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Low-energy building design, economics and the role of energy storage

Edward MOROFSKY
Acting Manager, Energy & Sustainability
Public Works and Government Services Canada
Innovations and Solutions Directorate
Place du Portage, Phase III, 8B1
Hull, Quebec K1A 0S5 Canada
ed.morofsky@pwgsc.gc.ca

Doug CANE
Caneta Research Inc.
7145 West Credit Avenue
Suite 102, Building 2
Mississauga, Ontario L5N 6J7 Canada
caneta@compuserve.com

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ABSTRACT

Low-energy building design can contribute to dramatically reduced energy usage and can be applied to all new building projects. This paper explores the potential in Canada of applying available energy efficient building technologies in cost-effective applications. The objective was to determine the degree of energy reduction that can easily be achieved in new building design and the associated costs. The reference energy level was that specified by the minimum (or prescriptive) requirements of the Canadian Model National Energy Code for Buildings (MNECB) 1997. Costs and savings evaluated include energy, capital and maintenance. Typical small and large office buildings were analyzed. The role of energy storage was also considered. The results indicate that significant energy savings (greater than 50% reduction compared to the base case design) with attractive economic returns are possible through careful selection and application of existing technologies. Energy savings greater than 50% were achieved in four cases for the small office building with discounted payback periods between 2.5 and 6 years. The 50% energy reduction relative to the MNECB is considered as the high performance building threshold. It is possible to achieve 25% reduction compared to the base case building with no incremental cost. With careful selection and application of efficient building technologies at the early stages of design, and adjustment of equipment sizing to account for reduced demands, many designs result in energy savings of 30 to 40% with no incremental cost.

1. INTRODUCTION

The Canadian Model National Energy Code for Buildings[1] (MNECB) 1997 contains cost-effective minimum requirements for energy efficiency in new buildings. The MNECB provides maximum thermal transmittance levels for building envelope components per type of energy (oil, natural gas, electricity, wood, propane) for different regions of Canada. These levels were determined using regional construction and heating energy costs in a life cycle cost analysis. As well, the MNECB gives regional U-values for windows, references energy efficient equipment standards, and identifies when heat recovery from ventilation exhaust is required for dwelling units. To allow flexibility in achieving a minimum level of energy efficiency, the code offers three compliance approaches: a Prescriptive Path, a Trade-off Path, and a Performance Path. The Prescriptive Path was used as the reference level in this study.

Two generic office building models, the smaller having a floor area of 4,200 square meters, the larger having a floor area of 24,300 square meters were simulated using the DOE 2.1 E software. The two buildings provided different opportunities to significantly reduce energy use. These buildings were the base cases to which subsequent design modifications to the buildings were compared. This paper discusses the small building results. Full details on both the small and large buildings in various Canadian locations can be found in the project report.[2]

Some basic data on the small building is given below:

Natural gas-fired central boiler heating
Individual zone packaged rooftop DX air cooled (EER=8.9) with economizer cooling
Walls - Brick, batt and rigid insulation
Built-up roof, rigid insulation
Double-glazed windows, grey tint, aluminum frame with thermal break
Solar Heat Gain Coefficient (SHGC) = 0.54
Lighting load = 17.8 W/m^2
Equipment Appliance Load = 7.5 W/m^2
Outdoor air = 0.4 l/s/m^2 floor area

Elevator load 1 × 30 kW
Occupant density = 25 m^2/person
Percent fenestration = 40%
Fenestration U-value (W/m^2-C) = 3.2
Opaque wall U-value (W/m^2-C) = 0.55
Roof U-value (W/m^2-C) = 0.47
No below grade wall insulation
No perimeter floor insulation
Infiltration = 0.25 l/s/m^2 exterior wall

The MNECB provides the energy reference level. A reference construction budget was developed by applying and costing conventional equipment to satisfy the energy reference level. The small building has a packaged rooftop, direct expansion cooling unit with an economizer and a natural gas-fired central boiler. The large building has an individual floor variable-air-volume system with central make up air, a cooling tower and economizer with hydronic radiation heating supplied by a natural gas-fired central boiler.

