THE DEVELOPMENT OF A DYNAMIC ON-LINE WHOLE-BUILDING ENERGY ANALYSIS TOOL FOR HOMEOWNERS

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ABSTRACT

This paper presents the development of a dynamic on-line whole-building energy calculator for homeowners. The principal function of this home energy calculator is a "first-point-of-contact" to encourage energy-efficient choices for home renovations and new home building. The tool calculates a home's energy consumption over the course of a year, suggests generalized cost-effective renovation opportunities, and directs the homeowner to an EnerGuide qualified technician.

The software has two main components: the simulation engine and the web-based interface. The engine simulates the behaviour of the house and its HVAC system. The interface provides the user with a convenient method to enter data to describe the house and its HVAC system as well as being a vehicle to present the simulation results to the user.

The home's energy consumption is calculated based on a limited number of inputs; inputs that a typical homeowner would have access to. Conversely, the simulation engine is quite detailed, necessitating the derivation of the required simulation inputs from the small set of user inputs.

This paper explores tasks specific to the simulation engine, including: the definition of the required user inputs, the creation of default house archetypes, and the definition of the results to be presented to the user.

INTRODUCTION

This paper outlines the development of a tool[1] that compares the simulation of a generalized model of the homeowner's house – the average energy use of a house built in the same decade in the same geographical area – to typical energy consumption data for that location and house type.

The simulation is based on the house-as-a-system approach, where all the components in a house work together to form an integrated system. The performance of one component depends on its relationship with other components in the same system.

Results and potential energy savings are presented to the user in graphical format and are determined by the input-information provided by the user, weather data for their city or region and information about local construction standards and styles.

The website provides general information; the user is encouraged to contact an EnerGuide for Houses delivery agent for a more comprehensive house examination with tailored retrofit recommendations, as well as an EnerGuide rating.

The mapping between the limited user inputs and the extensive simulation requirements is clearly a non-trivial issue. A justification of the approach adopted will be the focus of the paper.

Background

The CANMET Energy Technology Centre (CETC) develops, distributes, and supports building simulation software for the Canadian construction industry. These software tools are used to optimize the energy performance of house and building designs as well as demonstrate compliance with energy rating programs such as EnerGuide for Houses[2] and performance-based compliance programs such as R-2000[3], and the Commercial Building Incentive Program[4].

One of CETC's principal software tools is HOT2000

[1] As the tool has not yet been released to the public, the URL address cannot be supplied to the reader.

[2] An energy-efficiency rating programme that offers to help homeowners make home retrofit choices that improve the comfort and energy efficiency of their homes. Independent energy advisors visit the home to identify how the house uses energy and where it is being wasted. http://oee.nrcan.gc.ca/houses-maisons/

[3] A housing programme that encourages the building of energy-efficient houses that are both environmentally friendly and healthy to live in. http://oee.nrcan.gc.ca/r-2000/

[4] CBIP offers a financial incentive to encourage building owners to reduce energy consumption of their buildings to 25% less than the National Energy Code for Buildings. http://oee.nrcan.gc.ca/newbuildings/

(2003), a residential energy analysis program. HOT2000 has evolved over the past 20 years by incorporating more complex and detailed calculation methods. The software has been thoroughly validated, and its user-friendly interface is designed around the needs of practicing building professionals.

The engine of our next-generation versions of HOT2000, coined ESP-r/HOT3000 (Haltrecht et al. 1997 and ESRU 2000), incorporates a time-step simulation, as well as many models of interest to the building industry. Some of these models include a residential fuel cell model and a comprehensive air-to-air heat recovery (HRV) model.

HOT2XP (2003) is a member of the HOT2000 family of energy analysis software and serves as a quick and easy tool for analyzing energy use in residential buildings. While its graphical interface is simple enough to be used by homeowners, the underlying analysis engine is that of HOT2000.

HOT2XP is designed to speed up the task of characterizing a house by requiring only a small amount of critical information. The user may, however, edit many of the program's underlying rules and assumptions, which allows for a far greater control of the analysis than is suggested by the main interface.

For example, in HOT2XP:

- The geometry of the house is derived from only a handful of inputs, and
- The house characteristics are defaulted based on age and location - based on the values defined in Habitat Design + Consulting Ltd. SAR Engineering (1997).

The tool under development incorporates a simple graphical user interface with the HOT2XP default house archetypes and the next generation HOT2000 simulation engine, ESP-r/HOT3000.

Objective

The objective of this project has been to develop an accurate Canadian on-line home energy evaluation tool that provides useful information for users.

As a by-product of the project, the online tool will serve to increase awareness of the EnerGuide for Houses service and encourage energy-efficient choices for home renovations and new home building.

