THERMAL AND MECHANICAL SYSTEMS DESCRIPTORS FOR SIMPLIFIED ENERGY USE EVALUATION OF CANADIAN HOUSES

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ABSTRACT

For a quick and reliable energy evaluation of houses, one needs simple energy analysis software. A key requirement for simplified inputs is to have default data for house geometry, thermal and equipment characteristics based on vintage, type and region in which the house is located. Using data collected from more than 634,000 homes, statistical representative archetype data sets were developed for 35 climates zones and eight vintage periods. Representative numerical approaches were applied to develop archetype house characteristics. These data libraries are integrated with energy simulation software to assist in defining required defaults for geometry, building envelope and equipment. These defaults then provide guidance for a energy advisor to check against actual house data. Comparative energy analyses showed that the archetype characteristics are useful in quick field surveys.

INTRODUCTION

Since mid-1998, Natural Resources Canada has supported home energy efficiency retrofit programs, such as EnerGuide for Houses and ecoENERGY-Retrofits Homes, to evaluate and rate the energy efficiency of low-rise residential buildings. The main goal is to provide retrofit advice to homeowners based on a field assessment and careful estimates of energy use using energy analysis software (NRCan 1998, NRCan 2007). A number of federal and provincial agencies and utilities provide homeowners financial incentives to perform the energy efficiency retrofits.

The energy advisor investigates the energy-related features of a house; estimates the home's annual energy requirements using energy analysis software; provides a comparative energy efficiency rating; and provides a comprehensive report including recommended retrofits. Once a homeowner implements retrofits, a second post retrofit evaluation is performed to update the energy efficiency rating and calculate any associated financial incentive.

To perform an energy evaluation of a house, one needs a simple but reliable energy analysis software tool. One of the key requirements for the simplified inputs is default data for thermal and equipment characteristics based on vintage, type and region in which the house is located. The region and age-specific default data provides the field evaluator with sufficient guidelines and depictions of the thermal behaviour expected for a specific house.

With the implementation of NRCan's retrofit programs a large amount of house characteristic data has been collected (NRCan 2007a, NRCan 2007b). This data is stored in a database comprising more than 846,000 homes.

The information collected includes: size and type of a house (typical dimensions); make and composition of envelope components (size and insulation values); predominant heating and hot water equipment data (type and steady state efficiencies); and, airtightness and ventilation parameters. Metered data for energy use provided baseline estimates for the base loads (mainly lighting and appliances) and operating parameters [NRCan 2009].

This paper provides a brief summary of the procedures used for developing archetype building characteristics libraries. Three specific applications are explained to show the utility of these archetype libraries.

METHOD

Housing Database

The EnerGuide for Houses (EGH) database is an information management tool and central depository for tracking residential energy evaluations and measuring the benefits from the energy evaluations delivered across Canada (NRCan 2007a). The process of data collection is as follows: Energy advisors collect house information during a detailed house energy efficiency evaluation. This data is then used to model the energy consumption of the house using the energy analysis software. The energy advisor also uses the energy analysis software to model and recommend energy efficiency measures for homeowners. The energy analysis software file stores the house energy model, retrofit recommendations and report information. The energy analysis software also generates a data file which contains a subset of the house characteristics and simulation results. Once the house evaluation is complete and the home modeled, the energy advisor e-mails the save file and data file to an automated file processor. The file processor performs validation and other processes on the received data file and stores the data and save files in the EGH Oracle database. Each database record contains information on the house's physical characteristics and its energy requirements. Information collected in the database can be used by internal program personnel to generate statistics such as the number of house evaluations performed across the country or compile technical house characteristics data and also assist in making policy decisions.

The database contains files for more than 846,000 houses rated across Canada of which about 634,000 have been re-evaluated after homeowners implemented energy efficiency retrofits. The concepts and database structure allow for the implementation and management of a large-scale energy efficiency program through various delivery channels.

