Maximising CO_2 emission reductions in the Canadian residential sector: a socio-technical analysis of housing stock retrofit potential

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1. SYNOPSIS

The socio-technical energy efficiency potential of Canadian homes (n=823) was examined using a Home Energy Rating System. Options to maximise the 'carbon-effectiveness' of residential sector initiatives in Canada are discussed.

2. ABSTRACT

As a signatory to the Kyoto Protocol, Canada has signalled its intention to reduce its greenhouse gas emissions to 6% below the 1990 baseline by 2008-2012. The residential sector in Canada is the third largest consumer of energy, accounting for approximately 20% of total end-use demand and 17% of greenhouse gas emissions. Significant potential for improvements in the energy efficiency of the residential sector exists, but to achieve the Kyoto target in Canada's growing economy will require an average 4% per annum efficiency gain from 2000 to 2010. The principal means to achieve meaningful carbon-dioxide emission reductions in this sector is improved energy efficiency in the home building envelope and fuel switching.

The paper assesses the extent to which greenhouse gas reduction potential varies across different age classes of Canada's housing stock. The study combined comprehensive structural data derived from Canada's national 'Home Energy Rating System' (HERS) with detailed occupant data from a 154-item social survey for a sample of over 800 homes in Waterloo Region (Ontario, Canada). The hypothesised socio-technical retrofit potential was based on technical potential (e.g., air leakage, heating-cooling technology) and social context (e.g., income, life stage, policy preferences). By identifying systematic variations in housing characteristics and the social acceptability of energy efficiency programmes, the case study demonstrates how the results could be used to maximise the 'carbon-effectiveness' of Canada's initiatives in the residential sector through focused HERS evaluation activity and tailored retrofit subsidy programmes.

3. AUTHORS' NOTE

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4. INTRODUCTION

Climate change has been recognised as a global concern by the Intergovernmental Panel on Climate Change (IPCC) and by the 185 nations that have ratified the United Nations Framework Convention on Climate Change (UNFCCC). The present pattern of energy production and consumption is increasingly acknowledged as unsustainable and most industrialised nations have announced policies to encourage reduced greenhouse gas (GHG) emissions. Despite ambitions to stabilise and eventually reduce emissions under the UNFCCC and the1997 Kyoto Protocol, the trend in the 1990s has been one of continued growth in energy consumption and GHG emissions.

Canada is one of the largest per capita consumers of energy in the world. The Kyoto target to reduce Canada's GHG emissions to 6% below 1990 levels by 2008-2012 appears modest. However, continued increases in GHG emissions resulting from population and economic growth during the 1990s (from 612 Mt CO_2 equivalent in 1990 to 692 Mt in 1998)(1), will mean that the required reduction during the 2000-2010 decade is equal to 2% per annum. To achieve this reduction while allowing for forecast population and economic growth is projected to require an average 4% reduction in GHG emissions per annum (2). While the Canadian economy has continued to become more energy efficient and emit less GHG per unit of economic activity, the required efficiency gain is historically unprecedented.

In view of the global and national challenge to reverse the GHG trend, what should be the response of individuals and communities? Personal decisions have a direct effect on global climate change, in particular choices regarding transportation and energy use in the home. The significance of energy consumption in our homes is sometimes overlooked, yet the cumulative effect of these energy choices is substantial. At the global level, energy use[1] in the residential sector is second only to industrial energy use, with 70 EJ (22% of global energy use) consumed annually in the mid 1990s) (3). In Europe and North America, homes are typically the largest energy use under direct personal control.

The distribution of Canadian energy consumption by sectors differs somewhat from the overall OECD average, as the residential sector is the third largest consumer of energy and source of CO_2 emissions. Nevertheless, the Canadian home is a significant contributor to national energy use, accounting for approximately 19% of the nation's total end-use demand and 17% of GHG emissions in 1996) (4). In 1990, the Canadian housing stock of 10 million occupied dwellings was responsible for 68 Mt of CO_2 equivalent through direct and indirect energy consumption (5). By 1996, residential energy consumption in Canada had grown by 12% (6). As the title of this conference fittingly suggests, the trend in energy use in the residential sector has indeed moved Canada 'Further than ever from Kyoto.' If the Canadian target for GHG reductions set under the Kyoto Protocol is applied equally to all sectors, the modest Kyoto target of 6% reduction from the 1990 baseline becomes a much larger target of approximately 20% within the residential sector, due in part to growth in the housing sector, larger average house size, and growth in household appliances and usage patterns. within the residential sector A critical question is whether or not these reductions can be achieved.