Tools Currently Available On-Line

Many Canadian on-line energy analysis tools determine the energy saving potential based simply on the location and age of the house and consolidation from annual energy bills. Few Canadian tools simulate the whole-house or the house-as-a-system.

LBNL (2002) evaluated 50 web-based residential calculators, of which 21 were considered to be whole-house tools. Of these,

- 13 provided energy calculations,
- 5 consolidated the results with actual energy bills, and
- 3 provided both options.

They conclude that these tools employ many approaches and levels of detail. Where some tools "require a relatively small number of well-considered inputs", others "ask a myriad of questions and still miss key issues".

Another interesting evaluation of Home Energy Analysis software tools – including on-line tools – is available from SAIC (2001).

For the tool under development, a significant amount of time was invested in defining well-considered user-inputs. The inputs were defined based on the goals of the simulation as well as a brainstorming session with industry experts. These user-required inputs are further explored in subsequent sections.

The following sections detail the structure of the software – including the calculated results and the information that presented to the user, the house types available for simulation, as well as the method of analysis – including the required user inputs, the default housing archetypes, and the modified simulation periods.

STRUCTURE OF THE SOFTWARE

The software is composed of two main components: the simulation engine and the web-based interface (Figure 1). The simulation engine performs all the calculations to simulate the behaviour of the house and its HVAC system. The interface provides the user with a convenient method to enter data to describe their house.

The on-line user of this calculation tool passes through a number of successive inputs to define all of the information required to complete the simulation of their home. The user interface communicates with the simulation engine through a series of ASCII text files - called the *simulator input files*. These files are created from the user-input data and from default data contained within databases.

The simulation engine – ESP-r/HOT3000 – reads the building and HVAC description from these ASCII text files and then performs the calculations to simulate the house and its HVAC system.

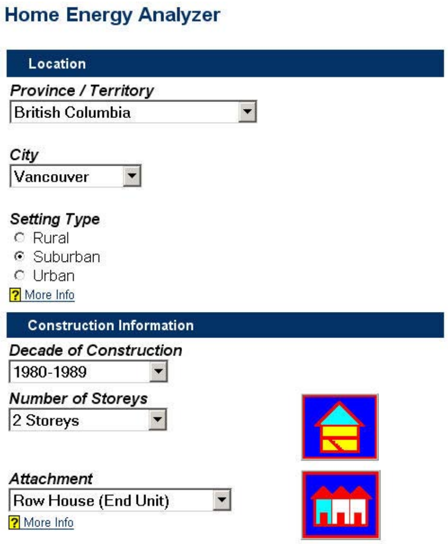

Figure 1: A Section of the Home Energy Analyzer User Interface

The simulation results are written to an ASCII text file, called the *simulator results file*. Once the simulation is complete, the interface reads the results contained in this file and displays the results to the user (Figure 2).

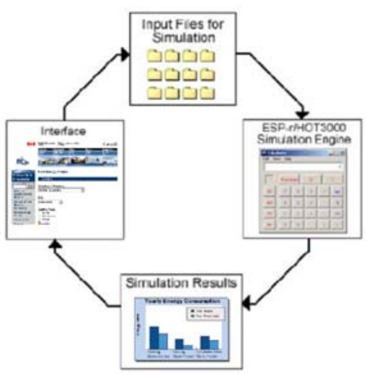

Figure 2: Data Flow from the Interface to the Simulation Engine and Back to the Interface

A significant amount of time was invested in ensuring that the user-inputs required in the interface were applicable to the typical homeowner. Through the use of pull-down menus, multiple-choice options and selected input boxes, the technical inputs were geared at non-technical users.

Additional information on the structure of the software – particularly the user interface and the mapping of the simulator input files – is available from Mombourquette and Wyndham-Wheeler (2004).

Calculated Results

Based on the input information – both the user inputs and the defaulted housing information – an annual simulation is performed. The calculated results of the simulation are presented to the user in graphical format (Figure 3).