Analysis Method

The housing stock data was extracted from the EGH database and were used to develop a master spreadsheet. For the purpose of developing archetype libraries, the project team only utilized those house files which have both pre- and post-retrofit information. These gathered data included about 634,000 house records each containing more than 270 information fields. The following steps outline the method employed for developing archetypes:

- Step 1. Information was assembled in a master spreadsheet. The quality of the data was checked extensively and suspect or incorrect data files were removed from further processing.
- Step 2. The criteria for correlating geometric and thermal characteristics was established.
- Step 3. Grouped and processed the data to arrive at representative thermal and performance values.
- Step 4. Verified the key parameters with known reports from Statistics Canada (StatCan 2007). These parameters include foot print area, type of housing, local code requirements for the era of construction, primary fuels, occupancy, energy use index and other.
- Step 5. Performed parametric energy simulations to determine the sensitivity of various archetypes based on the floor area, location and vintage classification.

The representative archetypes include geometric configuration, thermal characteristics and operating parameters components.

Geometric configurations

The geometric configuration includes the plan layout, dimensions of various components, volume, and orientation. The following are main forms of low-rise housing:

- split-level bungalows
- detached or single-family homes
- semi-detached (two attached houses)
- row houses (more than two attached and vertically separated)
- walk-ups (more than two dwellings vertically and horizontally separated)

House formation defines the size and volume. There are:

- the number of levels (storeys) which includes one-storey, one and half, two, two and half, and three storey structures;
- the shape of the plan which includes rectangular, L-shape, T-shape and forms with varying number of corners and other complex structures;
- the type of attic/roof which includes cathedral, sloped and flat; and
- the foundation types including slab-on-grade, full basement, shallow basement, walk-out basement, and crawlspace.

The field survey data was employed to develop typical geometry details for main housing forms. These included the development of geometric rules and co-relation based formulas for various components. The required primary inputs were the footprint dimensions (depth and width, or perimeter and area), house form, number of levels, shape of the house, type of attic, and the foundation. Based on these primary inputs, all required dimensions of house components were generated.

Thermal characteristics

The thermal characteristics include the make and composition of envelope components (size and insulation values), predominant heating and hot water equipment data (type and steady state efficiencies), and, in particular, airtightness and ventilation parameters.

The data classifications were as per the following:

- age or the year in which the house was built (or retrofitted)
- location and the region
- thermal insulation levels of building envelope components
  1. above and below-grade walls,
  2. attic/roof
  3. type of windows and doors
  4. foundation walls and floor
  5. air leakage and airtightness
- space heating, hot water and ventilation systems
  1. primary and secondary fuels used for space heating and hot water
  2. type of space heating and hot water systems and steady state efficiencies
  3. type of ventilation system and typical airflows

The profiles of thermal archetypes were based on the regions and the year of construction (or the year of major renovation). The construction practices heavily depend on the requirements of codes and standards. Therefore, the vintage periods of when the house was constructed become a primary factor. Data collation included the development of representative numeric rules and correlation based formulas for various components. Based on these primary inputs, all required effective thermal insulation and equipment specifications were generated.

Operating parameters

The operating parameters include the profiles of base loads (lighting and all house related appliances), occupancy and indoor temperature data. The operating parameters are intended to capture homeowner's lifestyle behaviour. The following information was assembled from the monitored data:

- indoor temperatures (heating and cooling seasons)
- use of ventilation systems, kitchen and bathroom fans and so on
- profile of kitchen appliances
- lighting
- appliances (include TV, VCR and other)
- domestic hot water use
- occupancy levels (number and percentage of time in the house)

The above information assisted in generating typical operating profiles and basic assumption for the energy analysis. For the operating parameters, typical profiles employed the full nationwide data. The region-specific variations showed modest differences.

Table 1. Assumptions for a typical house plan.

