AN OPTIMIZATION METHODOLOGY TO EVALUATE THE EFFECT SIZE OF INCENTIVES ON ENERGY-COST OPTIMAL CURVES

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ABSTRACT

This paper presents a methodology to measure the effect of economic incentives on energy-cost optimal curves. A case-study using a net-zero energy home, located in Montréal, demonstrated the methodology. An EnergyPlus model evaluated the net-energy consumption objective function using 17 design variables. The life-cycle cost objective function was evaluated by post-processing energy simulation results. A multi-objective evolutionary algorithm searched the solution space for energy-cost optimal curves. The proposed methodology may be useful for policy makers seeking opportunities to reduce the initial and life-cycle costs of high-performance buildings.

INTRODUCTION

> “But humankind has a great capacity for finding technological solutions to seemingly intractable problems, and this will likely be the case for global warming. It isn’t that the problem isn’t potentially large. It’s just that human ingenuity—when given proper incentives—is bound to be larger. Even more encouraging, technological fixes are often far simpler, and therefore cheaper, than the doomsayers could have imagined.
>
> *–Steven D. Levitt, SuperFreakonomics*”

The adoption of net-zero energy buildings (NZEB), like any new technology, is inhibited by cost. A cost premium to reach net-zero energy (NZE) is expected due to the higher initial costs associated with balancing on-site energy generation against energy conservation and efficiency measures. In essence, NZEB owners pre-purchase their future energy needs before occupying the building. Undoubtedly, there is consumer interest in high performance buildings due to the superior comfort and low operating costs these buildings provide. Given that it is technologically feasible to achieve NZEBs in most climates (Voss and Musall, 2012), perhaps, the factor limiting the wide-spread adoption of NZEBs is the capacity of consumers to manage higher upfront costs. Economists see such stalemates as perfect opportunities for economic incentives.

In Canada, the cost premium for specialized material and equipment of a net-zero energy home (NZEH) is thought to be between $50,000–90,000 depending on location (CMHC, 2009). If the immediate target of NZE for buildings is too ambitious, then what performance target is economically attractive? Can incentives be developed to encourage the transition towards a NZE building stock? What is the relationship between a cost-optimal building and an energy-optimal building? Building performance simulation tools combined with optimization techniques aid in the exploration of these question. Furthermore, this paper examines the opportunity for economic incentives to establish pathways towards cost-optimal NZEBs. It also further develops key concepts from previous cost and energy optimization research.

The BEOpt development team proposed “swoosh” curves to represent cost-optimal improvements relative to a Building America reference building (DOE, 2010), see Figure 1.

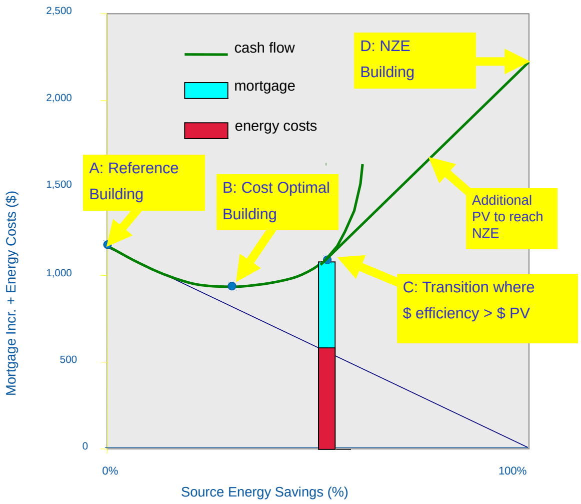

Figure 1: Energy-cost optimal curves in BEOpt (modified from Christensen et al. (2004))

The BEOpt team utilized a cost-optimization technique which identified all intermediate designs starting from a reference building to a cost optimal design and eventually a NZEH (Christensen et al., 2004). BEOpt optimal cost curves, shown in Figure 1, have several interesting features. The reference building, intended to represent the present housing stock, is marked by point (A). Several design improvements can be made to this reference design to identify a cost-optimal point, the most economically attractive building design, shown by point (B). The BEOpt sequential search prioritizes cost-improvements over energy performance improvements (Horowitz et al., 2008). The transition point (C), is the point where energy generation becomes more cost effective than improvements to energy efficiency and energy conservation. To attain the NZE performance target, point (D), from the transition point (C), a specified number of PV panels are used. The line from point (C) to point (D) is straight due to a linear cost assumption of PV panel costs.

