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SIMULATING A NZEH WITH A SOLAR COMBI-SYSTEM AND RADIANT FLOOR HEATING

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ABSTRACT

It is becoming increasingly important to find ways to reduce energy use in buildings in order to counteract climate change and rising energy costs. This paper presents a computer model, using the TRNSYS simulation environment, of a Net Zero Energy House (NZEH) equipped with a solar combisystem and radiant floor heating. Comparing the results from this model with those from the model of an average house in Montreal shows the potential improvement for energy performance, when new design approaches, equipment and materials are used. The simple payback time for solar collectors used with the combisystem is also addressed.

INTRODUCTION

Designing a house to be as energy efficient as possible can be a difficult task. There are many different components of a house that may have an impact on energy use depending on how they are designed as well as how they are combined with other components. One design decision may reduce energy consumption in one case, but increase it in another if it is not properly combined with other components.

Computer simulated design programs go a long way to help overcome the difficulties of designing a house to meet the specified needs and avoid costly mistakes that would only be discovered after construction, when it is too late. TRNSYS is one such tool and is the platform used in this paper to model and simulate a Base Case house and a more efficient NZEH equipped with a solar combisystem and radiant floor heating.

Although Net Zero Energy Houses are not commonplace, significant work is being done to further their development. This work covers research and development in the areas of new technologies, computer simulation models and actual construction techniques. Recent built examples include a million dollar home in Texas by AndersonSargent Custom Builder L.P as well as a more realistic $200,000 (USD) 150 m^2 (1,650 sq.ft.) house in Oklahoma (Oliver 2006).

The Canada Mortgage and Housing Corporation (CMHC) sponsored the Equilibrium project that selected 12 winning house designs across the country with the goal of producing as much or more energy than they use in a year. They should be completed sometime in 2008 (Canada Mortgage and Housing Corporation 2008).

Although there are many examples of projects around the world that originally intended to be net zero, a good number of them have missed this goal and ended up being low energy homes. Some reasons for this could be bad design, system malfunctions or occupant behavior. One way to reduce this unwanted underperformance is to use reliable building simulation software since it is very difficult to design an optimal NZEH without first simulating the energy performance. Many tools are available, with different functionalities and options. BEopt, for example, optimizes a NZEH based on pre-defined options that the user selects (Christensen, Horowitz, & Barker, 2005). Other tools include Energy-10 which can provide pre-design energy analysis in minutes with a user-friendly interface and EnergyPlus which has no user friendly interface but can provide detailed energy simulations of complex building systems (Sustainable Building Industry Council 2004, US Department of Energy 2007). TRNSYS is a very versatile simulation tool that can be used to model complex and non-standard buildings. The tool does have a user-friendly interface but also requires a significant time commitment to model detailed buildings and components.

A number of research projects have used TRNSYS and other tools to model NZEHs in Canada. Biaou & Bernier (2005) calculated a simple payback of 29 years in Montreal for a $7,500 solar system composed of 12m^2 of flat plate solar collectors and 5.2 m^2 of PVs that power a ground source heat pump and other household electrical needs. Tse & Fung (2007) calculated the simple payback of their entire Toronto NZEH design, thus factoring in the cost of all energy efficiency improvements as well as the GSHP, solar collector and PV system. With the price of electricity in

Toronto twice that of Montreal, they determined that it would take 31 years to pay off the $108,000 worth of modifications to their base case house. TRNSYS was also used by the International Energy Agency to perform simulations on nine different models for Task 26 – Solar Combisystems (Weiss 2003). The various combisystem models were all plotted as fractional solar energy savings vs. fractional solar consumption to help determine which designs were the most efficient.

THE BASE CASE HOUSE MODEL

The "Base Case" house is modeled as a wood frame house, typical of modern houses built in Montreal. The general construction details are based on standard wood frame house construction in Canada (Canada Mortgage and Housing Corporation, 1999) (Kesik and Lio, 1997). The other main characteristics of the Base Case house are based on average newly constructed houses in the province of Quebec in 1994. This information is from John Gusdorf of the Sustainable Buildings and Communities group at Natural Resources Canada. The 2-storey house is modeled in TRNBuild (a sub-program in TRNSYS) with 3 heated zones totalling 208 m^2.

