DEVELOPMENT OF ARCHETYPES OF BUILDING CHARACTERISTCS LIBRARIES FOR SIMPLIFIED ENERGY USE EVALAUTION OF 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. Representative numerical approaches were applied to develop archetype house characteristics using the data gathered from various surveys of housing stock in Canada. These characteristics include size and type of a house, composition of envelope components, heating and hot water equipment data, airtightness and ventilation parameters and, in particular, base loads and operating conditions. Data libraries provide the necessary defaults for building envelope and equipment. These defaults then become guidance for the field evaluator to check against the actual house data. Comparative energy analyses showed that the archetype characteristics are very useful in quick and useful field surveys.

INTRODUCTION

Since mid-1998, Natural Resources Canada has been promoting the EnerGuide for Houses (EGH) program to evaluate and rate energy efficiency of low-rise residential buildings. The main goal is to provide retrofit advice to homeowners based on the field assessment and careful estimate of energy use using the energy analysis software (NRCan 1998). Since the inception of the EGH program, more than 180,000 houses have been evaluated nationwide. With the introduction of the retrofit incentives in August 2003, on average, 7,000 houses are being evaluated every month.

The EGH evaluator 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 EGH evaluation is performed to update the energy efficiency rating.

To perform an energy evaluation of a house, one needs a simple but reliable energy analysis software tool. One of the key requirements for 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 'picturing' of the thermal behaviour expected for a specific house.

Over the years, there have been detailed surveys of Canadian housing (Parekh 1996). These surveys were conducted in the last 20 years and include detailed information for more than 3,800 houses located across Canada as shown in Table 1. The STAR housing study (statistically representative) included comprehensive details of thermal and energy use parameters for about 1,100 houses across Canada (Parekh 1993). In 1993, Natural Resources Canada conducted another detailed field survey of about 262 houses across Canada (NRCan 1993).

The information collected provided the following: the 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 thermal efficiencies); and, airtightness and ventilation parameters. The metered data for the energy use provided the baseline estimates for the base loads (mainly lighting and appliances) and operating parameters.

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

METHOD

The housing stock surveys presented in Table 1 were applied for developing a master spreadsheet. Each survey provided differing amount of information. The information was collated in some meaningful fashion. The following steps outline the method employed for developing archetypes:

- Step 1. Information from various sources was assembled in a master spreadsheet. The quality of the data was checked extensively and the suspect or incorrect datafiles were removed from further processing. In the end, the master spreadsheet contained information for 2,930 house files.
- Step 2. Established the criteria for correlating geometric and thermal characteristics.
- Step 3. Assembled various groupings of the data to arrive at representative thermal and performance values.
- Step 4. Verified the key parameters with known reports from Statistics Canada (StatCan 1995). 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.

Table 1. Sources of thermal and airtightness data.

Source of Data	Number of Records
1. 1982 Airtightness Tests on 200 New Houses (SRC) 1982, Canada	200
2. 1989 Airtightness Survey of New Merchant Homes (NRCan) 1989, Canada	194
3. Airtightness and IAQ of 78 Winnipeg Houses (CMHC) 1989	78
4. Airtightness Measurements in Saskatoon Houses (NRC-DBR) 1982, SK	176
5. Airtightness Tests of Ontario Houses 1995	108
6. Appin – Manitoba Houses 1989	73
7. CMHC STAR Housing Database (1993), Canada	1,100
8. Nova Scotia Report (NRCan) 1993	54
9. Efficiency Housing Database - Alberta (NRCan) 1993	55
10. Elliott Lake, Scanada 1992, ON	26
11. Espanola data, Scanada 1991, ON	29
12. Eval-Iso Project - Hydro Quebec (1995), Quebec	1,081
13. Field Energy Audit Survey (NRCan) 1994, BC	90
14. Field Testing (CMHC) and Aereco Houses, Scanada 1992, ON	24
15. Healthy Homes (NRCan) 1994, NS	20
16. MAPP Data, Scanada 1987, NF, MB, ON, QU, NS	125
17. Ontario Hydro, Scanada 1989, ON	85
18. Summary of Airtightness New Conventional Homes (NRCan) 1989, NS, NB, ON, AB, BC	68
19. Survey of 28 Homes, Bowser Tech 1990, ON	28
20. Survey of Airtightness of 40 New BC Homes (NRCan) 1993	40
21. Ventilation Control (SRC) 1994, SK	20
22. Airtightness and Energy Efficiency of New Conventional and R2000 Housing in Canada (NRCan) 1997	162
Total	**3,836**

- Step 5. Performed parametric energy simulations to determine the sensitivity of various archetypes based on the floor area and location and vintage classification.