This energy-cost optimal curve has also appeared in European building performance targets. In 2009, EU nations set a target that all new buildings should be NZE after 2020. One peculiarity in establishing this ambitious target is that no clear definitions were given regarding what a NZEB was. Furthermore, no practical guidance was given on how designers and contractors could achieve this target. It was later through the energy performance building directive recast that a firm definition of the NZEB target was formed (Kurnitski et al., 2011). The EU now mandates that all new buildings should be nearly net-zero energy (nNZEB) after 2020 (EU Parliament, 2010). A nNZEB is the cost-optimal building using a life-cycle cost analysis on the optimized pathway to a NZEB, see Figure 2 (BPIE, 2010). The reference building suggested is defined in EN15316-1 (2007). The nNZEB performance target is less ambitious and favours cost-feasibility to dictate design. Regardless, optimization approaches are influential in forming energy-cost optimal curves.

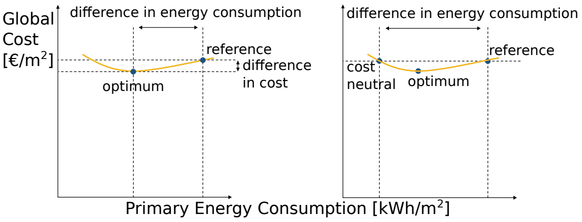

Figure 2: Identification of cost optimal and cost neutral buildings (modified from BPIE (2010))

The Building Performance Institute Europe (BPIE) recommended that designers pursue cost neutral or cost equivalent designs, see Figure 2. A cost neutral design has similar life-cycle costs but resides on opposing limit of energy use intensity reductions on the energy-cost optimal curve. They found that economic optimums involved a minor reduction in energy use intensity (EUI) and cost compared to present energy standards. To encourage further reductions in EUI, it was recommended that new buildings be cost neutral with present standards. This means that a given building should be no more expensive, using a life-cycle analysis, than the reference building but have significantly reduced energy consumption. Reference buildings can be a particular energy code or customized to represent a particular building stock. Although it has not been discussed in literature, economic incentives may positively effect energy-cost curves.

The remaining sections present a methodology for identifying incentive opportunities which create cost-optimal pathways towards NZEB design.

METHOD

This section proposes a methodology to evaluate the effect of several financial incentives on cost-optimal pathways towards NZEBs. In addition, the relationship between cost and energy optimized buildings are examined. To accomplish these goals, the energy-cost curves introduced in the previous section measured the effect of incentives. The following incentive types are explored: (i) incentives which reduce the initial cost premium of a NZEH; (ii) incentives which create revenue streams for part of the life-cycle period; and (iii) disincentives to a typical reference building which indirectly incent the NZE objective.

To exemplify the approach, a NZEH located in Montréal was used. The goal of the multi-objective analysis is to find Pareto curves which minimize both net-energy consumption and life-cycle cost.

Objective function 1 (obj. 1) is the net-energy consumption described by equation 1 and evaluated using EnergyPlus (EnergyPlus, 2011)..

$$f(\mathbf{x}) = COP_H \cdot Q_{heat} + COP_C \cdot Q_{cool} + E_{elec} - E_{PV} \quad (1)$$

where: $\mathbf{x} = (x_1, x_2, \cdots, x_N)^T$ is a design variable vector. Table 5 shows the discrete variables and step-sizes used in the optimization analysis; $f(\mathbf{x})$ is the annual net-electricity consumption of the building (kWh); COP is the average annual coefficient of performance of the Ground Source Heat Pump (GSHP) in heating and cooling mode, 3.77 and 2.77 respectively; Q is the annual heating and cooling load of the house (kWh); E_{elec} is the gross annual electricity consumption in lighting, domestic hot-water, appliances and plug-loads (kWh) and; E_{PV} is the electricity generated by the roof-top PV (kWh). A NZEH is achieved when $f(\mathbf{x}) \leq 0$ implying an annual energy balance. The combined coefficient of performance (COP) of the GSHP including circulation fans, pumps and auxiliary heaters was specified from seasonal-averages of monitored data. Since the heating system uses a GSHP, the COP does not vary significantly over an annual period. Electric lighting ensured that a minimum illuminance of 200 lx was present in all occupied spaces regardless of the window-to-wall ratio. A heat recovery ventilator with an efficiency of 60%, taken from manufacturer specifications, maintained the ventilation rate at 0.3 air-changes per hour in all occupied spaces. Roller shades were automatically deployed if exterior solar radiation on the exterior window surface exceeded 150 W/m^2 and if exterior temperature on the window exceeded 20 °C. These values ensured that blinds were closed if there was potential for zone overheating (O'Brien, 2011).

