Residential Energy Use Characterization and Mapping: Research and development of information for community energy and greenhouse gas planning in Canada

Introduction

The availability of rigorous yet easy-to understand information on energy use is key to evidenced-based land use planning decisions that result in reduced energy use and greenhouse gas emissions in Canadian communities. This paper presents community energy characterization and mapping research conducted by CanmetENERGY, Canada's knowledge centre for scientific expertise on clean energy technologies and a division of the federal government department of Natural Resources Canada (NRCan). Two research projects – the Urban Archetypes Project and Prince George Residential Energy Use Characterization and Mapping Project – are described. Both focus on the residential sector and the development of quantitative information providing evidence for the linkages between urban form, demographics and energy use in residential neighbourhoods.

While many real estate development projects within Canada feature near-zero houses[1] and sustainable neighbourhood design,[2] there remains a need for energy usage and greenhouse gas emissions to be better managed within existing neighbourhoods. In 2006, total secondary energy use in the residential sector in Canada was estimated to equal 1347 petajoules (PJ), roughly 16% of the total national secondary energy use. In that same year, cars, trucks and motorcycles used for personal transportation consumed an additional 1069 PJ, or 12.7% of total secondary energy use.[3] Together these sectors account for 28.7% of total national secondary energy use and 29.6% of Canada's GHG emissions.[4]

In Canada, the legal mandate for both energy and land use planning resides with provincial governments. Introduction of legislation by several Canadian provinces is beginning to tie energy and greenhouse gas management to the land use planning process. For example, in British Columbia the mandatory Green Communities Legislation involves the development of targets, policies and actions in Official Community Plans and Regional Growth Strategies, while the voluntary Climate Action Charter involves measuring and reporting community GHG emissions.[5] Although the provinces are the key actors when it comes to legislation that regulates community planning, there is still a role for the federal government to conduct research and develop information in support of energy efficient, low-carbon communities. In *Combining Our Energies: Integrated Energy Systems for Canadian Communities*, the House of Commons Standing Committee on Natural Resources recommended that Natural Resources Canada continue working on reliable measurement of energy use within communities.[6] Recently, the International Standards Organization, the International Energy Association and the International Electrical Commission held a joint meeting entitled *International Standards to Promote Energy Efficiency and Reduce Carbon Emissions,*[7] reflecting a broader recognition of the need for research and standardization in this domain. Urban energy and GHG characterization and mapping present a challenge not only for Canada, but also for the wider international community.

This paper will describe the residential energy characterization methodology employed in both the Urban Archetypes and Prince George research projects. As the purpose and background of the Urban Archetypes Project have been presented at the 43rd ISOCARP 2007 Congress in Antwerp, Belgium[8], this paper will focus on the project's results including overall results on variables of urban form identified for their influence on Vehicle Kilometres Travelled (VKT) as a proxy for transportation energy consumption. Examples will be provided of results obtained for energy use, GHGs and cost for representative dwelling types (houses and apartments) and vehicular transportation as portrayed in the project's community case studies. [9]

Description of the Prince George project will focus on the collaboration by NRCan with Prince George in its Smart Growth on the Ground initiative and NRCan's specific research objectives and contribution to this project. Conclusions will be drawn on energy characterization and the role of GIS and next steps will be described for the Prince George Project and for CanmetENERGY's continued involvement in this emerging area.

Defining Residential Energy Use Characterization

Characterizing residential energy use involves quantifying total annual energy consumed for space heating and air conditioning, hot water, lighting and appliance use in a house or apartment unit. It also involves describing features of the dwelling that impact on household energy consumption, such as geometry (size, number of storeys and other characteristics), and mechanical systems (such as furnace and hot water heater); occupancy is also factored into the characterization of residential energy use. By integrating residential energy figures, building characteristics and occupancy information in a Geographical Information System (GIS),a place-based, scalable characterization of residential energy use can be achieved. Using this method, urban form variables contributing to energy use can also be analyzed, yielding information to support a variety of urban planning decisions.

A whole-systems approach to residential energy use characterization should ideally also quantify energy transportation use as demonstrated in the Urban Archetypes Project. Owing to project timelines and data availability, energy use associated with water and waste management was not considered in either project. Data from the *National Municipal Water and Wastewater Benchmarking Initiative*[10] could be accessed for use in future similar projects. Consistent data on residential household waste is available as a provincial average or on a per capita basis in Statistics Canada's Human Activity and the Environment Survey.[11]

Units of Measurement

A brief explanation is warranted of units of measurement commonly used to describe and compare energy use. A gigajoule (GJ) is a metric unit into which energy consumed from all energy sources can be converted; as such, it is a useful measurement for establishing a baseline, comparing one house or apartment with another or even comparing transportation energy use to housing energy use. One gigajoule is equivalent to 277.8 kWh of electricity or 26.86 m3 of natural gas or 28.85 litres of regular vehicle fuel. One gigajoule of electricity would meet the electricity needs of an average Canadian household for 11.5 days.