Two recent studies have examined this question. Under technically optimal conditions, the residential version of the Intra-Sectoral Technology Use Model showed how per capita energy demand in the residential sector of Canada's three largest provinces (Ontario, Quebec, British Columbia) could be reduced 65% between 1988 and 2008 (7). It was argued that the principal means to achieve these energy savings is improved energy efficiency in the home building envelope and domestic appliances. The conclusions of a later study differed slightly in terms of how energy use reductions could be achieved. (8) found the magnitude of potential CO_2 emission reductions from home appliance efficiency improvements in Canada was small (7% with 100% market penetration), and concluded that meaningful reductions in the residential sector would have to come from improvements to house structures, heating systems, and fuel substitution.

The concept of unfulfilled technical potential is central to most current energy policy assessments, as demonstrated by the process to develop Canada's National Implementation Strategy for its Kyoto Protocol commitments and the IPCC greenhouse gas emission modelling scenarios. It is well recognised that technical potential is greatly constrained by social factors, often resulting in an 'efficiency gap' (9). As a result, any notion of purely technical potential, abstracted from its social context, is at best an optimistic measure (10). Robinson (11), Mullaly (12) and

Shove (10) lament the lack of interaction between technical and social energy research. Energy efficiency in the residential sector is a complex issue, requiring a multi-dimensional research approach to avoid the limitations of examining only the technical or social dimensions of the issue. New research is called for, whereby the social context of individual actors is better recognised.

The purpose of this article is to examine the socially contextualised potential to reduce GHG emissions in Canada's residential sector, using Waterloo Region (Ontario, Canada) as a detailed case study. Having established the context of GHG emission reduction targets and the importance of the residential sector as a source of GHG emissions, the paper proceeds as follows. The Residential Energy Efficiency Project (REEP) case study and research methods used to examine the 'socially negotiated' energy savings potential are described in section two. Section three assesses the current energy efficiency status of the homes in the case study and how the potential for GHG reduction varies across different age classes of the housing stock. The fourth section examines strategies to enhance Canada's initiatives to reduce GHG emissions from the residential sector. Finally, the main findings are summarised and some conclusions offered.

5. THE RESIDENTIAL ENERGY EFFICIENCY PROJECT (REEP) CASE STUDY

The overall vision for REEP is citizen action to contribute to a healthier, more sustainable community, while simultaneously furthering Canada's international commitment to the Kyoto Protocol. The project is situated in Waterloo Region (population 450,000) in south-western Ontario, Canada ($43^0$30'N-$80^0$30'W). REEP is comprised of a number of inter-related studies that examine structural energy efficiency and energy savings potential, energy consumption patterns and behavioural change, fuel substitution and willingness-to-pay for 'green' power, public attitudes toward and response to restructuring of the electricity marketplace, residential energy policy preferences, and the implications of projected climate change for heating and cooling needs.

As part of its efforts to convert shared international policy objectives into national programmes to reduce GHG emissions associated with energy use, the government of Canada established a national home energy rating system programme called *EnerGuide for Houses* (EGH). HERS have also been utilised in a large number of residential energy programmes in the USA (13), often as part of energy utility demand side management (DSM) initiatives mandated by the federal Residential Conservation Service. The technical data used to determine the current energy efficiency of the housing stock examined in this analysis, was collected using the *HOT 2XP*[2] home energy model that is used in Canada's HERS programme.

Through a comprehensive analysis of the home structure and heating-cooling systems, HERS determine how energy efficient a home is, independent of how the owners choose to use energy, and provide recommendations for improvement. Each home energy evaluation entailed a visit by a two-person team for 2-3 hours. A detailed inspection is made of wall construction, insulation type and thickness, heating-cooling equipment, and major appliances. An air leakage test was conducted with an infiltrometer and the number of air changes per hour calculated. Between May 1999 and January 2001, REEP completed energy evaluations of over 2000 homes in the study area. The analysis reported in this paper is based on 823 single detached dwelling (the results for row housing can be found in 14) evaluated in the first year of the project. These data files have been reviewed for quality control and have been accepted into the national EGH database. The age profile of the sample of houses used in this analysis is very similar to that of the total housing stock in Waterloo Region (for each age class the sample is _4% of the total housing stock).

