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The Archetype Sustainable House: *Investigating its potentials to achieving the net-zero energy status based on the results of a detailed energy audit*

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ABSTRACT

A detailed energy audit was performed on the Archetype Sustainable House in Vaughan, Ontario. The LEED Platinum certified duplex intended to achieve high energy efficiency by using advanced materials and mechanical equipment. This paper presents the results of the detailed energy audit, which consists of a series of depressurization test, thermal imagery, and energy modeling. The paper aims to illustrate the potential of the house to achieve net-zero energy status using the energy audit results. Results show the capacity of the installed renewable systems is insufficient to meet the annual energy requirement. Either further improvements to the energy efficiency of the dwelling are needed or more renewable energy capacity needs to be installed to meet net-zero energy status.

1. INTRODUCTION

The Archetype Sustainable House, located north of Toronto was developed by the Toronto and Region Conservation Authority (TRCA) in partnership with the Building Industry and Land Development (BILD) Association. It is the mandate of the design team to demonstrate an affordable, low-energy house that can be mass-produced with a small ecological footprint.

Ontario is the most populated province in Canada. More than 200,000 housing units were built in Canada in 2008 with more than 35% in the province of Ontario (Canada Mortgage and Housing Corporation [CMHC], 2009). The population in the province is expected to rise in the years to come. The population in the Golden Horseshoe area is expected to increase from 3.7 million in 2001 to 11.5 million in 2031, rendering the area to be the fastest growing community in the country (Ministry of Public Infrastructure and Renewal, 2006). To limit the increase of total energy requirements for Ontario's residential sector, existing dwellings need to be upgraded, and new houses need to be built with higher energy efficiency standards. Currently, low-energy homes are not mass-produced because it is not mandatory, and developers have limited knowledge and lack of the required skill set.

The Archetype Sustainable House represents a conventional semi-detached home with two units forming a duplex, named "House A" and "House B": House A is equipped with common energy efficient technologies used in local housing. House B features advanced and innovative technologies not commonly used in new construction practices. The Archetype Sustainable House was developed based on an initiative that can play a large role in not only transforming the residential market, but also reducing the amount of energy needed to sustain future housing. The

house is believed to be able to achieve net-zero energy status through its use of advanced materials and mechanical equipment. This paper will illustrate the potential of the dwelling to meeting net-zero energy through a detailed energy audit and energy simulations.

2. METHODOLOGY

2.1. Building Energy Simulation using HOT2000

Natural Resources Canada (NRCan)'s HOT2000 version 10.50 software was used to evaluate the energy performance of the house. HOT2000 is a microcomputer program that has been validated using HERS BESTEST, and calculates the monthly and annual space heating requirements of the house, which must be provided by the heating system based on the input data such as weather conditions, building envelope configurations, thermostat schedules, infiltration rates, and heating and ventilation systems (Haltrecht *et al.*, 1997; U.S. Department of Energy [DOE], 2008; Natural Resources Canada [NRCan], 2010). Results will be discussed in Section 3.1.

2.2 Depressurization Test

The two units were depressurized individually and simultaneously as a collective unit to measure the airtightness of the duplex. The south facing doors of the units were chosen to set up the blower door equipment. The fans were calibrated, and the indoor pressure was set to 50 Pascal (Pa). A total of 8 readings at intervals of 5 Pa were taken to measure the indoor pressure. Results will be discussed in Section 3.2.

2.3 Thermal Imagery

Indoor and outdoor thermal images were taken using a thermal infrared imager to qualitatively identify locations of heat loss through the building envelope. These images were used to reveal the most problematic areas such as a defective window in House B. To show a greater contrast in the infrared images, blower door tests were performed simultaneously. Results will be discussed in Section 3.3.

2.4 Net Zero Energy Analysis

Net Zero Energy status of House B was determined by comparing the total annual energy requirements to the total energy production of both the installed photovoltaic (PV) system and wind turbine. The total annual energy requirement was obtained from using HOT2000 default values for hot water load, interior/exterior lighting, and plug loads. EnerGuide values for the major appliances (e.g., refrigerator, freezer, range, dishwasher, clothes washer and dryer) are gathered and used as the appliance loads for the HOT2000 model.