A gigajoule per square meter or per hectare is a measure of energy intensity. It can be used to represent the total annual energy consumed for lighting and appliances, space heating and hot water per square meter of conditioned floor area. Gigajoules per square meter (GJ/m2) is an energy indicator that is spatial, describing where energy is consumed in space. As such, it enables energy use to be indicated on a map and used at different scales, with either megajoules per square meter (MJ/m^2) or GJ/m^2 describing energy use at the building scale and gigajoules per hectare (GJ/ha) describing energy use at the neighbourhood or community scale.

The Method for Developing Energy Use Profiles for Houses and Apartments

For both the Urban Archetypes and Prince George projects, profiles were developed using computer simulation for energy use in representative houses and apartment types. Significantly, in addition to providing figures for total annual energy use, this method links that use to representative dwelling types classified according to their physical characteristics.

Due to the different characteristics of houses and apartments, two different approaches were taken to model energy use. Profiles for houses were developed using audit records from EnerGuide for houses, now renamed ecoENERGY Retrofit Homes, and the HOT2000 software.[12] Totalling 500,000 and counting, these records compiled by NRCan represent a significant source of national data on houses and their energy performance. Recognizing a need for better energy information for integration into urban planning processes, NRCan is exploring the use of these records to characterize residential energy use.

EnerGuide audit records for each of the Urban Archetype neighbourhood study areas and for the entire city of Prince George were sorted according to building type and building code vintage, and representative types were identified. Using HOT2000 software, a batch of audit records for a given housing type and vintage were synthesized to create a general profile of expected energy performance. In cases where a limited number of records existed for a particular area, simulated values were checked against the regional building archetype. In the Urban Archetypes Project, occupancy data from interviews with neighbourhood residents were used; For Prince George, occupancy was assumed to be three persons per household. The weather file used to determine heating use was based on a 30-year historical average.[13]

To develop profiles of residential energy use in apartments for the Urban Archetypes Project, an assessment was done by building energy auditors of representative building types. For Prince George, data was provided on buildings identified by city staff including building age, floor area, roof area, wall area, window area, number of stories and number of suites. Additional assumptions were made regarding building performance characteristics in keeping with the date of construction, and where there was no other source of information default performance assumptions from the Model National Energy Code of Canada for Buildings (MNECB)[14] were used. Energy performance of each whole building was then simulated using the *Screening Tool for New Building Design*.[15] Whole building energy performance values were then divided by the number of suites, resulting in total annual energy consumption per suite. Included in this number is the suite's portion of energy use in common areas. Occupancy for apartments was assumed to be two persons per suite.

Urban Archetypes Project Results

From 2005-2007 the Urban Archetypes Project studied 31 neighbourhoods in 8 Canadian communities, exploring the relationships between urban form, demographics and residential energy use. The project's objectives included identifying data required for a neighbourhood energy use profile, developing a library of case studies and developing the ability to make a case for or against certain development patterns based on their energy implications.

Housing Types

In total, data from 65 house and apartment units were modeled. As illustrated by *Figure 3* single family dwellings were over-represented in the Urban Archetypes project sample in contrast to national housing figures[16] and apartments and other dwellings were under represented. Row houses were approximately proportional to national figures.

	Urban Archetypes	National Figures	Variance
Single Family Dwelling	78.5%	55%	+ 23%
Apartments and others	10.7%	34.4%	- 23.7%
Row houses	6%	5.6%	- 0.4%

Figure 3 Comparison of percentages of dwelling types in the Urban Archetypes Project and national figures.

When the project was initiated, planners were asked to identify neighbourhoods of contrasting urban form of interest for study from an energy perspective. The result was a purposeful yet random sample of neighbourhoods and dwelling types, not pre-selected for their urban form characteristics. This explains the variance in dwelling types in contrast to national averages.

