IMPLEMENTATION OF A CANADIAN RESIDENTIAL ENERGY END-USE MODEL FOR ASSESSING NEW TECHNOLOGY IMPACTS

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ABSTRACT

This paper discusses the present status and implementation of a new energy model that is used for evaluating the impact of new technologies when they are applied to the Canadian housing stock (CHS). The model batch processes a database of nearly 17,000 real house descriptions that statistically represent the CHS. The model employs statistical and heat/mass transfer techniques to encompass energy consumption due to occupancy and thermal conditioning.

So far, a majority of the features required for adequate building simulation have been implemented in the model. Simulation of all 17,000 houses requires two days on a dedicated computing system, resulting in annual energy consumption of major loads. The key strength of the model is its capability to accurately predict performance of new technologies as applied to the wide variety of houses encountered in the present CHS. It is enabled to do this by providing the ESP-r simulation engine with detailed descriptions of each dwellings' thermal envelope, air tightness, and plant systems.

INTRODUCTION

There is ongoing development of technologies for the efficient capture, conversion, and utilization of energy within the housing stock. Focus is placed on such technologies due to the recognition of the sector's significant energy consumption and resulting impact in the form of greenhouse gas (GHG) emissions. For example, the Canadian housing stock accounts for 17% of national end-use energy consumption, primarily due to space heating (OEE 2006a). From the perspective of policy development, such as government initiatives and incentives, it is important to estimate the potential impact that new technologies can have on energy consumption and the resultant GHG emissions. Such an assessment is not trivial for Canada as it has a broad range of climatic conditions, house construction types, and energy sources, all of which vary by region. Furthermore, the performance of new technologies such as renewable or alternative energy devices vary considerably throughout the day and year as a function of energy source or demand, requiring high resolution modeling. The accurate estimate of the impact of technologies upon the broad range of housing requires a detailed energy and emissions model.

A recent evaluation of residential energy models identified that different modeling techniques have significantly different capabilities (Swan and Ugursal 2009). The 'top-down' regression approach requires only aggregate data and macroeconomic indicators to provide long-term projections in the absence of discontinuities such as energy shocks or technological breakthroughs. In contrast, the 'bottom-up' approach utilizes any of a number of methods to assess individual or groups of houses, and then extrapolates these results to be representative of a region or nation. The bottom-up 'engineering' technique uses heat transfer and thermodynamic relationships to explicitly calculate energy consumption and therefore possesses the capabilities to model new technologies. The bottom-up 'statistical' technique regresses metered energy consumption onto a variety of indicator variables and in doing so can account for loads that vary with occupant behaviour. Therefore, for use as a technology assessment tool, the bottom-up approach is used in this work. To take advantage of the engineering and statistical techniques, a 'hybrid' modeling methodology has been devised (Swan et al. 2008).

The new Canadian hybrid residential end-use energy and emissions model (CHREM) relies on the 17,000 detailed house records of a representative database called the Canadian Single-Detached & Double/Row Housing Database (CSDDRD) (Swan et al. 2009). This database contains sufficient detail for energy performance simulation while accounting for the broad range of climate, construction types, and energy sources found throughout Canada's regions. The combination of modeling technique and database presents the opportunity to examine the impacts of application of new technologies to the present housing stock. The CHREM includes a GHG emissions component described by Mohmed et al. (2008). The following sections focus on the present status and implementation techniques of the energy component.

OVERVIEW OF THE CHREM

The CHREM model consists of two energy modeling components, statistical and engineering. These are used to estimate the energy consumption of the major end-use groups:

- Domestic appliances (e.g. refrigerator, stove) & lighting (AL)
- Domestic hot water (DHW)
- Space heating and cooling.

The AL and DHW loads are predominately influenced by occupant behaviour. In contrast, space heating is primarily a function of building construction fabric, plant components, and climatic conditions. Space cooling load is a function of both occupant behaviour and the dwelling thermal characteristics. Aydinalp et al. (2003) and Aydinalp and Ugursal (2008) examined the bottom-up approach and found that statistical techniques excel at predicting AL and DHW energy consumption through the use of neural network analysis. However, new technologies require the use of engineering techniques as there is no relevant historic data for statistical analysis.

Therefore, the CHREM employs a calibrated neural network (NN) as the statistical half of the model for use in estimating the annual energy consumption for AL and DHW loads.