The thermal insulation (RSI) value of the walls is shown in Table 1. All of the walls meet or exceed Quebec regulations.

The windows are double pane, 6/16/4, Sunguard Clear Argon, with an RSI value of 0.39 m2-K/W and SHGC of 0.44. This type of window exceeds the Quebec regulation. The two above ground stories each have a window-to-floor area ratio of 11.1%. This ratio is within the maximum limit of 15% based on the Quebec regulation. All of the windows in the house have translucent roller shades as internal shading devices, with a reflection coefficient of 0.6. The blinds are down from 9 am to 9 pm between May 1st and October 17th .

The mechanical ventilation supplies fresh outdoor air at a constant rate of 0.35 ACH year round (McQuiston et al. 2005). When the outdoor air temperature is below 21^{o}C, the air is first heated to 21^{o}C and then supplied to the zones. Since the house has no mechanical cooling system, when the outdoor air is above 21^{o}C, it is supplied to the zones at the outdoor air temperature. In order to reduce the heating energy use, a heat recovery ventilator (HRV) with 70% efficiency is used to recover heat from the exhaust air and preheat the fresh incoming air (Venmar n.d.). The 122 W electricity demand of the circulating fan is considered in the analysis. The natural air infiltration rate is set to 0.1635 ACH, which corresponds to 3.27 ACH @ 50 Pa (Hamlin & Gusdorf 1997). Since there is no mechanical cooling system, natural ventilation is used during the warmer months by opening the windows at night. This supplies an additional 10 ACH of outdoor air (Kreider, and Rabl, 1994) (Siviour, 1991).

Electric baseboard heaters are used for heating, with an efficiency of 100%. The heating functions from October 17th to May 1st. On the two above ground floors the thermostat is set to 21^{o}C from 7 am to 11 pm and 18^{o}C from 11 pm to 7 am. The basement is set 1^{o}C less than the other zones.

The model also considers the heat transfer between the ground and the basement walls and floor using Type 701 in TRNSYS. The daily domestic hot water use totals 236 L/day and is defined by an average consumption schedule for a typical family (Perlman and Mills, 1985). The tank is exclusively heated by an electrical element.

THE NZEH DESIGN

Changes were made to the Base Case house so as to model the more efficient NZEH. In order to make meaningful changes, a sensitivity analysis was performed on several important aspects of the house. Six physical parameters were selected to determine the extent at which they influence the house annual energy use and indoor temperatures. These parameters are: thermal insulation levels and air infiltration as well as window type (ex. RSI-value and SHGC), size (Window/Floor area), location (e.g. % of window area on south side) and shading. The design of the NZEH reflects the conclusions drawn from this sensitivity analysis. Table 1 shows all of the main design changes that were made to the Base Case in order to achieve the energy efficient NZEH.

MODELING IN TRNSYS

TRNSYS is a very versatile tool for modeling complex situations such as all of the interacting systems in a house. The main systems and how they are modeled are described here. This model uses a 10 minute simulation time step.

The House. The centerpiece of this model is the Multi-Zone Building (Type 56) which contains most of the details that make up the structure, envelope and contents of the house being simulated. The components that are not embedded in Type 56, or can be more accurately modeled with other TRNSYS Types, are discussed in the following sections. One important

Table 1: Energy efficiency improvements transforming the Base Case house into the NZEH

Design Parameter	**Base Case**	**NZEH**
Insulation of above ground walls (RSI-value)	3.52 m^2·K/W Fibreglass	6.25 m^2·K/W Mineral wool
Insulation of basement floor (RSI-value)	0.67 m^2·K/W Air space	1.9 m^2·K/W Cork (below the radiant floor)
Insulation of attic floor (RSI-value)	5.81 m^2·K/W Fibreglass	10.42 m^2·K/W Mineral wool
Window distribution of facades	25%-S/ 25%-E/ 25%-W/ 25%-N	70%-S/ 5%-E/ 5%-W/ 20%-N
Window/Floor Area	11%	20%
Windows: RSI Insulating value SHGC	 0.391 m^2·K/W 0.44	 0.862 m^2·K/W 0.265
Natural Air Infiltration (ACH)	0.1635 ACH 3.27 ACH @ 50 Pa	0.061 ACH 1.22 ACH @ 50 Pa
Lighting type Average installed power density	Incandescent 5 W/m^2	CFL 1.25 W/m^2
Appliances (Total Annual kWh)	Standard models 6846 kWh	Energy Efficient 3864 kWh
Domestic Hot Water Use	236 litres/day Electric heating element in the tank (5.5 kW)	Low flow faucets: 165 litres/day Thermostatic mixing valve reduces the use of hot water from the tank Solar Collector & Electric Heating (1 kW)
Domestic Hot Water Energy Recovery	N/A	Drain Water Heat Recovery
Heating System	Electric Baseboard Heaters	Radiant Floor Heating Solar Collector & Electric Heating (2 kW & 4 kW electric elements)
Electricity	Electrical Utility	Photovoltaic Panels