Rather than examine technical energy saving potential in abstract by upgrading structural and heating-cooling systems of each house as closely to the Model National Building Code as possible, the research utilised the HERS results to discuss what changes the residents would consider.[3] In other words, two technically identical houses may have different sets of upgrades outlined in their home energy plan if the discussions between the homeowner and evaluator differ and indicate that certain actions are very unlikely to be taken. The estimated socio-technical energy saving potential derived from this 'socially negotiated' approach incorporates some of the social constraints to individual action. This enables REEP to go beyond the abstract technical question of whether it is possible to have more efficient houses, to examine what actions to improve energy efficiency might be reasonably expected.

The technical data on the houses are complemented by a 154-item survey, used to collect information on respondent demographics, self-reported energy conservation and home retrofit behaviours, environment and energy-related attitudes, energy sector knowledge and policy opinions. Of the 823 questionnaires distributed, 527 valid surveys were returned, for a response rate of 64%.[4] No refusal survey was implemented and no follow-up procedures were used to increase participation. The demographic profile of survey respondents reflected the population characteristics of the Region of Waterloo (1996 Canadian census) reasonably well when the proportion of homeowners (94%) in the sample is considered (see 15 for respondent profile).

6. SOCIO-TECHNICAL ENERGY EFFICIENCY POTENTIAL ACROSS HOUSING AGE CLASSES

The current energy efficiency of the sample of houses in each age class is presented in Figure 1. Canada's EGH rating system uses a standardised linear scale (0-100) where a rating of 100 indicates that the house requires no net energy from external sources (i.e., the house as a system is self-sufficient through the use of solar panels or other on-site technologies). New homes built to Canada's energy efficiency standard (R-2000[5]) rate 80. A house with a rating of 60 uses twice as much energy as a house with an 80 rating (a 40 rating = 3 times the energy, 20 = 4 times, 0 = 5 times).

When Canada's R-2000 standard was established in 1982 it was hoped that by the year 2000 all new houses would be built to this high standard of energy efficiency. This has not been the case and between 1990 and 1996, less than 1% of new homes in Canada are registered as R-2000 (4). The additional costs associated with constructing a new home to the R-2000 standard (estimated at CDN$5000 – corresponding to 3550 Euro) is cited at the primary barrier. While the return on investment from energy savings over the lifetime of the home would pay for the higher initial construction costs several times, Canadian home buyers generally opt for other upgrades instead.

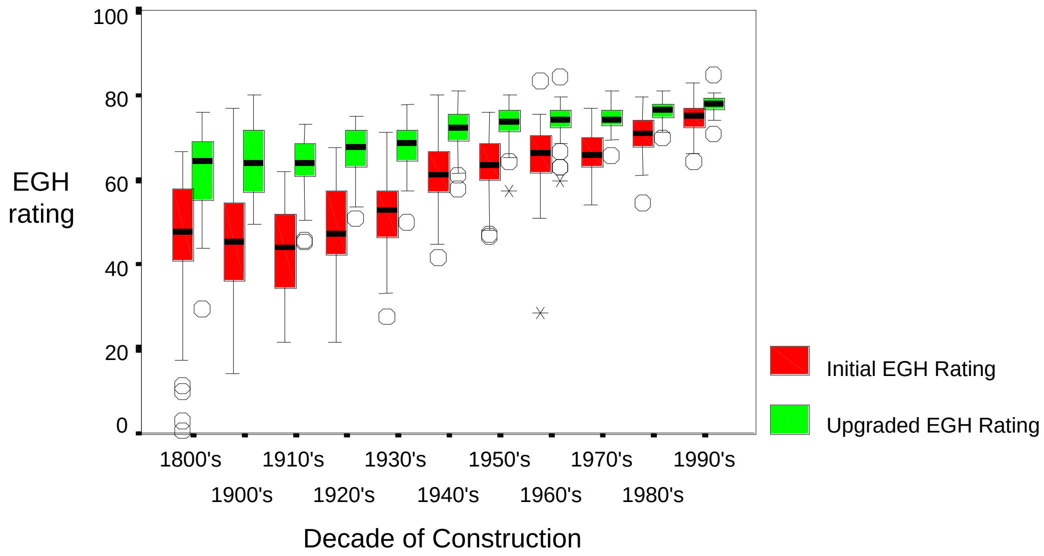
Only six of the 823 single detached houses evaluated in Waterloo Region achieved a score of 80 or above. Two houses achieved the highest rating (83) in the sample by using water-based heat pumps to meet a significant share of their energy needs. At the other extreme, seven houses scored less than 20 and three of these had scores less than 10. These houses were all built before 1905. The box-plot in Figure 1 represents the middle 50% of the cases in the shaded rectangle, with the tails representing the maximum and minimum values (excluding outliers indicated as circles or stars). This provides an indication of how similar or divergent the ratings of houses in each age group were.