Estimation of space heating and cooling loads is accomplished using the high-resolution building performance simulation package ESP-r (ESRU 2002, Clarke 2001). The ESP-r simulator uses numerical heat and mass balance methods applied at discrete time steps to a representation of the building using many finite volumes. ESP-r has been extensively tested and verified (e.g. Strachan et al. 2009), and was selected by the Government of Canada as the basis for its residential simulation tool development (Haltrecht et al. 1999). The simulator has the capacity to estimate the sub-hourly energy consumption of the dwelling due to space heating and cooling, inclusive of solar gains and the operating characteristics of energy supply and conversion equipment (plant networks).

Both the NN and engineering components require a detailed description of dwelling characteristics that are supplied by the CSDDRD as shown in Figure 1.

OVERVIEW OF THE CSDDRD

The CSDDRD is a database of house descriptions representative of the Canadian housing stock. It is a subset of the EnerGuide for Houses Database (EGHD), which is the culmination of over 200,000 requested home energy audits collected from 1997 through 2006 by Natural Resources Canada (SBC 2006). The audits, conducted by professional auditors, measured and recorded the location, type,

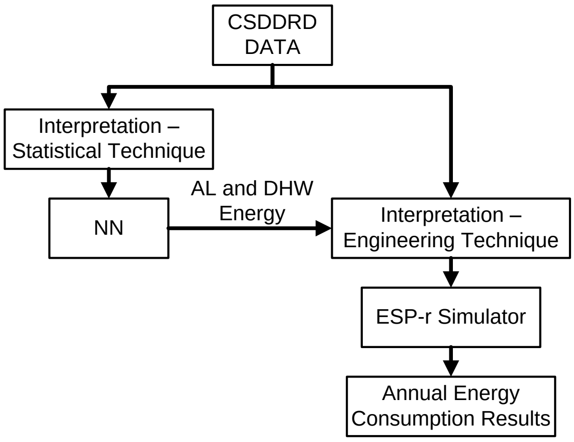

Figure 1: Process flow of the CHREM

geometry, storeys, foundation, attic, construction materials including windows and doors, blower door test results (air-tightness), and DHW and space heating systems. Variables were entered in accordance with the definitions and available selections of the HOT2XP monthly bin type energy simulation software (SBC 2008). Blais et al. (2005) describes in detail the EnerGuide objectives and the development of the EGHD.

Using an iterative selection process described in detail by Swan et al. (2009), a total of 14,030 single-detached (SD) and 2922 double/row (DR) house records were selected from the EGHD, totalling 16,952 records which, based on the selection parameters, statistically represent the 8.9 million SD and DR houses of the CHS. The parameters used for selection were:

- House type (SD or DR)
- Region (Atlantic, Quebec, Ontario, Prairies, British Columbia)
- Vintage (1900-1945, 1946-1969, 1970-1979, 1980-1989, 1990-2003)
- Storeys (one through three, including half storeys)
- Living space floor area (25-56, 57-93, 94-139, 140-186, 187-232, 232-300 m2; excluding basement or crawl space)
- Space heating energy source (electricity, natural gas, oil, wood, propane)
- DHW energy source (electricity, natural gas, oil).

The CSDDRD includes detailed information on each dwelling: location, geometry and orientation, thermal zone presence, construction fabric including windows and doors, air-tightness, and HVAC and DHW components

By using the CSDDRD as the source data for the CHREM, the opportunity is presented to simulate the wide variety of dwellings and construction types found in the Canadian housing stock, as well as to assess the impact of targeted upgrades of suitable dwellings with new technologies on residential energy consumption and GHG emissions within the sector.

CHREM'S STATISTICAL TECHNIQUE

The NN statistical technique for the estimation of AL and DHW energy consumption is implemented mathematically by reading and operating on input data, scaling functions, and coefficient and bias values using an automated Perl script. Perl is a powerful text file manipulator script language (CPAN 2009). The script calculates each successive 'neuron' value of a layer based on the preceding layer's results. This process allows for a high level of interaction between input information, and results in an output value which is scaled back to units of annual energy consumption.