The representative archetype of housing form includes three components:

- Geometric configurations
- Thermal characteristics
- Operating parameters

Geometric configurations

The geometric configuration includes 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), 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 survey data was considered to develop a profile of thermal archetypes based on the location 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 co-relation based formulas for various components. The required primary inputs were the age of the house and the location. Based on these primary inputs, all required 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.

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 2 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.

Table 2. 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

Thermal descriptions

The database of houses provided enough information for each province for a range of vintage. The database can allow a large number of archetypes based on vintage, location and type of houses. However, a large number of typical archetypes defeat the main purpose for simplifications. Therefore, the following criteria was utilized for developing 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), house levels, shape of plan, type of ceiling and type of foundation.

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

- Vintage period: This is defined based on various changes in the applicable codes and standards. The following vintages were classified:
  1. Pre-1945
  2. 1946 to 1960
  3. 1961 to 1970
  4. 1971 to 1980
  5. 1981 to 1990
  6. 1991 to 1995
  7. 1996 onwards
- Location or climate region: Initially, each province was classified with one or two climate zones. However, the further data analysis showed that the region-specific classification was adequate. The following regions are grouped:
  1. Atlantic region (includes Newfoundland and Labrador, Nova Scotia, New Brunswick and Prince Edward Island),
  2. Quebec region (with two climate zones)
  3. Ontario region (two climate zones south/west and north/east)
  4. Prairies and North region (Manitoba, Saskatchewan, Alberta, NWT, Nunavut and Yukon)
  5. British Columbia (with two climate zones)

The above matrix allowed for 56 (7 vintages x 8 climate zones) archetypes. The database of information was first collated and sorted using the above matrix. In most cases, the number of data points were sufficient (at least 10 observations or more) to perform the statistical functions such as mean, median, average, 25th percentile, 75th percentile. One such example is shown in Table 3 and Table 4 for the Atlantic region. Figure 1 shows the airtightness values for Quebec housing. As shown, there have been steady improvements in the thermal insulation levels over time. The airtightness of houses improved significantly.

Table 5 shows the summary of equipment efficiencies of space heating, hot water and space cooling systems over the years. Over the years, the space heating and hot water equipment improved significantly. The regulatory requirements have played a significant role in these improvements.

Table 3. Analysis of main wall insulation levels for Atlantic region (expressed in m^{2}K/W, RSI).

Maritimes - Main Wall Insulation Levels (RSI)							
	<1921	1921-45	1946-60	1961-70	1971-80	>1980	All ages
Sample size	7	21	36	16	35	17	132
Average	**1.94**	**1.65**	**1.88**	**1.88**	**2.26**	**3.59**	**2.17**
Std. Dev.	0.69	0.69	0.75	0.80	0.37	0.50	0.85
Minimum	0.93	0.91	0.83	0.68	0.74	2.68	0.68
Maximum	2.61	3.20	3.76	3.91	3.34	4.84	4.84
10 %tile	1.01	0.96	0.93	1.00	2.00	3.22	0.97
25 %tile	**1.44**	**1.04**	**1.07**	**1.06**	**2.25**	**3.52**	**1.74**
50 %tile	2.28	1.27	2.11	1.97	2.30	3.52	2.25
75 %tile	2.45	2.27	2.38	2.30	2.34	3.52	2.42
90 %tile	2.52	2.34	2.52	2.33	2.42	4.23	3.52

Table 4. Archetype data of above-grade wall insulation levels for Atlantic region.