element that is embedded in Type 56 is the ability to define active layers. This option for the floor layers is used to model radiant floors containing pipes filled with hot liquid.

The Solar Combisystem. This is a system that combines the radiant floor heating with the domestic hot water (DHW). Figure 1 shows a physical schematic of the combisystem but does not include the controllers that are modeled in TRNSYS. These are explained in the following text. Both the Radiant Floor Tank (RFT) and the DHW tank are 300 litre Vertical Cylinder tanks (Type 534) which allow for stratification in a user defined number of layers; in this case, 4 layers. These layers are defined as nodes, with node 1 being the top node where water exits the tank. Water enters the tank at the bottom through node 4.

An evacuated tube solar collector sends the hot glycol-water mixture at 100 kg/h to either a heat exchanger in the RFT or to one in the DHW tank, with priority given to the RFT. A Differential Controller (Type 2d) and an Equation (a useful component in TRNSYS where user-defined formulas using inputs can be created) feed information to the flow diverter (Type 11f) to control the flow of glycol. The hot glycol will only flow to the RFT heat exchanger if it meets all three of the following conditions: 1) the glycol entering the heat exchanger in the tank is hotter than when it exits, 2) the temperature of the water in node 1 of the tank is less than 55°C, and 3) it is the heating season (Oct 17th to May 1st). If any of these conditions are not met, then the fluid is directed to the DHW tank. The fluid will also only flow through the DHW tank heat exchanger if conditions similar to the first two above are met, except the temperature limit in the DHW tank is for node 3 (where the heat exchanger enters the tank) and is set to a maximum 85°C. This is imposed by a second Differential Controller. When conditions for both tanks are not met, the glycol does not circulate through the collector.

