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CANADIAN HOUSING STOCK DATABASE FOR BUILDING ENERGY SIMULATION

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ABSTRACT

Simulation of the Canadian housing stock (CHS) for the purpose of evaluating the impact of energy saving upgrades and technologies requires a detailed housing database representative of the stock. Such a database has been assembled by selecting house records from the EnerGuide for Houses database to form a subset which statistically match parameter distributions defined by the Survey of Household Energy Use 2003 (SHEU-03). The SHEU-03 is considered representative of the CHS. The parameters considered during selection include: location, type, vintage, geometry, and heating systems.

This selected database is comprised of over 17,000 records of single-detached and double/row houses. Each record is of equal weighting. Based on the selection parameters, each house record represents approximately 500 houses in the Canadian stock.

Detailed information regarding the geometry, construction fabric, air-tightness, and heating equipment of each house in the database may be used to develop input files to conduct detailed energy simulation using software based on heat and mass transport equations. The conversion of the database to such a software package is an ongoing project.

INTRODUCTION

The housing stock constitutes over 17% of Canadian end-use energy consumption (OEE 2006b). This consumption is composed of domestic uses, lighting, ventilation, cooling, and heating. As the climate dictates significant heating energy, Canada has had incentive programs in place for over a decade to support upgrades or the addition of technologies to the housing envelope through the EnerGuide and ecoAction programs (OEE 2004 & 2007). As residential energy consumption is further scrutinized, a nationally and regionally representative energy model of the Canadian housing stock (CHS) is required to estimate the impact that upgrades or additions of technology may have on energy consumption and associated greenhouse gas (GHG) emissions.

In order to develop such an energy model there is a need for a representative database of houses. It must contain data on each house of sufficient detail for use with sophisticated building energy simulation software that is capable of high resolution simulation (time step of one hour or less) to realistically predict the performance of renewable energy technologies.

Key to the database is a large number of houses which represent the CHS. This should encompass the variety of housing styles, construction materials and techniques, heating equipment, and weather conditions. The database must also properly distinguish vintage, allowing for determination of impacts to recently constructed houses. Quantifications such as these may be used in the assessment of changes to the national building or energy codes. Incorporating the wide variety of houses of the CHS, while remaining regionally representative, allows for targeted application of upgrades or technologies to meet desired reductions in energy consumption or GHG emissions.

In this paper, the development process of a new, Canadian single-detached and double/row housing database is presented and the characteristics of the database are discussed. The database is both nationally and regionally representative with respect to the parameters used in its development. The database will be used to develop an end-use energy and emissions model of the CHS.

DATA SOURCES

To develop a database which statistically represents the CHS and is inclusive of the wide variety of houses found in the CHS requires detailed data on house characteristics for a large number of dwellings. These requirements are met by the EnerGuide for Houses Database (EGHD) and the Survey of Household Energy Use 2003 (SHEU-03).

Energuide for Houses Database

The EGHD (SBC 2006) is the culmination of over 200,000 requested home energy audits collected from 1997 through 2006. The audits, conducted by professional auditors, measured and observed the house geometry, construction fabric, air-tightness, and

heating equipment. Blais et al. (2005) describes in detail the EnerGuide objectives and the development of the EGHD. The basis for the audit was to estimate the house's annual energy consumption using NRCan's software *HOT2XP* to quantify the energy savings of retrofits for federal and provincial incentive purposes.

The audit measured and accounted for the following: location, type, geometry, storeys, foundation, attic, construction materials including windows and doors, blower door test results (air-tightness), and domestic hot water (DHW) and space heating systems. The EGHD is unprecedented due to its size and parameter inclusion which provides far more detail than most housing databases (e.g. the *American Housing Survey* 2005 which includes 50,000 samples (US Census Bureau 2006)). A file composed of 187,821 complete house records from the EGHD, each with over 161 distinct data fields, was received for this project from Natural Resources Canada (NRCan).

The EGHD does not include apartments or mobile home dwelling types. It does account for single-detached (SD) and double/row (D/R) houses, representing 80% of the CHS, as shown in Figure 1 (OEE 2006a). SD is defined as an entirely separated standalone single unit. D/R is similar, but shares one or more walls with another house.

From a national housing energy perspective, the SD and D/R house types represent more than 85% of the sector's energy consumption (OEE 2006a). This is because the other significant dwelling type, apartments, typically has fewer walls exposed to ambient conditions and less floor area per dwelling.