Floor space	*Bedrooms*	*Living areas*	*Service/utility rooms*
less than 83 sqm	2	1	1
83 to 120 sqm	2	2	2
121 to 168 sqm	3	2	2
169 to 230 sqm	4	3	2
above 231 sqm	5	3	3

DEVELOPMENT OF ARCHETYPES

Geometric details

Using the geometric details of a variety of types of houses, standard configurations were developed to define different forms and style of houses. The data for the typical dimensions of bedrooms, living and recreation rooms, kitchen, bathrooms and utility/service rooms were obtained from standard architectural planning handbooks. Table 1 shows the assumptions for the plan layouts. Interior floor area is divided appropriately to define the house form along with windows and exterior entry doors.

Thermal descriptions

The database of houses provided enough information for each province for a range of vintages. The database can be used to generate a large number of archetypes based on vintage, location and type of houses. However, a large number of archetypes would defeat the goal of simplification. Therefore, the following criteria were utilized for developing the archetypes:

- Primary requirements should only include the age and the location of the house.
- Secondary requirements are the typical dimensions (width and depth or perimeter and area), house levels, shape of plan, type of ceiling and type of foundation.

With the above information, the archetype definitions should be sufficient to generate all of default inputs required to conduct an energy analysis of the house. The following is the matrix for generating the appropriate archetypes:

- Vintage periods: The norm was to define the vintage periods based on major code changes which affected the housing construction, particularly the energy efficiency. The following vintages were classified:

1. Pre-1945
2. 1946 to 1960
3. 1961 to 1977
4. 1978 to 1983
5. 1984 to 1995
6. 1995 to 2000
7. 2001 to 2005
8. 2006 onwards

- Location or climate region: Each province was classified with one or more climate zones.
  1. three climate zones covering Atlantic region (includes Newfoundland and Labrador, Nova Scotia, New Brunswick and Prince Edward Island),
  2. three climate zones covering Quebec region
  3. two climate zones covering Ontario (south/west and north/east)
  4. four climate zones covering Prairies and North region (Manitoba, Saskatchewan, Alberta, NWT, Nunavut and Yukon)
  5. three climate zones covering British Columbia

The above matrix allowed for 120 (8 vintages x 15 climate zones) archetypes. The database of information was collated and sorted using the above matrix. In most cases, the numbers of house files were sufficient (at least 100 observations or more) to meaningfully define statistics such as mean, median, average, 25th percentile, 75th percentile. One such example is shown in Table 2 and Table 3 for British Columbia Zone A covering Vancouver, Victoria and the lower mainland. As shown in these tables, there have been steady improvements in the thermal insulation levels and the airtightness of houses in different regions.

Table 4 shows the summary of equipment efficiencies of space heating, hot water and space cooling systems from pre-1960 to present. Over the years, the space heating and hot water equipment efficiency have increased significantly. Regulatory requirements have played a significant role in these improvements.

As shown in Table 3, average airtightness data. Energy Advisor is required to do blower-door test to produce the airtightness data.

Table 2. Analysis of above-grade wall insulation levels for British Columbia Zone A (expressed in m^{2}K/W, RSI).

	Above-grade wall effective insulation levels (m2K/W)							
	<=1945	**>1945-1960**	**>1960-1977**	**>1977-1983**	**>1983-1995**	**>1995-2000**	**>2000-2005**	**>2005**
Sample Size	2,434	2,858	6,926	3,631	5,474	558	500	290
max	3.17	3.52	3.25	4.13	5.28	2.79	3.95	4.16
75%tile	1.75	1.84	1.89	1.95	2.10	2.11	2.61	2.82
avg	**1.28**	**1.61**	**1.76**	**1.92**	**1.99**	**2.09**	**2.26**	**2.47**
median	1.24	1.67	1.76	1.90	1.92	2.10	1.92	2.31
25%tile	0.67	1.58	1.67	1.76	1.86	1.89	1.87	2.10
min	0.28	0.53	0.59	0.98	0.66	1.70	1.30	1.91
stddev	0.57	0.39	0.27	0.27	0.33	0.30	0.66	0.62

Table 3. Example archetype data for BC Zone A.