Two trends are immediately apparent from Figure 1. First, the influence of the oil crises in the 1970s, which stimulated increased concern about energy consumption and improved building standards, is clearly evident. Houses built in the 1980s and 1990s are more energy efficient, averaging EGH scores of 71 and 75 respectively, than the 1960s and 1970s. Second, the EGH scores of newer houses have a smaller standard deviation, indicating that they are more consistently built to higher standards. Improved building techniques and in some cases improved building codes explain this trend.

EGH scores for houses built in the 1950s, 1960s and 1970s were generally similar with averages near 65 and a standard deviation of 7. Houses built in the 1940s have an average score of 61 indicating that they consume almost twice as much energy as an R-2000 house. The lowest scores were found in houses built before 1930 with averages below 50 on the EGH scale. Houses in these age classes were also highly variable, with some using far more energy than a new house, while others had energy ratings similar to houses built 50 years later.

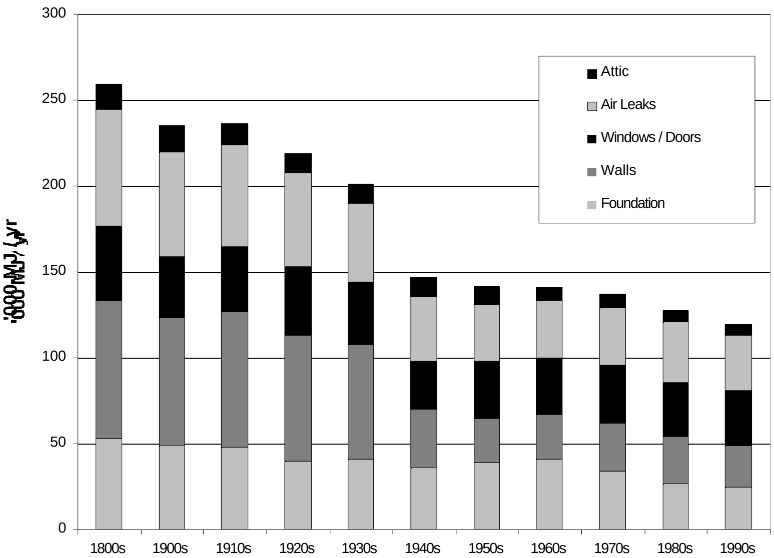
Canada is a Nordic nation and space heating is the most important single use of residential energy, accounting for 60% of residential GHG emissions (5). Consequently, it is particularly important to examine sources of heat loss when assessing the energy efficiency of Canada's housing stock. Figure 2 illustrates the average heat loss from five areas of the building envelope (by the date of construction), as derived from the HOT 2XP model and measurements of the physical characteristics of the building envelope. The oldest houses had the greatest heat loss, with a house built in the 1800s on average losing twice as much heat as one built in the 1990s. The 1940s marked a change in the pattern of heat loss as improvements were made throughout the building and with walls, in particular, becoming better insulated. Average heat loss was similar for houses built during the 1950s, 1960s and 1970s. Further improvements in the 1980s and 1990s were again inspired by the energy crisis of the 1970s.