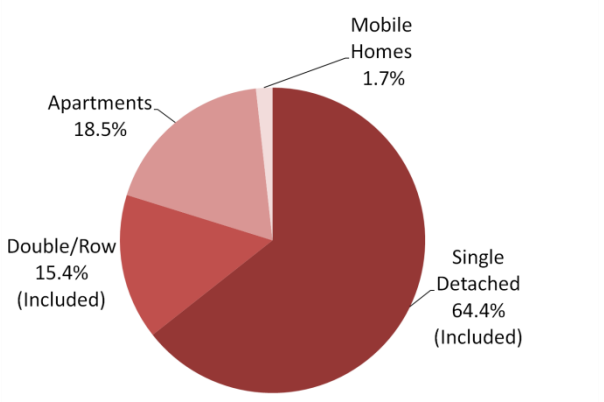

Figure 1: Distribution of the CHS by type. Inclusion in the EGHD is noted.

Survey of Household Energy Use 2003

SHEU-03 is a housing survey which was designed to quantify the energy use characteristics of the CHS and assess the effectiveness of federal energy efficiency programs over time (OEE 2006a). The SHEU was conducted in 1993, 1997, and 2003 and is expected to be continued. Statistics Canada conducts this survey of randomly selected dwellings based on population distribution. The data for the 2003 survey was collected from 4,500 dwellings. The survey results were extrapolated to be representative of the entire CHS (11.1 million dwellings). SHEU-03 accounts for parameters such as dwelling type and floor area, but does not include detailed information such as construction materials (most notably insulation) or infiltration/ventilation values which are desired for energy simulation. Furthermore, records for individual dwellings were unavailable for this project.

The results of SHEU-03 are compiled into regional distributions of parameters. Data tables further discretized by dwelling type were received from the Office of Energy Efficiency (OEE), NRCan. Due to its unbiased nature, the distributions of key parameters in SHEU-03 are used as the baseline reference to assess the final selected set from the EGHD.

METHODOLOGY

The EGHD is the source dataset from which a *subset* of nationally and regionally representative houses was selected with respect to certain parameters. The selection is based on comparison with the national and regional parameter distributions obtained from SHEU-03. This selection technique keeps each house record unmodified and intact.

To limit the number of house records in an effort to obtain a reasonable batch energy simulation computational time of less than one day[1], a subset of 18,000 to 20,000 house records was desired. This is approximately a 10:1 reduction from the original 187,821 EGHD house records.

Inspection of the EGHD

The received EGHD was initially inspected for duplicates caused by resubmission. 7,772 duplicates were found and the earlier of the two records was removed to account for an auditor resubmitting with a change due to a previous error. The remaining set was then divided into the five distinct Canadian regions defined by SHEU-03. They are: Atlantic (Newfoundland and Labrador, Prince Edward Island, Nova Scotia, and New Brunswick), Quebec, Ontario, Prairies (Manitoba, Saskatchewan, and Alberta), and British Columbia. House records from the territories were not included due to their low population and limited data. This further reduced the EGHD set by 1,211 records.

[1] Simulation time is estimated to be 6-12 hours using two dual-processor (1.86Ghz) quad-core computers.

The following key parameters of the houses were tested for validity: vintage, storeys, living space floor area, and DHW and space heating energy sources. Entries that had unrealistic values were discarded. Vintage (built prior to 1900) and floor area (less than 25m^2) were the dominant parameters which resulted in the discarding of 9,307 houses. Of the original EGHD set 169,531 house records remained; 156,571 SD and 12,960 D/R type houses.

The distributions of SD and D/R houses of the remaining EGHD set are shown as a function of region in Figure 2. As the EGHD only includes these dwelling types, the summation of SD and D/R values is considered 100%. To provide reference to the CHS, SHEU-03 distributions (also totalled for SD and D/R types only) are shown as a thick black outline in Figure 2.

Figure 2 shows that in comparison with SHEU-03, the EGHD is lacking D/R houses and the SD type is overrepresented in the Prairies region. Aydinalp et al. (2001) found different SD distributions, indicative of regional marketing changes of the EnerGuide program over its life. This simple regional analysis by house type shows that the EGHD must undergo significant reduction of overrepresented house records to achieve distributions representative of the CHS, as defined by SHEU-03.

