Strategies to Reduce Residential Energy Use and Carbon Emissions: Reversing Canadian Consumption Patterns

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Abstract:

Canadian houses are more energy efficient than in the past, but the overall trend is continued growth in residential energy demand and greenhouse gas (GHG) emissions. A growing population, expanding economy, larger houses, greater demand for summer cooling, and increased ownership / use of a broader array of appliances, all contribute to increased demand for direct and indirect energy use by the residential sector. To reverse the pattern, strategies need to be devised to convert national policy objectives into actions at the local level. The *EnerGuide for Houses* (EGH) programme, administered by the Office of Energy Efficiency in Canada, provides standard ratings of energy efficiency and serves as a tool to identify improvements that can be made to existing houses. The programme is delivered by different agents across Canada and local participation rates vary widely. A successful community-based project (Residential Energy Efficiency Project) with a unique partnership of federal and local governments, local utilities and energy firms, an environmental non-governmental organization and a university is examined in detail. EGH participation rates among different regions are measured and the effectiveness of the local social marketing campaign in Waterloo Region is highlighted. Participation in the residential energy evaluation is only the first step and detailed surveys were conducted to assess the changes in behaviour and energy retrofit investment decisions made by residents in the first 1035 houses that participated in the case study. Factors contributing to community and individual actions are identified for use in the design of similar programmes in other jurisdictions.

Strategies to Reduce Residential Energy Use and Carbon Emissions: Reversing Canadian Consumption Patterns

Residential energy use continues to grow in OECD nations despite repeated reports of the opportunities to reduce energy consumption and associated greenhouse gas (GHG) emissions from this sector. This paper examines residential energy consumption as a global issue that requires a program of action at the local level. International and national policies may set overall targets, but local and individual action is required if the targets are to be achieved. The United Nations Framework Convention on Climate Change (UNFCCC) was opened for signature at the Earth Summit in Rio de Janeiro in 1992, and five years later the Kyoto Protocol established targets for the reduction of greenhouse gas emissions. By September 2000, 185 countries had ratified the UNFCCC and 84 countries had signed the Kyoto Protocol. On 8 September, 2000, Heads of State and Government expressed their resolve in the United Nations Millennium Declaration, to make every effort to ensure that the Protocol enters into force, preferably by the year 2002 (UNFCCC Secretariat, 2000). Negotiations in the Hague (December 2000) and in Nairobi (February 2001) failed to reach agreement among the parties on the rules to calculate net GHG emissions and to implement the Protocol. Despite international consensus among scientists (e.g. Intergovernmental Panel on Climate Change) that deferring action could cost trillions of dollars each year in damage related to climate change, a critical question remains. How do we devise strategies to enable people to take action where they live?

This paper sets the context of residential energy consumption by examining energy consumption and GHG emissions trends at the, international, national and provincial levels. Improvements in energy efficiency and reductions in carbon intensity are documented. However, aggregate demand and emissions continue to grow, thus making the modest Kyoto targets increasingly difficult to achieve overall in Canada and particularly in the most populous province, Ontario. A brief review is made of Canadian efforts to improve residential energy efficiency through national programs, such as the R-2000 building standard and the *Energuide for Houses* (EGH) program. The literature on energy efficiency is typically divided between technical studies of potential savings and behaviour studies examining implementation effectiveness. The call for an integrated assessment of technical potential in a particular social context is answered by the case study where the technical assessment is contextualised through discussions with homeowners to identify changes that they would consider. The Residential Energy Efficiency Project (REEP) in Waterloo Region, Ontario is examined as a case study where high participation rates were achieved and the technical evaluation of houses was combined with behavioural studies through social surveys. A representative cross-section of the housing stock was evaluated and the potential to reduce GHGs measured for the first 1035 houses. A follow-up survey of the participants reports the level of actions taken in the first year of the program. These results highlight the areas where homeowners were most willing to take actions and identify areas where they plan to make further changes in the future. The conclusion offers suggestions for the development of programs to engage the public in activities to achieve some of the identified socio-technical potential to reduce GHG emissions from houses.

International Context: Residential Energy Efficiency and Consumption

At the global level, the energy required to operate our homes, to heat or cool them to a comfortable temperature, to heat water, and to operate lights and appliances is enormous. Residential energy use is second only to industrial energy use with 70 EJ (22% of global energy use) consumed annually in the mid 1990s (IEA, 2000). It is increasingly accepted that the present pattern of energy production and consumption is unsustainable (Patterson, 1999). In response, societies around the world are beginning to recognise the need to reconsider energy production and consumption patterns. High income cities have been identified as the most important arena to reduce our levels of consumption through technical and behavioural change (Rees and Wackernagel, 1996; Rees, 1998).

Rather than continuing the trend of increased energy use and carbon emissions, improved energy efficiency is advocated as a way to reduce emissions through improved efficiency and conservation. Residential energy use in the United States was shown to be 40% more efficient in the early 1990s than in the early 1970s (Schipper, 1997). However, these gains in standardised energy use (MJ/m2/degree day) were partially offset by the increased demand for more houses, larger houses and increased demand for temperature control (e.g. cooling for comfort). Haas (1997) found less than a 20% reduction in average American residential energy demand (MJ/capita) between the early 1970s and the early 1990s. When adjusted for temperature and floor space, American residential energy consumption is similar to that in other OECD countries (Schipper, 1997), but the total amount of energy consumed is the largest among OECD countries because of the size of the population and housing stock. The potential for further efficiency gains is considered to be substantial in OECD countries, including the United States and Canada.

The industrialised countries account for 41 EJ or 59% of the total residential energy consumed worldwide in 1995 (IEA, 2000). The trend of industrialised countries using a declining share (from 68% in 1970 to 54% in 1990) of global residential energy was reversed in the early 1990s when their share rose to nearly 60%. Given the adoption of 1990 as the base year for Kyoto Protocol targets, the trend of all sectors increasing their aggregate energy consumption in the 1990s creates a growing challenge if GHG emissions follow the same trend.