Neural network method

The statistical technique requires information of AL and DHW device inventory as well as weather conditions, size and type of the dwelling, and socioeconomic/demographic characteristics. As socioeconomic and demographic characteristics are not included in the CSDDRD, the database was augmented with information sourced from recent census data (Statistics Canada 2007) and appliance penetration rates (OEE 2006b, 1994).The calibrated NN values are presented by Aydinalp (2002). The AL NN originally included space cooling electricity consumption, but this was left to the engineering model component by eliminating the presence of an air conditioner to the NN. Each house of the CSDDRD was batch processed through the script, resulting in annual energy consumption estimates (GJ) of AL and DHW. The DHW energy consumption values predicted by the NN include the conversion efficiencies of the DHW equipment. These energy values were converted back to water volume (L) using the same representative DHW heating system efficiencies of the NN, and assuming a 50 ˚C temperature rise, thereby allowing for DHW technology upgrades to be applied and assessed using the CHREM.

AL and DHW results

Since the compilation of data of distribution of socioeconomic and demographic parameters has not been completed, the following are preliminary results of the NN: (1) Annual AL energy consumption for individual houses ranges from 18 to 72 GJ with an average value of 43 GJ. (2) Annual DHW consumption per house is in the range of 100 to 400 litres per day with an average value of 200 litres per day.

AL and DHW load profiles and simulation

Estimated annual AL energy consumption and DHW volume results must be translated onto representative sub-hourly load profiles for integration with the model's engineering component. Canadian AL load profiles developed by Knight et al. (2007) and European DHW load profiles developed by Jordan and Vajen (2001) were used. The translation was accomplished by normalizing the representative profiles by their corresponding annual consumption, and providing the normalized profiles and annual AL and DHW consumption results of each house of the CSDDRD to the engineering model component. During simulation of a house, the normalized profiles are multiplied by the annual consumption results to provide the time step load value. The engineering component can then account for increased or offset heating and cooling loads due to the AL casual gains as well as DHW heating system operation.

CHREM'S ENGINEERING TECHNIQUE

As the CHREM employs ESP-r, a demonstrated and credible simulation engine, appropriate interpretation of the CSDDRD house records and generation of suitable thermal house models represents the major development process. This process is described in congruence with the ESP-r house model structure, which is comprise of a set of ASCII (primarily) files that are read by the ESP-r simulator. Additional files, not directly required by the simulation engine were constructed to afford compatibility with other ESP-r modules such as the project manager graphical user interface with 3D rendering. This compatibility allows individual models to be verified or manipulated outside of the batch simulation processes. The file groups of interest that are described in the following subsections are:

- Model databases – climate, building materials and constructions, plant system components
- Configuration and zoning – model structure and layout
- Zone information – geometry, surface conditions, construction fabric, foundation considerations
- Operations and control – casual gains, continuous air flow and infiltration, plant systems.

The interpretation of the CSDDRD house records and generation of the ESP-r house models is a batch process. The construction of ASCII files was completed using a Perl script.

The generation technique resulted in as many folders as houses in the CSDDRD. On average 16 files were created for each house. The file generation script completes in less than 10 minutes. A common naming system is utilized to allow for targeted modification of certain files as dwelling upgrades or new technologies are examined.

Databases

The databases of ESP-r are used during the assembly or modification of a model to combine material and component properties and apply them to the building fabric, as well as plant and air flow networks. In addition, a climate database consisting of temperature, solar insolation, wind conditions, and relative humidity is required during simulation to calculate heat and mass flows. The ESP-r databases consist of a combination of text and binary files, which is primarily a function of size and access requirements.

Binary climate databases are available for 44 locations that are well distributed throughout Canada. Although there are 108 climatic reference locations in the EGHD, only 66 unique entries appear in the CSDDRD. These were mapped to the most representative climate database (with consideration of geography and heating degree days), as no finer resolution climate data is available. This mapping provides adequate representation of climatic conditions for the simulation of houses throughout the regions of Canada.

The CSDDRD uses multilayer construction codes of a six or ten digit format to describe both characteristics and materials used in the building fabric. Each digit of the code corresponds to a list of potential materials (e.g. brick) or construction types (e.g. number of glazing layers) for that layer or construction. These construction codes differ significantly from the ESP-r materials, multilayer construction, and transparent construction database formats which are described as:

- Material database – tagged text file of properties such as thermal conductivity, density, specific heat
- Multilayer construction database – columnar text file of material layers and thicknesses from exterior to interior
- Transparent database – columnar text file of optic properties such as total transmittance and layer absorptance.

