Energy Retrofit Opportunities for Multi-Unit Residential Buildings in the City of Toronto

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Executive Summary

The primary objective of this study was to look for correlations between multi-unit residential buildings (MURBs) typologies and energy use and then to evaluate energy retrofit options for the various building typology groups. In an earlier study, referred to as the 'Meta-Analysis', three building data sets were combined to include more than 100 buildings. Although correlations between building energy use and building age, ownership type, building size and construction-type were sought, the correlations were generally found to be rather weak. As a result of this Meta-Analysis, it was recognized that more detailed building and energy-use data were needed.

In this study, a 'Refined Data Set' was investigated using more detailed information from a sample of 40 mid- to high-rise buildings. Correlations and multi-variable regression analyses were carried out as patterns of energy-use were sought. Findings from this refined and more complete data set yielded results that were consistent with the findings of the earlier Meta-Analysis. It was found that energy usage was not necessarily correlated with building vintage and that window type and the efficiency of the boiler heating systems had a relatively significant influence on energy use.

Throughout the process of seeking energy-use correlations, one of the major challenges was first obtaining standardized data, and then consistently analyzing the data. To begin addressing this challenge, a MURB database and accompanying data processing tool was developed. The tool allows users to expand the database by entering new building characteristics and energy-use data that is then automatically normalized and analyzed. The database summarizes the input data and analysis with the assistance of a graphical 'dashboard' display. Since it is capable of continual updating, this tool can be made available for future research and benchmarking exercises.

Next, the impacts of common retrofit measures on the different building vintage groups were explored. To accomplish this, a detailed study of four buildings was carried out using computer modelling. Buildings from the 1960's, 70's and 80's were chosen. The energy intensities of these buildings were variable but were similar to the variability observed in the vintage groups reported in the first phase of the study. Using an energy software package known as eQUEST, models of the four building were calibrated using actual energy-use data. Once the models were calibrated, a series of test retrofit measures were carried out and the resulting energy usage was estimated.

It was found that the retrofits with the highest impact in terms of energy savings were improved boiler efficiency, reduced air leakage, and improved envelope thermal resistance through added insulation and window replacement.

Based on the modelled energy savings, carbon emission reductions associated with the energy retrofits were estimated:

- The modelled impact of a boiler "tune-up" (increasing efficiency from 75% to 80%) reduced the total energy use by 3% in three of the buildings resulting in annual CO_2 emission reductions ranging from 10 to 40 tonnes per building, depending on the building. The impact of a more moderate 10% increase boiler efficiency (from 85% to 95%) reduced total energy use by up to 5% for each of the four buildings resulting in an annual reduction in CO_2 emissions ranging between 15 to 60 tonnes, depending on the building.

- It was found that by halving the air leakage in a relatively loose building envelope (0.2cfm/ft^2), total building energy savings were 7% for Buildings 1960 and 1980 which corresponded to CO_2 reductions of between 24 to 114 tonnes annually for Buildings 1960 and 1980, respectively.
- By adding two inches of exterior insulation to Building 1960, which had the lowest level of wall insulation, the reduction in total annual energy use was 7% and the associated emissions reduction was estimated to be 128 tonnes. In the smallest building, Building 1980, the emissions reduction associated with the transition from two to three inches of wall insulation was estimated to be six tonnes. If the building has minimal insulation, the case for improving the thermal resistance of the envelope is obviously much stronger with respect to GHG emissions reductions but the building size must also be considered.
- The transition from single- to double-glazed units for Building 1960 and Building 1970b resulted in total energy savings of 7% and 21%, respectively, while the annual CO_2 emission reductions associated with these two buildings were estimated at 110 and 230 tonnes, respectively. The impact of the upgrading from double- to triple-glazed was responsible for less than a tenth of the impact of the transition from single- to double-glazed.
- Adding up to four inches of roof insulation to all of the buildings resulted in widely varying emissions reductions based on variations in the original insulation level and the size of the roof area.
- A 30% reduction in suite-based electricity loads did not significantly impact the overall energy load of the building, but rather shifted equivalent kilowatt-hours from electricity use to natural gas consumption during the heating season.

The final phase of the study involved generating policy recommendations based on the MURB energy-use trends explored. This research has found that there are many different building characteristics which affect energy performance. Thus, it is not appropriate to make general assumptions about current or potential energy performance based on building vintage or typology. The findings of this study have also highlighted the variability of energy performance in the existing MURB stock and the urgent need for energy retrofits in the buildings with the highest energy intensity. Therefore, changes to the City of Toronto's Official Plan were recommended to promote energy retrofits as part of regular building retrofits and maintenance. An example of legislation from New York City was used to illustrate one possible way to both collect standardized data and to promote energy retrofits.

Additionally, suggestions were made to improve the quality of the data set assembled for this study, since it is data that forms a strong foundation for informing and making policy recommendations about MURB energy use. Methods of institutionalizing data collection procedures as part of the daily operations of selected municipal bodies and industry organizations have been put forward in order to meet this goal.