Total energy production from the PV system was extracted from a previous paper submitted to the TRCA (Barua *et al.*, 2009). This paper used a combination of RETScreen analysis and on-site testing to determine annual production. Forty-eight monocrystalline PV modules, each having a capacity of 85 W were used. The total area of the PV modules is 31.0968 m² and has a 4.08 kWp of generation capacity. Sixteen modules have a tilt angle of 9.46°, 24 at an angle of 11.77° and the remaining eight at an angle of 33.69°, each having a 1.36 kWp, 2.04 kWp, and 0.68 kWp of generation capacity respectively. Most modules are connected with a 5 kW single inverter having an efficiency of 95.5% and the whole system is connected to the central grid system. A miscellaneous loss of 0.1% was used. The above specifications were used in RETScreen analysis conducted by Barua *et al.*, 2010. As well, total energy production of the installed 1.8 kW rated capacity wind turbine was determined with RETScreen. For simulation purposes, array, airfoil, and miscellaneous losses of 0%, 3%, and 3% were assumed. In accordance with on-site measurement, the hub height was set as 15m and Toronto's International Airport wind speed recordings were used to generate the power output of the wind turbine.

3. RESULTS

Detailed energy audit on the Archetype Sustainable House was conducted on December 16, 2009. In this section, the results are presented as follow: The findings of the building energy simulation will be summarized in Section 3.1. The results of the depressurization tests will then be discussed in Section 3.2. This will be followed by a discussion of the thermal imagery in Section 3.3.

3.1. Building Energy Simulation using HOT2000

3.1.1. Results

House A and B consist of three levels with one level below grade. The total floor area of House A and B is approximately 334 m² (3,594 ft²), and 325 m² (3,497 ft²) respectively.

Table 1 below summarizes the energy performance of HVAC systems installed in House A and B. Figures listed in the table are obtained from the study conducted by Fung *et al.* (2009a) and Barua *et al.* (2009) respectively.

Table 1: Energy Performance Levels of HVAC Systems in House A and B

Name	House A	House B
Heating	Wall mounted mini boiler @ 95.1% AFUE	Ground-source heat pump @ COP 3.2
Cooling	Air-source heat pump @ SEER 14.2	@ COP 4.32
Radiant floor	Basement only	Basement and other floors
Primary DHW	Flat plate collector	Evacuated tube solar collector
CSIA Rating (MJ/year)	10400	13600
Secondary DHW	Condensing gas boiler @ 0.95 EF	Electric heat pump 2.0 EF*
DHW load	225 L/day @ 45°C**	
HRV	HRV Sensible recovery efficiency of 74% at supply air temperature of -25°C	ERV Sensible recovery efficiency of 55% at supply air temperature of -15°C
Control	Continuous, 37.75 L/s supply and exhaust	
Base load	16 kWh/day***	

Note:

*Secondary DHW will be supplemented by the ground-source heat pump desuperheater. The Energy Factor of 2.0 was used for energy modeling purposes.

**For the grey water heat exchanger, a set point temperature of 44.6°C (or 45°C) was assumed.

***Base load of 6 kWh/day for major electric appliances, 3 kWh/day for lighting, 3 kWh/day for other electric appliances, and 4 kWh/day for exterior use was assumed.

Based on the parameters such as weather conditions, building envelope configurations, infiltration rates, HVAC systems (Table 1), the annual energy consumption levels for the house were determined with HOT2000 (Table 2).

Table 2: Annual Energy Consumption Levels (kWh) of House A and B

Name	House A	House B
Location	Vaughan (Woodbridge), Ontario*	
Heated floor area (m ²)	334	325
Space Heating (kWh)	9,438	4,497
Space Cooling (kWh)	2,147	1,272
DHW Heating (kWh)	1,834**	626**
Appliances and Lighting (kWh)	5,840	5,840
Total Energy (kWh)	19,259	12,235

Note:

*Due to HOT2000 limitations, Toronto's International Airport weather data was used for energy modeling.

** Includes grey water heat exchanger, solar thermal system and equipment efficiency.

3.1.2. Discussions

According to the energy simulation results, House B performed better than House A. This is believed to be due to the installation of a more efficient mechanical equipment and better insulated building envelope including windows.