Maritimes	Ceiling	Main Walls	Basement Walls	Overhanging
Envelope Defaults	**Effective RSI**	**Eff. RSI**	**Eff. RSI**	**Floor RSI**
Pre 1945	1.6	1.0	0.5	0.5
1945 - 1959	2.1	1.0	0.5	0.5
1961-1970	2.1	1.0	0.5	2.1
1971 - 1980	2.1	1.0	0.5	2.1
1981 - 1990	5.0	2.1	1.4	3.5
1991 - 1995	5.0	3.1	1.8	5.0

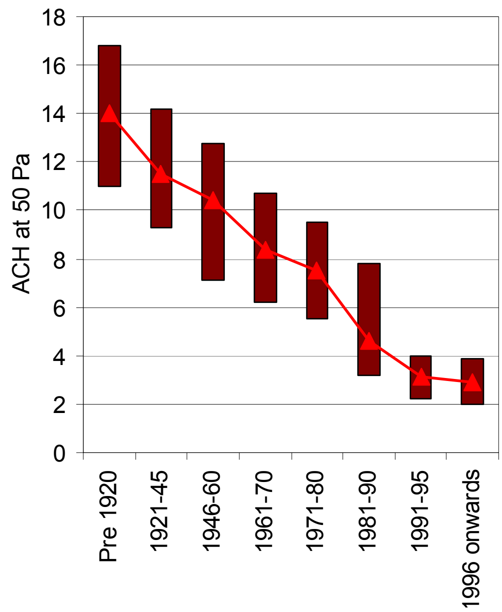

Figure 1. Airtightness characteristics for the Quebec housing – bottom of the bar is at 25th and top is at 75th percentiles.

Table 5. Analysis of equipment efficiency levels for space heating, hot water and space cooling systems.

Mechanical System	Unit	Pre 1960	1960-83	1984-1995	1996-present
Space Heating					
Gas furnace	AFUE	0.60	0.65	0.76	0.84
Gas boiler	AFUE	0.60	0.65	0.70	0.80
Oil furnace	AFUE	0.55	0.72	0.78	0.78
Oil boiler	AFUE	0.60	0.75	0.80	0.83
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
Wood stove	SS	0.50	0.50	0.55	0.65
Wood boiler	SS	0.40	0.40	0.55	0.60
Water Heating					
Storage Gas	EF	0.47	0.50	0.53	0.57
Storage Oil	EF	0.47	0.47	0.50	0.53
Storage Electric	EF	0.80	0.80	0.88	0.92
Instantaneous	EF			0.70	0.72
Space Cooling					
Air source heat pump	SEER	5.00	6.50	8.70	9.70
Ground source heat pump	EER	10.00	10.00	10.00	11.00
Central Air	SEER	5.00	6.00	8.20	9.70
Room air conditioner	EER	5.00	6.10	8.00	8.00

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

Operating conditions

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

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

From a set of 134 highly monitored houses (items 8, 9, 13, 17 and 22 in Table 1), 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. Table 6 shows the typical electricity consumption patterns for housing. **Figure 2** 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.

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 7 shows the typical profile of hot water use in houses. The hot water usage includes the needs for shower, dish and clothes washing.

Table 6. Profile of base electric use patterns for single-family homes.

No. of Occupants	Average Electricity Use, kWh/day	Standard Deviation, kWh/day
1	11.0	4.2
2	18.0	6.7
3	21.0	8.1
4	22.5	6.3
5	23.6	5.6
6	24.8	6.8
7	27.1	2.5

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

OccN = number of occupants

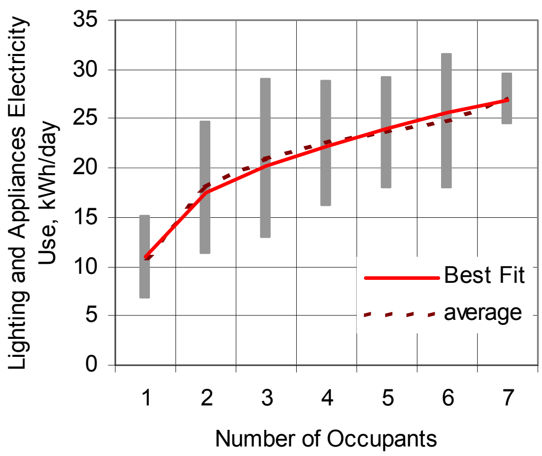

Figure 2. Profile of base loads in single-family housing.

Table 7. 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 'picturing' 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. As such, archetype defaults provide simply guidance to the energy evaluator. The following are three applications in which the archetype information is employed extensively.

Energy Evaluations for the EnerGuide for Houses (EGH) Program

The EnerGuide for Houses program is intended to provide professional advice to homeowners to improve energy efficiency of their homes. The energy advisor performs a walk-through assessment of the house along with a blower-door test. Using the HOT2 XP energy evaluation software, the energy advisor estimates the energy use profile for the house and recommends appropriate measures (HOT2 XP 1998). The software can also estimate the impact of potential retrofit measures.