Urban Form Variables

Spatial analysis was used to consistently measure urban form variables and enable a regression analysis using average estimated Vehicle Kilometers Travelled (VKT-avg) as a proxy for transportation energy use. Neighbourhood design characteristics found to be related in varying degrees to VKT-avg as a proxy for transportation energy consumption included gross density, percentage of single detached houses, land use mix index and total road length. The only characteristic of neighbourhood location that demonstrated a correlation to VKT-avg was distance to the central business district. Subsequent bivariate analysis further testing the strength of these relationships, found that while the demographic variable of income did not change initial results, household size skewed the degree of relevance of urban form variables in the model, with the exception of gross density [17]

Total Energy Use in Houses and Apartments, Energy Intensities and ERS Values

Total energy use for space heating, hot water and lighting and appliances in houses and apartment units was found to vary from low total annual energy use in apartment units to high total annual energy use in single family homes. A low value of 33GJ was identified for apartments in two separate Urban Archetype neighbourhoods: Clayton Park in Halifax and Mission in Calgary. A high value of 321 GJ total annual energy consumption was found in a pre-1945 single family dwelling in the same neighbourhood of Mission in Calgary. As household size is also a key factor influencing total annual energy use, an important indicator of energy use is megajoules per square meter (MJ/m^2). Values were found to range from 94.1 MJ/m2 in an apartment in Kirkwood, Ottawa to 1580 MJ/m2 in a pre-1945 single family dwelling in New Edinburgh, also in Ottawa.

EnerGuide Rating System (ERS) [18] values for houses evaluated were found to vary from a low of 41 to a high of 78 with the average being 65. Looking ahead to the example provided in *Figure 4,* an n/a appears in place of an ERS rating for apartments in Mission, Calgary. This is because in Canada there is no equivalent rating system and therefore no one consistent number that can be used to describe housing energy performance across dwelling types.

In general, energy use in residential dwellings was found to vary according to age, size and type. Older houses were found to consume more total energy on an annual basis and apartment units were found to be significantly more efficient that single family dwellings. A broader range of dwelling types and associated energy performance was observed in older neighbourhoods, the greater variability explained by the organic processes of urban renewal that occur over time through renovations, demolition and infill.

Total Annual Cost and GHG Emissions

Annual energy costs incurred by Canadian households are a function of the cost of the fuel or electricity and the rate set by the provincial or local utility. Total costs for housing energy ranged from $889 annually for an apartment in Clayton Park Halifax to $6,316 annually for a pre-1945 single family dwelling in Hydrostone, Halifax. Lowest costs were typically incurred in apartments and highest costs were incurred in older single family dwellings. Interestingly, both the lowest and highest costs incurred in Halifax, Nova Scotia.

GHGs emitted by households ranged from 3.4 equivalent $C0_2$ ($C0_2e$) for an apartment in Kirkwood, Ottawa to 22.2 $C0_2e$ for a pre-1945 single family dwelling in Hydrostone, Halifax.

GHG emissions from housing are a factor of not only the total amount of energy consumed, but also fuel types, method of electricity generation, and associated emissions factors. Emissions from dwellings in provinces where electricity is generated from hydro or nuclear will be lower than those where electricity is generated from coal or oil.

Transportation Energy

Information on estimated Vehicle Kilometres Travelled (VKT) as well as make and year of all vehicles owned or leased by a household was collected through interviews with study area residents. Given the significant numbers of non-responses for VKTs in some neighbourhoods, average reported estimated VKTs were substituted for non-responded creating the adjusted variable of average estimated VKT (VKT-Avg). This was found to range from a neighbourhood average of an estimated 12 000 km per year per household in Ottawa's New Edinburgh to a neighbourhood average of an estimated 45 600 km per year per household in Calgary's Lake Bonavista. New Edinburgh and Lake Bonavista were also found to have the lowest and highest annual fuel consumption values at 1568L (54GJ) and 6295 L (218 GJ) respectively; associated low and high values for GHG emissions, in these same neighbourhoods were 3.8 $C02_e$ to 15.1 $C02_e$ respectively.

