Net-Zero Energy Homes: Solar Photovoltaic Electricity Scenario Analysis Based on Current and Future Costs

Véronique Delisle, M.A.Sc.

ABSTRACT

The Net-Zero Energy Home (NZEH) Coalition has a vision that all new home constructions are to meet a Net-Zero Energy Home standard by 2030. During this time, the price of energy efficiency measures, renewable energy technologies, electricity and fuels will likely fluctuate, ultimately influencing the affordability of NZEH. To evaluate the potential impact of the price fluctuation on NZEH construction costs, this study compares various combinations of energy efficiency measures and renewable energy technologies integrated into a newly constructed all-electric single-detached Quebec residence such that the annual energy production is equal to the home's annual energy consumption. For each scenario, the study evaluates the cost of constructing a NZEH today based on actual costs to that if the house were to be built in 2030. The effect of a potential photovoltaic technology cost reduction due to increase market penetration is also examined.

INTRODUCTION

The feasibility of net-zero energy homes (NZEH) has been shown in several countries and as the interest for building more NZEH and optimizing the concept is growing, the economical aspect is becoming an issue. In Canada, the incremental cost of NZEH compared to a regular house is estimated to vary between $65,000 and $125,000 depending on technologies, house location and typology (Parekh 2010). With the relatively low cost of electricity in certain locations like Quebec, the current payback period of NZEH is fairly high. In the future, however, with the expected price decrease of certain technologies and the expected price increase of energy, it is more likely that NZEH will become more affordable.

In Quebec, hydro represents 94% of the electricity sources (Statistics Canada 2007) and through government policy; the electricity cost remains fairly low. As a result, most of Quebec houses energy requirements are fully supplied by electricity. The objective of this study is to present and compare the cost of building a single-detached NZEH today in Quebec to that if the house were to be built in 2030. In particular, this study aims at estimating the future incremental cost of NZEH, at identifying optimal actual and future energy savings levels and at evaluating the required future PV system price for NZEH to be the optimal solution in 2030. In order to achieve this objective, several steps were followed. First, the characteristics of the all-electric base case house were established. Then, several energy efficiency measures and renewable energy technologies were identified and their actual and future costs evaluated. Finally, from these measures, several combinations were implemented in the base case house so that it could achieve different stages of energy savings and ultimately reach net-zero energy producing as much energy as it consumes on an annual basis. The house energy simulations were performed with RETScreen (2009) using the Montreal International Airport Climate Normals from 1971-2000.

BASE CASE HOUSE

The base case house is a newly built two-storey single detached Quebec home built in the region of Montreal. It is south facing with a length to width ratio fixed at 1.15. It has a volume of 700m^3 (24,720ft^3), an overall gross exterior area of 232m^2 (2,497ft^2) and above-grade floor and basement areas of 186m^2 (2,002ft^2) and 93m^2 (1,001ft^2), respectively. The total window

Véronique Delisle is a research officer at CanmetENERGY, Natural Resources Canada, Varennes, Quebec.

area was set at 29.6m^2 (318.6ft^2) and was split on the North, South, East and West walls in the proportion 35%, 35%, 15% and 15%, respectively (NRCan 1997). In order to ensure future optimal integration of solar energy technologies and avoid snow accumulation, the attic type of roof was specified to be south facing and at a 45^o slope. The building envelope, as summarized in Table 1, was selected to fulfill the minimum requirements of the Quebec Provincial Code zone A (RBQ 1992). The average infiltration rate of this envelope was estimated at 0.226ach, a typical value for new houses (Hamlin and Gusdorf 1997). The area/volume ratio for this house is relatively high considering the importance of this parameter in NZEH design, but the dimensions selected are typical of a generic Canadian residence (Caneta Research 2003). Moreover, this typology is representative of the Canadian actual experience in building NZEH which mainly comes from the Equilibrium Housing Demonstration Initiative (CMHC 2010). For this project, about 13 NZEH projects have been or will be demonstrated and both Quebec single detached NZEH projects have heated area over 230m^2 (2,476ft^2).