The list of technologies considered is described in rows S1 to S26 in Table 1 and includes envelope, lighting, smart controls, HVAC, renewable energy and equipment aspects. Each measure was analyzed individually in terms of energy reduction and life cycle cost in comparison to the base case. The results are shown in the red bordered columns of Table 1 as percentage energy reduction and payback in years. Individual measures were then grouped into measure sets and shown as columns SA through SM in Table 1. For example, measure set SA contains individual measure S1, S7 and S10. Energy savings and payback of the measure sets are shown in the last two rows of Table 1 bordered in blue. Note that measure set energy reduction may be different that the simple sum of the savings associated with individual measures. For example, the savings of S1 (3.7%)+S7 (13.2%)+S10 (13%) equal 29.9%, while the simulated energy reduction of SA is 28%. The grouping into measure sets attempts to account for such interactions among measures.

Table 1. Individual measures and measure sets with energy and cost comparisons to the base case.

Measure	**Description**	**Energy Savings**	**Pay-back**	**SA**	**SB**	**SC**	**SD**	**SE**	**SF**	**SG**	**SH**	**SI**	**SJ**	**SK**	**SL**	**SM**
S0	Base case	0.0														
S1	Lighting power density of 11.5 W/m^2	3.7	2.5	*	*	*	*	*	*	*	*	*	*	*	*	*
S2	Perimeter daylighting with light dimming	2.5	2.8			*		*	*		*	*		*	*	*
S3	Occupancy sensors for lighting	3.1	5							*			*			*
S4	Active solar shading	1.1	137													
S5	Add low-emissivity coating to windows	8.0	7.7						*			*			*	
S6	Add low-emissivity coating and argon fill to windows	9.3	9.3													
S7	Add low-emissivity coating, argon fill, and vinyl framed windows	13.2	8.5	*	*	*	*									
S8	Triple-glazed low-e coated, argon filled, vinyl framed windows	21.0	10.4							*			*			*
S9	Increase wall insulation by ÄRSI = 0.9	3.2	6.1				*		*	*		*	*		*	*
S10	Condensing boiler (thermal efficiency = 95%)	13.0	5.6	*	*											
S11	Central air-to air heat recovery 60% annual effectiveness	4.9	6.3		*	*			*	*		*	*		*	*
S12	Solar air preheating system	2.8	28.6													
S13	Install high efficiency motors on supply fans	0.1	8.2													
S14	Variable speed pump on heating loop	0.0	never													
S15	WLHP system with condensing boiler and cooling tower	16.4	0			*										
S16	WLHP system (same as S15) plus thermal storage	16.7	0								*	*	*			
S17	WLHP system with ground source	34.0	14.2				*							*	*	*
S18	Radiant panel heating and cooling with displacement ventilation	18.6	0					*	*	*						
S19	Low flow faucets	0.8	0			*	*	*	*	*	*	*	*	*	*	*
S20	Heat pump water heaters	2.1	8							*			*			*
S21	Solar thermal domestic hot water system	2.0	24.6													*
S22	Photovoltaic electric array	2.2	244													*
S23	Microturbine with heat recovery	-	?													
S24	Low-energy office equipment	1.8	0					*	*	*	*	*	*	*	*	*
S25	Elevator efficiency measures	1.6	0					*	*	*	*	*	*	*	*	*
S26	Increase roof insulation by ÄRSI = 0.9	1.0	10.9							*			*			*
	Energy savings (%)			**28**	**32**	**40**	**46**	**31**	**44**	**56**	**30**	**43**	**53**	**52**	**56**	**65**
	Simple Payback (years)			12	6	0.5	15	0	0	3	0	0	5	6	6	22

Significant energy savings with attractive economic returns were attained. Energy savings over 50% were achieved in five measure sets (SG, SJ, SK, SL, SM) in the small office building and four of these had discounted payback periods between 2.5 and 6 years. The 50% savings relative to the MNECB is considered as the high performance building threshold. Thus, the small office can apply a variety of measure sets to achieve this high performance level.

2. SIMULATION RESULTS

The DOE 2.1 E model was used to simulate the various measures and measure sets. Figure 1 presents the energy usage for the small office building in Ottawa, Canada. Energy usage is disaggregated into eight end-uses to indicate where measure sets impact energy reduction. These simulation results show that applying proven technologies can reduce energy consumption from the reference MNECB level by 25 to 65%.