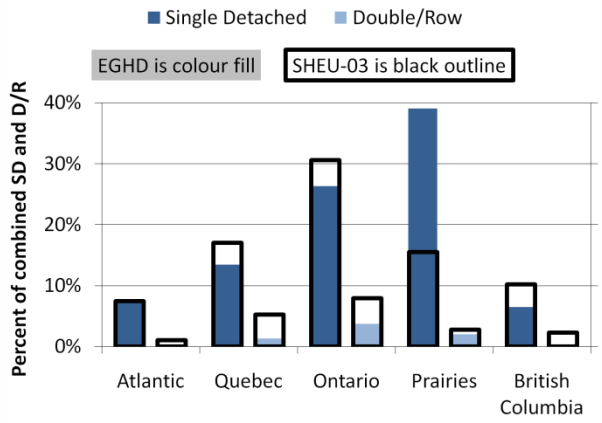

Figure 2: Regional distribution of SD and D/R houses in EGHD and SHEU-03

Selection of houses from the EGHD

Following a review and critical analysis of the data available in SHEU-03, the following parameter distributions ("selection parameters") were chosen to be used as the reference in selecting house files from the EGHD:

- House type (SD or D/R)
- Region (Atlantic, Quebec, Ontario, Prairies, British Columbia)
- Vintage (1900-1945, 1946-1969, 1970-1979, 1980-1989, 1990-2003)
- Storeys (1 through 3 including half storeys)
- Living space floor area (25-56m^2, 57-93, 94-139, 140-186, 187-232, 232-300; excluding basement or crawl space)
- Space heating energy source (electricity, natural gas, oil, wood, propane)
- DHW energy source (electricity, natural gas, oil)

EGHD house records which regionally matched these SHEU-03 parameter distributions were selected to form a nationally and regionally representative *subset* called the Canadian Single-Detached & Double/Row Housing Database (CSDDRD). This was accomplished by a forward selection algorithm with the intention of achieving parameter distributions for the CSDDRD equivalent to SHEU-03. This selection algorithm is described below.

Parameters such as number of occupants and temperature setpoints were not used in the selection process as they were typically left as the default value in the EGHD. This was due to standardized testing methods for EnerGuide comparison purposes.

The SHEU-03 parameter distributions of SD houses are listed on a regional scale; however, SHEU-03 does not consider the regional estimates for D/R housing to be reliable. Therefore, the regional D/R parameter distributions were assumed to be equal to the national D/R parameter distributions, except in the case of DHW and space heating energy sources. The D/R energy source distributions were set equal to the regional SD distribution values. This was considered appropriate due to the similar utility and fuel service received by both housing types within a region.

The selection of houses for the CSDDRD was accomplished by the following steps:

1) *Define the desired houses by type and region based on the SHEU-03 selection parameter distributions*- The ratio of SD to D/R houses defined by SHEU-03 was used to calculate the number of SD and D/R houses for the CSDDRD to achieve a desired total of 18,000-20,000. The number of SD houses was set to 15,000. This required 3,590 D/R house records to maintain a ratio equivalent to SHEU-03, resulting in 18,590 desired houses for the CSDDRD.

SHEU-03 specifies the regional distribution of houses by type, which was used to calculate the regional distributions of the 18,590 CSDDRD SD and D/R houses. Table 1 shows the regional distribution for the SD type. It can be seen that the regional distribution of CSDDRD and SHEU-03 houses are equivalent.

Table 1: SHEU-03 and desired CSDDRD SD house distribution

Region	SHEU-03	% of SHEU-03	CSDDRD	% of CSDDRD
Atlantic	662,335	9	1,381	9
Quebec	1,513,497	21	3,157	21
Ontario	2,724,438	38	5,683	38
Prairies	1,381,219	19	2,881	19
British Columbia	910,051	13	1,898	13
Total	*7,191,540*	*100*	*15,000*	*100*

Using the same approach, the desired number of houses was calculated for each element (option) of the selection parameters, forming arrays. An example parameter is *DHW Energy Source* and its elements are *Electricity*, *Oil*, and *Natural Gas* as shown in Table 2. Table 2 shows that the 1,381 Atlantic SD houses defined in Table 1 have been distributed by DHW elements (options) equivalent to that specified by SHEU-03. An organizational chart of the example selection parameter is shown in Figure 3. There are distinct selection parameter array sets for each region as a function of house type, totalling 50 (2 types, 5 regions, 5 parameters).