Table 1. Building Envelope Characteristics

Component	No	Description
Window	W1	Double-gl., air (U-value=2.87 (0.505Btu/hft^{2o}F), SHGC=0.49)
Wall	Wa1	2X6 construction with fiberboard exterior sheathing (RSI 3.96, R 22.5)
Roof	R1	6" fibreglass batt insulation, 3" EPS (RSI 5.4, R 31)
Foundation wall	FW1	Wood 2X4, fibreglass batt R12 (RSI 2.3, R 13)
Basement Slab	BS1	Uninsulated (RSI 2.5, R 14)

The energy consumption of the major appliances was estimated using NRCan's database for major appliances (NRCan 2009a) assuming that these had the EnergyStar qualification. For the small appliances and lighting schedules, the assumptions of Charron (2007) were applied and the house was considered to have 21 fixtures using 40W incandescent light bulbs. In Canada, the domestic hot water (DHW) consumption for a family of four is typically around 225L/d (59.4US gal), but for this analysis, it was reduced to 196L/d (51.8US gal) because of the EnergyStar appliances. In order to supply DHW, an electric water tank set at 55^{o}C (131^{o}F) with an overall seasonal efficiency of 89% including tank heat losses was selected. The mechanical ventilation was assumed to be provided strictly during the heating season by a 120W heat recovery ventilator with 65% seasonal heat recovery efficiency. The outdoor air ventilation rate was set at 60L/s (127cfm). An electric 15kW (51,182Btu/h) forced air furnace was selected for space heating. The heating setpoint was fixed at 21^{o}C (69.8^{o}F) on the main floors with a 2^{o}C (3.6^{o}F) setback at night and at 19^{o}C (66.2^{o}F) in the basement. No cooling was considered in the house eventhough most of newly built houses in Montreal will have a cooling system. The reason for this is because NZEH have optimal windows and doors location to ensure cross ventilation and are designed to encourage the stack effect. Thus, it is considered here that this will be sufficient to ensure the thermal comfort of the occupants.

Energy Consumption

The base case house annual energy consumption including the equipment efficiency is summarized in Table 2. According to NRCan (2007a), the average energy intensity of a Quebec household in 2007 was 26.3MWh (89.7million Btu), 40.3MWh (137.6million Btu) for a single detached house and 25.8MWh (88.1million Btu) for a dwelling built between 2000 and 2007. Thus, the annual energy consumption calculated for the base case house is representative of a Quebec home.

Table 2. Base Case House Annual Energy Consumption by End-Use

End-Use	Annual Energy Consumption
Space heating (including furnace fan)	18,803kWh (64.2million Btu)
Domestic water heating	4,582kWh (15.6million Btu)
Main appliances (excluding hot water)	2,147kWh (7.3million Btu)
Small appliances	1,450kWh (4.9million Btu)
HRV	692kWh (2.4million Btu)
Lighting	1,198kWh (4.1million Btu)
Total	28,872 kWh (98.5million Btu)

PROPOSED CASE HOUSE

The proposed case house options considered are presented in the next sections with their respective incremental cost compared to the base case option. These costs include both material and labour. They are presented in 2008 Canadian dollars for the city of Montreal, the year referred as the “actual” year, and so are all historic and future prices derived in this study.

Energy Efficiency Measures

The building envelope options for the energy-efficient house were selected according to that used by Charron (2007). The incremental costs are summarized in Table 3 and were all estimated using the 2008 RSMeans Building Construction Cost Data handbook (RSMeans 2008). In addition to the base case window scenario, the following wall glazing fractions were considered for the proposed case: 0% on the North side, 5% on the East and West sides and 40% on the South side. These two combinations were used since they were found to be the most cost-beneficial among a series of discrete combinations. It was more likely that the improvement of the building envelope insulation and its installation would lead to a more airtight house. Thus, when one improvement was applied to the base case house, the air average leakage rate was automatically reduced to 0.145ach, the average air leakage rate for R-2000 houses in 1997 (Hamlin and Gusdorf 1997).