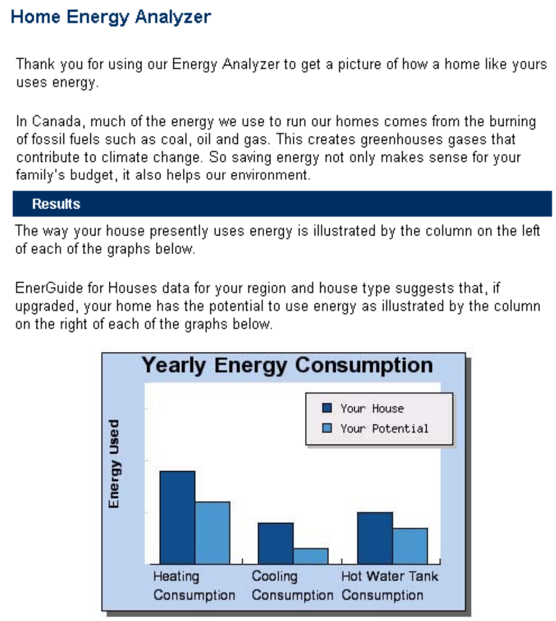

Figure 3: Typical Results Presented to the User

The simulator results file are brought into the interface and the user is provided with a graphical analysis of their current energy consumption as well as a comparison to a 'typical' energy efficient house.

These comparison values were derived from HOT2XP simulations based on a standard set of upgrades. These simulations were run for each location and age of construction.

Additional Information for the Homeowner

In addition to the calculated information, the tool will suggest generalized cost effective renovation opportunities and direct the homeowner to an EnerGuide qualified technician.

The homeowner will be given suggestions of the most effective measures for reducing energy costs. These will include:

- Options and suggestions for energy efficient upgrades, and
- Directing homeowners to EnerGuide for Houses professionals

Documentation and On-Line Help

To ensure the results of the energy analysis are as appropriate and informative as possible, the user is helped through the on-line data entry process by a series of on-line pop-up windows (Figure 4). These windows clarify the input information required for house envelope (construction and insulation), windows, the heating and cooling system and settings and hot water systems.

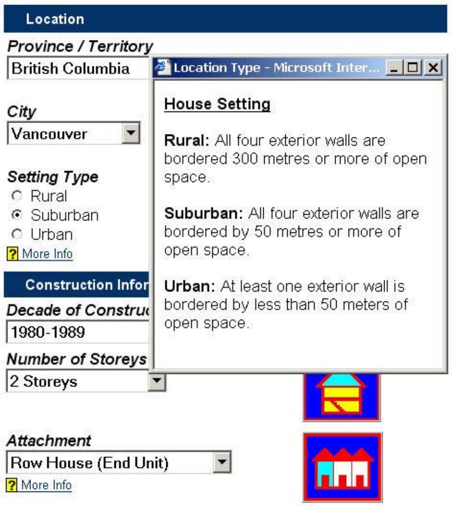

Figure 4: Sample Pop-up Window for additional user information.

HOUSING TYPES AVAILABLE FOR SIMULATION

The online tool can simulate most types of houses. The following sections define the major user inputs.

Number of Storeys

The user is presented with a pull-down menu and graphic to select the number of floors or storeys in your house. The options include: 1, 1½, 2, 2½, or 3 storeys. 1½ and 2½ storey houses are assumed to have conditioned attics.

The user is informed that if their house does not fit within these options, to choose the input that most closely resembles their house.

House Attachment Type

The options available are single, row house middle unit, row house end unit. For this input Row house (end unit) is equivalent to a semi-detached house.

The tool currently simulates single-family houses – not duplexes, triplexes, walk-ups, or apartments.

Foundation Type

The options available are basement, no basement, crawl space and walkout. A crawl space is assumed to be an unheated space below the main floor of the house.

The user is required to identify if the basement is heated. It is assumed that if the basement is finished, and therefore part of the living space of the house, or if there are heating vents into the basement, then the basement is heated.

HVAC Systems

The user is offered several HVAC systems for simulation. These include: furnace, boiler, baseboards, radiant flooring, ground source heat pumps, air source heat pumps, wood stoves, central and window air-conditioners.

While many Canadian homes use more than one of these systems, the user is instructed to choose the equipment that satisfies the majority (roughly 80%) of their heating requirements.

House Operations

In addition to the physical systems in the house, operational factors are also considered, including the number of occupants and the use of setback thermostats.

INFORMATION REQUIRED FOR THE ESP-r/HOT3000 SIMULATION

This tool calculates the heating and cooling energy consumption using the ESP-r/HOT3000 building simulation program. The program performs a modified annual simulation using a typical weather year after the user inputs the necessary information describing their house.

Three sets of data are used in the *simulation input files* for the ESP-r/HOT3000 simulation: user input data, data taken from the default archetypes, and that data assumed or defaulted for every case.

The steps undertaken to determine the user inputs,

i. Determine what information is required to perform an annual simulation.

ii. Investigate what information is available from default sources, including the STAR HOUSING Database (CMHC, 1992).

iii. Brainstorming sessions determine what inputs can be expected from the typical homeowner.

iv. The information that remained was assumed or defaulted.