When interpreting simulation results, it is important to be aware of the following limitations of the HOT2000 program. HOT2000 does not support user-defined operational schedule for lighting and appliances and therefore a year-round average for lighting and appliance load has to be assumed. Additionally, the HOT2000 weather database does not include Vaughan, Ontario, and Toronto's International Airport, Ontario weather data (Heating Degree Days base 18°C of 4200) was used as a result.

Another limitation in using HOT2000 is the program's incapability to simulate advanced building materials and mechanical equipment. Both houses use energy efficient materials and technologies that are not commonly used in current housing construction practices. HOT2000 database is based on standard building materials and technologies and therefore some of the materials and technologies that are implemented in the Archetype Sustainable House could not be found in the HOT2000 database (Fung *et al.*, 2009b). For instance, House B is equipped with a ground-source heat pump, drain water heat recovery system, and solar-thermal collector. In order to simulate the energy performance of these systems using HOT2000, the input parameters such as COP of ground-source heat pump for heating and cooling were determined using alternative software (RETScreen) and then entered into HOT2000. Furthermore, for the grey water heat recovery system, the expected rise of city water temperature through grey water heat exchanger was determined. The medium water usage temperature of 41°C with 6°C drop from tap to drain was assumed. The average temperature rise of 10.4°C was used as the temperature differential for the reduction of supply hot water temperature. HOT2000 used 55°C as the default value for hot water load and therefore using the temperature difference of 10.4°C, a set point temperature of 44.6°C (or 45°C) was assumed. On the other hand, novel materials such as bio-based insulated concrete forms in the below-grade wall and soy-based spray foam insulation in the above-grade walls are not included in the HOT2000 database and therefore these new materials have to be defined in the simulation model.

3.2 Depressurization Test

A depressurization test was conducted on the Archetype Sustainable House to evaluate the airtightness (Table 3). The tests were conducted with outside temperature of -7.7°C and inside temperature of 20.0°C .

Table 3: Summary of Airtightness Results for House A and B

	Units	House A	House B
Net Floor Area	m ²	334	325
Internal Volume	m ³	901	931
Volumetric Flow Rate	L/s (CFM)	329.7 (698.5)	313.8 (665.0)
Air Changes/Hour @ 50 Pa	ACH	1.317	1.214

The airtightness measured individually for House A and B were very similar to each other. To further explore the airtightness of the duplex, a second depressurization test was performed on both units simultaneously (Table 4).

Table 4: Summary of Airtightness Results for the Simultaneous Blower Door Test conducted on House A and B

	Units	House A and B
Internal Volume	m ³	1,832
Volumetric Flow Rate	L/s (CFM)	643.5 (1,363.5)
Air Changes/Hour @ 50 Pa	ACH	1.265

3.3 Thermal Imagery

3.3.1 Results

Thermal infrared imagery is a useful tool in performing non-destructive testing of a building envelope. This application can be used as a quality assurance tool physically showing problematic areas such as leaks around doors and windows, thermal bridging, and missing insulation.

Indoor and outdoor thermal images were taken. During this time, the outdoor temperature was -7.7°C with westerly winds approximately 15-20 km/h.

Typical heat loss was seen through bridging in the envelope around studs as were leaks around windows and doors. Interestingly, one window in House B (Fig. 1b) appears to have a much lower temperature when compared to the surrounding windows. Figure 1a and b illustrate the temperature difference. The window is the second from the top and is located on the east elevation. The lower temperature recorded is believed to be due to the window being defective or damaged. The defective window should be replaced to eliminate the unnecessary heat loss.

