaken. The other benefit is that the inclusion of lower cost conservation projects cuts the average price per tonne or kWh in half from that for photovoltaics alone.

CONCLUSION

The Ontario and Canadian governments are encouraging residents to adopt a culture of conservation and to reduce their GHG emissions, respectively. The solar industry can contribute to achieving both of these goals. This paper argues for the inclusion of energy efficiency projects in the assessment of potential contributions from solar projects to meet homeowner energy objectives. A large renovation industry offers services such as the installation of high efficiency windows. However, the cost to achieve the efficiency gain is rarely set in the broader context of what other options exist throughout the house. A systematic residential energy evaluation such as that undertaken for an EGH rating identifies a broad range of upgrades and provides information in the form of an energy plan to the homeowner for their selection of projects.

Energy efficiency upgrades serve the role of negawatts advocated by Lovins. The reduce the demand on conventional energy sources and thus have the same effect as being new sources of energy supply. If a household is planning to either be independent in energy supply or be a 'zero' home with no net demands on the grid, the reduction of demand through conservation avoids expensive investment in new capacity. However, at some point the cost of conservation will equal that of new capacity so the homeowner needs the information tools to decide on the appropriate action.

In projects where solar energy is planned to reduce GHG emissions, setting the project as part of a systematic energy evaluation of the house's performance enables the owner to make better informed decisions. In the case of houses heated with oil or electricity, energy efficiency upgrades can reduce GHG emissions by 7 tonnes on average. In houses that use natural gas as their primary fuel, identified reductions are only 2.4 tonnes. These houses represent 88 percent of the housing stock and thus create opportunities where the solar industry can help households reach GHG emission reduction targets. In the generic case described above, furnace upgrades and improvements to attic and foundation insulation are the most cost effective projects to save energy. To reduce emissions further households need to consider upgrades to walls or windows. Both of these areas are more expensive and solar projects can match the performance in terms of $/kWh or $/t$CO_2$. The solar industry currently can compete directly with window upgrades for energy improvements and should strive to become part of the residential renovation industry. The benefit of combining solar and energy efficiency projects is that the average cost per annual tonne of CO_2 emission reduction can be reduced to half of what it would be for solar projects alone.

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