Table 3. Building Envelope Characteristics and Incremental Costs

Component	No	Description	Incremental Cost
Window	W2	Doub.-gl., low-e argon, (U-value=2.10 (0.37Btu/hft^{2o}F), SHGC=0.47)	26.8\$/m^2 (2.5\$/ft^2)
	W3	Trip.-gl., low-e argon, (U-value=1.56 (0.28Btu/hft^{2o}F), SHGC=0.35)	81.4\$/m^2 (7.6\$/ft^2)
Wall	Wa2	2X6 construction, 6" fiberglass batt, 2" EPS (RSI 5.2, R 30)	0.6\$/m^2 (0.1\$/ft^2)
	Wa3	Structural insulated panels (SIP), 7.5" EPS (RSI 5.9, R 33)	15.4\$/m^2 (1.4\$/ft^2)
	Wa4	Structural insulated panels (SIP), 11.5" EPS (RSI 8.6, R 49)	29.4\$/m^2 (2.7\$/ft^2)
Roof	R2	12" fibreglass batt insulation, 2" EPS (RSI 7.6, R 43)	1.7\$/m^2 (0.2\$/ft^2)
	R3	12" fibreglass batt insulation, 4" EPS (RSI 9, R 51)	4.2\$/m^2 (0.4\$/ft^2)
	R4	12" fibreglass batt insulation, 6" EPS (RSI 10.3, R 58)	8.8\$/m^2 (0.9\$/ft^2)
Foundation wall	FW2	Wood 2X4, fibreglass batt R12, 2" EPS (RSI 3.6, R 20)	11.5\$/m^2 (1.1\$/ft^2)
	FW3	Wood 2X6, fibreglass batt R19, 3" EPS (RSI 5.2, R 30)	20.4\$/m^2 (1.9\$/ft^2)
Basement slab	BS2	Insulated with 2" EPS (RSI 3.85, R 22)	11.5\$/m^2 (1.1\$/ft^2)

The appliances were remained unchanged in the proposed case scenarios, but the use of 13W screw-in compact fluorescent light bulbs (CFL) was considered as an energy efficiency measure since there is a net-benefit to introduce this measure even in a heating dominated climate (NRC 2005). The 2008 incremental cost was estimated at 3.12$/fixture using the RETScreen database and the Bank of Canada historical consumer price index (CPI) (Bank of Canada 2009). In order to reduce the hot water load, the implementation of two low-flow shower-heads and two low-flow aerators at an approximated incremental cost of $35 was considered. The other measure was to integrate a drain water heat recovery unit (DWHR). It was estimated to recover 40% of the heat from the water going down the shower drain at a cost of $700 (Renewability 2009).

Energy Generation Technologies

One of the energy generation technologies considered in the proposed case house consisted of a 5.9m^2 (63.5ft^2) single-glazed solar domestic hot water heating (SDHW) system coupled with a 300L (79US gal) storage tank. The system was planned to be used strictly for DHW heating purposes and its cost was estimated at $6,000. Simulations performed with RETScreen showed that a 3.9kW (13,307 Btu/h) system mounted on the house roof had the potential of delivering approximately 1.9MWh (6.5million Btu) of heat. Another technology considered was a grid-connected photovoltaic (PV) system rated at 150Wp/m^2 at standard testing conditions (solar irradiance of 1000W/m^2 and cell temperature of 25^{o}C). With the Canadian PV maps (NRCan 2007b), the annual PV electricity production potential was evaluated at 1185kWh/kWp. The incremental cost of a PV system was estimated using NRCan’s 2008 National Survey Report (NRCan 2009b). According to this document, the price of a Canadian grid connected system of less than 10kW including modules, balance of systems

(BOS) and installation was 6.5$/Wp in 2008. The last energy generation technology considered was a 3 ton ground source heat pump (GSHP) with vertical loop and back-up electrical having a coefficient of performance (COP) for heating of 4.2 to be used for space heating purposes. The seasonal COP of this system was estimated at 3.5 and its incremental cost was approximated at $20,000, including the costs of the ground loop, heat pump and installation.