House Age	Nr. of Houses	Floor Area (m2)	ACH at 50 Pa	Insulation (RSI)		
				Ceiling	Walls	Foundation
<=1945	2,434	213	10.8	2.64	0.99	0.95
>1945-1960	2,858	195	9.5	3.52	1.67	1.00
>1960-1977	6,926	210	9.2	3.52	1.77	1.30
>1977-1983	3,631	214	8.4	3.52	1.93	1.45
>1983-1995	5,474	243	6.3	4.93	1.94	1.42
>1995-2000	558	311	4.1	7.04	2.12	1.89
>2000-2005	500	320	3.7	7.04	2.06	1.98
>2005	290	345	3.5	7.75	2.57	2.04

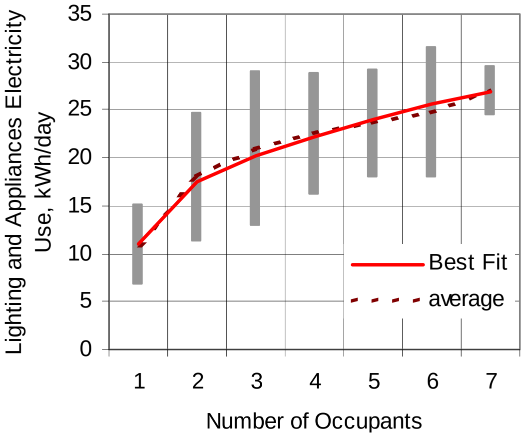
Operating conditions

One of the key components of the simplified energy analysis is the homeowner's lifestyle assumptions. These include:

- base loads associated with lighting and appliances;
- occupancy and percentage of time present in the house;
- thermostat setting for indoor temperatures during day and night occupancy;
- average hot water use per day; and
- usage of other energy consuming equipment and appliances.

From a set of 134 highly monitored houses (NRCan 2000), the following profiles were generated to define the operating parameters.

Base electric loads – The base electric loads include the energy use for lighting, kitchen appliance, entertainment and other electricity consuming devices. Figure 1 shows the data analysis graph for the base electric loads. The best-fit equation shows the approximate correlation for the electricity use and number of occupants in the house. This load profile is further segmented in individual components based on average electricity use for lighting, kitchen appliances, dryer and other.



$$Base\_Load = 11 + 6.5\sqrt{OccN - 1.0} \text{ kWh/day}$$

OccN = number of occupants

Figure 1. Profile of base electricty loads in single-family housing.

Table 4. Analysis of equipment efficiency levels for space heating, hot water and space cooling systems.

Mechanical System	Unit	Pre 1960	1960-83	1984-1995	1996-2000	2001 to -
Space Heating						
Gas furnace	AFUE	0.60	0.65	0.76	0.87	0.91
Gas boiler	AFUE	0.60	0.65	0.70	0.80	0.85
Oil furnace	AFUE	0.55	0.72	0.78	0.83	0.85
Oil boiler	AFUE	0.60	0.75	0.80	0.83	0.85
Air source heat pump	HSPF	4.30	4.70	5.60	5.80	
Ground source heat pump	COP	2.70	2.70	3.00	3.30	3.50
Wood stove	SS	0.50	0.50	0.55	0.65	0.72
Wood boiler	SS	0.40	0.40	0.55	0.60	0.70
Water Heating						
Storage Gas	EF	0.47	0.50	0.53	0.57	0.60
Storage Oil	EF	0.47	0.47	0.50	0.53	0.55
Storage Electric	EF	0.80	0.80	0.88	0.92	0.92
Instantaneous	EF			0.70	0.72	0.80
Space Cooling						
Air source heat pump	SEER	5.00	6.50	8.70	9.70	12.00
Ground source heat pump	EER	10.00	10.00	10.00	11.00	12.00
Central Air	SEER	5.00	6.00	8.20	9.70	12.00
Room air conditioner	EER	5.00	6.10	8.00	8.00	9.00

Units: AFUE – annual fuel utilization efficiency
COP – coefficient of performance
SS – steady state efficiency
EF – energy factor
SEER – Seasonal Energy Efficiency Ratio
EER – Energy Efficiency Ratio

Occupancy levels – The data for occupancy levels followed closely with the Statistics Canada data on population studies. On average, each house is assumed to be occupied by two adults and two children. One adult and one child are in the house for 50% of time and the other for 90% of the time.