Table 1: OECD Primary Energy Use and Carbon Emissions by Sector (1960-1995)

In the OECD, energy consumption in the residential sector grew at 2% per annum (1990-95) while carbon emissions grew more slowly (0.8% per annum) because of changes in the fuel mix. The gains made in reduced CO_2 emissions from housing stock in the industrialised countries during the 1980s were quickly erased in the early 1990s (Table 1). Clearly, it is time to consider how a country could convert shared international policy objectives into national programs to address their pattern of GHG emissions associated with energy use.

Canadian GHG Emissions and the Residential Sector

In Canada, the need to reduce energy consumption and GHG emissions is particularly apparent. As a nation, Canada is one of the largest per capita consumers of energy in the world and among the ten largest emitters of industrial GHGs in absolute terms (despite its relatively small population) (WRI, 1998, 175). The Canadian government signed and ratified the UN Framework Convention on Climate Change and has indicated its desire to reduce GHG emissions by 6% from 1990 levels under the Kyoto Protocol. Nonetheless, the overall trend in Canada is to continue to increase GHG emissions (from 612 Mt CO_2 in 1990 to 692 Mt CO_2 in 1998, EC, 2000).

Improved energy efficiency is a proven means to reduce energy consumption and GHG emissions. The Canadian government established an Office of Energy Efficiency in 1998 and releases its report on *The State of Energy Efficiency in Canada*, annually. The report concludes that improved energy efficiency during the 1990-98 period reduced national energy use and GHG emissions from even higher levels if new technologies had not been introduced (OEE, 2000a). Efficiency gains restricted the growth in secondary energy use over the 1990-98 period to 9% and GHG emission growth to 10%. If no gains had been made, energy consumption would have grown 15%. The financial savings from reducing 1998 energy use by 6% are estimated at $5 billion (CDN) per year (OEE, 2000a).

The distribution of Canadian energy consumption and GHG emissions by sectors differs from the OECD average because of the size of the country, its industrial structure and its low density pattern of development. Industry is the largest consumer of secondary energy while transportation has grown to exceed industry as the single largest source of GHG emissions in the late 1990s. The residential sector is the third largest consumer of energy and source of CO_2 emissions in Canada (17% and 15% respectively in 1998, OEE, 2000a). The trend over time shows that direct Canadian residential CO_2 emissions peaked in the early 1970s and then declined with the efficiency gains stimulated by high oil prices and government programs in the 1970s and early 1980s (Figure 1). Efficiency gains since the early 1980s have been offset by increased demand and overall emissions rose slowly from 1980 to 1995. Considering that the residential sector accounts for 1 of every 6 tonnes of GHGs emitted, it provides an important opportunity to address global climate change through individual actions to reduce emissions.

Figure 1: Residential CO2 Emissions in Canada, 1960-95

Significant potential for improvements in the energy sustainability of the residential sector exists. The Pembina Institute and David Suzuki Foundation (1999) reported that the Canadian housing stock could be made 20 to 30% more energy efficient and residential sector greenhouse gas emissions reduced 39% by 2010 (from a 1990 baseline). The Ontario Global Warming Coalition (1991) concluded that a 34% reduction in CO_2 emissions resulting from residential sector energy use in Ontario was possible by 2005 (from the 1988 level). Under technically optimal conditions, the residential version of the Intra-Sectoral Technology Use Model projected that per capita energy demand in the residential sector of Canada's three most populated provinces could be reduced by 65% between 1988 and 2008 (Jaccard et al., 1996). The principal means to achieve these energy savings is improved energy efficiency in the home building envelope and domestic appliances.

Energy efficiency in houses has been addressed both through the use of advanced designs and technology in new houses and the upgrade of the existing housing stock. The advanced design approach is illustrated by the R-2000 standard adopted in Canada. Established in 1982, the R-2000 Home Program aims to encourage the building of 'energy-efficient houses that are environmentally friendly and healthy to live in' (OEE, 2000b). Although the standard has been available across the country since 1982, the adoption of the standard is estimated at 0.7 % of the new houses built between 1990 and 1996 (NRCAN, 1998, 57). More commonly new houses are built to offer as low an entry price as possible while meeting the provincial building code. Energy savings opportunities may be lost in the rush to achieve low purchase prices.

Forecasting Future Residential GHG Emissions

The combined direct and indirect energy use of the residential sector grew in Canada and most industrialised countries during the 1990s. This continued growth in energy use and the associated GHG emissions creates the need to revise forecasts of future emission levels. When the Analysis and Modelling Group of Natural Resources Canada prepared their 1997 and 1999 forecasts of Canadian energy use and GHG emissions to help frame the Climate Change National Implementation Strategy, they identified the residential sector as the only sector expected to reduce GHG emissions by 2010. However, the optimism of the 1997 report that expected the residential sector to reduce its 2010 GHG emissions by 14%, relative to the 1990 base level, was not maintained (NRCAN, 1997). The revised data and methods used in the 1999 study concluded that residential emissions would only decline 2% below the 1990 level by 2010 (NRCAN, 1999). To achieve this reduction, the average annual use of 133 GJ of energy per household in 1990 is forecast to decline by 22% to 104 GJ per household in 2010 (NRCAN, 1999).

In addition, the forecast 2% decline shown for the residential sector only relates to direct consumption and emissions. Actual energy use and emissions resulting from residential activity should include the indirect emissions from the electricity and fossil fuel production sectors that are expected to increase emissions, by 25% and 64% respectively, in part to provide electricity and fuel (e.g. natural gas and oil) for use in the home (NRCAN, 1999). The inclusion of the residential share of expected growth in emissions from these sectors results in the residential sector increasing its total (direct and indirect) emissions over the 1990-2010 period.