To assist in the generation of material and construction information of house files while maintaining backward compatibility to ESP-r databases, an XML format was selected to store information of materials and constructions in a hierarchal format. A script reads through the CSDDRD and generates lists of unique materials, multilayer constructions, and transparent constructions it encounters. This limits the number of types exported to ESP-r databases to those in use within the CSDDRD. At present, simplified versions of these types are located in global databases for use by each house of the model. If database size exceeds the limits of ESP-r, individual databases for each particular house will be generated and placed with the house model.

ESP-r has no user-friendly facility to account for parallel heat conduction paths caused by framing and insulation, although this has been identified as having a significant impact on energy consumption by Purdy and Beausoleil-Morrison (2001). As such, framing considerations were not included in the development of ESP-r databases from XML format, but were included in each house model using parallel path and effective thermal mass algorithms which modified thermal conductivity and density of the insulation. Although this creates uniformity, temperature difference and condensation considerations at the level of individual framing members are beyond the scope of the CHREM.

The plant component database of ESP-r is used directly due to the level of detail and requirements of individual components. Sufficient components exist to support common technological upgrades to the CSDDRD, and more are being developed through the Solar Buildings Research Network (Athienitis and Stylianou 2006).

Configuration and zoning

ESP-r requires a set of model files to describe each house: approximately six building-level files plus four files for each thermal zone. To facilitate quick identification of house types, regions, and individual houses, a directory structure was generated as shown in Figure 2. All files associated with a particular model are held in one directory and follow the naming structure of the CSDDRD with extensions of the zone name and ESP-r convention (e.g. 11DDA00082.main.geo)

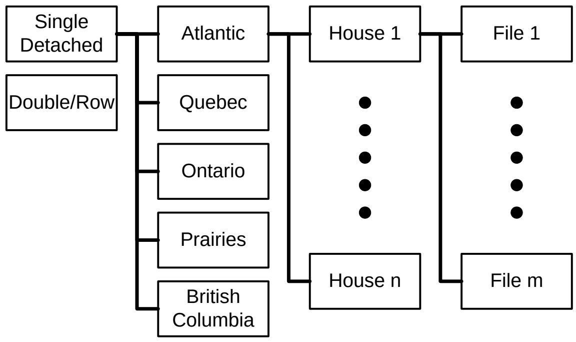

Figure 2: Directory structure

Houses within the CSDDRD were found to have the following considerations for thermal zones:

- Foundation – basement, crawl space, slab, or exposed floor
- Main – main living area with one to three storeys
- Attic.

These were condensed into four unique zone types of which a maximum of three are applicable to one model: basement, crawl space, main, and attic. By HOT2XP definition, basements are heated and exchange air with the main zone. Crawl spaces are unheated and experience a level of ambient air infiltration. Exposed floor, due to an ‘open’ crawl space or slab on grade, are modifiers to the main zone that do not require a basement or crawl space zone. The storeys of the main zone are not identified individually, but amalgamated into one thermal zone with a modification to height to account for each storey’s floor area. This simplification was made due to the lack of information regarding interior partitions and air flows between storeys. The attic is unheated and detected by a flat main zone ceiling with a sloped roof. The attic has high exterior air infiltration rates.

Zone information – vertices and surfaces

Zone generation follows a logical path, progressively defining vertices, surfaces, surface conditions, and construction fabric.

Although the floor plan shape (e.g. rectangular, 'T', 'L') is listed in the CSDDRD, it is of limited use as there is no indication of which wall is the front, nor are exact vertex locations specified. Therefore, all houses were created rectangular in shape using the specified main zone footprint area. Consideration was given to the width to depth ratio. This method partially accounts for the perimeter to area relationship that affects energy consumption due to exposed surface area. Width is defined as the front of the dwelling, and the ridge of a pitched roofline was assumed parallel to the longest side. Orientation of the house with regard to the front wall is specified and this was used to ensure specified window areas were applied to the appropriate side.

