Energy Savings by Retrofitting Multi-Unit Residential Buildings: Case Studies

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ABSTRACT

There are thousands of multi-unit residential buildings in and around Toronto, Canada. Many of these buildings were constructed during the 1960's and 1970's when energy was relatively inexpensive and therefore energy efficiency was not a major concern. Although new, low-energy buildings can gradually reduce the average energy intensity of this sector, replacement of the existing building stock by new construction is occurring at a very slow rate. With this building form accounting for approximately 40% of the total greenhouse gas emissions in Toronto, efforts must be taken to retrofit this existing stock. As energy prices increase and occupants demand more comfortable interior environments, many building owners recognize the need to undertake energy retrofits. However, costly retrofit projects tend to be avoided because the returns may initially seem unattractive. The four case studies presented here reveal that when the interaction between various building systems is understood, retrofit strategies can be carefully planned and implemented so that the projects are financially viable. This paper concludes with a number of lessons learned that may encourage building owners to undertake comprehensive energy retrofits. These lessons summarize ways in which owners can maximize their return on investment, while reducing their operating costs and the burden on the environment associated with energy use.

KEY WORDS multi-unit residential building, retrofit, energy savings, carbon emissions

INTRODUCTION

With increasing urbanization (Statistics Canada 2008) comes a greater need for resource-efficient higher density housing. Second only to New York City, Toronto has the greatest number of high rise buildings in North America (Kesik and Saleff 2009), housing approximately one third of the population of the City. A large proportion of these buildings were constructed in the 1960's and 1970's (McClelland and Stewart 2008), a time when energy prices were low. Thus, energy-efficiency was not a primary design consideration. The energy use associated with operating these buildings accounts for about 40% of the greenhouse gas emissions in the City (City of Toronto 2008). To reduce the environmental impact of this sector, either the building stock needs to be replaced or existing buildings need to be energy retrofitted. The replacement of the existing building stock is currently only 1-2% annually (ECOFYS 2004), so the priority must be to improve the energy efficiency of these buildings. Rising operating expenses, caused in part by increasing energy prices, have prompted building owners to examine ways of reducing energy use. However, the industry's focus on the simple payback period for a retrofit measure does not promote comprehensive retrofit strategies. Accordingly, owners may dismiss larger, more expensive projects because of a long payback period and miss opportunities for greater energy savings. To encourage

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energy retrofits that go beyond the "lowest hanging fruit," organizations like the Toronto Atmospheric Fund (TAF), whose mandate is to improve air quality in the City, are providing financial and resource support for building owners.

This paper describes four buildings that have undergone energy retrofits. Each case study includes a description of:

- the retrofit motivation;
- the work completed;
- the pre- and post-retrofit energy use;
- a financial analysis of the retrofit given the resulting energy cost savings.

In an effort to demonstrate that there are opportunities regardless of the legal form of ownership, the four cases include both free-hold condominium properties where suites are owned by individuals, and rental properties, where a single building owner leases to tenants. The properties vary in size between 32 and 210 units and range in date of construction from the 1930's to the 2000's. Each project achieved energy savings using different strategies and all of the building owners and managers involved considered their retrofit a success.

METHODOLOGY AND ASSUMPTIONS

Interviews were conducted with the building owners and managers to gather qualitative information about each retrofit process such as decision-making criteria, construction challenges and lessons learned. Building owners and managers also provided construction costs and pre and post-retrofit energy consumption data for the analysis of each project. The available energy data varied from building to building and details of what data were used for each analysis are provided below.

A software program called Metrix 4 was used to weather normalize the pre-retrofit natural gas use to generate a "baseline" annual usage for each building. Then the baseline was adjusted to reflect the post-retrofit weather data allowing for a direct comparison of the pre and post-retrofit natural gas use. Pre and post-retrofit electricity use was analyzed for Building 4 only. Energy savings resulting from each retrofit project were determined by comparing the weather-normalized pre and post-retrofit energy use. Then energy cost savings were determined using the historical rates shown in Figure 1. Similarly, water cost savings were determined for those buildings that completed water fixture retrofits. Buildings 1, 2 and 4 are located in Toronto and Building 3 is located in Brampton, a suburb of Toronto.

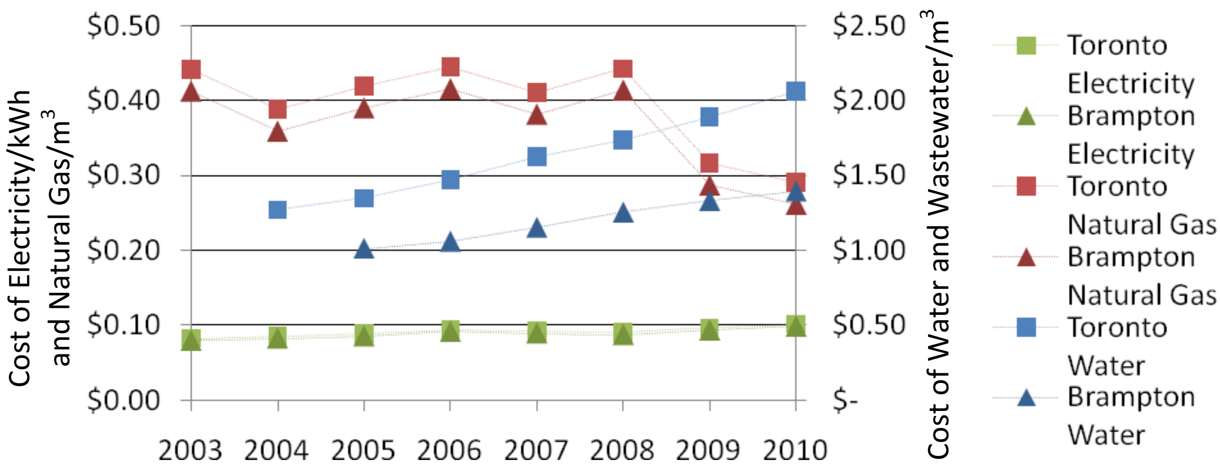

FIGURE 1: Historical Utility Rates

Sources for Figure 1: City of Toronto 2010; Energy Shop 2011a; Energy Shop 2011b; Hydro One Brampton 2011; Ontario Energy Board 2010a; Ontario Energy Board 2010b; Region of Peel 2011

The financial analysis of each retrofit project was assessed over a 10-year performance period. In reality, many of the retrofits will last longer than this performance period, including: roof replacement (25 years); window replacement (30 years); and boiler replacement (25 years) (Genge and Rousseau 1996). Thus, cost savings associated with these investments will continue to accrue beyond the performance period.