Finally, the concept of Heating and Cooling Climate Indices (HCI and CCI) was introduced as a means of supplementing Canadian Weather for Energy Calculations (CWEC). With the Climate Indices, the CWEC data can be modified by an index factor to reflect the changes in climate since the time of CWEC's establishment. The index factors can be generated for any time period to allow for better estimates of future energy savings and associated CO_2 emissions reductions compared with data normalized to CWEC.

In conclusion, this study revealed the wide range in energy consumption of Toronto MURBs and that typology-specific energy-use trends could not be established. The work presented here confirms the major contributing factors to building energy use presented in the Refined Data Set analysis (window and heating system characteristics) and presents impacts of other building characteristics not previously examined (air leakage and suite-based electricity use). The projected impacts of a selection of retrofit measures applied to Toronto MURBs have been quantified in terms of energy intensity and CO_2 emissions reduction and suggestions have been made to direct policy to strive to make these projected savings a reality in buildings across the City.

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A/G	Above Ground
CCI	Cooling Climate Index
CDD	Cooling Degree Days
CERT	Carbon Emissions Reduction Target
CMU	Concrete Masonry Unit
CRB	Certified Rental Building
CWEC	Canadian Weather for Energy Calculations
DG	Double-Glazed
DHW	Domestic Hot Water
EPC	Energy Performance Certificate
FR	Fenestration Ratio, the ratio of window to wall area
FRPO	Federation of Rental-Housing Providers of Ontario
GTA	Greater Toronto Area
HiSTAR	High-Rise Building Statistically Representative
HCI	Heating Climate Index
HDD	Heating Degree Days
kWh	Kilowatt-Hour
MAU	Make-up Air Unit
MBTU	One-million BTU, used to express boiler capacity
MURB	Multi-Unit Residential Building
R^2	Correlation Coefficient
SEER	Seasonal Energy Efficiency Ratio
SG	Single-Glazed
SHGC	Solar Heat Gain Coefficient
USG	U.S. Gallon
U-value	Thermal Conductance

Introduction

Multi-unit residential buildings (MURBs) comprise over half (55%) of the dwellings in the City of Toronto (Binkley, Touchie, & Pressnail, 2012). The combined electricity and natural gas consumption of Toronto MURBs is responsible for 2.6M tonnes eCO_2 emissions annually. Mid- and high-rise MURBs are responsible for 68% of these emissions and low-rise MURBs are responsible for 32%. With the high-rise MURB sector totalling over 2000 buildings and MURBs with fewer than five stories totalling approximately 4000, this vast building stock represents a tremendous opportunity to reduce energy use and therefore greenhouse gas emissions.

Fortunately, many of these buildings are constructed similarly, and can potentially be grouped for the purposes of energy-use analysis. The primary objective of this study was to look for correlations between building typologies and energy use and then to evaluate energy retrofit options for the various MURB typology groups. By carrying out such a study, both the public and policy-makers will be better informed. The public needs to know the nature of the energy and environmental burden that our MURBs place upon us. Further, policy-makers require a better understanding of MURB energy use in order to design fair and more effective policy interventions.

An earlier study, the Meta-Analysis, conducted by the authors combined three building data sets which included more than 100 buildings. Correlations between building energy use and building age, ownership type, building size and construction were sought. From this study, the need for more detailed data was recognized. In the Refined Data Set Phase of this study, more detailed data gathering was carried out on a sample of 40 mid- to high-rise buildings. Correlations and multi-variable regression analyses were carried out as patterns of energy-use were sought. This report begins with a summary of these two phases including the data collection procedures, data processing and analysis, as well as the conclusions from these phases.

A product of these analyses was the development of a database tool better to manage Toronto MURB energy-use data. This tool allows for the organization and analyses of data as additional buildings are added to the database. As the database is expanded, it is expected that clearer and more convincing correlations may emerge. A description of the tool is included in this report.

The next phase of this study involved using a numerical energy modelling tool called eQUEST to establish the baseline energy performance of four buildings. Once the baseline energy use was calibrated with the actual energy use, various energy retrofit options could be modelled and the resulting energy savings predicted. These retrofit options included improvements in the efficiency of the heating systems, better windows, improved air-tightness, over-cladding the walls with thermal insulation, and improving the thermal insulation levels of the roofs. Building details and retrofit measure selection, as well as modelling procedures and results, are presented here.

This study concludes with several policy suggestions and recommendations regarding improving the energy and environmental performance of our MURBs – a goal that we all share.

2 Previous Work: Meta-Analysis Study

This section will describe the approach and findings of the Meta-Analysis of MURB energy consumption in the Greater Toronto Area (GTA). This project phase combined data from three existing data sources in order to characterize the energy performance of GTA MURBs and to better understand the correlations between energy performance and various building characteristics. The research was motivated by the need to improve our understanding of the energy use of our building stock in order to support policy and programmatic interventions. Through policy interventions, we can promote retrofits designed to achieve significant energy-use and greenhouse gas emissions reductions in existing buildings.