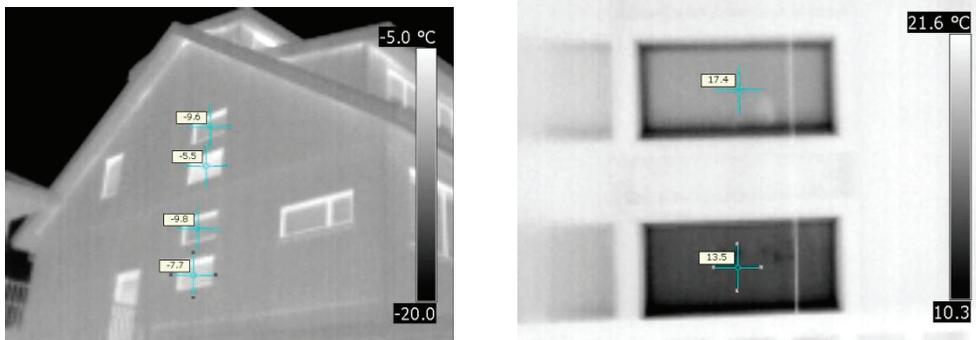


Figure 1a – Exterior thermal image of east windows in House B

Figure 1b – Interior thermal image of top 2 east windows in House B

3.3.1 Discussion

Figure 1a shows that the second window from the top is much warmer than the surrounding windows. This second window has a temperature of -5.5°C while the one above and below it are -9.6°C and -9.8°C respectively. This implies more heat is being transferred through this window. Figure 1b shows how the same second window from the top is cooler than the top window. The cooler window has a temperature of 13.5°C and the top window is 17.4°C . This implies heat is being transferred at a faster rate through the glazing compared to the top window.

It is difficult to accurately determine problematic windows with thermal imagery because of the tool's sensitivity to reflections and angles. Since the same phenomenon was seen through both the interior and exterior, and since other windows in close proximity were present for comparison, it can be concluded with high confidence that the second window from the top on the east elevation is deficient. Since significant heat loss was not visible in the casement, the window most likely lost its argon gas within the glass panels.

3.4 LEED Canada for Homes

The LEED Canada for Homes is an example of commonly adopted energy efficiency standard for new housing in Ontario. This standard is developed based on the U.S. Green Building Council (USGBC)'s LEED for Homes program, and modified to suit the nature and practices of the residential sector in Canada.

The certification is based on the accumulation of a point/rating system, and is broken down into eight categories as follow: Innovation and Design Process (ID): Location and Linkages (LL): Sustainable Sites (SS): Water Efficiency (WE): Energy and Atmosphere (EA): Materials and Resources (MR): Indoor Environmental Quality (EQ): and Awareness and Education (AE) (Canada Green Building Council [CaGBC], 2009a). It should be noted, both Energy and Atmosphere (EA), and Indoor Environmental Quality (EQ) are based on the ENERGY STAR for New Homes specifications, which is another commonly adopted energy efficiency standard in Ontario, developed based on the

U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA)'s ENERGY STAR program (NRCan, 2009).

Figure 2 summarizes the overall points achieved by House A and B, in comparison to the maximum points allowed for each category.

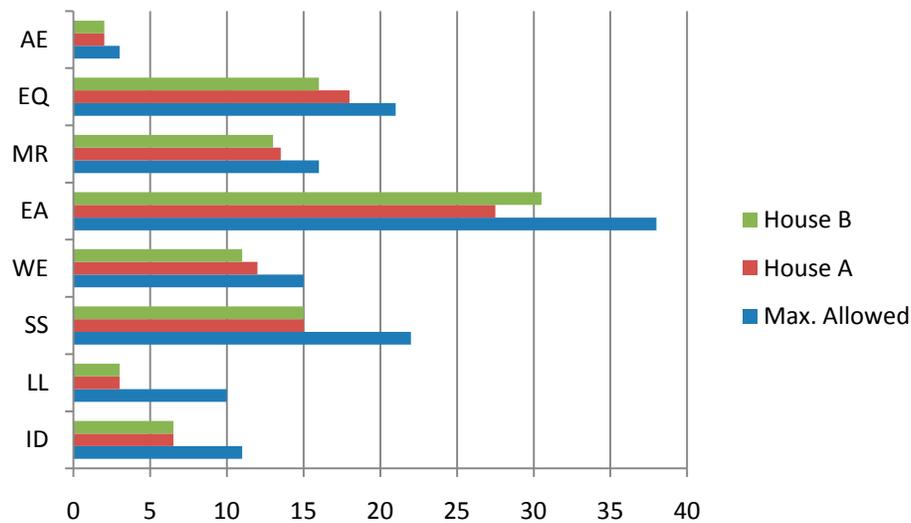


Figure 2: Summary of LEED Points achieved by House A and B

House A and B received total points of 97.5 and 97 respectively meeting the highest certification level, the Platinum level. This level requires a minimum of 90 points or higher (CaGBC, 2009b). Both houses gained the most points, 28% and 31% of overall points respectively, on the Energy and Atmosphere (EA) category, followed by the Indoor Environmental Quality (EQ) category, at 19% and 17% respectively.