Figure 1. Initial and Upgraded EGH Rating of Single Detached Dwellings (by Decade of Construction)



Walls are a major source of heat loss in houses built before 1940. Some walls remain uninsulated while others are only partially insulated. These walls typically represent 20-40% of the potential improvements that can be made to the building envelope of a pre-1940s house. In some cases, walls can be filled with insulation. In other cases, it is easier to install rigid insulation panels and update the exterior of the house.

Figure 2. Average Heat Loss in Single Detached Houses



Source: REEP EGH files

Uninsulated foundations and the header area where foundations support the floor are a major source of heat loss in most homes built before 1980. Construction practices improved with most basement walls being fully insulated in the 1980s. In the mid-1990s, partly to reduce the initial costs of new homes and thus increase construction starts, building codes were changed in some areas of the Province of Ontario (including the study area) to reduce insulation requirements on basement walls to only the above ground portion and to reduce required insulation levels in non-foundation (from R21 to R19) and foundation walls (R14 to R10). This weakening of standards was regressive from an energy efficiency perspective, as building envelope insufficiencies can go unaddressed for decades.

Air leaks are a major source of heat loss in old and new homes alike. In older homes air leaks typically account for 20-30% of heat loss. In newer houses (i.e. built since 1980), air leaks are smaller in absolute size, but larger in relative terms and may account for two-thirds of the potential to reduce heat loss because other areas of the building envelope have been improved to higher standards. Reduced air leakage is possible, but these newer houses often are quite ‘tight’ with limited fresh air entering the dwelling and additional ventilation must be added to ensure sufficient air exchange to avoid moisture and mould problems. A heat recovery ventilator or exchanger is often recommended to ensure a controlled source of fresh air without heat loss.

Windows and doors can be replaced to reduce heat loss, although the potential gains are typically smaller than those found in other areas of the house. Upgrading to insulated metal doors instead of wooden doors offers potential gains. Windows can be upgraded to triple-glazed, argon-filled or other advanced models, but the relatively high cost and limited fuel savings result in very long payback periods. Though when major maintenance or refurbishment is required, installing high performance windows and doors is very economically beneficial. Traditional solutions such as storm windows, stretch plastic sheets, or insulating drapes are more cost effective means to reduce heat loss through windows.

Attics are the final area of heat loss considered. The potential to reduce heat loss through attics was the lowest of the five areas, averaging only 10% of the total potential savings in the house. This result is partly explained by the success of the Canadian Home Insulation Program (CHIP), which operated from 1977 to 1986 and provided 2.4 million grants (approximately CDN$900 million, corresponding to 639 million Euro) to homeowners to meet part of the cost of increasing the energy efficiency of houses. Almost one-third of the eligible Canadian housing stock was upgraded under this program (16). Insulation installers promoted the program with a focus on increasing insulation in the attic because the attic is often easily accessible and increasing insulation there may be much less expensive than in other areas of the home.

If the ‘socially negotiated’ improvements were implemented (including each of the five areas described above), the EGH rating of the houses would be raised to the upgraded rating, with the attendant energy savings and CO_2 reductions (Table 1). Improvements can be made to houses in any age class, but the energy saving opportunities are not uniformly distributed. The least efficient 20% of houses account for 49% of the aggregate energy savings potential and the least efficient 50% of houses account for 82% of savings opportunities. Generally, the oldest houses offer the greatest opportunity for energy savings, but even those built in the 1980s and 1990s still can be improved to move toward the R-2000 standard score of 80. Energy savings of 30% or more were identified for each group of houses built prior to World War II. The savings were only slightly lower for houses built from the 1940s to the 1970s with savings averaging 26 or 27% for each group. Steps to reduce energy consumption further were identified for the higher efficiency homes of the 1980s and 1990s, but the absolute and relative size of these savings is smaller (20% and 12 %, respectively).

Overall, discussions between energy evaluators and homeowners have identified steps to reduce average CO_2 emissions from single detached houses by 21%. Actions were identified to reduce CO_2 emissions from the pre-1940 housing stock by 25-30% on average, while newer houses offered declining opportunities (e.g., only 10% reductions for houses built in the 1990s).