FUTURE COSTS

Electricity and Consumer Price Index

Prior to estimating the future cost of the options described in the previous section, the future price of electricity and CPI were evaluated. In 2007, the National Energy Board (NEB) published a report on the future of energy in Canada using three different scenarios of energy demand forecasts (NEB 2007). The first scenario assumed similar economic, social and political trends as what is currently observed. The second scenario considered that policies would lean on securing reliable sources of energy and the third scenario assumed an increase of regulations to promote energy efficiency and clean sources of energy. The 2030 predicted electricity prices for the province of Quebec using these three scenarios were found to be 0.0953$/kWh, 0.1107$/kWh and 0.1089$/kWh, respectively. The average of these three prices corresponds to 0.1050$/kWh and this value was used for future calculations. The CPI for each year from 2008 to 2030 was also estimated using the average of the three NEB predictions. Using a CPI of 100 for 2008, the actual reference year, the 2030 CPI was estimated at 145.

Energy Efficiency Measures

Two scenarios were considered to evaluate the future costs of the building envelope upgrades. In the first scenario, historical trends were determined from the 1995-2008 editions of the RSMeans handbooks and used to project future costs. In the second scenario, the future cost was assumed to vary strictly with inflation. Certain components only had data available for a short period of time, so the first scenario did not always predict 2030 costs that seemed representative of what could happen in the future. As a result, the second scenario was selected as a conservative approximation.

A method often used to evaluate the future costs of technologies consists of applying the learning curve theory (Delionback 1995). This theory can be used if the market growth (MG) and learning rate (LR) are known with the learning rate defined as the rate at which cost decreases every time the cumulative production doubles. According to the International Energy Agency (IEA 2008), the global learning rate of CFL between 1990 and 2004 was 10%. In 2000, Iwafune (2000) reported that the worldwide learning rate of all types of CFL was 21.4% between 1986 and 1998 and predicted that the prices of CFL would decline by 45% and 50% between 1998 and 2030 using market growths of 31% and 34%, respectively. In this analysis, the future price of CFL was estimated using an average market growth of 32.5% and a learning rate of 10% as suggested by the IEA (2008), since it was determined over a more recent period. The price of incandescent light bulbs was assumed to remain constant in the future since this technology has been on the market for a long time. As a result, the 2030 CFL incremental cost was estimated at 2.95$/fixture. The future cost of low-flow shower heads and faucet aerators was estimated using the conservative approximation that it would only vary with inflation until 2030. For the DWHR unit, the cost of this device is dependent on the market copper cost. Therefore, event if its cost is expected to decrease in the future due to its increase of market penetration, this diminution could be counterbalanced by the increase of copper price (F. Michel, personal communication, April, 2, 2009). Consequently, the cost of this measure was assumed to remain constant until 2030.

Energy Generation Technologies

In a 2001 NRCan report, it is shown that PV experienced an average annual growth rate of 26% during the 1995-1999 period. It is also indicated that the learning of PV modules from 1977 to 1997 has been between 18% and 20%, respectively. In the 2008 PV market survey (NRCan 2009b), historical data are showing that the annual PV market growth in Canada has been around 26% since 1993 and 36% since 2000. In 2006, the US National Renewable Energy Laboratory published a report in which it is predicted that inverter prices will go down by about 42% by 2020 considering an annual market growth of 20% and a 10% learning curve (NREL 2006). In order to estimate the future price of PV systems, the four following scenarios were investigated:

1. PV system: LR=20% MG=26%
2. PV system: LR=20% MG=36%
3. BOS LR=10% MG=20%; PV module LR=20% MG=26%
4. BOS LR: 10% MG=20%; PV module LR=20% MG=36%