It is also important to note if a home were to receive a LEED point for meeting or exceeding the performance of ERS (EnerGuide) 76 or HERS 80, the program does not mandate the depressurization test as part of the evaluation process (CaGBC, 2009c; CaGBC, 2009d). Thus, if the evaluation of House A and B were to take the "Prescriptive Approach" as opposed to taking the "ERS or HERS Method" as being done in this case, three additional LEED points could have been obtained for House A and B as a result of the depressurization test done (CaGBC, 2009d).

4. POTENTIAL TO ACHIEVING NET ZERO ENERGY

In order for House B to meet net zero energy status, it must produce as much energy as it requires on an annual basis. The house produces energy from both the PV system and wind turbine. RETScreen analysis identified the installed PV system produces 4,970 kWh annually (Barua *et al.*, 2010), while the wind turbine generates 2,180 kWh annually. As the house requires a total of 12,235 kWh annually (Table 2), House B does not meet net zero energy status (Table 5).

Table 5: Summary of energy produced by renewable resources and required by House B

	Units	House B
PV Generation	(kWh/year)	4,970
Wind Turbine Generation	(kWh/year)	2,180
Total Renewable Energy Generation	(kWh/year)	7,150
Energy Requirement of Home	(kWh/year)	12,235

In order to achieve net zero energy status, an upgrade case was explored and simulated with HOT2000. Tse *et al.* (2008) investigated on conservation strategies on appliance, lighting and DHW loads. Their figures were used in the upgraded case for this study. Additionally, the designed ACH value of House B was 0.5 and was also implemented in the upgraded case. Simulation results of the upgraded case are as summarized in Table 6. As seen, the total energy requirement dropped from 12,235 kWh/year to 9,177 kWh/year, or 25%. However, even with 57% reduction in air leakage rates, and with the appliance, lighting and DHW loads drastically reduced, House B still requires an additional 2,027 kWh/year of renewable power to reach net zero energy status.

Additional PV panels cannot be installed on the roof since there is no additional available roof surface area. Ground mounted arrays are an option, however the governments Feed-in-Tariff rate is lower, which would increase the payback period. Additional wind turbines can be installed.

Table 6: Annual Energy Consumption Levels (kWh) of House B with Reduced ACH

Name	House B	% Reduction
Air leakage rate@ 50Pa (ACH)	0.50	57%
Equivalent Leakage Area @ 10 Pa (cm ²)	173.70	77%
Space Heating (kWh)	4,387	2%
Space Cooling (kWh)	1,157	9%
DHW Heating (kWh)	169*	73%
Appliances and Lighting (kWh)	3,464**	41%
Total Energy (kWh)	9,177	25%

Note:

*DHW heating load of 98.5 L/day @ 45°C was assumed, and includes grey water heat exchanger, solar thermal system and equipment efficiency.

**Base load of 3.77 kWh/day for major electric appliances, 0.87 kWh/day for lighting, 3 kWh/day for other electric appliances, and 1.85 kWh/day for exterior use was assumed. The assumptions are based on the study conducted by Tse *et al.* (2008).

5. CONCLUSIONS

The purpose of the Archetype Sustainable House was to demonstrate an affordable, low-energy house that can be mass-produced with a small ecological footprint. Through the detailed energy audit, the house demonstrated to be air-tight, as evidenced by achieving less than 1.5 ACH at 50 Pa. The airtightness recorded in the house is significantly lower than new housings being constructed in Ontario nowadays.

Although through its use of advanced technologies and building materials, the house was able to meet the LEED Platinum level, this paper reveals the house is far off from reaching net-zero energy status. A significant investment is required to meet this goal. Further studies would have to be conducted to determine if the home could reach this status by just replacing mechanical equipment, lighting, and appliances or if additional renewable technologies would need to be installed. A detailed cost-analysis of each of these options would help determine the most cost-effective path. Additional renewable system such as wind turbines would present a high upfront investment however, with the current Feed-in-Tariff rates, a relatively fast payback can be achieved. Since this is a new house, the owners may not see the value in replacing the mechanical equipment and appliances, which could ultimately create waste if not recycled properly defeating some of the LEED criteria.