Where possible, the actual historical energy prices from Figure 1 were used to determine the post-retrofit energy savings. However, the performance period for all of the buildings extends beyond the time of writing so future energy costs had to be estimated. With an average inflation rate of over 2% during the last decade (Bank of Canada 2011), water and electricity rates prices have been increasing at rates over inflation:

- Electricity prices have increased by more than 3.5% per annum since 2003 (Ontario Energy Board 2010a)
- Water prices in Toronto have increased by 6.6% per annum since 2005 and in Brampton by 2.5% annually (City of Toronto 2010; Region of Peel 2011)

Natural Gas prices, on the other hand, have declined on average by 9% annually since 2003 (Ontario Energy Board 2010b).

Using the average energy and water consumption of multi-unit residential buildings in Ontario (Natural Resources Canada 2010) along with the 2010 utility prices from Figure 1 and the average annual escalation rates provided above, Figure 2 shows the annual utility cost per square metre of an average multi-unit residential building for a ten-year period. Even if the downward natural gas price trend continues, the average utility cost will likely increase over time.

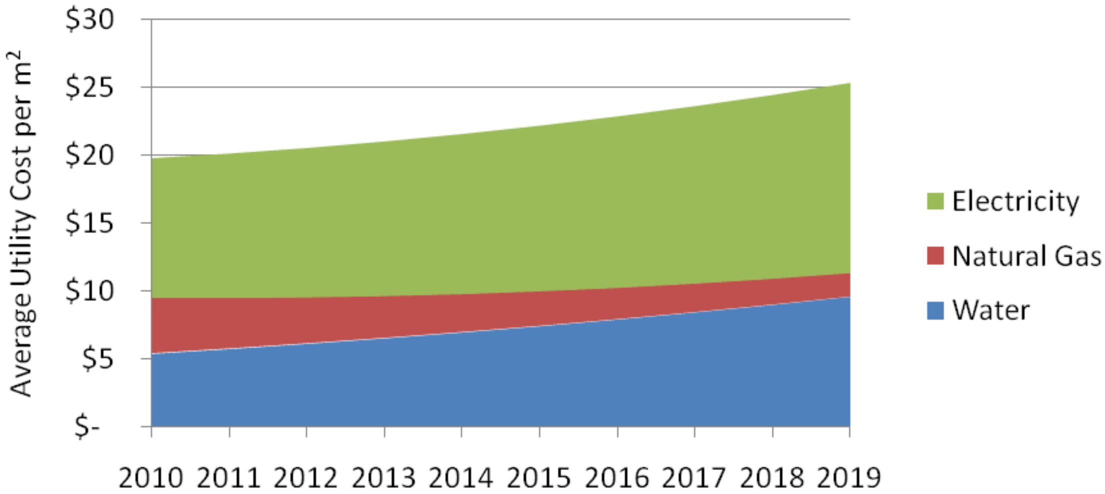

FIGURE 2: Average Utility Cost in Ontario Multi-Unit Residential Buildings

Given the overall utility cost increase in Figure 2 as well as the uncertainty of future energy prices and inflation, two scenarios were used to estimate future energy savings:

- **Scenario 1:** 2010 utility costs remain constant for the remainder of the performance period;
- **Scenario 2:** 2010 utility costs are adjusted by the average annual increase over inflation for the past decade. (+1.5% for electricity, +4.6% for water in Toronto, +0.5% for water in Brampton and -11% for natural gas).

The financial performance indicators used for this analysis include: simple payback, internal rate of return (IRR), and net present value (NPV). It is important to note that these indicators only capture operational cost savings and do not include the effects of increased property value or increased rental income as a result of the improvements. The IRR and NPV calculations include ten years of utility cost savings following the completion of the retrofit project or, for multi-year projects, the last year of the retrofit program. Two discount rate scenarios were considered for the NPV calculation:

- 1% which reflects the return over inflation of a 10-year Government of Canada bond (an example of a low-risk investment vehicle that might be used for condominium reserve funds)
- 4% which reflects the return over inflation of a typical retrofit loan (an example of a higher-risk investment vehicle that might be an alternative investment for a building owner of a rental property)

As a higher discount rate results in a lower NPV, the 4% discount rate was used to more conservatively estimate the NPV.

In addition to examining resource use and financial performance for each project, the avoided CO_2 emissions were estimated based on the factors shown in Table 1.

TABLE 1: CO_2 Emission factors for various utilities in Ontario

Emission Type	Electricity (kWh)	Natural Gas (m^3)	Water (m^3) *
Carbon Dioxide (g CO_2/unit)	170	1879	
Methane (g CH_4/ unit)	0.01	0.037	
Nitrous Oxide (g N_2O/ unit)	0.003	0.035	
Sulfur Oxide (g SO_2/ unit)	0.568	0.0101	
Nitrogen Oxides (g NO_x/ unit)	0.263	2.5305	
Particulate Matter 2.5 (g $PM_{2.5}$/ unit)	0.01	-	
Particulate Matter 10 (g PM_{10}/unit)	0.027	0.0314	
Volatile Organic Compounds (g VOC/ unit)	0.005	0.0909	
Mercury (g Hg/ unit)	0.00000174	-	
Nuclear Waste (Uranium) (g U waste/ unit)	0.00899	-	
Carbon Dioxide Equivalents (kg CO_2e/ unit)	**0.17**	**1.89**	**0.188**

Sources for Table 1: Loop Initiatives Inc. 2011; Racoviceanu and Karney 2010

** Based on an analysis of Toronto (Includes water treatment and distribution)*

CASE STUDY 1 (RENTAL)


FIGURE 3: Building 1

Constructed in the 1930's, Building 1 shown in Figure 3 is the oldest building in the case study series and with 32 units, it is also the smallest. Since minimal work had been done since the date of the original building construction, there was great potential for the owners to increase the value of their investment as well as to improve the comfort of their tenants. By mitigating operational inefficiencies and equipment breakdowns, they were able to reduce high operating expenses. Further, by improving the aesthetics of the building, they were also able to increase their rental income. One such operational inefficiency was the space heating control which was exacerbated by a poor building envelope. Without insulation in the attic space, it was difficult to maintain thermal comfort using the only thermostat in the building. For example, during the heating season, to ensure the top floor suites adjacent to the attic space remained comfortable at about 22°C (72^{o}F), the remainder of the building was subjected to interior temperatures as high as 27°C (81^{o}F). This resulted in tenants on the lower floors opening their windows to achieve a comfortable temperature while effectively dumping the heated air outside.