Table 1 defines the information required for a typical ESP-r/HOT3000 simulation. The following sections detail the columns in Table 1: the user input data, the data taken from default libraries, and the calculated or assumed data for every case.

Required Data	User-Input Data	Data Available in Default Libraries	Calculated or Assumed Values
House			
Location	Province		
	City		
	Urban, Rural, Suburban		
Layout	Number of Storeys		Plan Shape
Size	Floor area (excl. basement)		House Volume
			Surface Areas
Envelope Construction			
Wall, Floor, Roof		RSI Values	Construction layer specifics
		Roof Shape	
Windows	Window Area	RSI Values	Location
		Optical Properties	Construction layer specifics
Foundation	Configuration[5]	RSI Values	Construction layer specifics
		Soil Properties	
		Insulation Placement	
Operations			
Infiltration		Blower door Inputs	
Controls	Temperature Set points		Location of thermostat
	Heated Basement		Duration of heating/ cooling seasons
Internal Gains	Number of Occupants	Hours typically at home	
HVAC and DHW Equipment			
Heating Equipment	Type	Efficiency	Capacity
	Fuel	Pilot Light	
	Age	Fan Power	
Cooling Equipment	Central or window unit	COP	Capacity
DHW	Number of Tanks	Efficiency	Heat Injector Power
	Location of Tanks	Draw schedule	Hot Water Supply T
	Fuel Type		Tank Insulation RSI
	Size of Tanks		

Table 1: Information Required for an ESP-r/HOT3000 Simulation.

Required User Inputs

The user will be required to input data relating to their house geometry and several systems contained within the house, including: space heating, hot water heating, and any air-conditioning.

[5] The configuration options are: basement, no basement (slab-on-grade), crawl space, or walkout

The required user input information will include:

Basic Housing Type
- Size/Area
- Number of Floors/Storeys
- Attachment
- Location
- Age of House

Foundation Type

Heating Equipment
- Type
- Fuel Type

Air-Conditioner Properties

Hot Water Heater
- Number and Volume of Tanks
- Fuel Type

Day, Evening, and Night Thermostat Setpoints

Number of House Occupants

Default House Archetype Values

The default house archetype values are based on the default values specified in a number of sources – from the HOT2XP defaults, from STAR-Housing Database, *Defining Selected Technical Defaults for the Canadian Home Energy Efficiency Rating System* (1997) as well as through personal conversations with housing experts.

The STAR-Housing Database is a statistically representative picture of existing Canadian housing stock, developed using data from NRCan, Ontario Hydro and CMHC, and contains:

- Age, location of house,
- Type of house and construction details,
- Area and thermal characteristics of – windows, walls, doors, roof, basement and crawlspace,
- Airtightness information,
- Heating system and DHW information,
- Occupancy information, and
- Measured energy use records.

These defaults are defined for the following

Locations	B.C, Prairies – including the North, Ontario, Quebec, and Maritimes
Dates	Pre-1921, 1921-1945, 1946-1979, 1971-1980, and Post-1981, and
Fuel Types	Gas, Oil, Electric, and Heat Pumps

For the purposes of this tool, the housing stock in Canada has been classified into archetypes based on age of house and location. These archetypes define the following:

Building construction
Air-tightness
Window construction
Insulation RSI-values for:

- Walls
- Roof/Ceiling
- Floors

Table 2 gives an example of the default RSI-values used for BC.

	Ceiling	Main Walls	Basement Walls
Pre-1945	1.20	0.85	0.735
1945-1959	1.20	0.85	0.815
1960-1969	2.10	1.70	0.96
1970-1979	2.20	1.70	1.06
1980-1989	3.50	2.10	1.205
Post-1990	3.50	2.10	1.205

Table 2: Default RSI-values for BC, including Ceiling, Main Walls and Basement Walls

Calculated/Assumed Values

In this section, each of the calculated or assumed values will be defined

Layout/Plan Shape: The layout for each house is assumed to be rectangular.

Size: Based on the user-input value for floor area, the base area of the building is calculated. A typical wall height is assumed for all cases. The house volume and wall surface areas are calculated knowing the base area and wall height of the rectangular plan.

Wall, Floor, and Roof Construction Layers: In ESP-r/HOT3000, detailed envelope and window construction information is required. For each wall, floor and roof, the detailed construction layer specifics are required. For example a wall would require a multi-layer construction definition of:

Brick,
Air gap,
Sheathing,
2x4@16 O.C,
Insulation, and
Gypsum

As well, for each construction material, i.e., brick, or insulation, the following properties are required:

Thickness

- Including the thickness of any air gap

RSI or conductivity, and if possible
Density
Specific Heat

The assumed exterior wall construction is as follows.