Objective function 2 (obj. 2) is the incremental cost of materials and operational energy costs over the life-cycle, see equation 2. Materials were scheduled for replacement based on an expected serviceable lifetime (RSMeans, 2011). A marginal electricity rate of 7¢ with an escalation rate of 2.0% was used (Hydro-

Québec, 2010). Note that all monetary amounts refer to Canadian dollars. Life-cycle costs were calculated over a 30 year time horizon.

$$g(\mathbf{x}) = C_{NPV} + E_{NPV} + R_{NPV} - S_{NPV} - I_{NPV} \tag{2}$$

where: $g(\mathbf{x})$ is the net-present value of all cash-flows; C_{NPV} is the capital costs of materials and equipment; E_{NPV} is the operational energy costs; R_{NPV} is the replacement cost for materials and equipment; S_{NPV} is the salvage or residual value using a linear depreciation method; and I_{NPV} is the income generated through incentives such as feed-in tariffs.

The NPV of each term is calculated using:

$$\text{NPV} = \sum_{t=0}^{N} \frac{C_t}{(1+a)^t} \tag{3}$$

where: C_t is the future net-cash flow at year, t (Net meaning $C_t = cash_{out} - cash_{in}$); a is the minimal acceptable rate of return (MARR); and N is the number of years considered in the life-cycle (t=0 is the present year).

If $NPV = 0$, the investment is cost neutral over the considered life-cycle. For this paper, $NPV < 0$ is a profitable opportunity for a given MARR, and if $NPV > 0$, the investment is considered unprofitable over the evaluated life-cycle period. The transition between non-profitable and cost neutral deserves a special cost-metric, called the internal rate of return. The goal of the cost optimization study is to minimize NPV.

Equation 4 specified the minimal acceptable rate of return used for net-present value calculations.

$$a = (1+r)(1+i) - 1 \tag{4}$$

where: r is assumed bank rate, a 2.14% return from a 10 year GIC from 2002 to 2012 (Bank of Canada, 2009); i is the annual inflation rate, 2.0% in Canada (Bank of Canada, 2009); a is the calculated minimal acceptable rate of return, 4.18%.

Initial costs were broken down as follows:

$$\begin{aligned} C = {} & \text{wallinsCost} + \text{ceilinsCost} + \text{baseinsCost} + \text{slabinsCost} + \\ & \text{roofCost} + \text{overhangCost} + \text{concrCost} + \text{PVCost} + \\ & \text{winCost} + \text{airtightCost} \end{aligned} \tag{5}$$

where: C is the total material cost; insCost is the cost of wall, ceiling, basement and slab insulation; winCost is the cost of windows based on glazing area; roofCost is the incremental cost of additional roof framing beyond 30 degrees slope; overhangCost is the cost of overhangs; concrCost is the cost of concrete walls and slab for passive thermal storage; PVCost is the cost of PV panels and inverters; and airtightCost is the incremental cost associate with tighter envelopes. These costs were specified from RS-Means data (RSMeans, 2011, 2012).

Including replacement costs creates a potential problem: the possibility that costs are incurred just before the end of the life-cycle. This results in a misleadingly large NPV. Thus, salvage values need to be associated with each material. This is especially important for equipment, such as PV panels and inverters, where costs can vary significantly from design to design depending on the array size. Salvage values were incorporated using a linear depreciation method, see Figure 3.