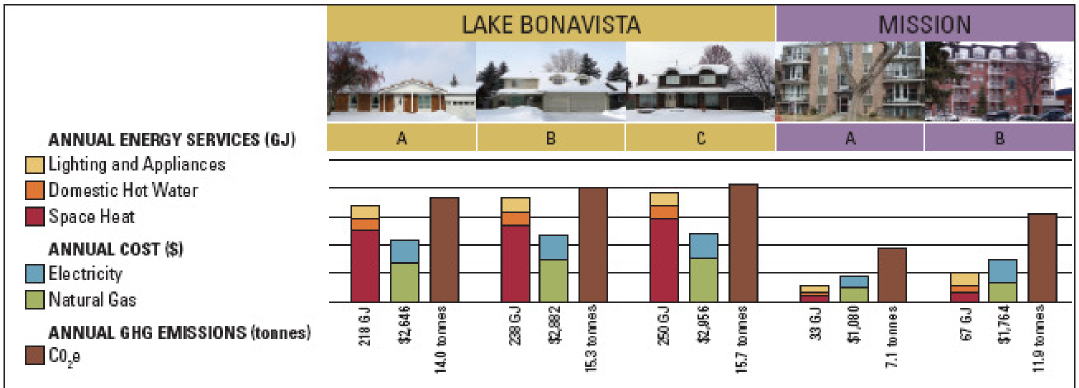
Community Case Studies

To communicate basic project results, eight community case studies were compiled, comparing the results of different neighbourhoods in the same community. Below are highlighted results over the 31 neighbourhoods for housing and apartment types and vintages, total energy use, cost and ghgs, and for transportation energy use, cost, GHGs and relevant land use variables.

Energy Profiles of Houses and Apartments

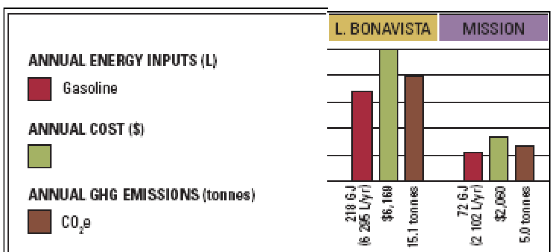
Figure 4 is an example of the energy, cost, GHG and building information developed for houses and apartments in two neighbourhoods in the City of Calgary. Notice the neighbourhood names at the top of the chart, Lake Bonavista and Mission; photos provide visual context for the representative house and apartment types. The legend on the left gives the reader a means of interpreting the bar graphs showing total household energy, cost and GHGs for each house or apartment type. The information contained in the chart below the bar graph provides EnerGuide Rating System (ERS) and energy intensity values, and the building, lighting appliance characteristics used to simulate the house or apartment's energy performance.

Importantly, these are profiles for representative house and apartment types in a given neighbourhood. Due to the heterogeneous nature of neighbourhoods, it was felt that developing an average value for energy use did not adequately highlight the variability in energy performance between house and apartment types. Furthermore, because more detailed information on housing type, including number of stories and approximate conditioned floor area was not collected for all of the houses and apartment units in the Urban Archetypes project neighbourhoods, calculation of total energy use of houses and apartments in the study neighbourhoods through aggregation of values for representative house types up to the neighbourhood or community scales was not possible. The community case studies therefore present only the values of representative dwelling types as illustrated below to summarize housing energy use.



		Lake Bonavista A	Lake Bonavista B	Lake Bonavista C	Mission A	Mission B
EnerGuide Rating System		66	65	65	n/a	n/a
Energy Use Intensity		624 MJ/m²	720 MJ/m²	719 MJ/m²	462 MJ/m²	475 MJ/m²
Building Type	Storeys	one storey	two storeys	two storeys	four storeys / 16 suites	six storeys / 38 suites
	Attachment	single detached	single detached	single detached	MURB	MURB
	Built	1961-77	1961-77	1978-83	1966	1998
Heated Floor Area		348 m² (3 749 sq.ft.)	330 m² (3 554 sq.ft.)	348 m² (3 746 sq.ft.)	73 m² (785 sq.ft.)	140 m² (1 506 sq.ft.)
Insulation	Ceiling	4.6 RSI (R-26)	4.3 RSI (R-24)	3.6 RSI (R-20)	2.6 RSI (R-15)	4.3 RSI (R-24)
	Walls	1.9 RSI (R-11)	1.9 RSI (R-11)	1.9 RSI (R-11)	1.8 RSI (R-10)	2.9 RSI (R-16)
	Foundation	1.0 RSI (R-6)	1.2 RSI (R-7)	1.2 RSI (R-7)	none	none
Space Heating	Fuel	natural gas	natural gas	natural gas	natural gas	natural gas
	Furnace	with continuous pilot	with continuous pilot	with continuous pilot	boiler, natural draft, on-off	boiler, natural draft, on-off
	Efficiency	78%	78%	78%	80%	80%
	Ventilation	none	none	none	none	mechanical outdoor air supply
Hot Water	Fuel	natural gas	natural gas	natural gas	natural gas	natural gas
	Tank	conventional	conventional	conventional	conventional	conventional
	Efficiency	55%	55%	55%	80%	80%
Lighting		incandescent	incandescent	incandescent	incandescent	incandescent
Appliances		conventional	conventional	conventional	conventional	conventional
Occupants		3	4	4	1	2

Figure 4 Table of energy, cost, GHG and building characteristics for five house and apartment types in two neighbourhoods in the City of Calgary.