Domestic hot water use – Table 5 shows the typical profile of hot water use in houses. The hot water usage includes the needs for showers, dish and clothes washing.

Table 5. Profile of hot water use.

Occupancy	*Hot water use, L/day*
1	80
2	140
3	180
4 or more	225

APPLICATIONS

Archetypes provide default data for energy analysis. Archetypes must be used as a tool for describing the thermal and architectural features of a specific house. While conducting the field evaluation of a house, the default data must be replaced with actual information pertaining to the house. Benefits of the default data set are as follows:

- for existing homes, it is sometimes difficult to decipher thermal insulation levels and types of building envelop components;
- defaults provide vintage-specific information space heating, hot water, ventilation and cooling equipment; and
- the estimated energy use for the house can be approximated within the range of the code-built vintage.

Following are three applications in which the archetype information is employed extensively.

Energy Audits for the ecoENERGY Retrofit Program

The ecoENERGY Retrofit program is intended to provide professional advice to homeowners to improve the energy efficiency of their home (NRCan 2007). The energy advisor performs a walk-through assessment of the house along with a blower-door test. Using the HOT2000 energy evaluation software, the energy advisor estimates the energy use profile for the house and recommends appropriate measures (HOT2000 1998). The software can also estimate the impact of potential retrofit measures.

This evaluation is a quick examination of energy use of a house. Each evaluation is generally completed in about 2 to 3 hours. The 'House Wizard' in HOT2000 simplifies data entry immensely. The energy advisor follows these steps to perform an energy analysis:

- Step 1. Choose the region and vintage of the house and provide the dimensions of the house. Define the general description of the house as shown in Figure 2. By clicking the 'Next" tab, all input geometry data fields are populated with the archetype information.

- Step 2. An energy advisor can now go through other input screens, such as those shown in Figure 4 and Figure 3, and either change the data to match information collected during the field evaluation or accept the defaults. Airtightness data taken from the blower door test is entered later. Once the 'House Wizard' data input is complete and a house model is generated, the house geometry, construction details and thermal values are fine-tuned.
- Step 3. Perform the energy analysis and estimate the baseline energy consumption for the house. Using the field observations and simulation results, the energy advisor performs further energy analyses and provides energy efficiency improvement recommendations. A detailed report of the performance of the house and the upgrade recommendations is generated and given to the homeowner.

The readymade archetype information for geometry and thermal characteristics provide useful defaults when a house characteristic cannot be observed or easily determined. Most of the time the advisors change everything once they exit the house wizard. It seems it is most beneficial in that the wizard generates a starting point with the general structures (walls, foundation, heating system etc). The advisor can then correct the entries to match their observations. The defaults themselves are not often used.

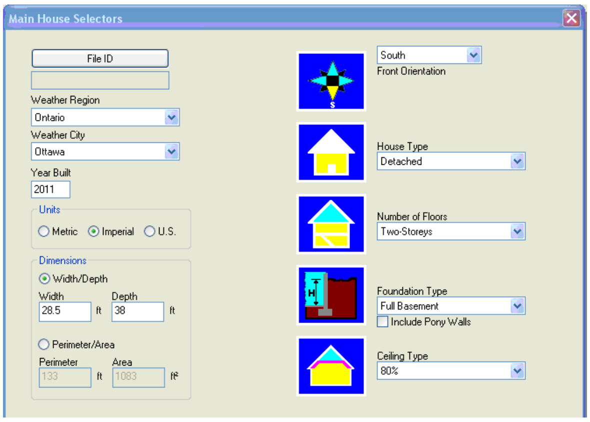


Figure 2. Quick data entry screen of HOT2000.

The data structure in the software enables the user to create custom libraries of the archetypes. This is useful for specific styles of a large group of houses which can be evaluated effortlessly.