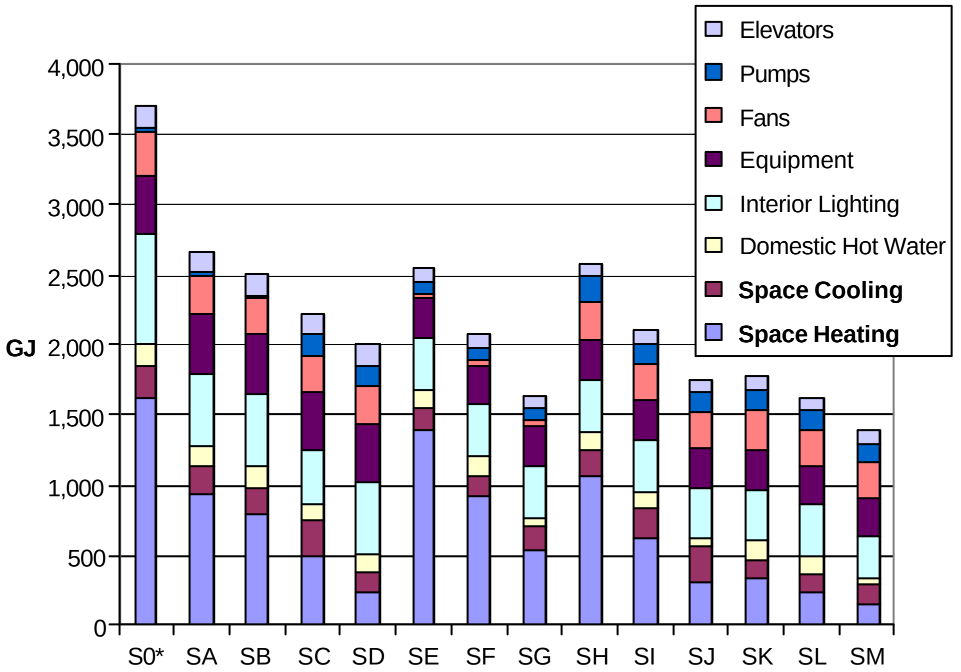

Figure 1. Energy Usage versus Measure Sets for a Small Office Building in Ottawa, Canada.

2.1. Projects

There is a number of recent building projects in Canada that confirm the simulation results presented in this paper. Cost-effectiveness of some of these buildings is even greater than the simulated results due to savings in areas not modeled. A brief summary of some recent projects is available, including both new and retrofit projects.[3]

2.2. The role of energy storage

Measure S15 is a water loop heat pump system and reduces energy by 16% with an immediate payback. When included as part of measure set SC it achieves a 40% energy reduction at a payback of 0.5 years. Measure S16 is S15 with an increased storage capacity of about 30%. The cost is roughly $50 per kW cooling capacity. This gives a 16.7% energy savings with an immediate payback. When

S16 is included in measure sets SH, SI and SJ it can achieve 3, 43 and 53% energy reductions at 0, 0 and 5 years paybacks, respectively. This storage measure (S16) does not have much of an impact on energy reduction, but when grouped with compatible measures in SI and SJ it is effective. Measure S17 is a ground source heat pump system and individually saves 34% energy at a payback of 14.2 years. When included in measure sets SK, SL and SM is reduces energy usage by 52, 56 and 65% at 6, 6 and 22 years paybacks. In actual projects small storages also serve to reduce the capital costs of ground source heat pump systems and can be used as a backup with standby electric or natural gas-fired boilers.[4]

Table 2 gives the heating and cooling requirements for each measure set and the percentage reduction from the base case. It is seen that reduction in heating requirements is generally greater than cooling requirements, in many measures twice as great. Cooling is generally electrically-driven and more expensive per unit of heating or cooling delivered. Cooling storage has always been more popular in Canada and the increase in energy efficient building designs should maintain this preference. For storage systems supplying both heating and cooling, energy efficient designs are better balanced in heating and cooling requirements. A complication is the low temperature needed for latent cooling due to the high summer humidity. Separate latent and sensible cooling need to be considered.

Table 2. Space heating and cooling versus measure sets for Ottawa.