Another study, the *1999 Buildings Table Options Report* prepared for the first ministers of Canada, forecast GHG emissions from the residential sector to decline slightly from 68 Mt CO2 in 1990 to 66 Mt CO2 in 2010. This 3% decline represents a 7% decline in direct GHG emissions and a 2.6% rise in indirect emissions (Marbek, 1999). Space heating remains the most important single use of energy accounting for 60% of residential GHG emissions. Water heating is second (22%) followed by appliances (13%) and lighting (4%) (Marbek, 1999). Space heating is thus selected as a primary area for improvement through the federal government's EGH program.

Residential GHG Emission Trends in Canada and Ontario

The residential sector highlights two conflicting trends (Parker et al., 2000a). Direct energy used in the home for space heating is expected to decline through improvements in energy efficiency in furnaces and house construction. However, indirect energy consumption and the associated GHG emissions are expected to rise because of the increased penetration and use of electrical equipment and appliances (Marbek, 1999). Canadian residential energy consumption is forecast to rise 6% above 1990 levels by 2010 and not decline as reported in earlier forecasts (NRCAN, 1999). In Ontario, the province with one-third of Canada's population, residential energy consumption is forecast to rise twice as fast as the national average (by 13% from 1990 levels). Unlike the national pattern where GHG emissions are forecast to decline by 2% through switching to less carbon intensive fuels, Ontario is expected to increase the carbon intensity of its energy supply system. Electricity is increasingly coming from fossil fuel sources as the nuclear and hydro generating capacities are constrained, respectively, by aging equipment and the limited potential of remaining sites.

In addition to the expected increase in direct GHG emissions from houses in Ontario, an even faster growing source of GHG emissions is expected to come indirectly from electricity produced for use in appliances and equipment located in the home. Ontario Power Generation (OPG ,2000) expects residential sector electricity consumption to continue to grow (to 37.5 TWh in 2003) despite the promotion of more efficient houses and appliances. The residential sector accounts for 26% of total electricity demand in Ontario and creates an uneven load with peaks in hot and cold seasons. The traditional pattern of Ontario having a peak winter demand is changing to one of peak demand in the summer as occurred in the summers of 1998 and 1999. The long term trend of winter peaks growing at 0.8% per annum and summer peaks growing at 1.6% per annum results in Ontario being forecast to shift to a summer peak load by 2005 (OPG, 2000). These trends are accelerated by the expected effects of climate change and highlighted by the hot summers of 1998 and 1999.

The GHG emissions associated with increased energy use in Ontario's residential sector are forecast to be 17% above 1990 levels by 2010 (NRCAN, 1999). This 17% growth rate in emissions from Ontario houses is exactly the same as the growth rate for total Ontario emissions. To achieve significant reductions in Canadian GHG emissions, substantial changes are required in Ontario.

If expected improvements in residential energy efficiency are not enough to reduce GHG emissions, let alone achieve the Kyoto Protocol target, what can be done to improve energy efficiency in the residential sector further? The literature on reducing energy demand can typically be divided into two approaches: technical and behavioural. Essentially, the residential energy efficiency related research consists of those who determine the 'technical potential' for energy efficiency and those who endeavor to change energy consumption patterns and have the technology applied to close the 'efficiency gap' (Shove, 1998).

The technical approach to energy efficiency

At the macro-scale, the technical literature consists of nationally aggregated studies of energy consumption and conservation potential in the residential sector. The Canadian Residential Energy End-use Data and Analysis Centre (CREEDAC) at Dalhousie University has been at the forefront of this research in Canada. Ugursal and Fung (1998) found that the magnitude of potential carbon dioxide reductions from home appliance efficiency improvements in Canada was small (7% with 100% market penetration), and that meaningful reductions in the residential sector would have to come from improvements to house structures, heating systems, and fuel substitution.

At the household level, a number of Home Energy Rating Systems (HERS) have been developed. Through a comprehensive analysis of the home structure, HERS determine how energy efficient a home is (usually on a standardized scale) and provide recommendations for improvement. HERS have been utilized in a large number of residential energy programmes in the USA, often as part of energy utility demand side management (DSM) initiatives mandated by the federal Residential Conservation Service. Canada Mortgage and Housing Corporation (CMHC) and Natural Resources Canada (NRCan) have jointly developed a highly detailed computerized HERS model (*HOT 2XP)*, that now serves as the basis of the national *EnerGuide for Houses* (EGH) programme.

The *HOT 2XP* model has also been used to identify the potential savings in a house if an upgrade is made. The upgrade can then be applied universally to the entire housing stock that could accommodate the change (CREEDAC, 1999). The same technique is used to estimate the potential reductions in GHG emissions by undertaking particular upgrades (CREEDAC, 2000). Many upgrades are possible, but even the universal adoption of the list of upgrades shown in Table 2 is not sufficient to achieve a 20% reduction in energy consumption.

Table 2 about here

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. However, it is clear that technical potential is greatly constrained by social factors (Hirst and Brown, 1990). Rees (1998) concludes that the present political environment makes it unlikely that the full potential of 'green buildings' will be realised. As a result, any notion of purely technical potential, abstracted from its social context in, is at best an optimistic measure (Shove, 1998). If participation is less than 100%, then the savings are reduced accordingly. To illustrate the problem a study by Pembina / Suzuki (1999) assumed that 50% of the population participated in upgrade programs. The immediate result is that to achieve an overall 20% reduction, participants would need to make 40% reductions on average.

The behavioural approach to energy efficiency

In contrast, the behavioural approach recognises the central role of people if the desired changes in energy consumption and GHG emissions are to be achieved. Two houses may be technically identical, but differences in the choices and behaviours of the two families living in the houses may result in significant differences in consumption levels. Social scientists interject the human dimension that a US National Research Council study (Stern and Aronson, 1984) concluded was missing from technically driven initiatives to improve energy efficiency in the residential sector.