The EGH evaluation is a quick examination of energy use of a house. Each evaluation is generally completed in about 2 to 3 hours. The 'house builder' in the HOT2 XP simplifies the data entry immensely. The energy advisor follows these steps to perform energy analysis:

- Step 1. Choose the region and vintage of the house. Provide the dimensions of the house. Define the general description of the house as shown in Figure 3. By clicking the 'Default All' tab, all input data fields are populated with the archetype information.

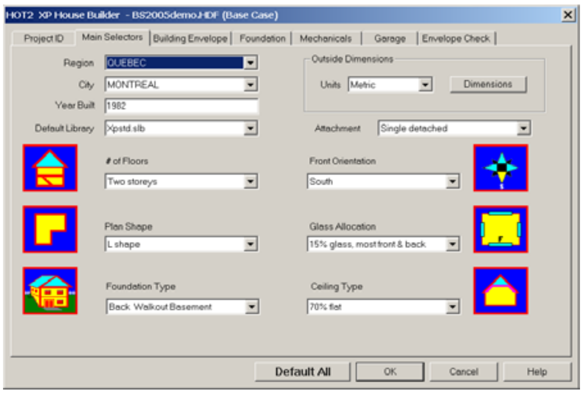

Figure 3. Quick data entry screen of HOT2 XP.

- Step 2. Energy advisor can now go through other input screens, such as shown in Figure 4 and Figure 5, and either change the data or accept the defaults found on the field evaluations. The airtightness data is taken from the blower door tests. The archetype defaults provide the guidance to Energy Advisors. Once the data input is complete, the 'Envelope Check' provides final manipulation of input data for geometry, construction details and thermal values.

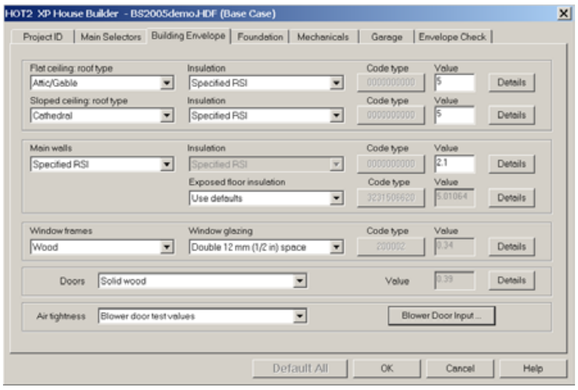

Figure 4. Data input for the building envelope components.

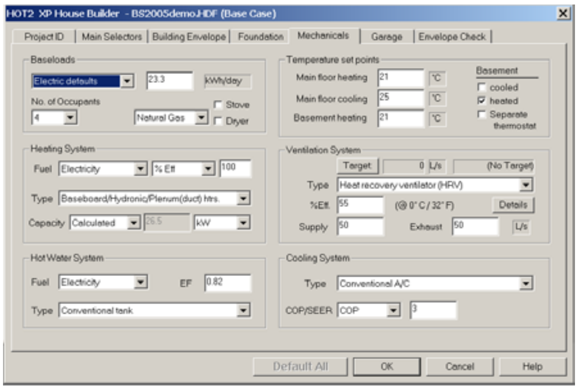

Figure 5. Data input for the mechanical systems.

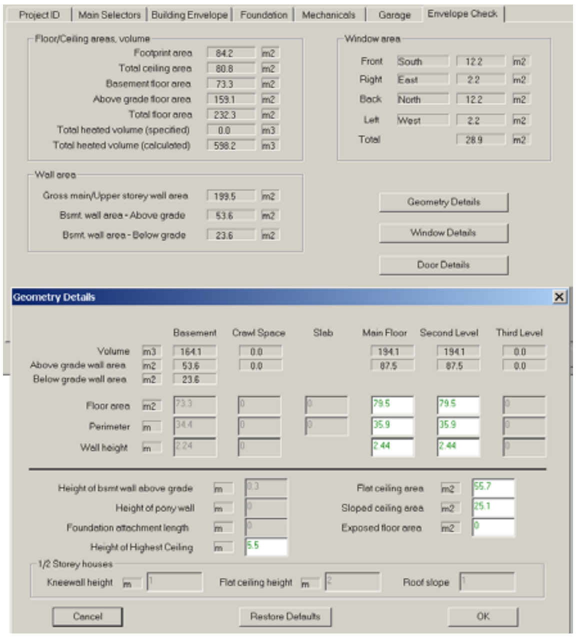

Figure 6. Checking and correcting geometry details.