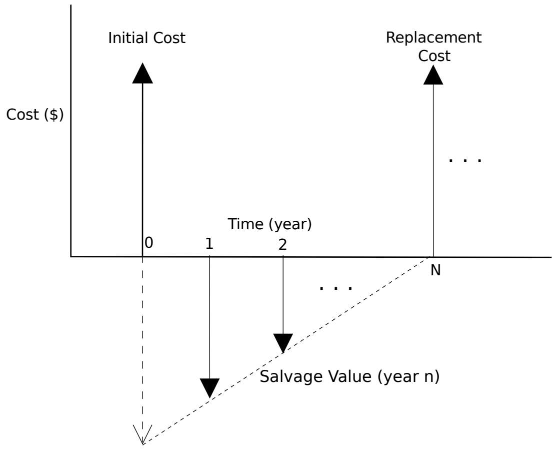

Figure 3: Salvage values: Linear depreciation of initial and replacement costs

As shown in Figure 3 materials depreciated linearly over-time until replacement is required. Thus, at the end of the specified life-cycle period, it is assumed that the materials purchased have some residual value. In some instances this can be related to a real resale value, such as PV panels, whereas in other instances, such as insulation replacement, salvage values are strictly used to compare different life-cycle periods.

The time horizons for replacement costs are summarized in Table 1. Columns with dashes indicate that replacement costs are not considered.

Table 1: Serviceable life-cycle of materials

MATERIAL CATEGORY	REPLACED?	REPLACEMENT PERIOD (YEARS)
Cellulose insulation in Walls	✓	25
Cellulose insulation in Attic	✓	25
Spray insulation in Attic/Basement	✗	–
Rigid insulation under Slab, exterior wall	✗	–
Windows	✓	40
Shingles on Roof	✓	25
Inverters	✓	15
PV Panels	✓	40
Miscellaneous PV array costs	✗	–

To identify the effect of incentives on pathways towards NZEBs, several objectives are identified: (i) formation of a reference building; (ii) creation of energy-cost performance curve using no incentives (base case); (iii) implementation of incentives by post-processing energy simulation results; (iv) evaluation of incentive effects on energy-cost performance curves; (v) identification of a reference, cost optimal, cost-equivalent and energy optimal building on all energy-cost performance curves; (vi) measurement of effect size by comparing the energy-cost curve with incentives to the base case energy-cost curve from step (ii).

To establish a pathway toward cost-optimal and cost-equivalent building designs, a point of reference is required. A reference building represents a business as usual scenario. The method for determining the reference building is shown in Table 5. Values in Table 5 are specified from the following resources: (i) locally enforced building codes, and (ii) a database of 180 thousand audited Canadian homes (Swan, 2010; NRCan, 2012). For example, since envelope air-tightness is not specified by local building codes, physical measurements from the dataset using standardized blower-door test were used, see Figure 4. The most probable air-tightness value for a home in Canada is around 3.5 ACH at 50 Pa. This value was used for the reference infiltration rate. Similarly, other values were determined from this dataset if they could not be determined from building code.

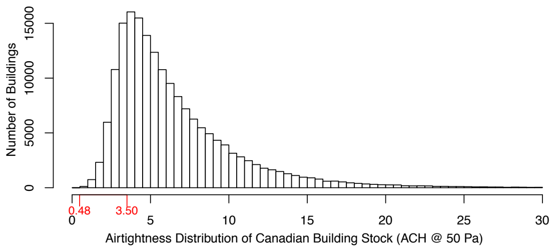

Figure 4: Distribution of air-tightness in the Canadian housing stock

The cost-equivalent performance criterion was defined by identifying buildings which have the same life-cycle cost as the reference building, but resides on the opposing limit of net-energy consumption of the energy-cost optimal curve, see Figure 5.

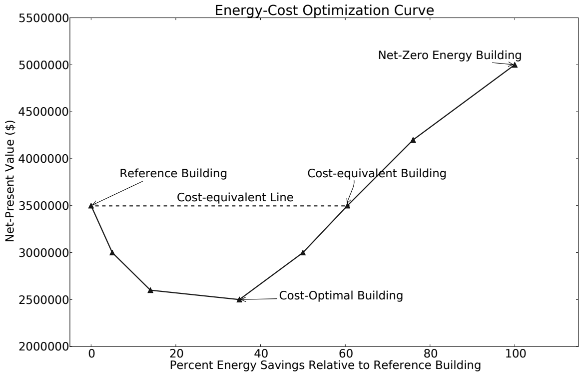

Figure 5: Identification of a cost-equivalent design

The incentive effect is the shift in net-energy consumption of the energy-cost curve with an incentive relative to the baseline energy-cost curve without an incentive, see Figure 6. The larger the shift, the more beneficial the incentive is in achieving the NZE objective.