Attitudinal studies of energy use and conservation have shown that general environmental attitudes are not highly predictive of self-reported energy conservation (Olsen, 1981; Nevitte and Kanji, 1995). In contrast, studies of energy specific attitudes have identified four attitudinal dimensions that comprise a common 'frame of reference' concerning energy consumption: 1) comfort/health, 2) high effort/low payoff, 3) personal efficacy, 4) legitimacy of energy problems (Samuelson and Biek, 1991). 'Socialisation' has been shown to be another important factor: if there is a feeling that 'everyone is doing it', then the individual is more likely to participate in energy efficiency or renewable energy-related activities (McGuire, 1985). The way in which participation (or non-participation) in the activity is 'seen' by the immediate community will also be important (Stern, 1992). The relative importance of motives and socio-demographics has been shown to vary situationally. For low-cost investment and repetitive energy management actions, personal norms and energy attitudes can make a difference, while expensive technology investments are influenced more by positional factors like home ownership (Black et al., 1985).

The ‘rational-economic’ model of behaviour has been shown to be inadequate to explain residential energy use patterns and its adoption was an important contributor to the ineffectiveness of early technical-based residential energy efficiency programs in Canada and the US (Mackenzie-Mohr, 1994). Nonetheless, financial considerations exert a strong influence on energy consumption and energy efficiency decision making. When energy prices fell in the 1980s, conservation patterns related to resetting thermostats began to diminish (US Dept. of Energy, 1989).

The ‘interventionist’ research has primarily employed two types of strategies to change energy consumption: 1) information or consumption feedbacks, 2) incentives or disincentives. While lack of knowledge or program awareness are salient barriers to energy efficiency improvements, simply providing information has not proven effective (Geller, 1992). Information designed to appeal to multiple motivations and framed in terms of loss prevention rather than gains has been shown more effective for behaviour change (Mackenzie-Mohr, 1994). The credibility and trustworthiness of the information source have also shown to be highly relevant (McGuire, 1985). Information is most likely to lead to behaviour change when energy prices or public awareness are high (Kempton et al., 1992).

Robinson (1991), Mullaly (1998) and Shove (1998) lament the lack of interaction between the technical and social bodies of literature. Shove (1998) challenged researchers to reject the conventional split and to pursue an integrative socio-technical course of research. The Waterloo Region of Ontario is the location of the REEP study that responded to this integrative challenge by evaluating the technical potential for savings based on the choices made by householders in their particular social context (Scott et al., 2000). It integrates the technical and behavioural approaches at the local level.

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 (REEP, 1998). The project is situated in Waterloo Region (population 450,000) in south-western Ontario, 100 kilometers from Toronto. The project is designed to build public awareness and understanding of the climate change issue and to provide technical information and social dialogue about the link to personal energy consumption (Parker et al., 2000b). More importantly, through direct personal contact, the project aims to empower behaviour change by identifying the sustained benefits of energy efficiency and providing a practical course of action for homeowners to follow.

Each home evaluation entails a visit by a two-person team for two hours on average. The certified energy evaluator initiates discussion with the homeowner regarding issues of concern such as comfort, cost, particular problems, house construction, and fuel selection. A detailed inspection is made of wall construction, insulation type and thickness, heating equipment, cooling equipment and major appliances. The student (intern) team member measures the size of the house, its walls, windows, doors and other features and enters the data into a portable computer on-site. An air tightness test is conducted with an infiltrometer and the number of air changes per hour is calculated. Areas where significant air leakage occurs are identified.

The study was funded in large part by the Canadian government's Climate Change Action Fund and the EGH programme. The REEP project completed 1,035 evaluations (823 single detached dwellings and 212 row houses) between May 1999 and May 2000. The single detached houses in the sample have a similar age profile as the total Waterloo Region housing stock (Parker et al., 2000a). The technical data on the houses are complemented by a comprehensive survey of attitudes and behaviours related to energy use (Scott et al., 2000b) and policy preferences (Rowlands et al., 2000). The survey was given to homeowners at the time of the evaluation and a prepaid envelop was included for the return of the initial survey. A total of 527 valid surveys were returned from residents in the 823 single detached dwellings for a response rate of 64%. In August and September of 2000 a follow-up survey was mailed to each of the homeowners and questions were asked about actions taken or planned since the REEP visit. A total of 197 surveys were returned for a response rate of 24%. In contrast, the row houses were typically evaluated as a group and discussions were held with the maintenance manager instead of the resident, so no surveys were distributed to this group.

REEP Results

The technical and behavioural data generated by the project offer many insights into the implementation of a community-based program to reduce residential GHG emissions. The technical component of the project generates data that are standardised across Canada. The EGH program is delivered across Canada by a variety of delivery agents (OEE, 2000c; Table 3). In each case, technical evaluations are made of houses to measure their current energy requirements and to identify areas for potential improvement. The Green Communities Association (GCA) delivers EGH throughout Ontario (with the exception of the Sudbury area), through its member environmental non-government organisations (ENGOs) located in 11 Ontario communities. The Elora Centre for Environmental Excellence is the GCA partner in REEP. The REEP project is also the only EGH delivery agent to include a university (the University of Waterloo) in the partnership. In other provinces private interests take the lead as demonstrated by the Home Builders Association in Nova Scotia or the Sun Ridge Group in Saskatchewan and Building Insight Technologies in the other western provinces. The latter firm has the distinction of generating more evaluations than any other agent in the country. Their approach is a traditional direct marketing technique with phone calls made from a central call centre to prospective clients. In contrast, the Yukon delivery agent is in the public sector where the Yukon Housing Corporation not only makes evaluations, but offers a subsidy in mortgage rates to houses that achieve an EGH rating of 80 or more (OEE, 2000c).

Table 3 Technical EGH evaluations by Canadian region

The REEP project illustrates how a project with strong local linkages in a region that accounts for just 1.4% of Canada's population (Table 3) can grow to contribute 10% of all EGH evaluations across the country in its first 1 1/2 years of operation. By October 2000, the project had the second highest participation rate in the country with over 3 evaluations per thousand population. The Yukon Housing Corporation achieved the highest participation rate of over 10 evaluations per 1000 population. The private firms operating in the western provinces averaged 1 evaluation per 1000 population while the eastern provinces had lower participation rates.