		L. Bonavista	Mission
Resident Lifestyle	Vehicle kilometres travelled (VKT-AVG)	45 600 km/yr	16 200 km/yr
	Average number of vehicles per household	2.4	0.9
Neighbourhood Design	Gross density (units per hectare)	7.02	55.5
	Percent of housing units Single detached	98%	4%
	Land-use mix index*	0.20	4.00
	Total road length	5.3 km	0.9 km
Neighbourhood Location	Distance to central business district	12.2 km	1.6 km

Figure 5 Urban form variables and VKT, energy, cost and GHGs comprise the transportation information collected by the Urban Archetypes Project.

Transportation Energy and Land Use Profiles in the Urban Archetypes Project
As previously mentioned, the characterization of transportation energy use and associated land use variables was accomplished using a door to door survey and spatial analysis respectively. *Figure 5* is an example of the transportation and land use results. As in the housing energy chart, the legend on the left assists the reader to interpret the bar graphs for energy, cost and GHGs associated with each neighbourhood. In the lower chart, bar graph values appear for VKT-avg, average number of vehicles per household as well as measured variables of urban form.

The Prince George Residential Energy Characterization and Mapping Project
Known as British Columbia's northern capital, Prince George has a population of 77,000 and is situated at the confluence of the Fraser and Nechako Rivers. A leader in municipal energy and greenhouse gas planning, the city is at Milestone 4 in the Federation of Canadian Municipalities' Partners for Climate Protection program. Current Mayor Dan Rogers is co-chair of the Community Energy Association[19] and one among many local energy planning champions.

NRCan's opportunity to collaborate with Prince George was to contribute science-based energy information to the Smart Growth on the Ground (SGOG) process. SGOG is an innovative program designed to change the way that development is done in British Columbia. Through the creation of sustainable neighbourhood plans, built examples of smart growth occur 'on the ground'. Using guiding principles, an inclusive process, a design charrette,[20] and practical science-based research, a collective community design process is undertaken, resulting in a concept plan that is then used to guide future planning decisions within the community. Energy and climate were the specific scientific topics of the Prince George SGOG process and a number of researchers were convened to tackle various aspects of these complex issues. By initiating the its Prince George Residential Energy Characterization and Mapping Project, CanmetENERGY committed to the development and contribution of residential energy use information that would not otherwise have been available to the process.[21] For this project, CanmetENERGY's research objectives consisted of refining the residential energy characterization method originally developed in the Urban Archetypes Project, evolving it by integrating simulation results into GIS and understanding what role residential energy information plays in a charette process. Prince George was selected as a SGOG community in 2007, the engagement process began in 2008 and the charette was held in May 2009; both the refinement of the energy and land use model and the development of the concept plan resulting from the charette were ongoing at the time of writing in mid-2009.

Development and Delivery of Residential Energy Information to the SGOG Process
Residential energy use characterization in Prince George was carried out in much the same manner as for the Urban Archetypes Project with two important improvements. First, for the simulation of energy performance of representative house types, EnerGuide Records for the entire city were obtained; second, the representative housing types identified from those records were verified against building stock information contained in the integrated land use model. The integrated land use model was developed for the project by combining Prince George's Geodatabase and British Columbia Assessment Authority (BCAA) or property tax data. For apartment units, selected buildings were identified and basic data provided by the city and simulation carried out by CanmetENERGY. Energy profiles of representative house and apartment types were integrated into the target setting workshop, summarized in a Foundation Research Bulletin and presented at the design charette.

At the priorities workshop held in November 2008, participants identified a key priority to "*incorporate green building practices into new building construction and existing building renovation*." At the target setting workshop in March 2009, participants were asked, "*What should the energy intensity of residential buildings be in 2035?"* Energy intensity values for representative houses and one apartment unit were presented and two percentage reduction estimates were calculated. The first estimate involved modelling a building with characteristics to achieve a 25% reduction from the Model National Energy Code for Buildings (MNECB), the LEED pre-requisite. The second estimate was a building with high performance characteristics, modelled to achieve a substantially reduced base load and operating energy costs and a 50% reduction from MNECB. This information enabled public participants to establish a target range for this indicator of between .24 – .36 GJ/m^2, consistent with an improvement of energy performance of between 25% and 50% on the MNECB.