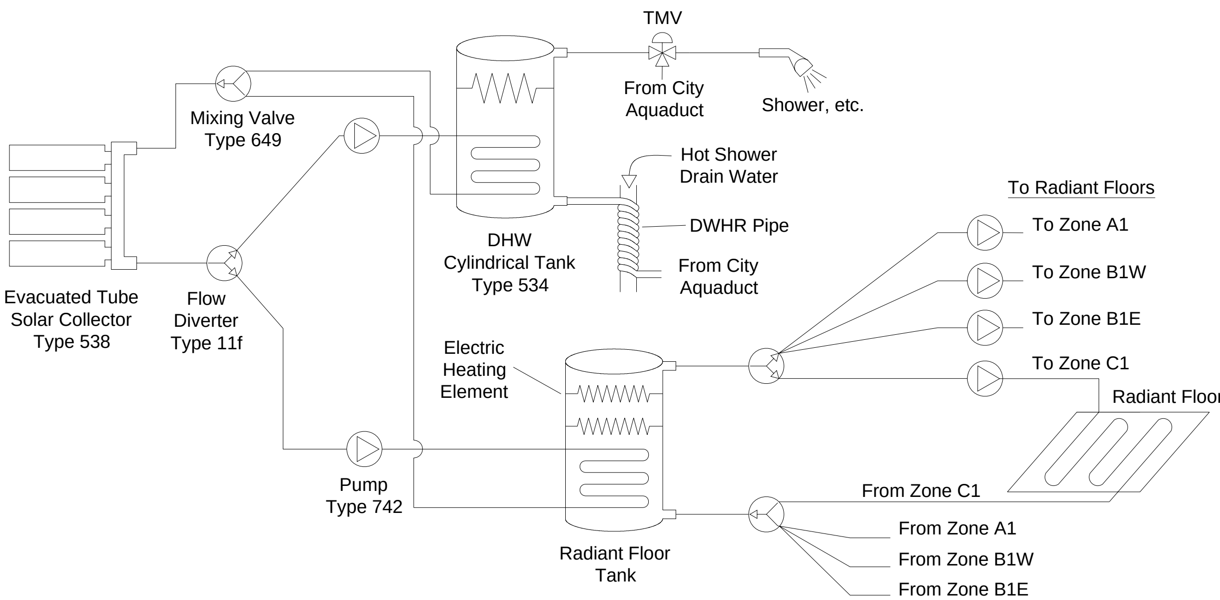

Figure 1: Schematic of the Combisystem

The RFT has two electrical heating elements to heat the tank water which are controlled based on the temperatures in the house. Since the control of the radiant floor heating is based on maintaining comfortable living conditions, the 2 kW heating element in node 1 of the RFT is activated when the operative temperature on the top floor of the house drops below 21^{o}C. If the temperature drops below 18^{o}C, the 4 kW heating element in node 2 is also activated. These criteria are set back by 3^{o}C at night. The DHW tank heating element is activated when the water in the top of the DHW tank falls below 55^{o}C. The back-up electrical heating elements in the two tanks are modeled using an Equation and the 3-Stage Room Thermostat with heating set back and temperature deadband (Type 8b).

There are four separate radiant floor heating loops in the house; one in the basement, two on the ground floor and one on the top floor. The approximately 55^{o}C water is pumped independently through these zones at 300 kg/h each. The hot water only flows through the radiant floors when the following conditions are met: 1) the operative temperature in the zone is below 21^{o}C and 2) it is the heating season (Oct 17th to May 1st). Since the top floor (Zone C1) is twice as large as the other zones, the flow is doubled in this zone (600 kg/h). In addition, since the basement (Zone A1) is normally less occupied, the temperature setting is 1^{o}C less than the other floors. An Equation and Type 8b, the Three-stage Room Thermostat, are used to control these flows as well as a 3^{o}C temperature set-back from 11 pm to 7 am. The electricity needed to power all of the pumps for the combisystem is included in the overall house electricity demand.

DHW Energy Saving Devices. A few other energy saving devices were modeled with respect to the DHW. Firstly, low flow faucets reduce the DHW usage by 30% to 165 l/day. Secondly, a thermostatic mixing valve (TMV) is installed downstream of the DHW tank where it mixes the DHW tank hot water with municipal cold water and supplies a stable 49^{o}C. This allows the water in the tank to be at least 55^{o}C, and in this case up to 85^{o}C. The water needs to be heated above 55^{o}C to avoid the danger of Legionnaire's disease and to meet code requirements (Reliance Water Controls 2005). The TMV also saves energy because without it, the water coming out of the tap is often either much hotter than 49^{o}C or the temperature is regulated by the user by adding more cold water to the flow rather than reducing hot water flow. This applies to taps that have separate hot and cold knobs. The TMV is modeled with an Equation. Finally, a Drain Water Heat Recovery (DWHR) unit is modeled to recover wasted heat from the hot water flowing down the drain. The DWHR system consists of a copper pipe section containing the incoming city water flowing into the DHW storage tank. This pipe is located just upstream of the DHW storage tank and is tightly coiled around the 75 mm (3 in.) drain pipe which contains the drain water from all of the drains in the house. Therefore, as the cold city aqueduct water flows through the coiled pipe into the storage tank, heat from the warm drain water is transferred to the incoming cold water and it is pre-heated to reduce the energy use. This is modeled using a Heat Exchanger (Type 91) with a thermal effectiveness of 60% based on company specifications and a study performed by NRCan (RenewABILITY 2007, Zaloum, Lafrance & Gusdorf 2007).