The success of REEP in engaging local homeowners is argued to be a function of active community participation and the removal of information and financial barriers. The project participated in 46 community events in its first year and reduced the evaluation fee paid by homeowners to $25 (Kennedy et al., 2000). As well, local marketing initiatives were found to be more effective than national advertising campaigns.

Potential Energy Savings

The study found that residential energy efficiency has improved dramatically over the last century (Figure 2). The sample of 823 single detached dwellings was assessed for space heating energy consumption under a standard set of conditions (e.g. 22 degree temperature). Houses built before 1940 consumed over 1,000 MJ/m2/yr, whereas houses built in the 1990s were three times more efficient. Clearly building techniques and materials have improved significantly. One surprising finding was that the houses built in the 1800s were better than those built in the first three decades of the 1900s, on average. One suggestion is that the least efficient houses from the 1800s may have been replaced and only the better houses maintained. The general pattern is for older houses to consume more energy with continuous improvements made throughout the century and a bigger step achieved in the 1940s. The oil crises of the 1970s stimulated increased concern about energy consumption and improved building standards that further reduced average energy consumption among houses built in the 1980s and 1990s. Further improvements are possible as more houses are built to meet the R-2000 standard.

Figure 2 Residential space heating efficiency, 2000 housing stock by date of construction

The findings of improved residential energy efficiency in Canadian houses support the findings of (Schipper, 1997) who measured 40% efficiency gains between the 1970s and the 1990s in American residential energy patterns. However, the improvements in efficiency per unit of floor space are partially offset by the trend to build bigger houses.

Given the high energy consumption levels of older houses, the challenge is to identify areas where heat loss can be reduced and to persuade the homeowner to take action. The EGH evaluation examined five areas of the building envelope where opportunities for improving energy efficiency could be found (attic, walls, windows/doors, foundation and air leaks). The average potential to reduce heat loss in each of these areas is shown in Figure 3. Uninsulated foundations and the header areas where foundations support the floor are a major source of heat loss in most homes built before 1980. Construction practices changed with most basement walls being fully insulated in the 1980s.

Figure 3: Recommended areas to reduce heat loss in single detached dwellings

Overall, recommendations were made to reduce the average heat loss of houses built before 1940 by 60-70 GJ/yr. Reducing air leaks, and insulating the walls and foundations were the three most important areas for improvement in these homes (Parker et al., 2000a). Houses that were built in the 1940s, 1950s and 1960s could reduce their heat loss by 30 GJ/yr on average. Insulating foundations, sealing air leaks, and upgrading doors and windows offer the greatest potential savings for these houses. Houses built in the 1980s and 1990s still can have air leaks sealed, but adequate ventilation must be ensured. In some cases, selected doors and windows should be replaced, or insulation added to the foundation or attic. The actions appropriate for each particular house were identified by the energy advisor and discussed with the homeowner. The reduction in heat loss through the building envelope reduces the amount of energy used to heat or cool each house and thus cuts fuel consumption and the associated GHG emissions.

Overall, discussions between energy evaluators and home owners 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).

Reported Actions by Homeowners

The literature on energy savings recognises a major divide between studies that identify the technical potential to improve energy efficiency and those that examine personal behaviour. In Canada, the federal government followed up its EGH delivery program with a survey of selected participants (310 homeowners). The results of the survey indicate that 69% of respondents implemented the recommendations with 31% of those taking action doing all of the recommendations (Tremblay, 2000). Given the delivery of the same EGH technical evaluation, but with more opportunity to discuss actions and the environmental consequences with the student intern, the implementation rates of REEP participants were assessed.

A follow-up survey was distributed to 823 households and 197 responses were received. An extensive list of potential actions was provided and 80% of respondents reported undertaking at least one action after the REEP visit (Table 4). The 20% of respondents who reported taking no action were followed by 23% who reported undertaking a single action. This single action could be a small action such as the addition of weather stripping around windows or doors.

Alternatively, the action could have major energy consumption implications, such as replacing the furnace. The majority of respondents (47%) took multiple actions with 21% reporting five or more actions.

Table 4: Number of actions reported by residents following an energy evaluation

The installation of insulation is one of the most common means to reduce heat loss in houses. Table 5 presents the proportion of respondents who reported installing insulation before the REEP visit, after the REEP visit, or that plan to install more insulation in the next two years. The items are arranged in order by the proportion of respondents who took action following the REEP visit. The most common area for the addition of insulation after a REEP visit was the basement header (13%). Basement walls, attic, heating ducts, and exterior walls follow with 4-7% of respondents adding insulation in each of these areas. The insulation of exposed floors, such as above a garage, was less common (2%) due primarily to this configuration being unusual in a home.

Table 5: Insulation added or planned, % of respondents

The identification of the header as the most common area for action (13%) is interesting because it is also the only item where installation after the REEP visit is much higher than installation before the visit. This suggests that the evaluation serves an educational role in identifying an area of heat loss that fewer people were aware of. In comparison, the addition of insulation in the attic is the most common action (16%) taken before the REEP visit. The attic is both an obvious place for the addition of insulation, and is also the area where many insulation installers focussed their efforts when the Federal government provided an incentive program (Canadian Home Insulation Program) to improve insulation levels in the late 1970s and 1980s (Ferguson, 1993). The attic is also the area where the largest proportion of respondents plan to add more insulation in the next two years.

Homeowners also took actions to install a wide range of items to improve the energy efficiency of their houses (Table 6). The most common action taken following a REEP visit was the installation of weather stripping around doors and windows (19%), followed by weather stripping around vents and pipes (13%). New roof vents were added in 12% of the houses. Programable thermostats were installed by 11% of respondents after the REEP visit, but this item was also the most frequent action taken prior to REEP (34%) indicating that its benefits are widely known. New exhaust fans were installed by 9% of respondents following the REEP visit with a further 19% of respondents planning to install new fans. Heat recovery ventilators were recommended to ensure a supply of fresh air in houses that were tightly sealed and 6% reported installing these air exchangers with a further 7% planning to take this action in the future. The proportion of people planting trees for shade or adding awnings for shade was lower (5% and 1%, respectively).