As a result, PV system prices of 1.27$/Wp, 0.74$/Wp, 1.96$/Wp and 1.64$/Wp were predicted for scenarios 1, 2, 3 and 4, respectively. For this analysis, a PV system price of 1.96$/Wp was used, since it was the worst case scenario. The future price of GSHP and SDHW systems were evaluated using a 2007 IEA report (IEA 2007). In this report, it is indicated that the average cost reduction of GSHP systems from 2005 to 2030 is expected to be 9% for heating systems. For SDHW systems, their cost reduction is projected to be 42% from 2005 to 2030. Assuming a linear cost reduction from 2005 to 2030, the 2030 GSHP system and SDHW system costs were estimated at $18,407 and $3,715, respectively.

SIMULATION & RESULTS

Simulation Strategy

The energy saving potential of the different options considered was evaluated by performing simulations in RETScreen. To limit the number of simulations, all proposed cases were assumed to have CFL, low flow shower heads, faucet aerators and a DWHR unit. When PV was implemented, simulations were performed with PV area corresponding to 100%, 80%, 60%, 40% and 20% of the south-facing roof area. The actual electricity price was set at 0.068$/kWh since it was the average price of electricity for a Montreal residential customer in 2008 (Hydro-Quebec 2008).

NZEH Affordability

The various scenarios were divided in 8 groups according to the energy generation technologies implemented. The 2008 and 2030 incremental costs and simple payback of the different options are shown in Figure 2 (a) and (b), respectively, where the term “EEM” includes both improved building envelope and energy efficiency measures. In this study, the simple payback is defined as the number of years required for the total electricity savings to equal the incremental investment. According to Figure 1, the incremental cost of a NZEH today is between $80,000 and $91,000. In the future, however, this incremental cost is estimated to be between $39,000 and $50,000. Also, it can be observed that a simple payback between 40 to 45 years is expected in order to achieve 100% electricity savings with the particular house under study today whereas in 2030, the simple payback is estimated to be between 13 and 16 years.

Solutions to Reach Net-Zero Energy Consumption

In Figure 1, it is shown that the implementation of a GSHP system and a PV system is essential to reach net-zero energy consumption. This is with the particular measures used in this house where the energy consumption could be reduced to a maximum of 36% with only energy efficiency measures and high performance building envelope components. When including a SDHW system to this scenario, energy savings in the order of 43% could be achieved and when integrating both GSHP and SDHW system, the energy consumption could be reduced by as much as 70%. Therefore, even with the most energy-efficient measures, PV is still required to supply at least, the last 30% of energy required for this house to reach net-zero energy. Another observation to make is that by strictly considering the initial incremental cost, the most affordable NZEH scenario is different whether the 2008 or 2030 prices are considered. When using the actual costs, the most affordable scenario has a 7.8kWp PV system that supplies approximately 32% of the energy requirements. With the future costs, however, the most affordable NZEH has a 9.8kWp PV system that contributes to 40% of the overall energy needs.