Retrofit Strategy

The owners chose to address the space heating issues quickly so that they could reduce maintenance costs and benefit from energy savings. Due to the age of the building, they were also able to easily identify a number of other energy conservation measures. The projects for Building 1 included:

- replacement of the original, air-leaky, single-glazed windows with new insulated glazing units with a low-e coating;
- replacement of the boiler controls and steam traps;

- installation of attic insulation of which there was none (increase the thermal resistance to approximately RSI 7.8 m^2K/W (R-44 $hr \cdot ft^2 \cdot °F/BTU$));
- replacement of the original 25 L/flush (6.6 gal/flush) toilets with 6 L/flush (1.6 gal/flush) toilets;
- replacement of all faucets and showerheads with low-flow shower heads (7.5 Lpm, 2 gpm) and low-flow aerators;
- replacement of the common area lighting (each 192W F40-T12 fluorescent bulb was replaced by two 13W compact fluorescents).

Project Costs

The required capital funds were available so the owners did not have to incur borrowing costs or wait for rental income to accrue before beginning the retrofit project. The schedule and cost of work for each part of the retrofit is shown in Table 2.

TABLE 2: Details of Building 1 Retrofit Project Costs

	Retrofit Measure	**Completed**	**Cost**
Natural Gas	Replace Boiler Controls	Apr 2003	C$7,000
	Replace Windows	Jul 2003	C$55,000
	Install Attic Insulation	Jun 2004	C$3,000
Electricity	Replace Common Area Lighting	Feb 2006	C$3,200
Water	Replace Toilet/Showerhead, Add Aerators	Nov 2006	C$10,000
	Incentive for Toilet Retrofit*		**C($4,000)**
	Total Project Cost		**C$74,200**

**The City of Toronto WaterSaver Program provided a rebate of C$125 per toilet which offset some of the capital cost of the water reduction retrofits.*

Project Performance

Figure 4 shows the natural gas and water consumption for Building 1. One year of pre-retrofit data was available for each fuel source to generate baseline usage: 2002 and 2004 for natural gas and water, respectively. With only annual totals provided, the natural gas data could not be weather normalized beyond a crude estimation based on total annual heating degree days as shown by the Projected Natural Gas in Figure 4.

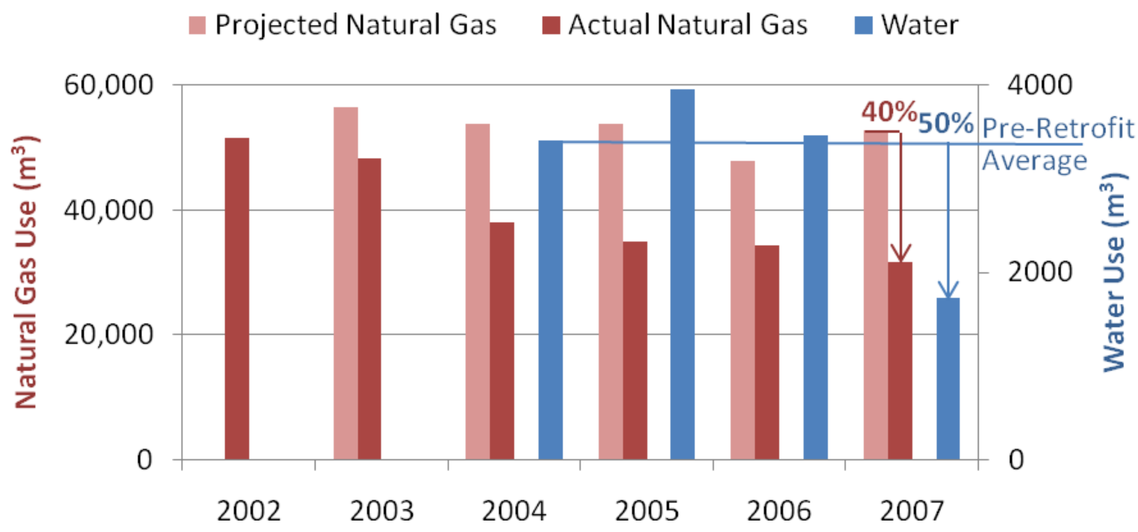

FIGURE 4: Building 1 Natural Gas and Water Use

By improving window air tightness, replacing the boiler controls and installing attic insulation, natural gas consumption was reduced by approximately 40% based on the projected natural gas consumption as shown in Figure 4. In addition to energy savings, the white, vinyl window frames enhanced the appearance of the suites and the new windows contributed to quieter, more comfortable suites. The low-flow toilets, showerheads, and faucets resulted in a water use reduction of 50%. As electricity data were unavailable, savings due to the common area lighting retrofit was estimated at 86% using the lighting specifications, as shown in Table 3.

TABLE 3: Lighting Specifications

	Number of Fixtures	Power (W)	Annual Operation (hrs)*	Annual Consumption (kWh)
Pre-Retrofit	20	192	8760	33,500
Post-Retrofit	40	13		4,500

**Common area lighting is on 24 hours a day*

Considered together, all of the measures resulted in an estimated annual reduction of approximately 46 Tonnes (51 Tons) of CO_2e.

Financial Analysis

Table 4 shows the simple payback, IRR and NPV for the first ten years following completion of the majority of the projects in 2004.