Table 2: SHEU-03 and desired CSDDRD DHW parameter distribution for the Atlantic region SD house type

DHW Energy Source	SHEU-03 (Atlantic)	% of SHEU-03 (Atlantic)	CSDDRD (Atlantic)	% of CSDDRD (Atlantic)
Electricity	487,023	76	1,043	76
Oil	157,855	24	338	24
Natural Gas	0	0	0	0
Total	*644,878*	*100*	*1,381*	*100*

2) *A computer program was written to consecutively progress through the EGHD, evaluating the parameters of each house record and comparing them to the selection parameter arrays*- If the house record's parameter values matched those desired by each selection parameter the house was added to the subset and the corresponding element in each parameter array was decremented. If a parameter option was not available (e.g. natural gas in the example of Table 2) or if that option had been decremented to zero by previously selected house records, the house record was discarded.

The consecutive nature of this technique has a limitation: the first house record encountered in the EGHD which fits with the desired distributions is selected for the CSDDRD. Because of this, a certain popular parameter option may fill, limiting the selection of subsequent house records that have desired characteristics as well as the filled characteristic. This was encountered for houses with underrepresented characteristics. Assigning weights to underrepresented houses (i.e. counting each underrepresented house as two or more) was not desirable due to the correlation between house parameters and the reduction of the total number of houses in the CSDDRD. Instead, this problem was addressed by initially sorting the EGHD in such a way that house files with underrepresented parameters were placed at the beginning of the dataset. While this gives preference to houses with underrepresented characteristics, it does not bias the CSDDRD because the selection parameter arrays limit the inclusion of these houses to the value which is desired.

Characteristics of the CSDDRD

The regional distributions of the two house types are compared with SHEU-03 in Figure 4. Figure 4 shows the CSDDRD distribution closely matches that of SHEU-03. Figure 4 may be compared to the original EGHD distribution shown in Figure 2.

As described, certain parameter options limited the complete fill of the arrays and therefore the CSDDRD has fewer houses than initialized (desired). The CSDDRD is comprised of 14,036 SD and 3,205 D/R house records. This totals 17,241 records which, based on the selection parameters, statistically represent the 8.9 million SD and D/R houses of the CHS.

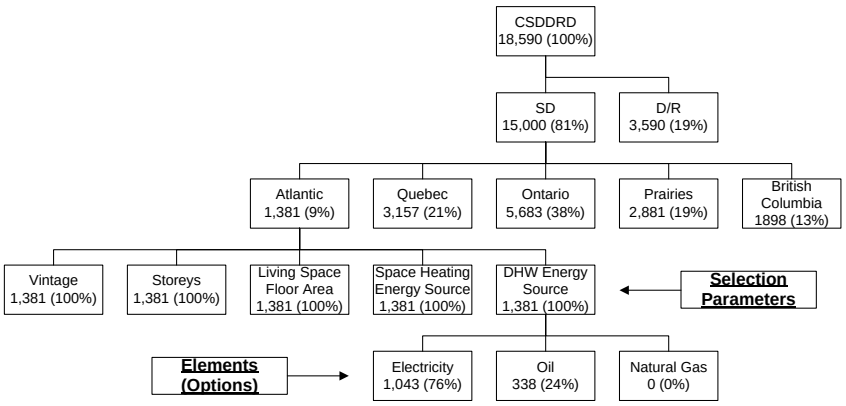

Figure 3: Organizational chart of desired selection parameter arrays

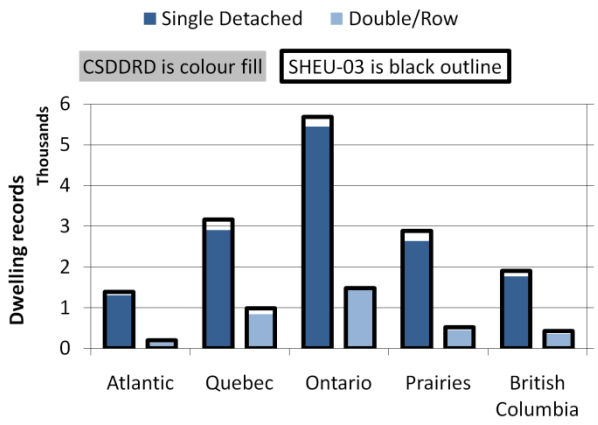

Figure 4: CSDDRD region and house type distributions compared to SHEU-03

Based on the selection parameters, each record of the CSDDRD is of equal weight and represents 517 houses of the CHS. This constant weighting scheme differs from other housing databases such as *Survey of Household Energy Use 1993 micro-data* (Statistics Canada 1993) and a collection of US homes (Persily et al. 2006). The primary reason that representation weights changed for each house in these databases was due to non-responses within the original random sample.