Table 6: Items installed or planned to improve energy efficiency, % of respondents

Many people reported replacing household equipment with more energy efficient units (Table 7). The most common item for replacement was windows with 13% reporting action taken since the REEP visit and a further 13% planning action in the future. The furnace is the most important single item in the energy efficiency of a home and 11% of respondents reported replacing their furnace following the REEP visit and a further 10% plan to replace their old furnace within the next two years. A substantial number of households (5-10%) reported replacing their water heater, ceiling fans, air conditioner, kitchen appliances, laundry appliances, or doors following the REEP visit. Some of these items were replaced because of routine needs, but in other cases energy efficiency was a primary consideration. The increased energy efficiency awareness generated by the EGH evaluation is hoped to raise the attention given to energy ratings, such as the national *EnerGuide* rating system for appliances and heating equipment, for the selection of items to purchase.

Table 7: Items replaced to improve energy efficiency, % of respondents

Conclusion

Houses are a major global energy consumer (70 EJ in the mid-1990s compared to 41 EJ in 1971) and source of GHG emissions. Significant technical potential to reduce these emissions is known. However, previous energy studies highlighted the need to include social and behavioural considerations in studies assessing ways to achieve these potential reductions. In Canada, the energy efficiency of houses has improved by a factor of three over the last century, however, further advances of 20-30% are still possible. Advanced building techniques and standards (including a well insulated and sealed building envelop with mechanical heat recovery ventilators for fresh air) have been established through the R-2000 program. Although less than 1% of new houses are certified as meeting the R-2000 standard, many builders are incorporating some of the features as part of their regular practice. The general improvement of energy efficiency in houses built in the 1990s can be interpreted as the successful transfer of improved techniques to the building industry.

If the average Canadian house achieves the 22% gain in efficiency (between 1990 and 2010) optimistically assumed under a 'business-as-usual' scenario (NRCAN 1999), residential sector direct GHG emissions will only decline by 2% nationally. In Ontario, residential sector GHG emissions are expected to rise by 17%. To achieve the Kyoto target of a 6% reduction in this sector, the housing stock needs to be improved far more rapidly than forecast. Since the majority of houses are already built, improvements must come from retrofits of this stock.

One of the principal barriers to improving the existing housing stock is the lack of information that homeowners have about the impact that changes would have on their energy use and the associated GHG emissions. Home Energy Rating Systems (HERS) overcome this problem by providing a standardised rating of household energy consumption. The Canadian HERS (*Energuide for Houses* - EGH) is used both to evaluate houses and to provide a set of recommended upgrades. To achieve residential energy improvements, homeowners must first decide to participate in the program and second to implement the recommendations.

Participation in the EGH program is highest in the Yukon where mortgage subsidies are offered to owners of houses that achieve a rating of 80 (equivalent to an R-2000 house) or higher. In southern Canada, the Region of Waterloo in Ontario has achieved a high participation rate through the REEP project. The project focussed on social marketing techniques and participated in 46 community events in its first year of activity. Active involvement in the community was combined with a broad based partnership of respected institutions (local government, national government, utilities, ENGO and university) to strengthen the trust in the providers of the evaluation service. Social recognition and trust were combined with a low fee ($25) to encourage participation from a broad spectrum of residents.

A follow-up survey was conducted to determine whether or not residents took action, and if so, to identify the areas of greatest activity. Overall, 80% of the respondents who returned the follow-up survey implemented one or more of the recommendations made during the energy evaluation.

While 23% of respondents indicated that they only took one of the listed actions, a similar proportion (21%) reported taking five or more actions after the REEP visit.

The seven-page home energy report given to the homeowner by REEP provided a reference list for the homeowner to make well informed decisions about improving the energy efficiency of their home. An indication of the value of the information service is the change in actions taken before and after the REEP evaluation. The most common area to add insulation prior to a REEP visit was the attic. However, the basement header area jumped from being the fourth most common area for insulation (8% of respondents) prior to REEP visits to being the most common (13% of respondents) after the evaluation. It is suggested that this area is often overlooked and illustrates how additional information can change homeowner priorities in selecting actions to improve the energy efficiency of their homes.

Homeowners undertook both inexpensive actions, such as installing weather stripping around doors and windows, and made major investments, such as new furnaces or heat recovery ventilators, following their REEP visit. The provision of home energy evaluations is thus argued to be an effective step in enabling homeowners to take steps to improve the energy efficiency of their homes. These steps also reduce the cost of energy to homeowners, stimulate the local economy and reduce GHG emissions to help achieve Kyoto targets.

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Table 1: OECD Primary Energy Use and GHG Emissions By Sector

Sector Primary Energy Use	1960 EJ	1971 EJ	1980 EJ	1990 EJ	1995 EJ	1990-95 %AAGR
Industry	27.7	48.6	55.0	54.3	56.9	0.9
Residential Bldgs	16.6	28.3	33.0	36.7	40.6	2.0
Commercial Bldgs	11.7	16.2	19.3	25.6	27.9	1.8
Transport	14.7	26.2	32.5	39.4	43.3	1.9
Agriculture	1.2	1.8	2.1	2.8	3.0	1.6
Total	71.9	121.1	141.9	158.8	171.7	1.6

Sector GHG Emissions	1960 MTC	1971 MTC	1980 MTC	1990 MTC	1995 MTC	1990-95 %AAGR
Industry	622	932	970	887	851	-0.8
Residential Bldgs	323	522	549	539	560	0.8
Commercial Bldgs	111	268	336	377	398	1.1
Transport	287	494	612	743	816	1.9
Agriculture	22	35	38	48	51	1.3
Total	1565	2252	2506	2593	2677	0.6

note: MTC (million tonnes carbon); %AAGR (% average annual growth rate)

source: IEA 2000

Table 2: Potential GHG Emission Reductions from Residential Upgrades

	kg/yr /house	% of Stock	% of resdiential emissions cut
Space heating to high efficiency	1,682	37	9.4
Hot water to high efficiency	82	87	1.0
Ceiling RSI = 8.8	236	92	3.2
Basement ceiling RSI = 5.28	994	8	1.2
Basement wall RSI = 3.5	586	43	3.6
Windows single to low-E triple	582	11	0.9

Source: CREEDAC, 2000.