	Measure Sets													
	S0	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM
Space Heating MJ	1,613	935	791	503	227	1,392	922	541	1,055	623	318	344	230	148
Reduction Heating %	-	42%	51%	69%	86%	14%	43%	66%	35%	61%	80%	79%	86%	91%
Space Cooling MJ	235	192	190	244	152	162	149	168	199	208	240	125	131	140
Reduction Cooling %	-	18%	19%	-4%	35%	31%	37%	28%	15%	12%	-2%	47%	44%	41%

2.3. Economic analysis

A life cycle cost analysis was done to evaluate the economic attractiveness of the various measure sets. Included in the analysis is the impact on equipment sizing, usually a saving. The sizing changes can result in a significant cost reduction for the measure sets. In order to realize the payback periods shown, equipment must be sized in accordance with load reductions.

The analysis used projected average annual escalation rates of commercial sector electricity and fuel input prices supplied by Natural Resources Canada. A real discount rate of 10% was used to convert all future expenses and savings into current dollars. This allowed calculation of the net present value of the savings and costs. Also calculated were the discounted payback period and the simple payback period. Each of these quantities was calculated over a life cycle analysis period of 20 years, the assumed life of the mechanical system. Maintenance costs were considered to remain constant in real terms.

There are several measure sets with immediate payback; SE, SF, SH, SI. Measures SE and SF are radiant panel systems with displacement ventilation. These systems have a similar cost to the base case, but they offer energy savings. Furthermore, significant sizing reductions, mainly in the cooling tower and chiller sizes, offset the incremental cost of the envelope and heat recovery measures. Because the elevator efficiency measures offer a net savings in capital cost, the capital cost of the other measures is further offset.

Measures SH and SI are hydronic water loop systems with water to air heat pumps. These systems also offer energy savings over the base case, but have an incremental cost over the base case. Other than the system type, these measures are the same as SE and SF, so either payback period is immediate for similar reasons.

A microturbine with heat recovery was one of the measures modeled. It has not been included in any of the measure sets. A more comprehensive analysis was done that took account of the different treatments of electricity and thermal energy and the effects of varying electricity and natural gas prices. This analysis is available in a separate report.[5]

2.4. Conclusions

The performance and economics of the measure sets applied to the small office building have demonstrated that significant energy reductions with attractive economic returns, are possible through careful selection and application of individual measures. Energy savings over 50% were achieved in five measure sets (SG, SJ, SK, SL, SM) in the small office building and four of these had discounted payback periods between 2.5 and 6 years. The 50% savings relative to the MNECB is considered as the high performance threshold. Thus, the small office can apply a variety of measure sets to achieve this high performance level.

It is possible to achieve 25% reductions compared to the base case building with no incremental cost (SE, SF, SH, SI). With careful selection and application of efficient building technologies at the early stages of design, and adjustment of equipment sizing to account for reduced demands, designs can result in energy savings of 30 to 40% with no incremental cost.

To successfully apply energy efficient designs, it is helpful to use an integrated design process involving energy simulation specialists to facilitate and support the architect and the mechanical and electrical engineers. The energy specialist works as an integral part of the design team to ensure that measures are properly planned and implemented and that their impacts are accounted for in HVAC equipment sizing. This process has now been applied in numerous designs where the energy reductions have confirmed simulation results.[3]

The existing stock of buildings represents a much larger opportunity than new buildings for energy savings. Many of the measures and results presented here would be applicable to existing buildings when major system upgrades, replacements or building retrofits are undertaken. There may even be cases where pre-mature retrofits could be justified on a life cycle cost basis.

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References

1. Canadian Model National Energy Code for Buildings 1997, National Research Council of Canada, Ottawa. http://www.nationalcodes.ca/mnecb/index_e.shtml#
2. Development Of Generic Office Building Energy Measures, 2002. ftp://ftp.tech-env.com/pub/ultraLow/UltraLowELM.pdf
3. PWGSC Energy Efficient Buildings Tour, March 2003. ftp://ftp.tech-env.com/pub/ultraLow/tour.pdf
4. Design Options For Ground Source Heat Pump Systems, 2002. ftp://ftp.tech-env.com/pub/ultraLow/gshp.pdf
5. Microturbine Economics, 2002. ftp://ftp.tech-env.com/pub/ultraLow/micro.pdf