VERIFICATION OF THE CSDDRD

The CSDDRD is regionally compared to the selection parameters distributions defined by SHEU-03 to determine similarity, indicating good representation of the CHS house type.

The effectiveness of the procedure used to select the houses from the EGHD to populate the CSDDRD is seen in Figures 5-8. While the distributions of houses in the EGHD with respect to vintage and living space floor area are substantially different than those of SHEU-03 (Figures 5 and 7), the distributions of houses in the CSDDRD match closely with those of SHEU-03 (Figures 6 and 8). These results indicate that the selection process was successful at improving the representation of newer houses (1990 and later) as well as house with very small and very large floor areas.

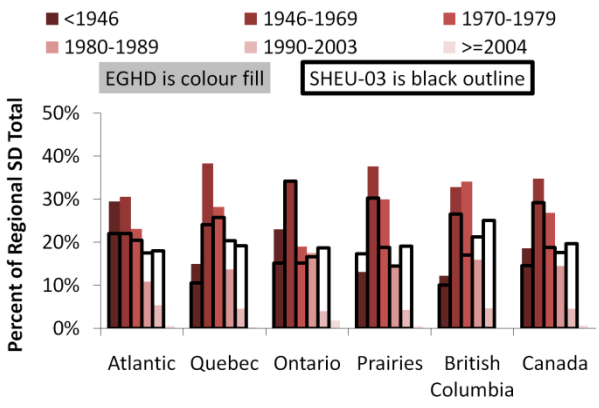

Figure 5: EGHD (SD) vintage distributions compared to SHEU-03

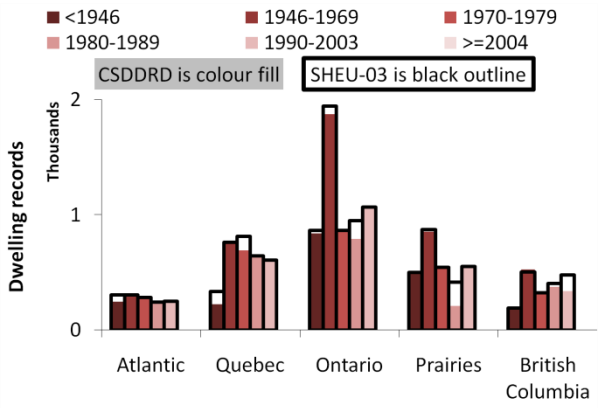

Figure 6: CSDDRD (SD) vintage distributions compared to SHEU-03

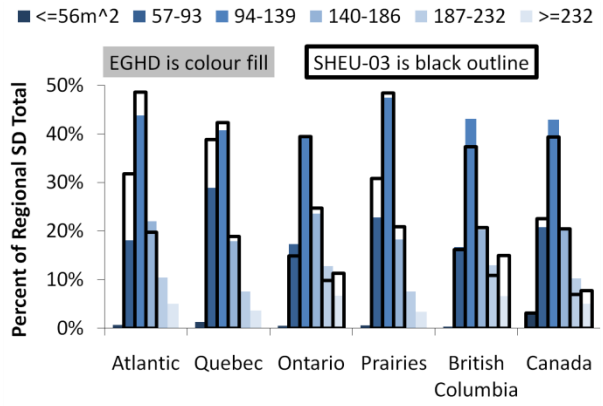

Figure 7: EGHD (SD) living space floor area (excluding basement) distributions compared to SHEU-03

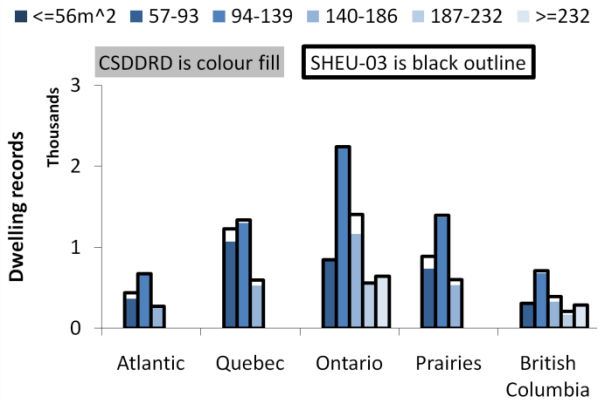

Figure 8: CSDDRD (SD) living space floor area (excluding basement) distributions compared to SHEU-03

Further investigation shows that the distributions of other selection parameters of the CSDDRD, for both SD and D/R types, also closely match SHEU-03.