Table 3: EGH Evaluations by Canadian Region and Year, #/'000 population

Region	Delivery Agent	1998/99 #/'000	1999/00 #/'000	2000/01 #/'000	Total #/'000	Population '000
Ontario, Total	Green Communities Association	0.07	0.27	0.14	0.48	11669
Waterloo Reg.	REEP	0.00	1.76	1.77	3.53	450
Ontario, Other	Green Communities Association	0.07	0.20	0.07	0.34	11525
Newfoundland	Heat Seal	0.07	0.02	0.27	0.37	539
Nova Scotia	Home Builders Association	0.00	0.31	0.22	0.53	941
Quebec	Agence de l'efficacite energetique	0.02	0.03	0.03	0.08	7372
Saskatchewan	Sun Ridge Group	0.01	0.51	0.54	1.07	1024
BC, Alberta, MB	Building Insight Technologies	0.44	0.59	0.54	1.56	8209
Yukon	Yukon Housing Corporation	2.80	6.25	1.14	10.20	30.7
Canada	All	0.15	0.30	0.24	0.69	30750

Note: Data are for financial years (April to March) except 2000/01 (April to October)
Source: OEE, 2000c. response to data inquiry

Table 4: Number of actions reported by residents following an energy evaluation

# of actions	% of respondents
0	20
1	23
2	15
3	11
4	11
5	6
6-7	9
8-9	3
10+	3

Note: n = 197 respondents

Source: REEP Follow-up Survey

Table 5: Insulation added or planned, % of respondents

Installed:	Action taken prior to REEP visit	since REEP visit	Plan to Within 2 years
	% of respondents		
Basement header	8	13	14
Basement walls	12	7	19
Attic	16	5	22
Heating pipes / ducts	6	5	6
Exterior walls	10	4	9
Floor	2	2	3

Note: n = 197 respondents

Source: REEP Follow-up Survey

Table 6: Items installed or planned, % of respondents

Installed:	Action taken Prior to REEP visit	since REEP visit	Plan to Within 2 years
	% of respondents		
WS doors or windows	22	19	17
WS vents or pipes	13	13	16
New roof vents	18	12	7
Programmable thermostat	34	11	7
New exhaust fan(s)	12	9	19
Foam pads: electrical outlets or switches	21	7	17
Heat-recovery air exchanger/ventilator	4	6	7
Storm windows or doors	22	5	6
Planted trees for shade	24	5	5
Water heater blanket	4	1	10
Awning(s) for shade	6	1	3

Note: n = 197 respondents

Source: REEP Follow-up Survey

Table 7: Replaced or plan to replace an old unit with a more efficienct unit, % of respondents

Installed:	Action taken prior to REEP visit	since REEP visit	Plan to Within 2 years
	% of respondents		
windows	20	13	13
furnace	19	11	10
ceiling fans	13	10	4
kitchen appliances	18	9	6
water heater	22	8	6
air conditioner	10	7	4
laundry appliances	19	7	6
doors	14	7	10