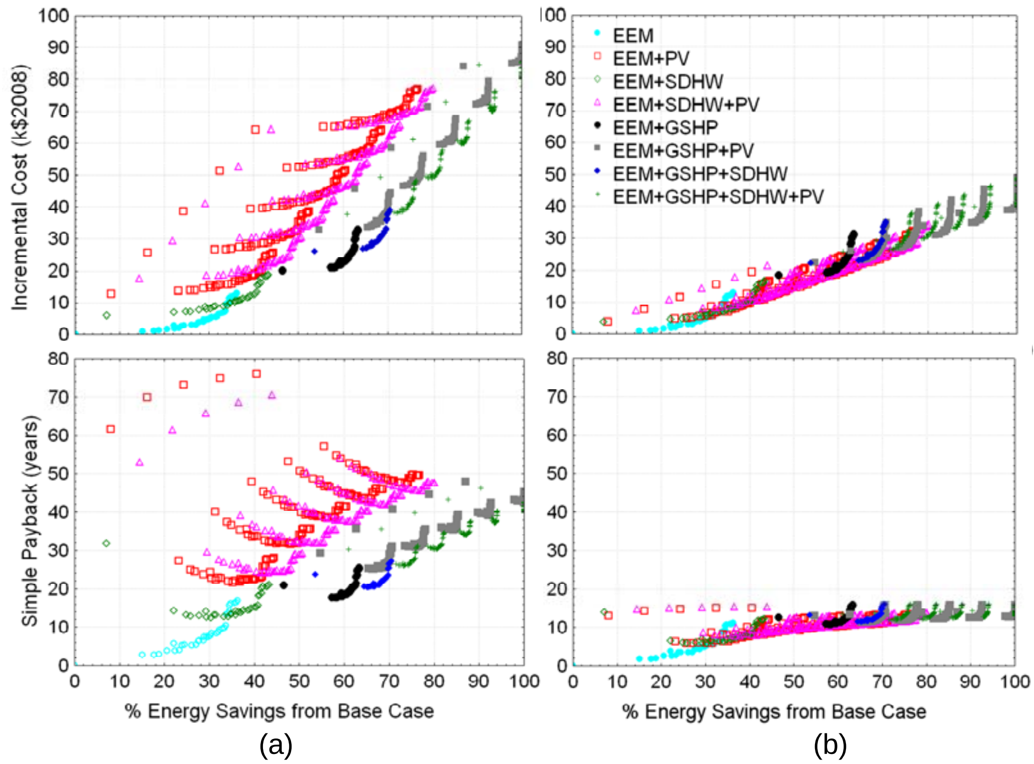

***Figure 1** Incremental cost and simple payback of using (a) actual costs (2008) (b) future cost (2030)*

Solutions on the Path to Net-Zero Energy Consumption

Considering that the simple payback of NZEH today was found to be more than 40 years, it is of interest to look at other options on the path to net-zero. For example, if a home owner wants to implement measures and technologies to remain within a 5 year simple payback, Figure 1 shows that 23% energy savings can be reached whereas this increases to 30% in 2030. If considering a 10 year simple payback, 33% savings can be achieved in 2008, but as much as 60% savings is possible in 2030. In order to obtain the optimal energy savings point, the net present value (NPV) of each option was calculated. Considering the importance of the selected financial inputs in the economic evaluation, calculations were performed with 3 different sets of financial parameters. These three cases were selected since they represented the worst case, average case and best case scenarios of all the combinations varying the debt ratio (DR) from 0% to 100%, the annual interest rate (r_i) from 6% to 8%, the escalation rate (r_e) from 3% to 5% and the discount rate (r) from 3% to 6%. In all three scenarios, the inflation rate was fixed at 2% and the debt term and project life were set at 25 years and 30 years, respectively. Figure 2 presents the NPV for projects starting in 2008 and in 2030. As it can be observed, today's optimal level of energy saving varies between 26% and 50%. In 2030, however, the NZEH is the optimal scenario for the best case and average case financial scenarios whereas the 45% energy savings level is optimal for the worst case financial set of parameters.

In order to find the maximum PV system price required for 100% to be the optimal level of energy savings in 2030, the NPV was calculated using the 2030 prices and various PV system prices. The results are shown in Figure 3a where it can be observed that the maximum allowable PV system price for NZEH to be the optimal solution in 2030 is 4.1$/Wp and 2$/Wp for the best case and average case financial scenarios, respectively. For the worst case financial scenario, it is more likely that the 100% level of energy savings will never be the optimal solution in 2030. In the possibility that the PV system price would remain at the 2008 price of 6.5$/Wp in 2030, the optimal energy savings from the base case house in 2030 would be between

40% and 77% which is still an improvement compared to the 26%-50% range observed in 2008. Considering that the NZEH scenario is optimal in 2030 for two of the three financial scenarios using a PV system price of 2$/Wp, the year between 2008 and 2030 at which building a NZEH becomes the optimal energy savings scenario was investigated. As it can be observed from Figure 3b, the net-zero option is already the optimal solution in 2022 using the most favourable set of financial parameters. For the average financial scenario, however, the NZEH option starts to be the optimal solution in 2030.