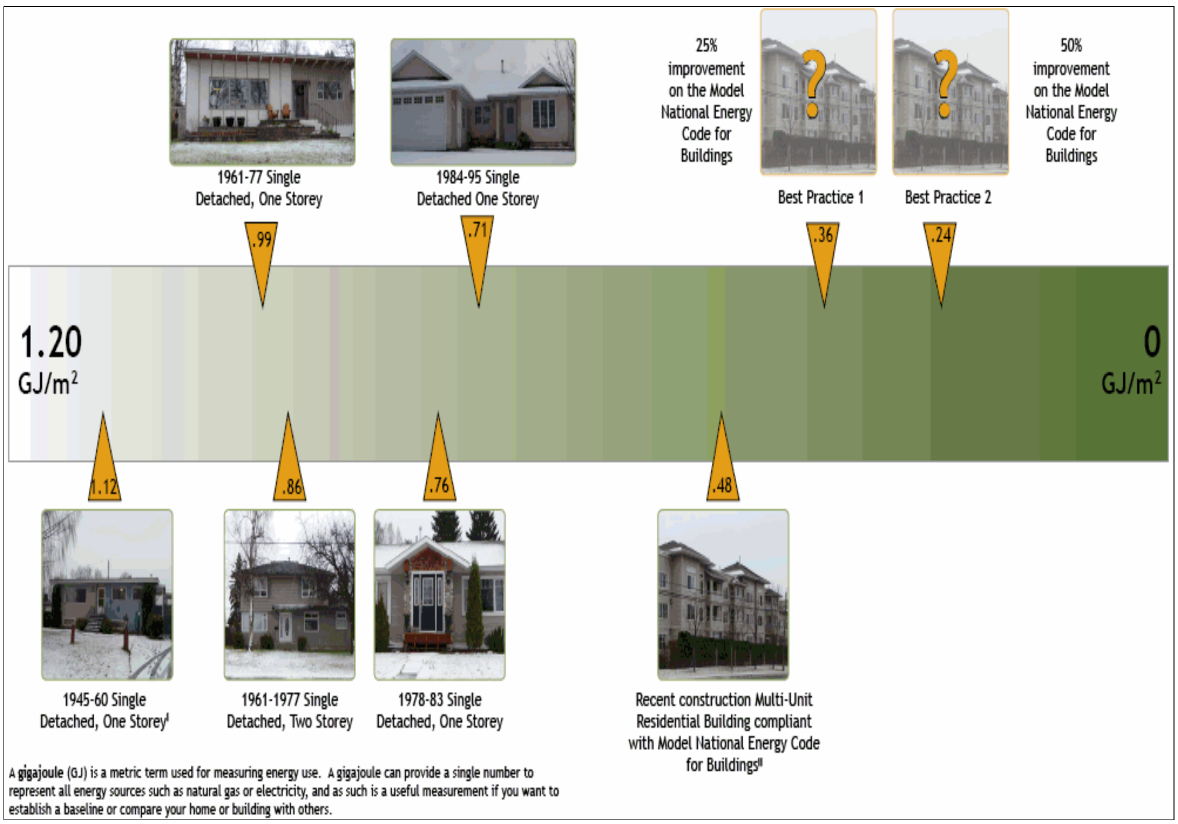


Figure 6 Five housing types and one apartment modelled for the March 2009 target setting exercise.

Tables summarizing simulation results for representative houses and apartments in Prince George can be found in the Foundation Research Bulletin entitled *Residential Energy Characterization,* posted on the SGOG website.[22] In addition to basic characterization, numerous actions for improving the energy efficiency on both the building and neighbourhood scale were provided. At the charette in May 2009, the community developed general designs for a building they envisioned would be built in the downtown. Based on general values extracted from this design, CanmetENERGY was able to run simulations that determined, assuming mechanical systems and wall and roof assemblies were of high performance, the planned building could potentially meet the high end of the community's target of a 50% reduction in energy use from the MNECB.

Integrated Land Use and Energy Model

The Prince George Project expanded upon the residential energy characterization method used in Urban Archetypes Project method by integrating residential energy information into GIS. The integrated land use model connects the spatial information of building footprints, parcel boundaries and land use zones stored in the City of Prince George's Geodatabase with the attribute information of building types and year built values from the BCAA. This combination of information provides a relatively accurate picture of the current building stock in terms of dwelling type, dwelling age, number of stories and floor area. Associating land use zoning with parcel boundaries enables the exploration of future development and build out scenarios based on dwelling type and location. The integration of relevant building characteristics and energy performance with spatial information in GIS enables the representation of existing residential energy use patterns across the community and possible future energy use patterns that would accompany retrofit schemes, new construction techniques and different residential density patterns.