TABLE 4: Financial Analysis Measures for Building 1

	Scenario 1			Scenario 2		
Utility Affected	Simple Payback	IRR over 10 yrs	$NPV_{4\%}$ in 2010	Simple Payback	IRR over 10 yrs	$NPV_{4\%}$ in 2010
Natural Gas	7.8 yrs	3%	C($2,500)	8.9 yrs	3%	C($5,500)

Water	2.1 yrs	51%	C$25,000	2.1 yrs	52%	C$28,000
Electricity*	1.4 yrs	294%	C$27,000	1.4 yrs	294%	C$27,000
Total Project**	**6.5 yrs**	**11%**	**C$39,000**	**6.5 yrs**	**10%**	**C$27,000**

**from common area lighting only*

***80% of the retrofit investment occurred in 2003 with the remaining 20% spread between 2004 and 2006. As such the performance period for the Total Project Financial Indicators was considered to be 2004-2013, but total project cash flows included the 2004 and 2006 investments.*

Low natural gas prices make the envelope improvements and boiler control retrofits seem less attractive than the other improvements but the owners decided to implement these retrofits because they solved tenant thermal comfort issues. Overall, this project is still financially attractive even if natural gas prices continue to decline.

Project Conclusions

Due to the age of the building, there were clearly a number of financially attractive retrofit opportunities. By blending short and longer term payback projects, the owners were able to improve tenant comfort (according to feedback from the owner) as well as generate long-term energy and water cost savings. Also by evaluating the entire building at the outset, they were able to identify complementary projects such as the envelope improvements and the boiler controls. Finally, the more attractive and comfortable suites have allowed the owners to charge a higher rental rate for new tenants.

CASE STUDY 2 (RENTAL)

The most recent retrofit project in this case study series was completed in 2010. It is a 10-storey, 128-unit apartment building constructed in 1970, shown in Figure 5. Similar to the owners of Building 1, this owner also saw the potential for increasing the value of his investment by reducing operating expenses.

FIGURE 5: Building 2

Retrofit Strategy

The strategy to achieve a more energy efficient building was to first reduce the energy demand and then to supply part of the reduced demand with a renewable energy system. Demand reduction was accomplished through the following building envelope improvements:

- Replacement of the balcony doors and the original single-glazed window units. Windows were replaced with higher performance argon-filled, double-glazed units with a low-e coating and an area-weighted USI value of 2.3 W/m^2K (U-0.4 $BTU/hr·ft^2·°F$) (Prohaska 2011).
- Replacement of the original roof, which had no insulation. The owner took this opportunity to include about 75 mm (3 in.) of polyisocyanurate rigid insulating board improving the thermal resistance of the assembly by approximately RSI-3.8 m^2K/W (R-21 $hr·ft^2·°F/BTU$).

Next, in order to supply heat for the domestic hot water (DHW) system, an evacuated tube solar collector was installed on the roof. The system included 84 evacuated tube collectors assembled in a gravity drainback system with an 11,000L (2,900gal) solar hot water tank.

Project Costs

The schedule of work and costs for the project are shown in Table 5.

TABLE 5: Details of Building 2 Retrofit Project Costs

	Retrofit Measure	Completed	Cost
Natural Gas	Add Roof Insulation	Feb-Mar 2010	C$64,000
	Replace Window and Balcony Door	May-Jul 2010	C$394,000
	Install Solar Hot Water System	Jan-July 2010	C$330,000
	Incentive for Solar Hot Water System		*C($220,000)*
	Total Project		**C$568,000**

As the original roof was due for replacement, only the incremental cost of the added insulation was included in the financial analysis. The SHW system qualified for incentives from the Federal government's EcoEnergy program and the Province's Ontario Solar Thermal Heating Incentive program totalling approximately C$220,000.

Project Performance

The building envelope improvements, particularly the window and door replacements, made it easier to maintain thermal control in the units. Through reduced air leakage and improved thermal resistance, tenants are now more comfortable and natural gas use has been reduced. Three years of natural gas data (2007-2010) were used to establish the baseline energy use and one year of actual performance data (2010-2011) was used to determine post-retrofit performance.

At the project outset, the estimated annual reduction in natural gas use was 28%. This was based on an estimate from the building owner of the effect of window and balcony door retrofits he had seen on other buildings as well as a RETScreen analysis of the SHW system energy production by the project engineer. Actual natural gas use from the first year of operation shows a savings of 21% from the pre-retrofit baseline, as shown in Figure 6. The owner is currently working with the SHW system installer to improve the performance of this equipment. In addition to reducing energy costs, the retrofit measures also contributed to an estimated annual reduction in greenhouse gas emissions of about 160 Tonnes (176 Tons) of CO_2e.

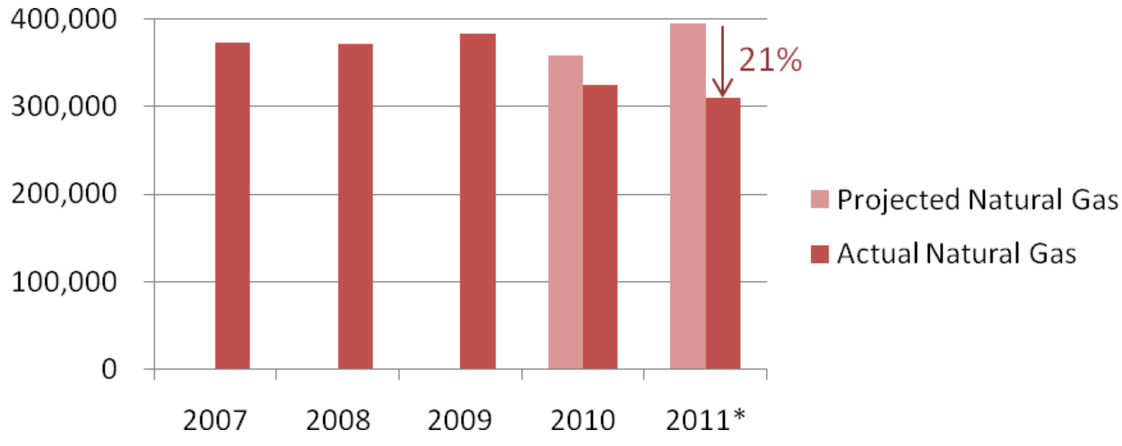

FIGURE 6: Building 2 Natural Gas Use

**Data estimated from July 2011 to December 2011 is based on usage from July 2010 to December 2010*

Financial Analysis

Table 6 shows the simple payback, IRR and NPV for the first ten years following the retrofit projects in 2010.