Table 1. Initial EGH Rating and Upgrade Potential of Single Detached Dwellings

Date Built	Initial EGH Rating average	Initial EGH Rating std. dev.	Upgraded Rating average	Upgraded Rating std. dev.	Average Energy Savings (%)	Average CO_2 Reduction (%)
1800s	46	15	62	9	30	25
1900s	45	14	64	8	35	28
1910s	43	11	63	8	34	27
1920s	48	11	67	5	37	30
1930s	51	11	68	6	34	28
1940s	61	7	72	4	27	22
1950s	64	7	73	4	26	21
1960s	65	7	74	4	26	18
1970s	66	5	75	3	26	19
1980s	71	4	76	2	20	15
1990s	75	4	78	2	12	10

The potential energy savings identified through this 'socially negotiated' home energy evaluation process (30%) is more conservative than the 'technically optimal' 65% estimated by (7).[6] Nonetheless, the GHG reductions required to meet the Kyoto target are possible in the residential sector of this case study region. To achieve the potential 21% CO_2 reduction identified in this study would however, require ***all of the*** homeowners to implement the full set of energy retrofit recommendations over the next decade. Furthermore, REEP has evaluated only 2.5% of the eligible housing stock in the case study communities. A greatly expanded HERS programme would be necessary to reach the remaining households in the case study, let alone all of Canada.

7. HERS BASED STRATEGIES FOR GHG EMISSION REDUCTIONS IN CANADA'S RESIDENTIAL SECTOR

In order to maximise GHG emission reductions from the residential sector, a strategic approach is required to increase the 'carbon-effectiveness' of Canada's EGH programme. Specifically, methods are required to identify those 50% of houses that contain 82% of the energy savings potential and directly recruit them for participation in the programme. If combined with initiatives to facilitate the types of energy related retrofits commonly required by these high-potential houses, substantial progress might be achieved.

Targeted HERS Activity

The analysis in the previous section indicated that to achieve meaningful GHG reductions in the residential sector would require retrofitting Canada's older housing stock. Consequently, the priority of the EGH programme should be to encourage the participation of owners of older houses. The majority of respondents to the REEP survey[7] (74%) supported mandatory EGH ratings for new houses. Similarly, in October 2000, the United Kingdom Government proposed that all new homes would have to display an energy rating notice. Although regulating the participation of newly constructed homes in HERS programmes would be beneficial for norm setting with regard to getting people to consider energy efficiency when purchasing a home, this approach does not target older homes where the most substantive energy savings generally exist. Conceivably, it could instead be required that before any house was sold, an energy rating had to be established for it. This is currently being explored as a policy option in Canada. As part of their Kyoto Protocol deliberations, the members of the Buildings Issue Table estimated that this initiative had the potential to reduce greenhouse gas emissions by 0.56 Mt in the year 2010, relative to their business-as-usual scenario (5).

Considering that all HERS programmes are currently voluntary, another approach is to identify neighbourhoods with the largest energy saving potential and actively recruit the participation of homeowners in these areas. REEP has experimented with a geographical information system (GIS) that incorporated six variables available from the Canadian census, in an effort to rank the suitability of neighbourhoods for HERS participation. Initial results have been positive and the selection criteria are being refined to better capture neighbourhoods that contain high priority houses (i.e., the 20% that hold 49% of the energy saving potential). Having identified high-potential housing areas, the challenge then becomes one of engaging homeowners in the HERS programme and facilitating action to improve energy efficiency of the home. The following section examines a range of strategies to accomplish this objective.

Facilitating Home Energy Retrofits by Homeowners

The REEP study also examined the barriers to energy efficiency actions in the home and the preferred strategies to overcome these obstacles. Participants were asked to indicate the importance of ten suggested barriers that prevented them from improving the energy efficiency of their home. The highest rated barrier was the initial cost of home retrofits, with more than 90% of respondents stating this was an important barrier for them. A number of options exist for governments to make it more economically attractive for individuals to make home energy efficiency improvements. Notably, the lack of information on what upgrades are needed was ranked second overall. This is an important barrier that REEP and EGH are specifically designed to overcome.

REEP participants were then requested to indicate whether they supported a number of energy policies and programmes. Table 2 outlines the level of support for the initiatives directly related to improved energy efficiency of housing. Regulatory initiatives that are not directly related to overcoming the financial barrier to home energy retrofits, but were discussed earlier in this paper (building codes and mandatory HERS), are included for comparison. A large majority of the respondents supported each of the proposed initiatives (both market-based and regulatory) and clearly expressed a desire for government policies that encourage homeowners to improve the energy efficiency of their homes.