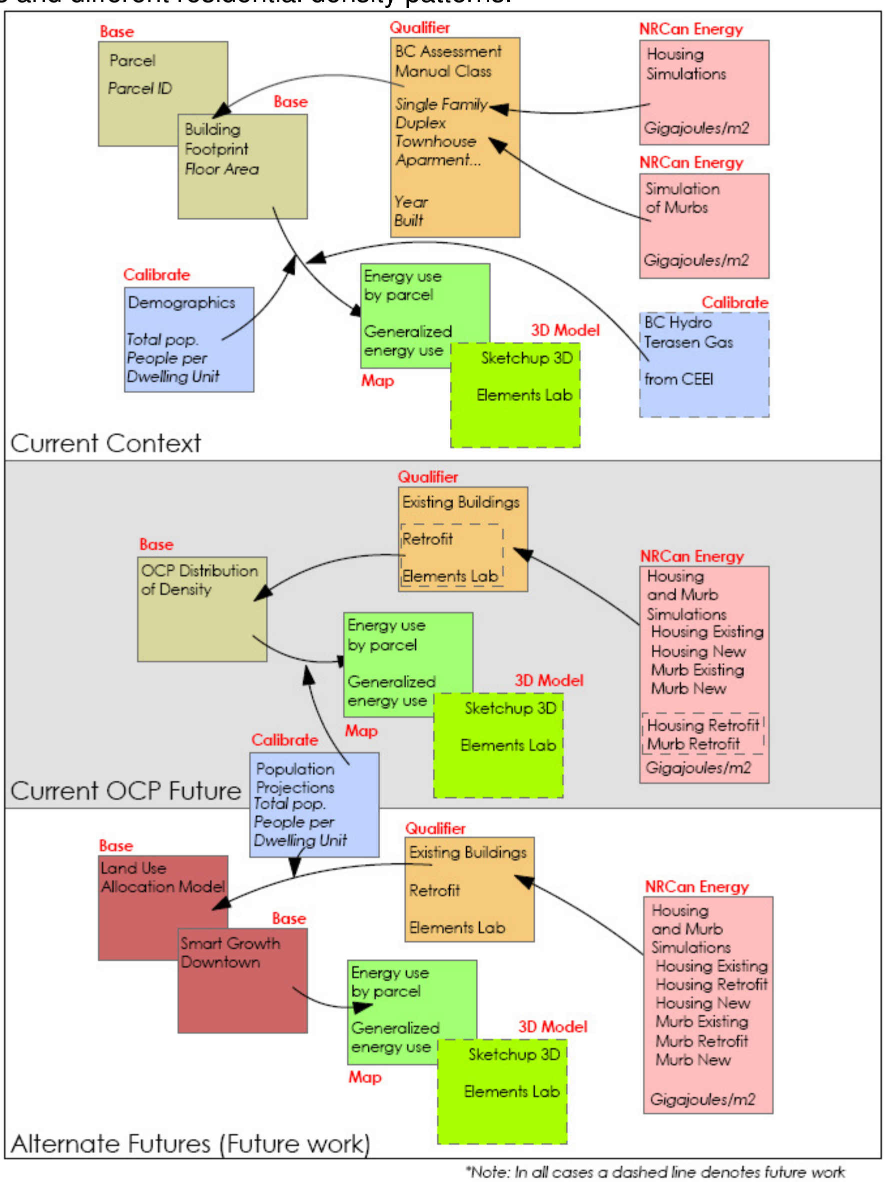


Figure 7 Integrated land use and energy model developed for the City of Prince George.

Prince George Results to Date

Results of the Prince George project to date can be grouped into two areas: First, residential energy information development and delivery to the charrette and second, development of the integrated land use and energy model.

Information developed by CanmetENERGY was relevant to the SGOG process by providing an understanding of the energy use and building characteristics of existing residential dwellings. This information was used as a basis to model and set targets for expected performance of new buildings. Informed by the recommended measures for energy efficiency supplied in the Foundation Research Bulletin, building designs created during the charette process were modeled, with resulting numbers showing charette designs were consistent with the percentage target of a 50% improvement on the MNECB.

The development of an integrated energy and land use model connecting residential energy use characterizations with spatialized information on the type, vintage and size of buildings, resulted in a model that is scalable from the building to the community level. Since the model was organized in such a way that it could present results on a by unit or by building basis, a clear comparison between the energy use patterns of single family dwellings versus apartments was produced. The ability to map total, average or other energy use representations at a variety of scales provided the ability to determine which residential density arrangements offer the greatest reduction in energy use.