TABLE 6: Financial Analysis Measures for Building 2

		Scenario 1		Scenario 2
Utility Affected	**Simple Payback**	**IRR over 10 years**	**$NPV_{4\%}$ in 2010**	**$NPV_{4\%}$ in 2010**
Natural Gas	17 years	(8%)	C($288,000)	C($407,000)

The financial indicators for this case are the least compelling in the series but it is important to note that none of the financial analyses include increased property value, increased rents or decreased vacancy rates. After one year of performance the owner feels that this has been a sound investment based on his estimate of the increased property value and his increased rental revenues. He hopes to improve the performance of the SHW system to improve operational cost savings as well.

Project Conclusions

By considering the building as a whole system, the owner is attempting to maximize the return on investment by first reducing energy demand through envelope improvements and then by focusing on supplying energy through renewable energy sources. The window and balcony door installations have improved the thermal resistance and air-tightness of the building envelope which, in turn, has reduced the space heating load provided by a system of hydronic radiators. Further, there is the potential to connect this radiator system to the solar hot water installation in the future. Thus, reliance on boilers fuelled by natural gas could be reduced even further.

CASE STUDY 3 (FREEHOLD CONDOMINIUM)

Constructed in 1974, Building 3 is a 210-unit condominium building, shown in Figure 7, which is located in Brampton, Ontario. Prompted by excessive energy bills and the need to reduce operating costs, the building manager began looking into retrofit strategies. Priorities for the retrofit work included minimal disruption to the suite owners and use of reserve funds for the project in order to avoid borrowing costs. Condo maintenance and operating fees for this building were the lowest in the area and the board wanted to ensure these low fees were maintained.

FIGURE 7: Building 3

Retrofit Strategy

Through phasing, the retrofit was paid entirely from the reserve funds and energy cost savings. Generally, the shortest payback projects were tackled first so that early returns could be used to fund subsequent projects. The retrofit work included:

- Replacement of two 45% efficient DHW boilers (1.05M and 0.77M BTU) with two 1.5M BTU 88% efficient boilers. The new boilers were purposely oversized so that when a new Air Handling Unit (AHU) was installed later that year, the DHW was used to pre-heat incoming air though a heat exchanger thereby eliminating the need for a separate AHU burner.
- Replacement of the five existing 55% efficient 1.5M BTU space heating boilers with two 85% efficient 2.0M BTU boilers.
- Replacement of the AHU motors with variable frequency drives to reduce electricity cost and connection of the DHW supply to the AHU.
- Replacement of the 13L/flush (3.4 gal/flush) toilets with 6L/flush (1.6 gal/flush) toilets.
- Replacement of the chiller (following a provincial directive that prohibited the use of R11 gas) with a higher efficiency model.

Project Costs

Table 7 outlines the work completed, schedule, source of funding and costs.

TABLE 7: Details of Building 3 Retrofit Project Costs

	Retrofit Measure	Completed	Source of Funds	Cost
Natural Gas	Replace Boilers	Mar 2008	Reserve Fund	C$225,000
	Incentive for Boiler Replacement		*Natural Gas Supplier*	*C($15,000)*
Natural Gas & Electricity	AHU Retrofit	Nov-Dec 2008	Reserve Fund	C$98,000
Electricity	Replace Chiller	April 2010	Reserve Fund	C$290,000
	Chiller Upgrade			C$54,000
Water	Replace Toilets	Oct-Dec 2009	Op. Surplus from Boiler Savings	C$37,000
	Incentive for Toilet Replacement		*Regional Government*	*C($11,000)*
	Total Project Cost			**C$678,000**

Project costs were reduced by installing all of the boilers at once. The installation cost of one C$30,000 boiler is about C$25,000, but by installing all of the boilers at the same time, the installation cost per boiler was reduced to about C$12,000. Also the chiller was installed before July 1st, 2010, to avoid a sales tax increase, which resulted in a savings to the owners of C$16,000.

Project Performance

Given the staggered retrofit work and energy and water use data from 2007, there was one baseline year for natural gas use (2007) and two for water use (2007-2008). The retrofit measures resulted in an overall natural gas savings of 28% and a reduction in water consumption by 29% as shown in Figure 8.

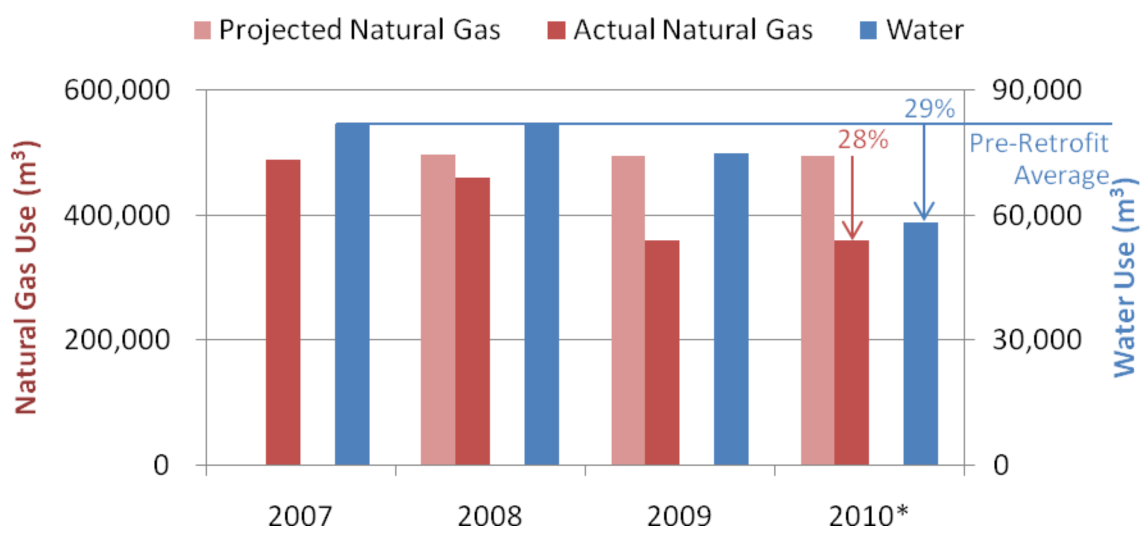

FIGURE 8: Building 3 Natural Gas and Water Use

**Actual water use. Estimated natural gas use based on actual post-retrofit 2009 use and heating degree days in 2010.*

Given the limited electricity data available, it was not possible to determine the exact reduction associated with the AHU refurbishment. However, using information about the pre and post-retrofit chillers, shown in Table 8, an estimate of the chiller-related electricity savings was made. As the mandatory chiller retrofit would have reduced energy consumption, only the savings associated with an upgrade from a constant speed drive (CSD) to a variable speed drive (VSD) was used to determine an annual electricity savings of 83,000kWh.