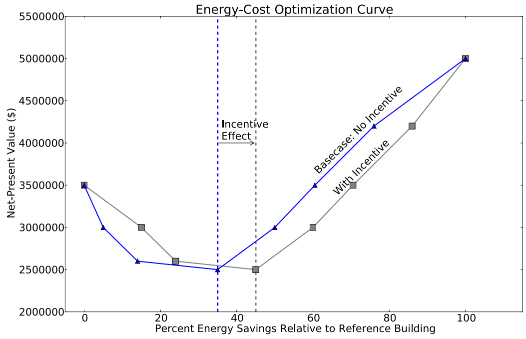

Figure 6: Incentive effect using an energy-cost diagram

The next step is to identify several performance points on the energy-cost curve. A previously developed multi-objective optimization algorithm found (Bucking et al., 2010): (i) the design with lowest net-energy consumption, or the energy optimal design (obj. 1); (ii) the cost optimal design relative to the reference building (obj. 2); and (iii) the set of Pareto optimal designs, or designs with trade-offs with respect to obj. 1 and obj. 2. Included in this set is the cost-equivalent design.

Energy-cost optimal curves were created for each incentive scenario and for a no-incentive scenario. Creating energy-cost curves required the following steps: (i) create datasets by running the multi-objective algorithm for each incentive; (ii) remove all designs with energy performance less than the reference building; and (iii) from the remaining data, identify four points (reference, cost optimal, energy optimal and cost-equivalent buildings). The optimization algorithm was run separately for each incentive. This ensured that the algorithm could exploit cost-saving aspects such as renewable energy rebates to reduce life-cycle cost. Multi-objective optimizations were run ten times to ensure the solution space was fully explored.

The effect of the following incentives were explored: (i) PV feed-in tariff; (ii) mortgage with a PV feed-in tariff; (iii) rebate on renewable energy technology; and (iv) TOU electricity billing.

A FIT incents the creation of on-site renewable electricity generation. This income is intended to provide an attractive return on investment for homeowners to accept the financial cost of additional material and labour associated with the PV system install. For this study, a tariff of 54.9 ¢/kWh was used for 20 years of the life-cycle based on an incentive program offered in Ontario (OPA, 2013). Feed-in tariffs have been successfully implemented in other countries such as Germany and Spain.

Fixed-rate mortgages were used to reduce initial costs to achieve NZE by amortizing them over a set 25 year term. The intention is to provide preferential mortgage rates to clients purchasing additional technologies for a NZEH. Since NZEHs have lower operational costs, owners should be more capable of making monthly mortgage payments; thus lenders should incur less risk for issuing mortgages to NZEH owners. Due to this reduced risk, NZEH homeowners should be eligible for preferential mortgage rates. A preferential mortgage fixed-rate of 3% was assumed.

A rebate was explored as a possible mechanism to reduce technology cost premiums incurred by NZEH owners. A rebate offsets the initial costs required to purchase a given good. Rebates can be in the form of tax deductions, Government issued grants, or provincial sales tax rebates. To have a measurable effect, the incentive must be significant. In 2008, the US Government offered tax rebates of 30% of initial PV system costs (USGOV, 2008). For this study, a similar rebate of 30% is explored. Rebates absorb some of the cost premiums associated with renewable energy generation technologies by reducing the initial price at year zero of the life-cycle cost analysis.

Finally, TOU electricity billing creates a disincentive to use electricity during peak electrical use periods, typically 7am to 7pm. This disincentive may be beneficial since a NZEH uses considerably less electricity compared to a reference building during peak hours. Higher operation cost for other building options may incent homeowners to purchase a NZEH. Table 2 describes the TOU schedule used.