Conclusions

The Urban Archetypes and Prince George Residential Energy Use Characterization and Mapping projects represent important advances in Canadian research on characterization of energy use and GHG emissions in existing communities and identify and communicate relevant information to facilitate the planning of low energy and low carbon communities.

The Urban Archetypes Project fulfilled some of its main objectives, including identifying relevant variables for creating profiles of energy use by residents and creating a library of case studies. Basic data required to simulate representative housing energy performance include building type, vintage, number of stories and total conditioned floor area for each dwelling unit within a study area; EnerGuide audit records and HOT2000 software were also valuable as a source of community-specific housing energy performance data. To simulate the energy use of apartments, *Screening Tool* inputs identified as relevant variables included: building age, conditioned floor area, roof area, wall area, window area, number of stories and number of suites, along with assumptions on insulation levels and mechanical equipment. The lack of detailed building-type data across all study neighbourhoods limited the scaling of representative housing type simulation values up to the neighbourhood scale. The project was also successful in characterizing transportation energy use by personal vehicles and identifying variables of urban form related in varying degrees to transportation energy consumption, although household size or occupancy appeared to alter these results. Vehicle Kilometres Travelled was identified as a key variable for place-based calculations of transportation energy use by vehicles. Basic results were presented in 8 community case studies.

The Prince George Residential Energy Characterization and Mapping Project took the characterization methodology developed in the Urban Archetypes Project one step further by systematically integrating simulated housing energy information into a land use model. This resulted in improved analytical capability including for example the ability to check representative house types to be simulated against the mix of housing types in the model. The scaling of representative housing type simulation values up to the neighbourhood scale was rectified through a GIS-based approach and the integration of the city's Geodatabase and BCAA data. Given reasonably accurate building energy information, a GIS is perhaps the key platform for linking energy to land use. An integrated land use and energy model developed in this way can serve a wide range of decisions by providing on-demand analysis for exploration of the energy implications of neighbourhood design plans or development proposals.

Although the full capabilities of the integrated energy and land use model were not fully explored in the context of the Prince George SGOG process, the information developed on the building scale both for existing houses and apartments and new apartments was informative to the process. The ability to deliver this information in both print and presentation formats and run simulation supported residents in developing energy efficient building designs.

Next Steps

Although the Urban Archetypes Project is substantially complete, areas for future work that can be identified from its findings include addressing data availability and developing best practices around energy and land use profile development. Data considerations include the accessibility of generalized housing energy performance information according to location, type, vintage and size, information which is not readily available. Although not discussed in detail in this paper, the lack of building energy data for apartments can also be described as a major gap. Neighbourhood-level occupancy data would also enable further calibration of both housing energy simulations and further evaluation for its influence on VKT.

With regards to transportation, while available in some communities, there is not consistent national VKT data coverage that would allow it to be used for place-based vehicle energy analysis on a consistent basis. More research is required to compare the merits of VKTs with other methods of transportation energy characterization such as fuel sales and transportation demand models. An opportunity for the development of best practices resides in the area of land use analysis and consistent quantification of land use variables..

Work on the Prince George Residential Energy Use Characterization and Mapping Research Project is ongoing. Possible areas for further refinement include calibrating the existing model including the incorporation of assumptions on performance improvements achieved through retrofits, checking simulated housing performance values against measured utilities data and incorporating more precise demographic information. A direct application of the integrated land use and energy model would be to develop residential carbon and/or GHG maps according to land use projections in conjunction with Prince George's Official Community Plan review. Possible areas that could be explored in an expanded energy mapping focus include integrating commercial and industrial energy use, or using 3D sketch-up models to visualize neighbourhood patterns. Refining database relationships to enable easier analysis by municipal staff members could also be addressed.

More broadly CanmetENERGY is expanding its involvement in GIS-based spatial analysis as a strategic research area. This will be achieved through the integration of spatial analysis into evaluation of projects proposed under the EQuilibrium™ Communities Initiative.[23] External initiatives in which CanmetENERGY is involved in an advisory capacity are a project entitled *Integrated Energy Mapping for Ontario Communities* which will develop energy maps for five municipalities in the province of Ontario and the *New Spatial Indicators for Canada's Settlements Project*, jointly led by Statistics Canada and Infrastructure Canada this initiative will make census occupancy data available on the city block scale.

Through this research and other innovative projects, Natural Resources Canada is demonstrating leadership in research on energy characterization and mapping in Canada.

Building on the findings of these projects, CanmetENERGY, with project collaborators, will continue to work to provide energy information to assist Canadian communities in making strategic energy-planning decisions towards low energy and low carbon communities.

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