The only selection parameter which did not closely match between the CSDDRD and SHEU-03 was *number of storeys* (see Figure 9). This is likely a result of two issues: auditor misunderstanding or misuse of half storey definition and no available option for the imputation of split level houses. This resulted in placement of certain half storey houses into the two storey category. As full storeys are the dominant type this representation issue has limited impact.

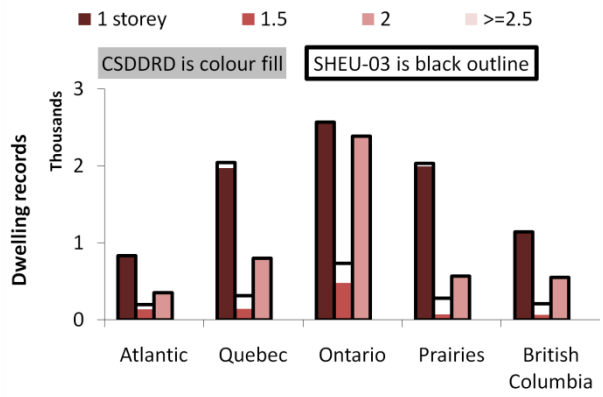

Figure 9: CSDDRD (SD) storeys distributions compared to SHEU-03

RESULTS

Key characteristics of the CSDDRD are:

- Nationally and regionally representative of both the single-detached and double/row house types of the CHS based on the selection parameters.
- Detailed geometry, construction fabric, infiltration/ventilation, and heating systems information.
- Encompassment of the wide variety of housing characteristics found in the CHS.
- Individual records which allow for assessment of interrelated characteristics (e.g. insulation levels as a function of region or vintage).

These characteristics allow the CSDDRD to be used as the dataset for energy simulation or interrelation/uptake investigation. A simple investigation of housing trends as a function of vintage and region was conducted for demonstration and is displayed in Table 3.

Values of particular parameters of the SD houses were averaged to determine trends within this house type of the CHS.

Beginning from the foundation of the house, it is apparent that slab and crawl space foundations are a minority compared to dug. Their construction rate remains stable and is predominant in British Columbia (BC). Although this was not a selection parameter for the CSDDRD, SHEU-03 shows similar results (OEE 2006a).

Living space floor area (excluding basement) of the SD house type has been increasing over the latter half of the twentieth century. It is presently averaging 144m^2, a value similar to that estimated by the OEE (2006a). Ontario and BC have the largest average areas, which is likely due to increasing rates of new construction (see Figure 6).

Window area and count also increased, although to a lesser extent; window size has remained nearly constant. Because of this and the floor area to perimeter relationship, the window to wall area (effective aperture) relationship is decreasing. Windows currently

account for 15% of the living wall area. The southern facing window area averages 5% of the living space floor area. Parekh and Platts (1990) recommend 8% for passive solar heating in northern climates, based on the thermal storage capacity of typical flooring to avoid overheating. Therefore, it appears that the CHS has significant potential for increased passive solar gain by the addition of southern facing windows, a parameter listed in the CSDDRD. Sadly, roof slope and orientation is not listed, limiting determination of applicability of solar collectors.

Thermal resistance has continuously increased, owing to better construction materials/methods and changes in building requirements. Ceiling insulation levels remain approximately twice that of walls. Basement insulation levels are increasing, perhaps due to understanding of ground losses and availability of force/water resistant extruded polystyrene.

Air change rates, as tested using a blower door, steadily decrease with newer construction. It can be seen that on average, for the same pressure difference, newly constructed houses have half the air change rate per hour (ACH). Chan et al. (2005) and Sherman & Dickerhoff (1998) found similar results in US datasets. In Canada where space heating is a dominant energy consumer of the domestic housing sector (OEE 2006b), this reduction has large impacts. The current R-2000 building standard requires a maximum value of 1.5 ACH at 50Pa depressurization (OEE 2005). This is less than half the current construction average of 4.4 ACH at 50Pa.