Table 2. Respondent Support for Housing Related Energy Efficiency Initiatives

Proposed Government Initiative	Level of Support *
The purchase and installation of energy efficiency technologies (e.g., high efficiency appliances, solar panels) should be tax exempt.	93%
Governments should implement stronger energy efficiency standards for new homes.	92%
Governments and banks should make available low or no-interest loans for home energy upgrades.	87%
Governments should provide tax credits for homeowners who have improved the energy efficiency of their home by 25% or more.	85%
Governments should offer home energy upgrade assistance to low income families.	83%
EnerGuide home energy evaluations should become mandatory for real estate full-disclosure requirements.	74%

* Those indicating they ‘strongly agreed’ or ‘agreed’ with the statement

Market-based mechanisms have become an increasingly popular means of addressing environmental challenges. Canadian governments have used market-based mechanisms to advance residential energy efficiency in the past. The previously mentioned Canadian Home Insulation Programme (CHIP) is one example of a successful grant programme that had observable impact on energy efficiency of the housing stock examined in this study. A contemporary equivalent to the CHIP programme that specifically supported retrofit activity to reduce the primary sources of heat loss could build on the success of its predecessor. Unlike appliances and heating-cooling systems that eventually break down and are replaced or windows that are often replaced for aesthetic reasons, homeowners are often unaware of energy efficiency deficiencies in the building envelope. These building envelope defects offer substantial energy savings (see Figure 2) and the cost and inconvenience of addressing them are higher than some other energy efficiency upgrades. Promoting retrofits that capture these ‘hidden’ energy efficiency opportunities should be the focus of incentive programmes (specifically, wall and foundation insulation, reducing air infiltration and providing mechanical ventilation).

Ferguson's (16) analysis of the Canadian Home Insulation and Canadian Oil Substitution Programmes found that dwelling characteristics (age and fuel type) overshadowed the effect of socio-economic variables on programme participation. Nevertheless, he also found that the energy retrofitters that participated were significantly older and wealthier than non-retrofitters. Special efforts are required to ensure that lower income (particularly the 'fuel poor') households are able to access assistance for energy efficiency improvements. Programmes tailored to energy improvements in lower income housing were supported by over 80% of REEP respondents.

Two other Canadian residential energy efficiency initiatives specifically linked to HERS activity are the 'Home (Energy) Performance Rating Rewards Programme' (currently being piloted in a single Ontario community) and the energy efficient mortgage offered by the Yukon Territory Housing Corporation. The Home Performance Rating Rewards Programme offers rebates to homeowners that use Canada's EGH programme to identify and install energy efficiency improvements. The value of the rebate is based on the difference between the initial EGH rating and the verified post-improvement rating (a 10 point improvement would receive a rebate of approximately CDN $500, 355 Euro).

In 1999, the Yukon Housing Corporation began to offer homeowners access to mortgage financing that was 1% less than average posted interest rates. To qualify for the government subsidised energy efficient mortgage (EEM), homeowners had to undertake energy efficiency upgrades on an existing home or construct an energy efficient new home. This kind of activity is not restricted to governments. The Bank of Montreal, for example, offers 0.25% off of its mortgage rate when buying an R-2000 home (Edwards et al. 1999). Energy efficient mortgages are available throughout the United States and their use continues to grow significantly (i.e., EEMs supported by the US Federal Housing Administration increased eight fold from 1997 to 1999)) (13). It is hoped the EEM programmes offered by the Yukon Territory government and the Bank of Montreal, represent only the start of EEM use by Canadians. Supporters of EEMs in Canada argue that, if "government(s) were to guarantee a 0.5% reduction on 5-year mortgage rates [for R-2000 homes] it would save the new home owner approximately $4,000 (2,844 Euro) and reduce the length of his or her mortgage by roughly two years. If this resulted in 15% of all new homes being built to R-2000 standards, [greenhouse gas] emissions would be reduced by 0.5 Mt relative to projected levels for 2010." (17, pg 13).