Table 2: All TRNSYS Types used in this model

Name	TRNSYS Type
Differential Controller with Hysteresis	Type 2d
3-Stage Room Thermostat with heating set back and temp deadband	Type 8b
Flow Diverter	Type 11f
Weather Data Reading and Processing - TMY2	Type 15-2
Periodic Integrator	Type 55
Multi-Zone Building	Type 56a
Online Plotter With File	Type 65a
Heat Exchangers	Type 91
Photovoltaic Panels - Crystalline Modules	Type 94a
Heating and Cooling Season Schedule (TESS)	Type 515
Hourly Schedule - Weekdays Saturdays and Sundays (TESS)	Type 516
Hourly Schedule - 7 Identical Days (TESS)	Type 517
Cylindrical Tank - Vertical (TESS)	Type 534
Evacuated Tube Collectors (TESS)	Type 538
Mixing Valve (TESS)	Type 649
Ground Coupling - Basement Heat Losses (TESS)	Type 701a
Pumps - Variable-Speed (TESS)	Type 742
Equation	n/a

Interactions Between the Basement and the Ground. The Type 701 basement conduction component is used to model the detailed interaction of heat transfer between the building basement walls and floor with the ground around it. The user specifies information such as soil properties and the size and detail of the temperature grid around the building. The initial ground temperatures in the soil near the building (near-field) and those at a distance that is not affected by the building heat (far-field) are calculated using the Kasuda correlation. In this model the near field extends 4 m out from the basement walls and floor. As the simulation runs, the near field soil temperatures and the building underground wall temperatures from TRNBuild are used in heat transfer calculations to model the heat interactions. Type 701 linked with Type 56 (the house) dynamically determines the temperatures on both sides of the basement walls as well as throughout the underground near-field temperature grid at any point in time.

Photovoltaics and Other TRNSYS Types Used. TRNSYS Type 94a is used to simulate Sanyo mono-silicon HIP-200BA3 photovoltaic panels which are some of the most efficient PV panels on the market. They provide all of the required electricity to make this a NZEH. Finally, although they seem less remarkable, the other types used in this model play an integral role. The entire list can be found in Table 2. For example, schedules help regulate heat, lighting and flows, the weather file provides essential data such as temperatures, radiation and wind, and the plotters allow the user to analyze the simulation results.

RESULTS

Energy Efficient Design. The energy efficiency improvements that transform the Base Case house into the NZEH have a very significant impact on the annual total house energy use, reducing it by 45% before any active solar technologies are implemented. The Base Case house requires a total energy demand of 25,570 kWh/yr compared to the NZEH design that requires only 14,177 kWh/yr (before any active solar technologies are implemented). Relating specifically to the DHW and thus the combisystem, Figure 2 shows the impact that the three DHW energy saving schemes have on the NZEH before any active solar technologies are implemented. All three combined result in a 62% reduction in DHW energy demand which is an energy reduction of 2735 kWh/yr and thus an annual savings of $164.10 (at $0.06/kWh).

Active Solar Technologies. When the combisystem is used with solar collectors, the electricity demand is further reduced and then the remaining demand is supplied by an appropriate number of photovoltaic panels to complete the transformation to a NZEH. The amount of reduced electricity demand due to the solar combisystem depends on how many Thermomax Solamax 20 evacuated tube solar collectors are used. The collectors are installed at a 45 degree angle facing due south on the roof of the house located in Montreal, QC. Each collector contains 20 evacuated tubes and has an absorber area of 2 m^2. TRNSYS simulations were run to determine how many collectors are appropriate for this house based on electricity savings. These results are converted into cost savings based on $0.06 kWh and compared to the initial cost of the collectors. Table 3 details the results comparing the NZEH with varying numbers of evacuated tube solar collectors. Installing one collector reduces the house electricity use by 1,238 kWh/yr to a total energy use of 12,939 kWh/yr. This results in annual savings of $74. Quotes from Thermomax representatives suggest that the package of equipment and controls - including the collector, controller, pumps, tanks, etc. - should cost around $4500. This price includes the two storage tanks fitted with heat exchangers, minus the cost of two regular storage tanks which would be necessary with a non-solar system.

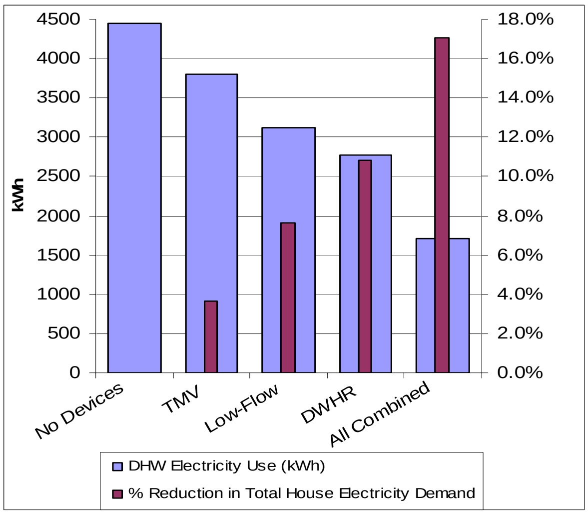

Figure 2: Impact of DHW Energy Saving Schemes on the NZEH without Active Solar Technologies