The simplified version of the energy analysis is not generally sufficient for complex houses with multiple foundations, multiple mechanical systems and intricate details. For complex houses, the energy advisor can build a preliminary model using the HOT2000 geometry wizard. This preliminary model can then be edited and modified in the detailed energy analysis interface. HOT2000 offers detailed inputs for the complex geometry, thermal parameters and multiple options for mechanical systems.

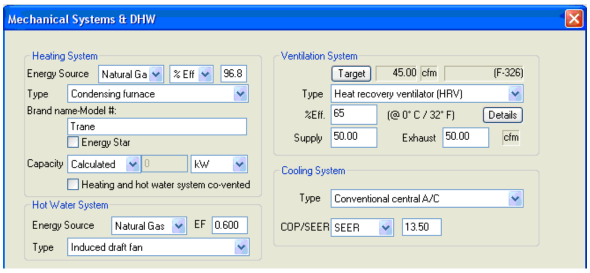


Figure 3. Data input for the mechanical systems.

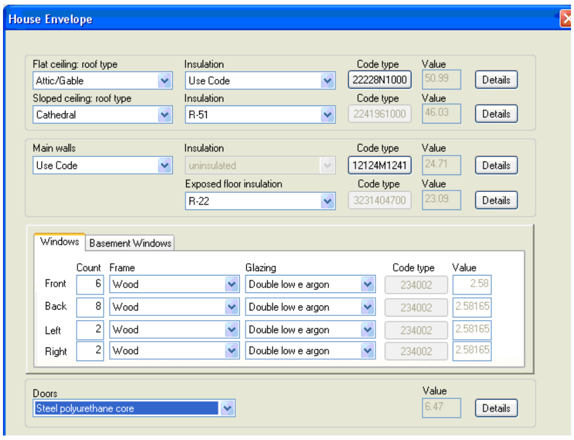


Figure 4. Modify geometry information as required.

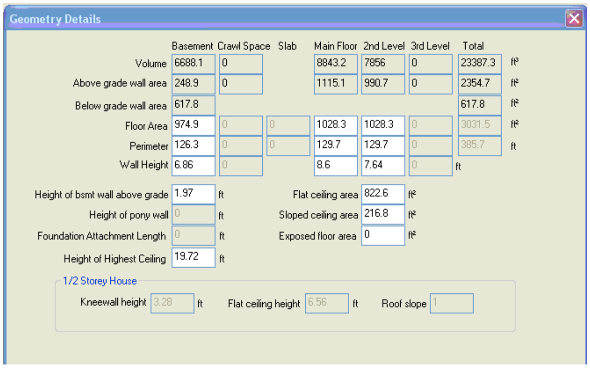


Figure 5. Checking and correcting geometry details.

Housing Policy Analysis

For setting and measuring the energy efficiency policy objectives for housing, the federal government uses comprehensive macro analysis models. The housing stock data is available from the Canada Mortgage and Housing Corporation (CMHC 2009).

In the past, the macro level housing model assumed the average thermal characteristics for the whole housing stock. This assumption was later adjusted based on weighing factors to account for various styles and vintages of houses. In all, the analysis provided cumbersome results and lacked the technical validity in the assessment process.

Since 2009, by implementing detailed archetype models for different segments of the housing stock, the macro analysis models have provided reliable results. All 120 archetypes have been assigned with an appropriate segment of the housing stock. The newly revised macro analysis model has been able to determine specific technology and program impacts.

For example, the macro analysis model accurately estimated the impact of housing retrofits for the market segment built before 1980. Macro analysis can also assist in projecting the potential energy efficiency gains associated with innovative technologies.

Tracking Energy Efficiency of Housing

The archetypes information is utilized for demonstrating the improvements in the housing stock over the years. These trends are useful in summarizing the overall improvements in the housing stock. Figure 6 shows the increase average wall and attic insulation over time in Canadian housing. Similarly, Figure 7 depicts the average improvements in the energy use of housing with time. As shown, the houses built today are almost 15% better than those built about 20 years ago. Archetype descriptions fairly correctly provide region-specific or national trends in the energy efficiency of housing stock.