The rectangular corner vertices of each zone are initialized at appropriate heights, with the first main zone vertex equal to 0, 0, 0. Basement and crawl space zones are placed below the main by their height, whereas the attic zone is placed above the main zone. If windows or doors are present, they were inserted within the appropriate wall of the main zone. Individual window areas of a wall were amalgamated and centered on the wall as a large window. Doors were placed to the right-hand-side of each wall and offset by 0.2 m.

Information of roof slope is not included in the CSDDRD, although it can be determined if the roof is sloped or flat. If an attic zone is present it is generated with a 5:12 roof pitch with either a gable or hip style roof. To maintain a minimum eight vertices for each zone (for script looping purposes), a 0.2 m wide horizontal surface is placed at the top of the attic. A representative house with three thermal zones (basement, main, and attic), windows on all four main zone walls, and doors on the front and back walls is shown in Figure 3.

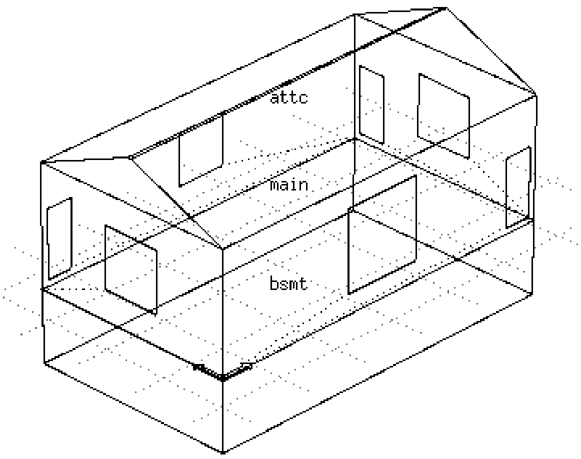

Figure 3: Representative three zone house facing south

Zone information – surface condition and construction fabric

The conditions on the outside face of each zone surface must be specified to ESP-r for heat transfer calculations. Typically, main zone walls face exterior ambient conditions. This is also the case for the attic's gable ends and roof, and the peak of the attic zone, as well as the sides of the crawl space zone. Windows and doors always face exterior ambient conditions. If the house is of DR type, adiabatic conditions are specified on one or both side walls with regard to opposing dwelling location and the thicknesses are halved to account for thermal mass attribution.

If a basement or crawl space or an attic zone exists, inter-zonal linkages are applied to the main zone floor and ceiling and vice versa for the opposing zone. The foundation is a special consideration due to the heat loss through soil. This is strongly affected by soil conductivity, density, and moisture movement. Therefore for the following surfaces the BASESIMP algorithm was applied (Beausoleil-Morrison and Mitalas 1997):

- Main zone floor for a slab on grade
- Floor of crawl space zone
- Floor and sides of basement zone with consideration of above/below grade depth

BASESIMP is a regression-based algorithm which expresses both above-grade and below-grade time dependent heat losses. It accounts for a variety of insulation levels and configurations, and ground temperature and heat conduction characteristics. The insulation level and configuration is provided in the CSDDRD. The result of the BASESIMP algorithm is a single value of heat loss/gain during a time step. It is then applied to relevant surfaces based on fixed distribution values. Distribution values were estimated based on size, shape, and insulation configuration and frequently resulted in equivalent values as the walls were insulated and the slab floor was not.

In addition to the conditions of each surface, the construction fabric definition is required. The fabric information is based on the construction codes of the CSDDRD and the newly developed XML databases. Separate construction codes are specified for the walls and floors of the main, basement, and crawl space zones, and the ceiling of the main zone. No information is included regarding the attic zone, other than inferring its floor is the reverse of the main zone ceiling. The attic wall construction was set to framing, sheathing, and siding equivalent to the main zone, and the attic roof was set to framing, sheathing, and asphalt shingles which is a common type of roofing material in Canada.

A number of modifications were made to the material properties as each layer of a surface was described in the ESP-r model file.