TABLE 8: Chiller Performance Specifications

Chiller	Size (tonne)	Capacity (kW/tonne)	Annual Operation (hrs)	Annual Consumption (kWh)
Pre-retrofit	206	0.9	1592	295,000
New (CSD)	260	0.55		228,000
New (VSD)	260	0.35		145,000

When combined, all of the retrofit measures together save a total of 277 Tonnes (305 Tons) of CO_2e annually.

Financial Analysis

As the chiller replacement was necessary to comply with the new R11 refrigerant gas guidelines, only the incremental cost and energy savings between a standard CSD and the higher efficiency VSD were considered in the financial analysis. The AHU cost was left out of the financial analysis as an estimate of electricity savings could not be made. Table 9 shows the simple payback, IRR and NPV for the first ten years following completion of the retrofits in 2010.

TABLE 9: Financial Analysis Measures for Building 3

	Scenario 1			Scenario 2		
Utility Affected	**Simple Payback**	**IRR over 10 yrs**	**$NPV_{4\%}$ in 2010**	**Simple Payback**	**IRR over 10 yrs**	**$NPV_{4\%}$ in 2010**
Natural Gas	5.3 yrs	15%	C$107,000	6.9 yrs	6%	C$10,000
Water	0.5 yrs	207%	C$285,000	0.5 yrs	208%	C$290,000
Electricity*	5.7 yrs	10%	C$15,000	5.5 yrs	12%	C$19,000
Total Project**	**3.7 yrs**	**26%**	**C$377,000**	**4.0 yrs**	**20%**	**C$267,000**

**from chiller only*

***Financial indicators for the Total Project were determine by shifting all expenses (gas, water and electricity-related) to 2009 and including savings generated over the following 10 year period (2010-2019)*

According to the building manager, the financial savings achieved were better than anticipated. A proposed condo fee increase of 3-4%, due to a change to the local sales tax, was reduced to a 2% increase because of the operating surplus. This operating surplus was also used to fund aesthetic improvements to the building such as fences and landscaping.

Project Conclusions

When completing a series of retrofit projects, it is important to plan ahead and make provisions for future projects both in terms of equipment compatibility and finances. For example, boilers were over-sized in order to eliminate the need for a burner in the AHU and projects were scheduled such that early energy cost savings were used to fund later projects. The building manager stressed the importance of proactive communication with residents. To move forward with this type of investment in a freehold building, the positive impact that retrofit projects can have on future operating costs must be demonstrated to the suite owners. Equally important is communicating the savings associated with the completion of the projects to the suite owners.

CASE STUDY 4 (FREEHOLD CONDOMINIUM)


FIGURE 9: Building 4

First occupied in 2001, Building 4 is a 12 storey condominium building. Shown in Figure 9, it has 116 suites and it is the newest building in the case study series. The Chair of the condominium board began the energy retrofit process by investigating the possibility of a solar energy installation for the building. He discovered that there were many cost-effective demand reduction measures that could be undertaken to reduce utility costs before considering the installation of a solar energy system. By examination of the current operating conditions at Building 4 and extensive research and consultation with energy management firms, the condominium board put together a three-year energy retrofit plan. Similar to Building 3, the board did not want to incur any borrowing costs so careful project scheduling was important.

Retrofit Strategy

The retrofit plan included some equipment upgrades which were strategically implemented to make maximum use of existing equipment. For example, implementation of a lead-lag boiler system meant that only one new boiler was purchased. This new high-efficiency boiler became the primary boiler while the older, existing boilers were only used when the primary boiler could not handle the entire load. The list, below, outlines the complete retrofit plan in chronological order:

- Replacement of T12 parking garage lighting with T8 lighting and electronic ballasts;
- Linking parking garage exhaust fan control to CO monitors to ensure fresh air is supplied only when needed;
- Replacement of one of two atmospheric DHW boilers with a high-efficiency condensing boiler and new controls;
- Installation of a variable frequency drive (VFD) on the make-up air unit (MAU);
- Replacement of one of four atmospheric fan coil boilers with a high efficiency condensing boiler providing half the total capacity and new controls;
- Replacement of one of two atmospheric domestic prime boilers (for heating the common areas, pool and slab) with a high efficiency condensing boiler and new controls.

Project Costs

The Board completed the lowest capital cost projects first so they could start slowly, thereby building credibility as cost savings were realized. This allowed them to later move forward with the more expensive projects such as the boiler replacements. The project costs and schedule are shown in Table 10.

TABLE 10: Details of Building 4 Retrofit Project Costs

	Retrofit Measure	**Completed**	**Cost**
Electricity	Parking garage lighting	Sept 2005	C$11,000
	CO sensor control of parking garage exhaust	Sept 2005	C$10,000
	Installation of VFD on MAU	Oct 2005	C$10,000
Natural Gas	DHW Boiler replacement	Sept 2005	C$44,000
	Replacement of atmospheric fan coil boiler	Oct 2006	C$52,000
	Replacement of atmospheric prime boiler	Oct 2007	C$37,000
	Incentive for boiler replacement from natural gas supplier		*C($18,000)*
	Total Project Cost		**C$146,000**

Project Performance

Figure 10 shows the natural gas and electricity consumption for three baseline years (2003-2005) and four years of performance (2006-2009).