- Step 3. Perform energy analysis and estimate the baseline energy consumption for the house. Using the field observations, energy advisor further performs the energy analysis for potential energy efficiency recommendations. A detailed report of recommendations is given to the homeowner.

The readymade archetype information for the geometry and thermal characteristics simplify the field data input. The energy evaluation process becomes much faster, reliable and easy to duplicate.

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 HOT2 XP. This preliminary model can then be imported in HOT2000 which is a detailed energy analysis program. HOT2000 offers detailed inputs for the complex geometry, thermal parameters and multiple options for mechanical systems.

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 2004).

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 1996, by implementing detailed archetype models for different segments of housing stock, the macro analysis models have provided reliable results. All 56 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 housing retrofits for the market segment which was 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 7 shows a profile of increase over the years in the average wall and attic insulation in Canadian housing. Similarly, Figure 8 depicts the average improvements in the energy use of housing over the years. As shown, the houses built today are almost 15% better than those built about 20 years ago. The R2000 houses lead the industry by about 30% compared to current housing. Archetype descriptions fairly correctly provide region-specific or national trends in the energy efficiency of housing stock.

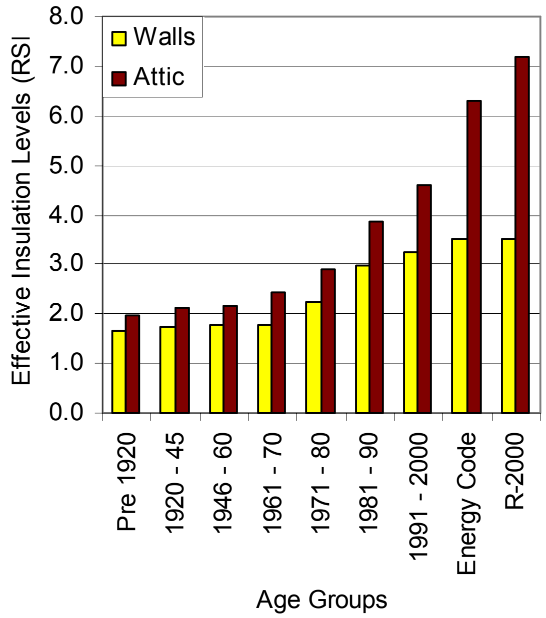

Figure 7. Improvements in envelope insulation.

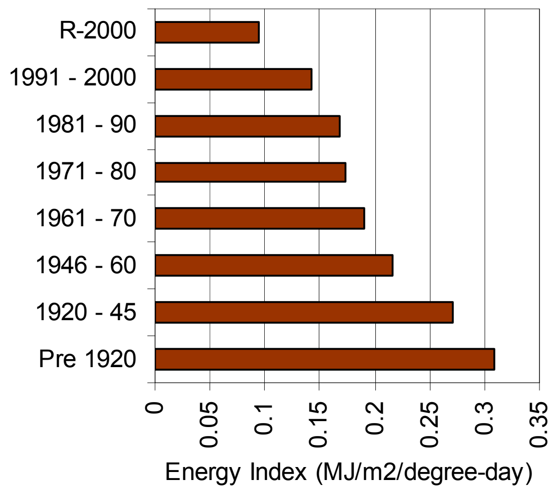

Figure 8. Energy use index for space heating and hot water use in Canadian housing.

DISCUSSIONS

The archetype libraries are meant for providing appropriate defaults for detailed energy analysis of houses. These defaults values must be checked for a specific house before performing energy analysis. In the absence of verification of thermal values, archetype defaults provide 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 defaults for the building characteristics, one needs to verify the inputs with field evaluations. If the archetypical defaults are used without verifications of actual inputs from building audit, then there is going to be significant difference in the energy use estimates. One such study, reported by Hamlin, showed a wide range of energy estimates for 58 Winnipeg homes (Hamlin 1996). 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 EnerGuide for Houses Program:

- The archetypical defaults for the envelope characteristics must be confirmed with the field survey.
- Space and hot 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 analysis 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. The metered data for the 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.

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