In addition, the Canadian Solar Industries Association estimates installation costs around $1600 (Jory n.d.) for a total cost of $6,100. This results in a simple payback time of 82 years for a system with one 20 tube solar collector. Adding additional collectors will only increase the cost by $2,000 each since the rest of the equipment doesn't change. With three evacuated tube collectors, 2,316 kWh/yr of electricity is saved which results in a simple payback time of 72.7 years. Since tripling the collector area does not result in a tripling of useful solar energy, the benefit of adding more collectors plateaus very quickly. Installing four collectors results in a simple payback of 76.5 years and is thus an inferior option, from a cost payback point of view. Although three collectors appears to be the best choice, if you consider that 73 years is nearly triple the average 25 year expected life of solar collectors, then it seems that with the current energy and installation costs, the main motivation to install this technology in Montreal is for energy independence and environmental concerns.

The electricity consumption of this NZEH is 11,861 kWh/yr with three solar collectors are installed. This electricity will need to be supplied by a PV system in order to achieve net zero status. Without the electrical backup heaters in the tanks, it is nearly impossible to fully satisfy the heating and hot water requirements 365 days a year. This is true, even with significantly larger tanks (3000 L RFT and 2000 L DHW tank) that store the heat to try to have enough during cloudy days and at night when heating is needed most. With these larger tanks and 25 solar collectors, the RFT still requires 1304 kWh/yr from the electrical heating element to satisfy the desired set points. The DHW tank needs only 38 kWh/yr. The results are not significantly different even when the system is doubled to 50 solar collectors. This shows that the output from increasing solar collectors levels off quickly if there aren't major increases in storage capacity.

The value of the electricity use after all energy efficiency improvements and heat energy systems (e.g. solar collectors) have been installed (11,861 kWh/yr, or 57 kWh/m^2/yr) can be compared to several other Canadian NZEH research projects. A Net Zero Energy Triplex in Montreal equipped with a GSHP and solar collectors for DHW uses 61 kWh/m^2/yr of electricity (Iolova K, Bernier M & Charneux R 2007). Biaou & Bernier (2005) modeled a house in Montreal that is heated with a GSHP and has DHW provided by four alternatives. When a 6m^2 flat plate solar collector is used, the electricity use is 70 kWh/m^2/yr. Finally, a Toronto NZEH also equipped with a GSHP and solar collector for the DHW uses 36 kWh/m^2/yr in electricity (Tse H & Fung A 2007). Unlike all of the other projects listed here that used TRNSYS, this project used HOT2000 and RETScreen.

Table 3. Energy and cost comparisons of the NZEH combisystem with varying numbers of solar collectors

	Combisystem		Electricity Use (kWh)						
House Model	**Total Energy Supplied to the DHW & RFT (kWh)**	**Solar Energy Delivered to the DHW & RFT (kWh)**	**RFT**	**DHW**	**Total House Loads**	**Absolute Change (kWh)**	**Relative Savings ($/yr @ $0.06/kWh)**	**Initial Cost of the Solar Combisystem**	**Simple Payback Time (yrs)**
NZEH - No Solar Collector	6220	0	4654	1709	14177	0	$0	$0	0.0
NZEH - 1 Solar Collector	6679	1838	4230	924	12939	-1238	$74	$6,100	82.1
NZEH - 2 Solar Collectors	6856	2640	3838	754	12329	-1848	$111	$8,100	73.1
NZEH - 3 Solar Collectors	6945	3205	3560	591	11861	-2316	$139	$10,100	72.7
NZEH - 4 Solar Collectors	7000	3586	3399	447	11540	-2637	$158	$12,100	76.5
NZEH - 25 Solar Collectors	6997	7838*	1304	38	8903	-5274	$316	$54,100	171.0
NZEH - 50 Solar Collectors	7024	8185*	1116	27	8638	-5539	$332	$112,100	337.3

* Solar Energy Delivered exceeds the calculated Total Energy Supplied since at year's end the large tanks contain unused energy. The calculation is based on the energy flowing out of the tanks. These two cases have larger storage tanks; 3000 L RFT, 2000 L DHW tank.