The HOT2000 program is a simplified thermal simulation program. More advanced simulation programs such as EnergyPlus and ESP-r that can take into account hourly schedules should be employed in future studies. It is the authors' opinion that HOT2000 overestimates the homes energy requirements because of its assumptions and limitations. Hot water use for example, was not measured in the home, and the HOT2000 default of 225L/day is quite high. Natural daylighting was also not incorporated in this analysis. The large south windows would provide a significant amount of light preventing the need to use artificial sources throughout most of the day. The findings

should be compared to successful examples of net-zero energy homes around the world, specifically buildings that meet the Passivhaus standards because of their low energy requirements.

REFERENCES

- Barua, R., Zhang, D., Fung, A. (2009). Implementation of TRCA Archetype Sustainable House Monitoring Systems, Project report submitted to TRCA, Reliance Home Comfort, and Union Gas. Ryerson University, December, 2009
- Barua, R., Zhang, D., Fung, A. (2010). Analysis of Energy Performance of the Sustainable Archetype House at Kortright Centre, submitted to *International High Performance Buildings Conference*, West Lafayette, IN, July 12-15, 2010
- Canada Green Building Council [CaGBC]. (2009a). LEED® Canada for Homes Certification Levels. *LEED GREEN BUILDING RATING SYSTEM*. March 2009: p. 7 [Electronic version] Retrieved April 13, 2010 from <http://www.cagbc.org>
- Canada Green Building Council [CaGBC]. (2009b). Overview of Rating System. *LEED GREEN BUILDING RATING SYSTEM*. March 2009: p. 12-13 [Electronic version] Retrieved April 13, 2010 from <http://www.cagbc.org>
- Canada Green Building Council [CaGBC]. (2009c). Optional Pathways through the EA Category. *LEED GREEN BUILDING RATING SYSTEM*. March 2009: p. 68 [Electronic version] Retrieved April 13, 2010 from <http://www.cagbc.org>
- Canada Green Building Council [CaGBC]. (2009d). Air Filtration. *LEED GREEN BUILDING RATING SYSTEM*. March 2009: p. 77-78 [Electronic version] Retrieved April 13, 2010 from <http://www.cagbc.org>
- Canada Mortgage and Housing Corporation [CMHC]. (2009). Housing Market Indicators, Canada, Provinces, and Metropolitan Areas, 1990 – 2008
- Fung, A., Ng, K.L.R., Masoumi Rad, F. and Tse, H. (2009a). Analysis of Different Mechanical Systems for Ontario Housing Market Using Hot2000 and RETScreen. *CANCAM 2009 Conference*, Halifax, NS, May 31-June 4, 2009
- Fung, A., Dembo, A., and Zhou, J. (2009b). Summary of Detailed Audit and Building Simulation on Archetype Sustainable House, Woodbridge ON. *CANCAM 2009 Conference*, Halifax, NS, May 31-June 4, 2009
- Haltrecht, D., and Fraser, K. (1997). Validation of HOT2000™ using HERS BESTEST. *International Building Performance Simulation Association [IBPSA] Building Simulation Conference*, Prague, CZ, September, 1997 [Electronic version] Retrieved April 13, 2010 from http://www.ibpsa.org/proceedings/BS1997/BS97_P009.pdf
- Ministry of Public Infrastructure and Renewal. (2006). Places to Grow: Growth Plan for the Greater Golden Horseshoe. [Electronic version]. Retrieved October 19 2009, from <https://www.placestogrow.ca/images/pdfs/FPLAN-ENG-WEB-ALL.pdf>
- Natural Resources Canada [NRCAN]. (2010). HOT2000. Retrieved March 18, 2010 from http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/hot2000.html
- Natural Resources Canada [NRCAN]. (2009). ENERGY STAR for New Homes. Retrieved March 18, 2010 from <http://oee.nrcan.gc.ca/residential/energystar-housing.cfm>
- Tse, H., Siddiqui, O., Fung, A.S. and Masoumi Rad, F. (2008). Simulation and Analysis of a Net-Zero Energy Townhome in Toronto, 3rd *Canadian Solar Buildings Conference*, Fredericton, NB, August 20-22, 2008
- U.S. Department of Energy. (2008). HOT2000. Retrieved March 18, 2010 from http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=45/pagename=alpha_list

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