- ESP-r has rudimentary facility to handle the addition of thermal mass inside of a thermal zone; however, due to increased vertex and surface complications, the thermal mass effects due to interior partitions (e.g. walls of rooms, counters), furniture, equipment and other material were estimated and applied as a density increase to the innermost layer of the dwelling construction fabric. The density increase was set equivalent to an estimated 15 kg of material (2 kJ/kg·K specific heat) per square meter of living and basement floor space. Thickness of the interior material remains unchanged so as not to affect thermal conductivity.
- The thermal bridging and capacitance effects of parallel insulation and framing were encompassed by modifying the properties of the insulation. This was based on a cross sectional area analysis of the components' contributions and results in effective thermal conductivity $k_{\mathrm{i,eff}}$ and density $\rho_{\mathrm{i,eff}}$ of the insulation for a thickness corresponding to that of the framing t_{f}. The reference length is to framing as the complete fill of the insulation cavity is a potential retrofit upgrade. The parallel equations for $k_{\mathrm{i,eff}}$ and $\rho_{\mathrm{i,eff}}$ are left in non-simplified form for clarity:

$$\frac{k_{\mathrm{i,eff}}}{t_{\mathrm{f}}} w_{\mathrm{s}} = \frac{k_{\mathrm{i}}}{t_{\mathrm{i}}}(w_{\mathrm{s}} - w_{\mathrm{f}}) + \frac{k_{\mathrm{f}}}{t_{\mathrm{f}}} w_{\mathrm{f}} \qquad (1)$$

$$\rho_{\mathrm{i,eff}} c_{\mathrm{i}} w_{\mathrm{s}} t_{\mathrm{f}} = \rho_{\mathrm{i}} c_{\mathrm{i}} (w_{\mathrm{s}} - w_{\mathrm{f}}) t_{\mathrm{i}} + \rho_{\mathrm{f}} c_{\mathrm{f}} w_{\mathrm{f}} t_{\mathrm{f}} \qquad (2)$$

  where i, f, and s refer to insulation, framing, and framing spacing, respectively; c is the specific heat; and w and t are the width (or framing spacing) and thickness.
- On the rare occasion where only construction thermal resistance was specified (construction code equal to zero), typical Canadian construction materials were used and the insulation conductivity was modified such that the total thermal resistance was as specified.

Ventilation and infiltration

ESP-r has facilities to support both constant and variable airflows due to exterior ambient air exchange and inter-zonal circulation. Exchange of air will act as either heating or cooling load as a function of temperature difference between the zone and outdoor ambient air. Circulation is capable of transferring heat between specified zones, as found in air distributions systems and large openings (e.g. doorway between main zone and the basement).

Each dwelling of the CSDDRD includes air tightness characteristics of the heated zones (AC/h at 50 Pa and estimated leakage area at 10 Pa), as measured by a blower door test. This data availability is a key strength of the CSDDRD as it describes the natural infiltration to the house through unintended cracks and joints. Infiltration to the main and basement zones is numerically solved using these values and as a function of ambient temperature and wind conditions. The numerical procedures come from the Alberta Air infiltration Model (Walker and Wilson 1998) and have been included in the ESP-r simulator (Beausoleil-Morrison 2000). Air leakage distribution across the ceiling, walls, and floor was set to a constant 0.3, 0.5, and 0.2, respectively. Local wind shielding was set to 'light' as shielding information is not present in the CSDDRD.

A fixed exchange rate to the attic space was specified at 0.5 AC/h (air change per hour) as most attics are well ventilated through soffit or gable vents. The crawl space options of the CSDDRD that resulted in a thermal zone are 'closed' and 'ventilated', and they receive fixed exchange as specified in HOT2XP of 0.1 and 0.5 AC/h, respectively.

There may also be continuous infiltration air flow to the heated zones due to an active ventilation system. Such a system, including the use of heat recovery, is taken into account by a ventilation file using flow rate values and characteristics (e.g. heat recovery efficiency) specified in the CSDDRD.

Additionally, air circulation is specified between the thermally linked basement and main zones. Air circulation rates between these zones are difficult to assess. As both zones are heated and are considered to have uniform conditions of air mass within the zone, the inter-zonal circulation was estimated to be 0.5 AC/h based on the basement zone volume.

Plant systems

A variety of plant systems and energy sources exist in the CSDDRD: boiler, furnace, baseboard, heat pump, stove, and electricity, natural gas, oil, and wood. An idealized implementation of these HVAC plant systems has been developed and implemented in ESP-r and is documented by Haddad (2001).

The plant systems are mapped from the CSDDRD to the ESP-r HVAC text file. Simulation using the HVAC file is completed using a continuously variable heating or cooling calculation on a time step interval larger than the typical plant component cycling frequency. A part load ratio is calculated within the time step to account for this duty cycle operation. This modeling method provides suitable annual energy consumption estimates for the CHREM.