An alternative approach to grants and subsidies is to reduce or eliminate taxes, so as to reduce the net cost of energy efficiency upgrades in the residential sector. This approach received the highest level of support from REEP respondents (93% - Table 2). A recent example can be found in the Province of Manitoba. When the government reduced provincial sales taxes on energy efficient windows, sales increased (18). When the tax break was eliminated, increased sales continued. It is clear that 'green tax' reform strategies such as this could be expanded considerably at both the provincial and national level.

8. CONCLUSIONS

The residential sector offers many opportunities for GHG mitigation through improved efficiency and substitution to less carbon intensive sources of energy. Residential energy consumption is examined in this paper as a global issue that requires a program of action at the local and individual scales. International and national policies may set overall targets, but local and individual action is required if the targets are to be achieved.

The current energy efficiency status of a representative sample of single detached houses (n = 823) in the case study of Waterloo Region (Ontario, Canada) was determined by detailed technical evaluations, using Canada's national HERS. Through interactive discussions with homeowners, energy efficiency upgrade plans were developed for each of the participants. This 'socially negotiated' approach identified potential energy savings that result in an average 21% reduction in attendant GHG emissions. Although the energy savings estimated in this study were substantially less than 'technically optimal' analyses of Canada's residential sector, they are socially contextualised and are still sufficient to meet Kyoto Protocol target levels (if Canada's 6% reduction target were applied equally to the residential sector).

The preceding analysis also investigated strategies to maximise the ‘carbon-effectiveness’ of Canada’s national HERS programme. Methods to target HERS activity to the 50% least energy efficient houses that hold 82% of the energy savings potential (or the 20% least efficient houses with 49% of the savings potential) are outlined. Respondents in Waterloo Region were supportive of both regulatory and market-based initiatives to advance the energy efficiency of the housing sector, clearly expressing a desire to move beyond the status quo. While co-ordinated efforts among different levels of government is most desirable, the results from the survey suggest that there may be sufficient public interest to support unilateral action on the part of any single level of government.

The overall vision for the REEP project has been community and citizen action to contribute to a healthier, more sustainable community, while simultaneously furthering Canada’s international commitment to the Kyoto Protocol. The Cities of Kitchener and Waterloo (within Waterloo Region) are members of the ‘20% club,’ a group of Canadian municipalities that seek to reduce GHG emissions within their community by 20%. The socio-technical analysis presented in this paper will assist these communities to implement a residential sector plan to contribute to their future goals of energy efficiency and sustainability. Through REEP, individuals are empowered to take action in their homes and to help cultivate a new community norm designed to improve energy efficiency and to reduce pollution and greenhouse gas emissions. The time for action on GHG mitigation has arrived and the authors are optimistic that the insights gained by this research and the collaboration displayed by the diverse set of organisations involved with the REEP project can help to illustrate initial pathways to foster GHG emission reductions in residential sectors of other North American communities.

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10. END NOTES

[1] The energy used by each sector includes direct consumption, also called secondary or end-use demand, (e.g., the natural gas burned in the furnace), and indirect consumption where a primary form of energy is converted to a more useful secondary form (e.g., coal or nuclear fuels consumed to generate electricity).

[2] The energy consumption and heat loss results are a product of the *HOT 2XP* computer model jointly developed by the Canada Mortgage and Housing Corporation (CMHC) and Natural Resources Canada (NRCan) and are dependent upon its internal structure and assumptions. For example, the standard set of assumptions in the HOT 2XP model includes: a household of four persons, thermostat setting of 22^0C for the heating season, uniform heating of all living space, and standard usage of a fixed set of appliances.

[3] The discussions between the energy evaluation team and homeowners were facilitated by the use of portable computers which displayed the results of the HERS analysis and what energy savings where possible.

[4] As of October, 2000. A copy of the survey instrument is available from the authors upon request.

[5] The R-2000 Home Program encourages the construction of new homes that go well beyond the minimum energy efficiency standard established in the 'Model National Energy Code for Houses' (MNECH).

[6] Unlike (7), the analysis presented here does not yet include the energy saving potential associated with upgrades to electrical appliances.

[7] It is important to acknowledge the limitations of the REEP survey responses. Because the survey respondents have shown an interest in energy issues by paying $25 to have a home energy evaluation completed, their opinions may differ from those of the general public.