Table 2: Time of use billing schedule

Pricing Schedule	Hours	TOU	Price (¢)
Summer Weekdays	21:00–07:00	off-peak	5.3
	07:00–11:00	mid-peak	8.0
	11:00–17:00	on-peak	9.9
	17:00–21:00	mid-peak	8.0
Winter Weekdays	21:00–07:00	off-peak	5.3
	07:00–11:00	on-peak	9.9
	11:00–17:00	mid-peak	8.0
	17:00–21:00	on-peak	9.9
Weekends and Holidays	00:00–24:00	off-peak	5.3

The effect of these aforementioned incentives on the cost-optimal and cost-equivalent point relative to a reference building are shown in the following results section.

RESULTS AND DISCUSSION

Figure 7 shows the energy-cost curve for a no-incentive scenario.

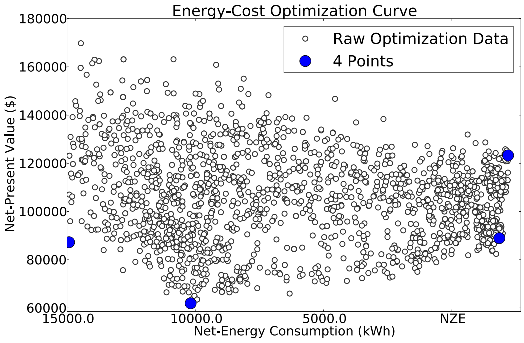

Figure 7: Energy-cost curve: No incentives

This plot shows a sample of non-optimal designs in the optimization search using black hollow circles. The reference, cost-optimal, energy-optimal and cost-equivalent designs are shown using large solid circles.

These results are used to measure the effect size of incentives. The cost-optimal point has an energy performance of approximately 10,000 kWh. Note the cost-equivalent design is a NZEH. This implies that a NZEH costs approximately the same as the reference building over a 30 year life-cycle.

Figure 8 shows the four points from Figure 7 as well for all incentives.

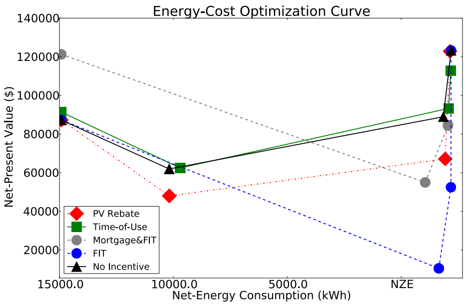

Figure 8: 4-point diagrams for various incentives

TOU billing had little effect on the energy-cost curve. PV system rebates reduced the cost of the cost-optimized design but did not significantly shift the energy-cost curve. Incentives such as FIT and a FIT combined with a mortgage had a large incentive effect. In fact, the use of a FIT is sufficient to move the cost-optimal point very close to the energy-optimal design. Figure 9 shows the raw data used to create the energy-cost optimal curve for the FIT incentive. Note that separations in raw points are caused by discrete variables in the optimization analysis.

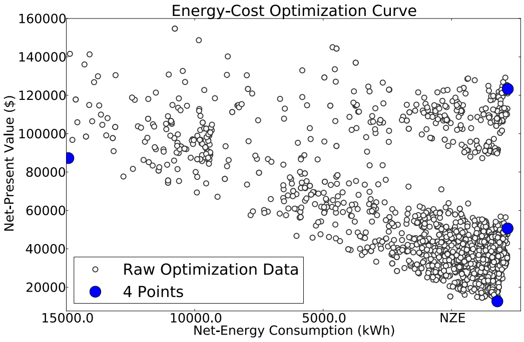

Figure 9: Energy-cost curve: PV feed-in tariff

Figure 9 shows a large disparity of almost $120,000 difference between the cost-optimal and energy optimal design over the life-cycle. This suggests that optimization studies can greatly aid in identifying pathways to cost-optimal NZEHs. Furthermore, since some NZEHs can cost up to 50% more than a cost-equivalent NZEH design, a life-cycle cost analysis is needed in addition to an energy analysis.

Table 3 shows the optimal NZEH parameter set for the cost-optimal individual in Figure 9.