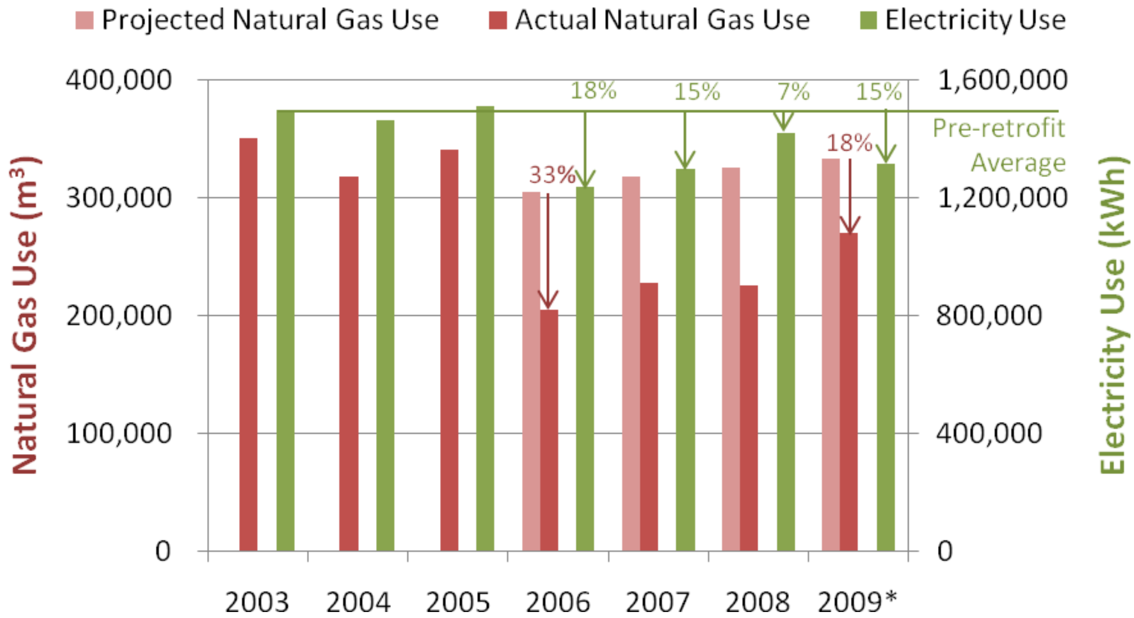

FIGURE 10: Building 4 Energy Use

**Estimate of December 2009 use based on 2008 usage and 2009 heating degree days*

When first installed, the VFD allowed the MAU to reduce airflows to 50% and 60% of capacity during off-peak hours and peak hours, respectively. This schedule was in accordance with the minimum setting recommended by the MAU manufacturer but the frequent on/off cycling during periods of moderate heating demand created premature maintenance issues for the relatively new equipment. To correct the cycling-induced maintenance problems, the system was operated at 80% of its capacity in 2009 resulting in eroded natural gas savings as shown in Figure 10. At the time of writing, the board was investigating options to rectify the problem. Fortunately, the savings achieved in the first few years of operation were enough to cover the cost of the investment.

As shown in Figure 11, a comparison of cooling degree days and pre-retrofit electricity use does not illustrate a strong correlation. Thus, the variation in electricity use from year to year shown in Figure 10 is likely associated with other building operations. The building manager has attributed part of the lower electricity use in 2006 to shutdown of the pool for maintenance and higher electricity use in 2008 due to a sensor issue with the ramp heater which left it on for most of the year. Therefore, 2007 and 2009 are assumed to be more representative of the estimated electricity reduction achieved by the three electricity-related retrofit measures shown in Table 10.

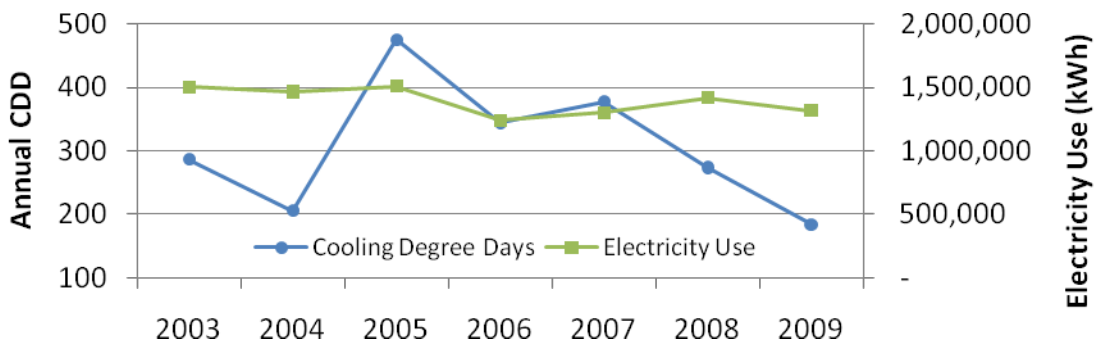

FIGURE 11: Cooling Degree Days and Electricity Use

Overall the natural gas and electricity savings resulted in an annual reduction of 153 Tonnes (168 Tons) of CO_2e.

Financial Analysis

Table 11 shows the simple payback, IRR and NPV for the performance period. The VFD installation on the MAU affects both natural gas and electricity consumption due to the reduction in fan speed and chiller use. However, given the variable operating speeds, and since the VFD was not sub-metered, it was not possible to isolate the electricity savings attributed to the VFD for the fan motor and chiller.

TABLE 11: Financial Analysis Measures for Building 4

	Scenario 1			Scenario 2		
Utility Affected	**Simple Payback**	**IRR over 10 yrs**	**$NPV_{4\%}$ in 2010**	**Simple Payback**	**IRR over 10 yrs**	**$NPV_{4\%}$ in 2010**
Natural Gas	2.8 yrs*	34%	C$117,000	2.8 yrs*	33%	C$104,000
Electricity	1.3 yrs	64%	C$153,000	1.3 yrs	64%	C$155,000
Total Project*	**2.4 yrs**	**45%**	**C$270,000**	**2.4 yrs**	**45%**	**C$260,000**

**As gas-related expenditures occurred over 3 years, all expenses were brought back to 2005 and the performance period extends from 2006 to 2015.*

Even with the maintenance difficulties induced by the VFD, the project returns are still excellent. All of the retrofit project costs were recouped from energy savings within three years after project completion.