The Solar Combisystem Tanks. Although a typical 300 litre (80 gal.) DHW tank is used in this model, it was not initially obvious how large the radiant floor tank (RFT) should be. After simulating the model with tanks ranging from 300 to 3000 litres (80 to 800 gal.), it was concluded that a standard 300 litre tank was the best choice. As the RFT is increased, it requires less electricity since it stores more solar energy, but that reduces the solar energy being sent to the DHW tank and increases the electricity it uses. Therefore, the end result balances out and is nearly insignificant. With three solar collectors, going from a 300 litre RFT to a 600 litre tank saves only 22 kWh/yr which is 0.2% of the electricity used by the house. Increasing the tank to 1000 litres only saves an additional 12 kWh/yr over the 600 litre tank so it is clear that increasing the tank size for this application is unjustifiable in terms of cost, embodied energy and wasted space.

CONCLUSIONS

The most important conclusion that can be drawn from these simulations is that energy saving designs and devices (such as better insulation, passive solar design, low flow faucets, etc) should always take priority over supplying power with renewable energy technologies.

Relatively simple design decisions will significantly reduce energy demand and thus result in the need for much smaller renewable energy systems (PV, solar collectors, etc). This is clearly demonstrated by the fact that the Base Case house requires a total energy demand of 25,570 kWh/yr compared to the NZEH design that requires only 14,177 kWh/yr before any renewable energy systems are installed. This is a 45% reduction in energy demand.

DHW is one area that should not be overlooked when trying to reduce energy use. With respect to the house prior to installing renewable energy systems, the DHW accounted for 26% of the house energy demand. After installing low flow faucets, a thermostatic mixing valve (TMV) and a drain water heat recovery (DWHR) pipe, the DHW accounted for only 12% of the house's reduced energy demand, a reduction of 2735 kWh/yr.

After addressing energy efficiency, the next step towards achieving a NZEH is to install the renewable energy technologies; in this case, solar collectors and photovoltaics. The shortest payback time for a combisystem powered partially by evacuated tube solar collectors is achieved with 8.6 m^2 (6 m^2 absorber area) of installed collectors. The entire system, including installation, costs approximately $10,100 and is capable of further reducing the electricity demand by 2,316 kWh/yr in Montreal. The annual savings from the solar collectors are estimated to be $139 @ $0.06/kWh, which results in a simple payback of 72.7 years. The remaining 11,861 kWh would need to be supplied by photovoltaics. Since this is a "Net" Zero Energy Home, it is connected to the electricity grid. This benefit provides unlimited storage capacity for any photovoltaic electrical power that is generated at a time when it is not needed in the house. Without this connection, large, expensive battery banks would be required to allow this house to become net zero. The simulation also revealed that it would require 38 Sanyo mono-silicon HIP-200BA3 PV panels to supply the remaining electricity needs to make this a NZEH. These would cover 44.8 m^2, and along with the 8.6 m^2 of solar collectors, they would fit nicely on the 59 m^2 south facing roof of the NZEH. Electrical backup heaters are necessary to fully satisfy the heating and hot water requirements of the house since useful heat output from added solar collectors levels off quickly without major increases in storage capacity. Therefore, a NZEH that uses a solar combisystem for the DHW and radiant floor heating is a feasible design for the Montreal climate but requires PV powered electrical backup heating elements in the tanks.

With the price of active solar technologies still at a premium and the bargain basement price of electricity in Montreal, achieving net zero energy for a new home is difficult to justify by current economic standards. If electricity prices would include the indirect social, health, economic and environmental costs associated with continued energy overuse and its effects on climate change, NZEHs would become much more cost effective. For example, the recommended solar collectors would pay for themselves during their expected 25 year life if electricity were priced at $0.17/kWh. With the cost of carbon likely to be factored into energy prices, this is certainly a possibility in the coming years. Therefore, as conventional energy sources become more expensive while solar technologies improve and prices drop, Net Zero Energy Homes will become increasingly affordable.

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