Note: n = 197 respondents

Source: REEP Follow-up Survey

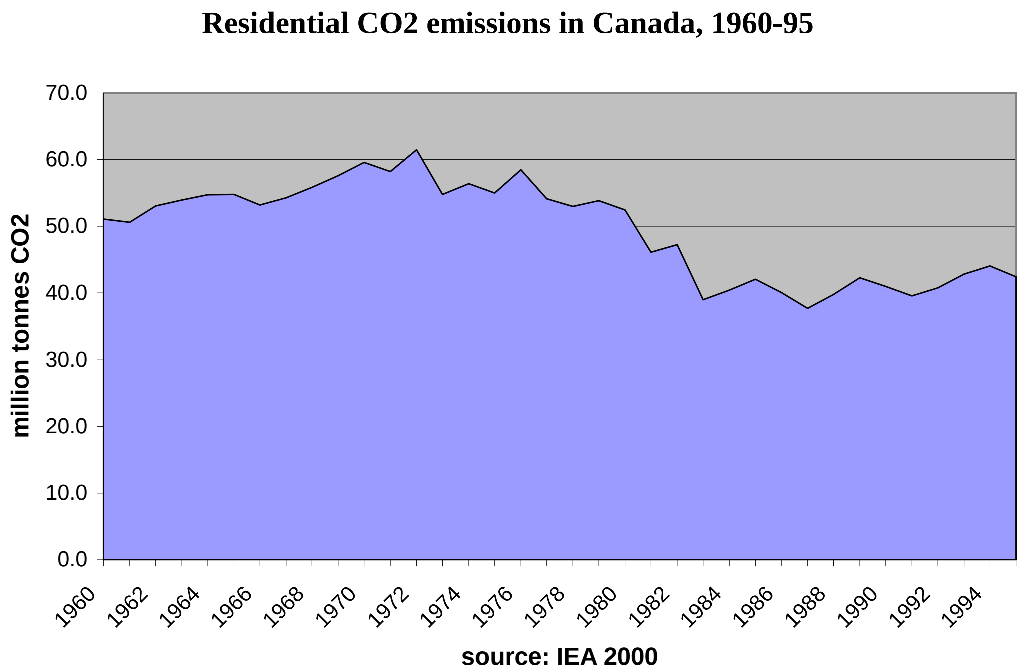
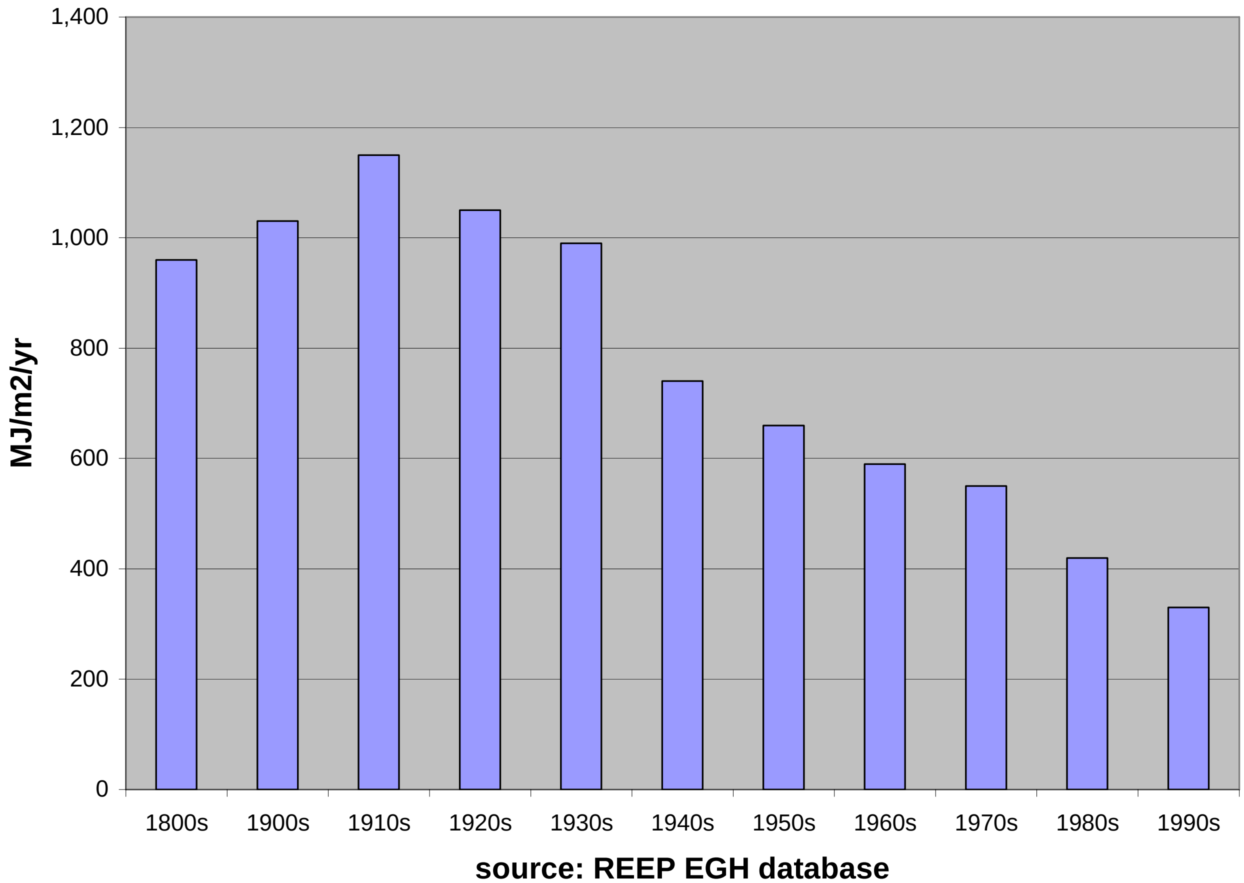


Figure 1: Residential CO2 emissions in Canada, 1960-95

Figure 2 Residential space heating efficiency, 2000 housing stock by date of construction



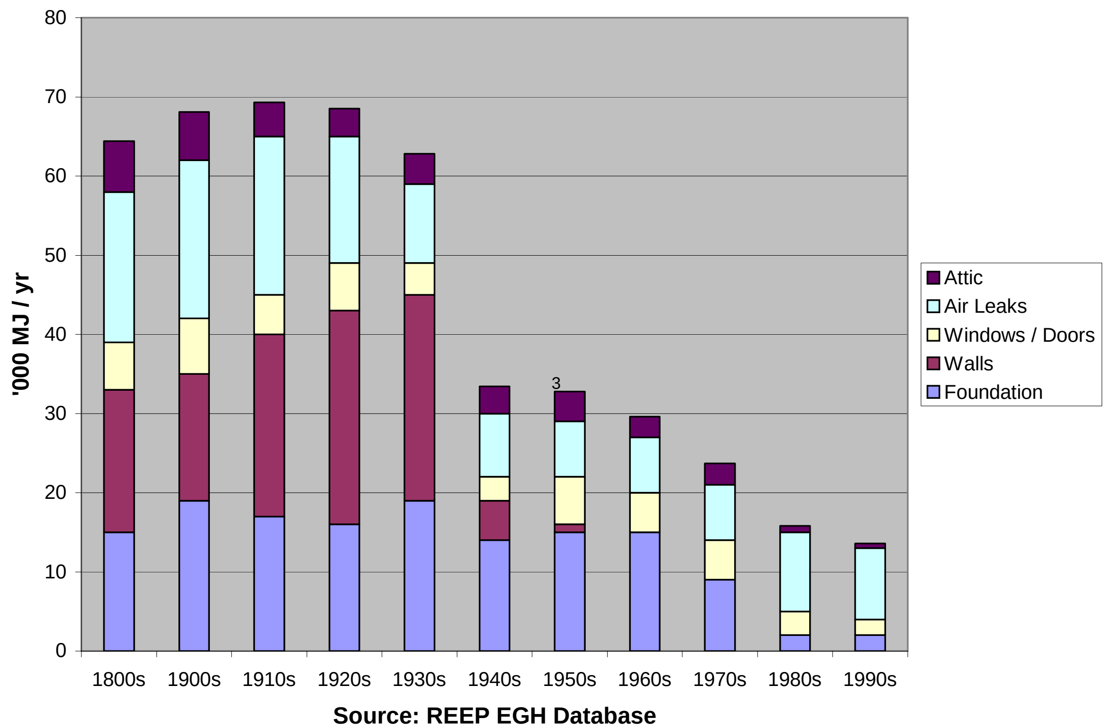


Figure 3: Recommended areas to reduce heat loss in single detached dwellings