Project Conclusions

This multi-faceted project combined both high capital cost projects with lower cost ones. This combination generated an acceptable overall payback period with impressive returns. Use of a lead-lag boiler strategy has resulted in new high efficiency equipment that provides the majority of the heating needs. By adopting this strategy, the entire heating capacity did not have to be replaced all at once. The installation of CO monitors in the garage area drastically reduced fan operating times. Such measures underscore the need to first understand the existing operating conditions of a building and then, where possible, change the operation to save energy, rather than applying a blanket approach to replacing all of the existing equipment with higher efficiency models. Further, as demonstrated in this building, by carefully analyzing the existing conditions, and by being strategic about equipment replacement, short paybacks and long term energy savings can be realized. With an overall project payback of just over 2 years, Building 4 is now generating energy savings of over C$35,000 each year. Given that the building was constructed in 2001, this case demonstrates that even recently constructed buildings may represent opportunities for energy and greenhouse gas savings.

SUMMARY OF RETROFIT IMPACTS

In addition to reducing utility cost and improving tenant comfort, the projects profiled in the case studies above also reduce the greenhouse gas emissions associated with building operation. Based on the capital cost and a conservative estimate of the component life cycle, a cost per tonne of CO_2 avoided has been established in Table 12.

TABLE 12: Cost of Retrofit Projects as Carbon Abatement Measures

	Bldg	Retrofit Project	Capital Cost	tCO_2/yr avoided	Life (yrs)	Cost/tCO_2 avoided
Natural Gas	1	Boiler ctrl/attic	C$ 65,000	41	20	C$ 79
	2	Roof insulation	C$ 64,000	4	20	C$ 854
	2	Window/door replacement	C$394,000	110	20	C$ 178
	2	Solar hot water system	C$110,000	45	20	C$ 123
	3	Boiler replacement	C$210,000	259	20	C$ 41
	4	Boiler replacement	C$115,000	120	20	C$ 48
Electricity	1	Lighting retrofit	C$ 3,200	5	13	C$ 49
	3	Chiller upgrade	C$ 54,000	14	20	C$ 193
	4	Lighting/exhaust/MAU	C$ 31,000	33	15	C$ 60
Water	1	Water fixture	C$ 6,000	0.3	15	C$ 1,333
	3	Toilet replacement	C$ 26,000	4	15	C$ 433

Sources for Table 12: Canada Mortgage and Housing Corporation 2000; Canadian Solar Technologies Inc. 2011

Using the cost threshold for GHG abatement measures in McKinsey & Company's Pathways to a Low-Carbon Economy ($83/$tCO_2e$), about half of the retrofit measures (shaded in Table 12) would be considered viable based on their abatement potential alone. However, the remaining higher-cost "abatement" measures are options that are generally more financially viable.

LESSONS LEARNED

In preparing the four case studies presented here, a number of common lessons have emerged regarding the planning, financing, construction, and ongoing operation of energy retrofitted buildings. When planning one or more retrofit measures, it is important to consider how building systems interact with one another to ensure that synergies are utilized where applicable. For example, when improving the air tightness of the building envelope, adjustments must be made to the air handling operations to ensure that thermal comfort and energy savings are attained.

It is also important to establish proper baselines so that valid before and after comparisons can be made. For example, before undergoing major retrofits, it may be worthwhile to sub-meter electricity use so that pre and post-retrofit performance can be monitored.

Scheduled maintenance and replacement projects are opportune times to consider upgrading to a higher performance system because the incremental costs may be insignificant compared to the potentially large energy savings over time. It may also be wise to consider replacing energy inefficient equipment sooner in order to avoid paying unnecessarily high energy costs for an extended period of time.

Projects with short payback periods may be economical, but may they may not generate deep energy savings. More comprehensive projects can be made financially viable by blending short and longer payback components to maximize energy savings. Careful sequencing of the project may also allow for the savings of earlier projects to pay for those later in the retrofit schedule. Payback is also a relatively short-sighted means of assessing the financial performance of a project because the savings that continue to accrue beyond the payback period are not taken into account. Instead, measures such as IRR and NPV should be used to compare different retrofit strategies. NPV is really the only measure that truly encourages comprehensive projects, because it takes into account the total volume of cash flow created not just the percentage return. Energy-saving incentives provided by government and the energy supply industry can also affect the financial viability of a project and should be investigated.

During the planning, design and construction process, open channels of communication with the building occupants must be maintained. The occupants will be inconvenienced in their daily lives during the construction period, but stand to benefit from a more comfortable interior environment upon the completion of a successful project. Minimizing occupant complaints and unanticipated disruptions often means keeping them updated and informed on the progress and resulting benefits.

Energy savings do not automatically arise once the retrofit construction has been completed. To keep the building operating efficiently in the years to come, building managers and operators must have the required training and knowledge to see that energy savings continue to accrue. Higher efficiency equipment is only more efficient if it is properly operated and maintained.

CONCLUSIONS

Since every building is different, there can not be a single “ideal” retrofit strategy. The priorities of the owner and occupants with respect to financing and indoor environmental quality as well as the current state of the building components and equipment must be considered in order to determine the most effective strategies for reducing energy use while maintaining or improving occupant comfort.

During the planning process, it is important to review upcoming maintenance issues in order to find upgrade opportunities. Careful sequencing and a mix of short and longer payback projects can ensure financial viability by using savings from one project to pay for another. Considering how the building acts as a system is the key to recognizing synergies between individual building components and systems. Communication between owners, managers and occupants is also essential during construction and conscientious building operation is the key to achieving projected performance.

Given the slow rate of renewal, much of the existing building stock will be required to provide housing in the coming decades, perhaps for a total building life cycle of 100 years or more. Unfortunately, HVAC systems and envelope components can become obsolete in 25-30 years. Building components such as these must be replaced to ensure efficient resource use and a comfortable interior environment for occupants. Given the success of these four illustrative retrofit projects, it is evident that the materials, equipment and expertise for financially viable retrofits that significantly reduce resource use are available now. In addition to improving resource efficiency, these owners also benefit from increased property values which have not been captured by the analysis here. By applying the general lessons learned and presented here, it is hoped that any building owner or manager can begin to plan and execute similar successful energy retrofit projects.

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