More complicated plant networks that are affected by load (e.g. photovoltaic or solar thermal collection and storage) will be modeled explicitly on a smaller time step to provide adequate representation.

Addition of AL and DHW loads

The AL and DHW sub-hourly consumption results, as calculated by the NN statistical technique, are incorporated into the engineering model, thereby forming the hybrid methodology. The time step value of AL electrical power and DHW flow rate is calculated as the product of the appropriate normalized load profile value and the house's annual consumption value.

The AL electrical load is imposed within the ESP-r model as a 'non HVAC electrical load', and is met by a simplified electrical distribution system within the dwelling. The simplified electrical system can be incorporated into a full electrical network such that energy required from the electrical mains may be offset using renewable energy devices such as photovoltaic panels. The energy consumed to support AL loads are assumed to manifest as casual heat gain within the dwelling, supplanting plant heat requirements and increasing plant cooling requirements (if applicable). This will be implemented through a modification to how ESP-r considers zone casual gains such that it references the time step value AL electrical power value.

The DHW flow rate is imposed as a load on an idealized DHW system that incorporates characteristics of the storage tank and heat source from the CSDDRD. The present implementation within ESP-r internally calculates the flow rate, and this will be modified such that it references the time step value of DHW flow rate.

SIMULATION

Although databases were created to support compatibility across the entire ESP-r program suite (21 applications), only the simulation engine is actually employed throughout batch runs. Simulation of each house requires approximately 60 seconds of single CPU time for a full year simulation on one hour time steps with results storage. Therefore, simulation of the entire CSDDRD on one processor is not practical (~300 h).

To support such simulation, two computing units, each with two quad-core processors, were purchased for this project, resulting in an effective 16 processor array. A Perl script was written to evaluate the directory structure and divide the house models into 16 lists for simulation. The script manages 16 simultaneous house simulations; initiating the next house simulation of a list upon completion of the previous simulation. Total simulation time is presently two days, but is expected to increase with model complexity.

It is recognized that as a tool for technological evaluation, only houses that are upgraded require re-simulation. This will be accomplished using a flagged approach where houses with applied upgrades are added to second simulation listing. In this fashion advanced technological components that required high resolution time step simulation may be applied to suitable housing without requiring weeks of simulation.

EXTRACTION OF RESULTS

ESP-r historically has stored results in binary form for random access use by its results analyzer. This is not conducive to batch processing and therefore the XML reporting technique is utilized. This result reporting feature provides a list of variables for export in comma delimited form with both time step data and summary compilation (minimum, maximum, average, and total).

Presently, results are being used in annual form to evaluate energy consumption and contributions due to a variety of housing components. Examples are:

- Heat gain due to solar radiation with consideration of orientation and window to wall area ratio
- Individual heat loss impacts due to windows, walls, and doors
- Heat gain/loss due to air exchange
- Effects of part load efficiency on supplied heating and cooling energy
- Heating requirement as a function of house type, region, floor area, and vintage.

Space heating results

Although the inclusion of certain loads and characteristics is incomplete, the following are preliminary results of the space heating simulation: average annual per house space heating energy consumption for the five Canadian regions range from 72 to 144 GJ with an average value of 108 GJ. This results in a national heating estimate that is approximately 75% of the total energy consumption predicted by OEE (2006b). This difference is to be expected as not all loads have been considered.

CONCLUSION

The status and implementation of the hybrid energy model CHREM is discussed. The quantity and quality of input data to the model and the energy estimation and simulation techniques allow it to capture the effects of new technologies as applied to the wide variety of houses found in the CHS.

The CSDDRD source data has strengths in its detailed descriptions of construction layer materials, air infiltration characteristics, and plant components, whereas it lacks in descriptions such as floor plan layout, surrounding obstructions which affect solar and wind (trees and buildings), and roof slope and roof orientation.

Because of these features the CHREM model is adept at investigating new technologies such as building fabric upgrades, air tightness measures, and co-generation plant components. The model can also account for integrated solar energy capture technologies, although they must be interpreted with care regarding unknown obstructions.

The CHREM is expected to be completed in 2009, with technology evaluation results provided shortly thereafter.

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