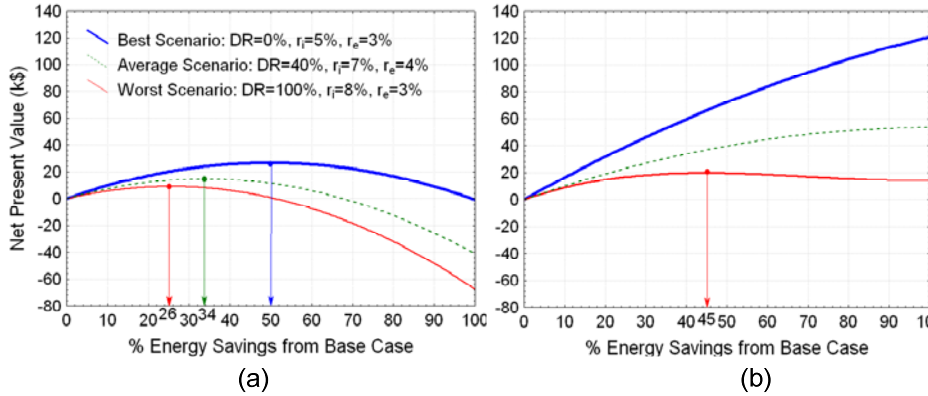

Figure 2 *Net present value for houses with variable levels of energy savings built in (a) 2008 (b) 2030*

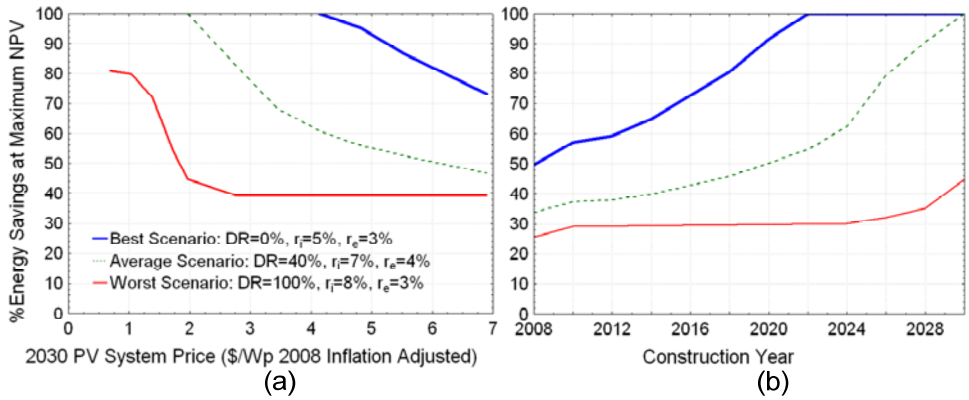

Figure 4 *Optimal energy saving solution to maximize the NPV as a function of (a) the 2030 PV system price (b) the house construction year*

CONCLUSION

This study aimed at providing an economic comparison of a NZEH built today to that if it were to be built in 2030. The first conclusion is that the incremental cost of a NZEH in 2030 could be lower than that in 2008 by 37% to 57%. Another important conclusion is that for the house under study and the measures considered, PV was still required to provide at least 30% of the energy requirements to achieve net-zero energy consumption. Also, even though the optimal level of energy savings is today between 26% and 50%, it is more likely that the net-zero option could be the optimal solution in 2030. Finally, in order for the net-zero energy goal to be the optimal level of energy savings in 2030, the average target PV system price required was estimated at 2$/Wp. This is very close to the estimated 2030 PV system price of 1.96$/Wp which shows that PV systems should have reached the target price necessary for NZEH to be an optimal solution. The results obtained in this study consist of the extreme case because of the size of the house considered and the low electricity price. Nevertheless, it remains representative of the current situation in Quebec.

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