Table 3: Cost optimal design using the PV FIT incentive

VARIABLE	DESCRIPTION	UNITS	OPTIMAL VALUES
azi	Building orientation/azimuth	degrees	0
aspect	Aspect ratio (south facing width to depth ratio)	–	1.5
wall_ins	Effective resistance of wall insulation	m^2K/W	8.56
ceil_ins	Effective resistance of ceiling insulation	m^2K/W	10.57
base_ins	Effective resistance of basement wall insulation	m^2K/W	5.08
slab_ins	Effective resistance of slab insulation	m^2K/W	1.39
ovr_south	Width of Southern Window Overhangs	m	0.34
pv_area	Percent of PV area on roof	%	80
pv_eff	PV efficiency	%	15
roof_slope	South facing roof/PV slope	degrees	45
wwr_s	Percent of window to wall ratio, south	%	48
wwr_n	Percent of window to wall ratio, north	%	5
wwr_e	Percent of window to wall ratio, east	%	5
wwr_w	Percent of window to wall ratio, west	%	5
GT_s	Glazing type, south (also N,E,W)	–	2
FT	Window Framing Types (1:Wood, 2:Vinyl)	–	2
slab_th	Concrete slab thickness	m	0.2
vwall_th	Concrete wall thickness (basement)	m	0.251
zone_mix	Air circulation rate between thermal zones	L/s	133
infil	Natural infiltration rate	ACH	0.05
Fitness of Individual (kWh)			-1053

This optimal design generated a net of $1053\ kWh$ of electricity. To achieve this level of performance required a balance of passive solar strategies, such as: air-tight envelopes ($0.05\ ACH$), high envelope insulation values ($8.56\ m^2K/W$), appropriate south-facing window-to-wall percentage (48%), sufficient circulation of thermal gains ($133\ L/s$) and sizing of thermal mass ($0.251\ m$ central thermal storage wall in basement). Note that the algorithm found diminishing returns for ceiling, wall and slab insulation.

Table 6 shows the raw results used to form Figure 8. This table also shows the incentive effect, or the shift in the cost-optimal building for each incentive from the no-incentive scenario as previously described by Figure 6.

Table 4 shows the initial cost of the cost optimal building and the life-cycle cost for each incentive. Homeowners are sensitive to the first cost of a home. Incentives which reduce the initial cost may be desirable. Ideally, incentives should reduce the initial cost and the life-cycle cost. This was achieved by combining a PV FIT with a mortgage. Note that mortgage loans decrease the initial cost but increase the life-cycle cost. PV system rebates decrease both. Feed-in tariffs reduce the life-cycle cost but do not significantly effect initial costs. The optimization algorithm did not select PV systems for the TOU and base case cost-optimal buildings. This explains the lower initial costs for these scenarios. All life-cycle values were positive indicating that payback was not achieved for the desired rate of return.

Table 4: Initial cost premiums for cost-optimal design using various incentives

INCENTIVE	INITIAL COST PREMIUM ($)	Life-Cycle Cost ($)
None	27,103.00	61,937.14
Time of Use	26,400.00	62,462.79
PV Rebate	21,800.00	47,990.89
Feed-in Tariff	58,900.00	12,626.34
Mortgage	6,263.85	101,029.03
Mortgage and FIT	9,295.62	54,988.48

CONCLUSION

Given the proper incentive, a NZEH can also be a smart financial opportunity. Incentives which generate revenue over the life-cycle period, such as feed-in tariffs for PV generated electricity, have a large effect on shifting the energy-cost optimal curve. As shown by Table 4, higher initial costs can be reduced using mortgage loans but at the trade-off of increasing life-cycle costs.

The shape and behaviour of energy-cost curves depends on available incentives. The proposed methodology can influence EU NZEB initiatives. Recall that the EU downgraded the target that all new buildings should be NZE by 2020 to nearly-NZE. However, using incentives the cost-optimal target can also result in an energy-optimal target. Carefully selected incentives can assist EU member states in achieving their 2020 goals.

Multi-objective building optimization using energy and cost objectives is a problem of context. The results presented are dependent on location, climate and time. The economic scenarios found in various countries will affect results. The local climate will dictate the energy performance limits of the building. New technologies will affect the potential performance of any building. Furthermore, future economic circumstances, such as inflation and fuel costs are in constant fluctuation. Likely, optimization outcomes will change every few years due to these circumstances. Thus, the proposed methodology can aid in identifying new opportunities for a cost-effective building stock. The results should not be viewed as being static and final. The issue is highly dynamic and depends on economic situations as well as the needs and wants of different countries. This emphasizes the importance of an optimization methodology over optimization results.