Presence of heat pumps, air conditioners, and heat recovery ventilation systems (HRV) were evaluated. The penetration rate of these appliances decreases with age, although not to the level expected by technological developments, due to their easy retrofit. Heat pumps have notably higher install rates in hydro based electrical systems. Occupants in Quebec and BC are accustomed to low electricity rates as compared to cheap natural gas and a very cold climate which limits heat pump penetration in the Prairies. As expected, air conditioners are predominant in Ontario due to a hot summer climate; however, SHEU-03 estimates a penetration rate closer to 65% (OEE 2006a). Penetration elsewhere is limited. HRV units are seeing significant increases as they are recommended for new SD houses (NRC 1997).

Table 3: Average CSDDRD (SD) parameter values as a function of Vintage and Region

	VINTAGE					REGION				
PARAMETER AVERAGE	<1946	1946-1969	1970-1979	1980-1989	1990-2003	Atlantic	Quebec	Ontario	Prairies	British Columbia
Slab Presence (%)	1.1	1.9	3.4	3.2	2.8	1.3	1.0	0.9	0.5	13.5
Crawl Space Presence (%)	9.0	6.2	7.9	7.3	7.5	7.3	6.2	4.1	2.8	26.0
Basement Presence (%)	89.9	91.9	88.7	89.5	89.7	91.4	92.8	95	96.7	60.5
Living Space Floor Area (m^2)	126.0	114.8	120.5	150.4	144.8	114.3	109.1	144.7	112.8	149.2
Gross Window Area (m^2)	19.4	20.3	20.2	23.7	23.5	18.9	19.7	23.1	17.8	25.6
Tot. Num. Windows	13.5	12.1	11.3	12.9	13.6	12.0	11.3	13.4	11.7	13.9
Avg. Window Size (m^2)	1.4	1.7	1.8	1.8	1.8	1.6	1.8	1.7	1.5	1.8
Percent Window of Living Space Wall Area (%)	14.2	17.2	16.4	15.6	15.2	15.9	16.8	15.7	14.5	17.4
Percent South Facing Window to Living Space Floor Area (%)	4.4	5.3	5.2	5.1	5.0	5.1	6.0	4.8	4.5	5.1
Ceiling Therm. Res. (RSI)	3.8	4.2	4.4	5.1	5.6	4.2	4.6	4.6	5.0	4.4
Living Wall Therm. Res. (RSI)	1.6	1.8	2.2	2.6	2.9	2.3	2.5	2.1	2.2	2.2
Basement Wall Therm. Res. (RSI)	1.6	1.6	1.6	1.9	1.9	1.4	2.1	1.4	1.7	2.5
ACH at 50Pa depressurization	10.2	6.9	5.8	5.2	4.4	6.9	6.1	6.5	5.0	8.0
Heat Pump Presence (%)	1.3	2.5	3.1	2.9	4.0	1.4	6.0	1.8	0.5	5.1
Air Conditioner Presence (%)	14.5	26.8	23.5	33.2	31.4	0.2	13.7	52.7	10.4	9.3
HRV Presence (%)	1.0	3.0	5.5	7.5	20.0	18.7	14.1	5.4	2.4	1.0

NATIONAL SIMULATION

The CSDDRD is currently undergoing conversion from delimited format into singular house files for detailed simulation using the software ESP-r (ESRU 2002). When complete, upgrades or renewable energy technologies will be applied to parametrically compare their impact on the energy consumption and GHG emissions of the housing sector. It is expected that certain house types, vintages, and regions will be identified as having greater impacts.

CONCLUSIONS

By comparison with the recent *Survey of Household Energy Use 2003* a subset of the *EnerGuide for Houses Database* has been selected which statistically represents the single-detached and double/row dwelling types of the Canadian housing stock.

The subset, titled *Canadian Single-Detached & Double/Row Database* (CSDDRD), includes over 17,000 house records with detailed values of geometry, construction fabric, air tightness, and heating equipment. Each house record is equivalent in weight and represents approximately 500 actual Canadian houses.

The CSDDRD may be used for energy simulation and assessment of the Canadian housing stock.

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