DISCUSSIONS

The archetype libraries are meant for providing appropriate defaults for detailed energy analysis of houses. These default values must be checked for a specific house before performing an energy analysis. In the absence of verification of thermal values, archetype defaults provide the next best estimate.

It is important to note that the simplified energy analysis tools are only advantageous when the accuracy is acceptable and controllable. For using the simplified energy analysis method along with building characteristics defaults, one needs to verify the inputs with field evaluations. If the archetypical defaults are used without verification of the model from a house audit, then significant inaccuracies may be introduced in the energy use estimates. One study of these inaccuracies, reported by Hamlin, showed a wide range of energy estimates for 58 Winnipeg homes (Hamlin 1996).

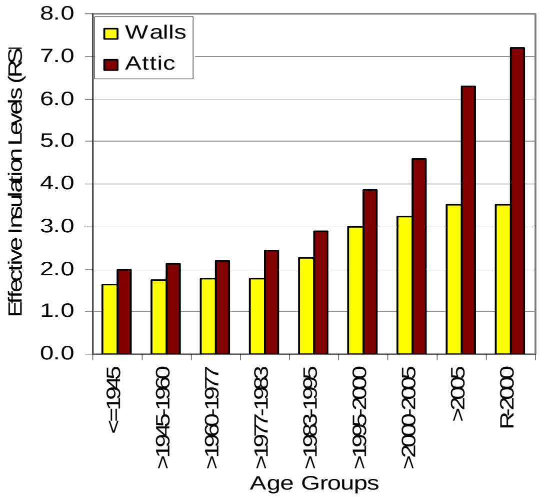


Figure 6. Improvements in envelope insulation.

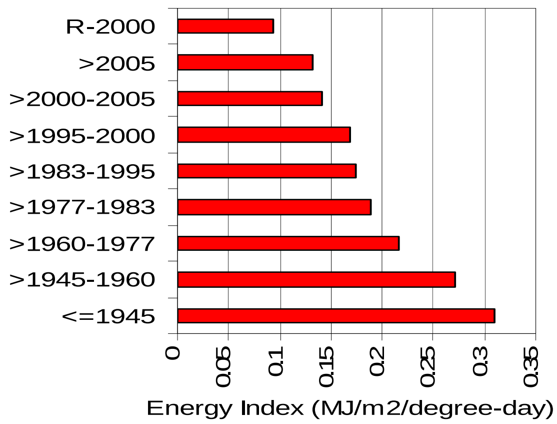


Figure 7. Energy use index for space heating and hot water use in Canadian housing.

The study showed the differences between the energy estimates using the archetypical defaults and actual field surveyed data for 58 houses. The difference in energy estimates ranged from a modest 10% to unacceptable levels of more than 100%. The difference in the energy estimates (default values versus the field survey inputs) was marginal for houses which were not retrofitted or improved since their construction. To avoid such discrepancies, the following requirements have been mandated for the use of simplified energy analysis tools for the retrofit programs:

- The archetypical defaults for the envelope characteristics must be confirmed with the field survey.
- Space and water heating inputs must be verified.
- Overall, only up to two default values (which may be difficult to verify) are allowed for the EGH evaluation.

The above requirements significantly improved the estimates of energy use and are able to provide reliable advice for energy efficiency retrofits to homeowners.

CONCLUSIONS

The archetypical information about the geometry and thermal characteristics is useful in quick energy analyses of houses. These characteristics mainly include the typical dimensions, make and composition of envelope components, predominant heating and hot water equipment data, and airtightness and ventilation parameters. Metered data of energy use provided the baseline estimates for the base electricity loads and operating parameters. The age and climate region-specific default data for a house provides enough guidelines and 'picturing' of the thermal behaviour expected for a specific house. Archetype information simplifies the data input for the quick energy analysis.

ACKNOWLEDGEMENTS

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