100 mm brick
25 mm air gap
12.5mm particleboard
2x4 @16 O.C with fibreglass insulation
12.5 mm gypsum

To simulate the different default RSI-values, the thickness of the insulation layer is modified.

Window Location: Based on the user-input for the area and distribution of windows on each wall, the area of each window is calculated. All the windows are amalgamated into one per wall, and are assumed to be located in the centre of each applicable wall.

Window Construction: To model a window in ESP-r/HOT3000 simulation, the number of panes and the gas fill between the panes is required. The following thermal and optical properties of the glass panes are required:

Thermal properties

- Thickness
- RSI

Optical properties

- Visible transmittance, absorptivity and heat gain at various incidence angles
- Refraction
- Reflectivity

Depending on the age of the house and the user-input value for the age of the windows, the following windows are simulated:

Window Performance	Typical Construction
Basic	Wood frame single glazed, clear glass usually with storm windows
Entry	Wood or Al frame, Al spacer with no TB double glazed, clear glass
Average	Wood or vinyl frame, Al spacer Double glazed, clear glass
High	Wood, vinyl, or fiberglass frame, Al spacer double glazed, low E coating, Argon fill
Superior	Wood, vinyl, or fiberglass frame, Al spacer triple-glazed, 2 low E coatings, Argon fill

Table 3: Window Properties based on user-defined age of house and age of windows.

Foundation Construction: A special case in ESP-r/HOT3000 is the construction of **basements** or **slabs-on-grade**; they are simulated using BASESIMP (Beausoleil-Morrison and Mitalas, 1997) and require additional information to the construction layers and materials specified above, including:

Basement configuration

- Height, depth, length, width

Insulation placement

- Full height of basement wall or fraction of sub-grade wall
- Interior or exterior insulation placement
- Full surface of floor or area around perimeter
- Above floor or below floor placement

Soil properties

- Conductivity
- Water table depth
- Soil temperature

The insulation placement and soil properties are defined for each location across Canada, but the construction of the foundation walls and slab are defined in the same way as the other house constructions.

Location of Thermostat: Each conditioned zone is assumed to have a separate thermostat controlling the heating and cooling injection.

Duration of Heating and Cooling Seasons: With the exception of houses built in areas North of 60°, the heating season is assumed to last from October 1 to April 30. For areas in the far North, heating is available all year long.

The assumed control strategies are defined based on the number of occupants and whether the house is located in a rural/urban location.

Heating and Cooling Capacities: The total heating and cooling capacities for the ideal controller associated with the main zone, heated basement or walkout are calculated by accounting for: the conduction through the main walls, windows, ceiling and floor; the heat loss/gain due to infiltration; the solar gains; and the internal gains.

Domestic Hot Water: The heat injector power is set to 2000 Watts; the hot water supply temperature is set to 55°C; and the tank insulation RSI is set to 0.

MODIFIED ANNUAL SIMULATION

In order to keep simulation times to a minimum, a modified annual simulation was performed. ESP-r allows for the option of five one-week simulations to be performed, thereby approximating the annual simulation.

These one-week simulations were performed for each of: early winter (January to March), spring, summer, fall, and late winter (October to December).

The exact one-week periods – the so called best-week – were determined through an analysis of the weather data for each location.

The concept of best-week is based on a determination of the heating and cooling degree days in each season as well as the available solar radiation. Each week is scanned in turn to find one with the least difference in these parameters.

Tests performed by ESRU (2003) indicate that seasonal demands predicted by this approach can be within a few percent of that predicted by simulating each day of the season - if degree-days correlate well with the performance of a particular design.

CONCLUSIONS

This paper describes the development of an on-line homeowner energy analysis tool. The development process involved the selection of appropriate user-inputs, the definition of defaulted values, simulation of the resulting house model, the definition of the results to be presented to the user, and finally the validation.

LBNL (2002) developed a best-practice guideline that was useful to development of the current tools. These guidelines were used in the development of the current on-line home energy analysis tool. These guidelines include:

- Targeting & Usability – the audience for this tool was carefully identified; the graphical user interface development focused on user convenience; and in addition to the calculation results, qualitative decision-support information was included.
- Technical Features & Rigor – the tool is applicable for location across Canada, thereby maximizing the applicable geographic range; and the tool has been extensively tested.
- Platform – web-based tools offer considerable advantages over disk-based tools. Among these are: platform independence (PC, MAC, Unix), lower cost of distribution, ease of updates, and the ability to implement links to related resources.

Future work in this area includes a sensitivity analysis of the impact of the defaulted assumptions on the simulation results.

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