In this paper, net-zero energy performance was made possible using a mix of passive solar design, improved mechanical efficiency and renewable energy generation using photovoltaic panels as determined by an optimization algorithm. Further technological advances will undoubtedly improve thermal storage, reduce peak loads, improve controls and enable distributed grids. However, without further economies of scale or strong economic incentives, net-zero energy buildings will likely remain a small fraction of the building stock due to their additional upfront costs.

Future work includes performing an uncertainty and sensitivity analysis on the energy and cost models to better understand multivariate interactions between these models and the significance of assumptions made in this analysis. Further research is needed to identify incentives which reduce initial and life-cycle costs by generating revenue over the life-cycle period. These types of incentives greatly improve the life-cycle cost outcome. Further work should focus on collaborating with policy makers to ensure that future buildings are both cost and energy optimal.

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Table 5: Definition of optimization values and reference building

VARIABLE	DESCRIPTION	UNITS	OPTIMIZATION VALUES MIN.	 MAX.	 NO. STEPS	REFERENCE
stories	Number of stories	–	–	–	–	same^a
area	Total floor area	m^2	–	–	–	same^a
azi	Building orientation/azimuth	degrees	-45	45	32	0
aspect	Aspect ratio (south facing width to depth ratio)	–	0.7	2.2	4	1.4
wall_ins	Effective resistance of wall insulation	m^2K/W	3.5	13.0	8	3.7^c
ceil_ins	Effective resistance of ceiling insulation	m^2K/W	5.6	15.0	8	7.7^b
base_ins	Effective resistance of basement wall insulation	m^2K/W	0.0	7.0	8	1.7^b
slab_ins	Effective resistance of slab insulation	m^2K/W	0.0	2.3	4	0^b
occ_loads	Occupant loads (percent of Canadian average consumption)	$\%$ CAD_{avg}	–	–	–	same^a
ovr_south	Width of Southern Window Overhangs	m	0.00	0.45	4	0
pv_area	Percent of PV area on roof	$\%$	0	80	8	0
pv_eff	PV efficiency	$\%$	12	15	4	0
roof_slope	South facing roof/PV slope	degrees	30	45	8	30
wwr	Percent of window to wall ratio (all directions)	$\%$	5	80	8	25
GT_s	Glazing type, south (also N,E,W)	–	1	4	4	2
heating_sp	Heating setpoint	$^\circ C$	–	–	–	18
cooling_sp	Cooling setpoint	$^\circ C$	–	–	–	26
FT	Window Framing Types (1:Wood, 2:Vinyl)	–	1	2	2	2
slab_th	Concrete slab thickness	m	0.1	0.2	8	0.05
vwall_th	Concrete wall thickness (basement)	m	0.00	0.35	8	0.05
zone_mix	Air circulation rate between thermal zones	L/s	0	400	4	50
infil	Natural infiltration rate	ACH	0.025	0.179	8	0.175^b

a: value is same as the compared design; *b*: value is taken from Canadian home dataset; *c*: value is dictated by building code.

Table 6: Energy and cost values for reference, cost optimal and cost equivalent buildings

Incentive	Reference Building Obj. 1 (kWh)	 Obj. 2 ($)	Cost Equivalent Building Obj. 1 (kWh)	 Obj. 2 ($)	Cost Optimal Building Obj. 1 (kWh)	 Obj. 2 ($)	Incentive Effect (kWh)
None	14,920.36	87,262.47	-1,849.18	88,959.54	10,180.96	61,937.14	–
Time of Use	14,920.36	91,386.38	-2,081.73	93,271.20	9,699.66	62,462.79	481
PV Rebate	14,920.36	87,262.47	-1,933.64	67,132.59	10,180.23	47,990.89	0
Feed-in Tariff	14,920.36	87,262.47	-2,181.88	50,646.65	-1,783.34	12,626.34	11,964
Mortgage and FIT	14,920.36	119,467.28	1,129.29	76,601.43	-2,135.04	125,167.93	12,316