2.1 Data Collection and Preparation

The Meta-Analysis Study analyzed MURB energy-use data derived from three different databases: Canada Mortgage and Housing Corporation's HiSTAR database and the Toronto Atmospheric Fund's Green Condo Champions and Tower Renewal Benchmarking Initiative. In addition to energy-use data, these sources also included information on a range of building characteristics such as height, number of suites, vintage and sometimes basic information about the building envelope and mechanical systems. Table 1 shows a summary of the data used from each source.

Table 1: Data Source Characteristics

Name of Data Set	Number of Buildings	Building Locations	Data Year	Electricity Data?	Natural Gas Data?	Comments
HiSTAR from CMHC	55	34 - Toronto 11 - GTA 10 – Ontario	1998 OR 1999	YES	YES	1 year of data: annual and monthly for most buildings, annual and only a few months for some
Condo Champs from TAF, Mann Engineering	42	Toronto	2006 to 2010	NO	YES	3-4 years of data: monthly
Tower Renewal Benchmarking Initiative	11	Toronto	2009	YES	YES	1 year of data: annual

The data inventory, which included 108 MURBs accounted for an estimated 4.8% of the entire mid- to high-rise population (five or more stories) and 1.8%[1] of the total MURB stock in Toronto (City of Toronto 2006). Considering the vintage and sizes sampled, the inventory was representative of the MURB stock

[1] The estimate of MURB population is based on the number of households in apartment buildings less than five stories and the number of households in apartment buildings with five stories or more from the 2006 Census. The number of apartment-based households combined with the median number of suites per building from this Meta-Analysis organized by floor were used to determine the MURB population estimate.

in Toronto. Building construction dates ranged from 1941 to 2009. Building heights ranged from four to 46 storeys and gross floor areas ranged from 2,000m^2 to 101,700m^2. A summary of the limitations of the energy data used in the Meta-Analysis can be found in Appendix A.

The energy-use data from the three databases were normalized to account for variations arising from different weather conditions and billing periods so that direct comparisons could be made between the data sets. In the process of normalization, base loads and weather-dependent loads were also identified.

2.2 Meta-Analysis Energy Intensity

Following the normalization process, the annual energy intensity of the buildings in the HiSTAR and Tower Renewal data was calculated by dividing the total annual energy provided from both electric and natural gas sources by the gross floor area of the building. This total energy intensity split out by natural gas and electricity consumption is shown in Figure 1. The 42 Green Condo Champions buildings do not include electricity data, but were included for reference.

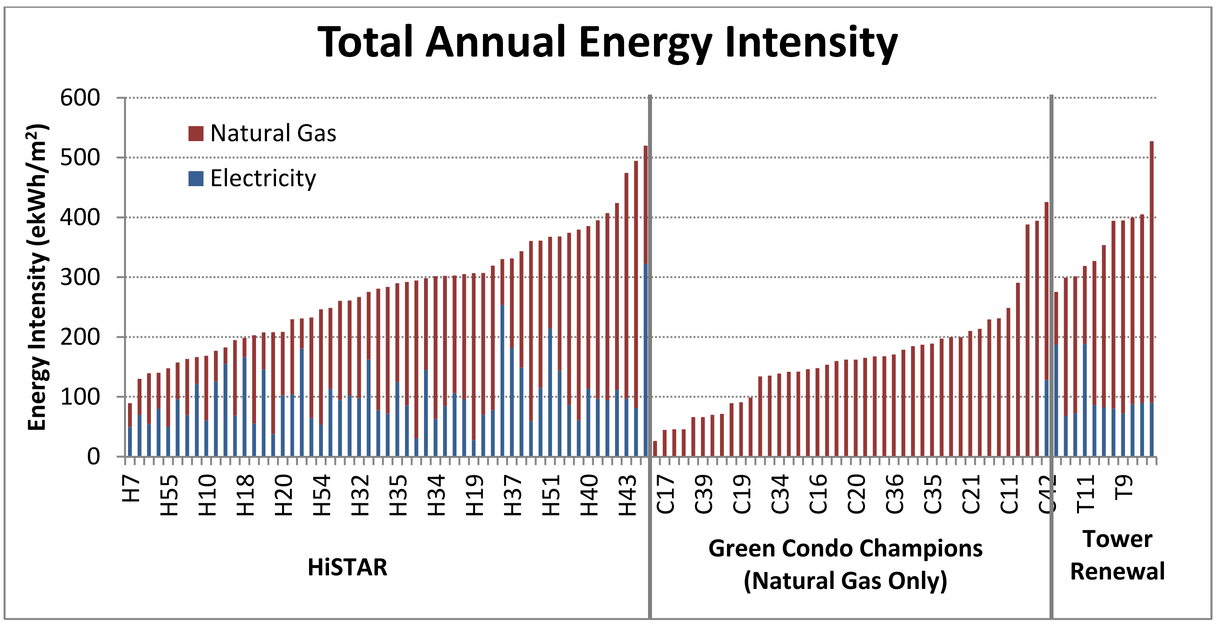

Figure 1: Energy Intensity from Meta-Analysis Data Set

The average energy intensity determined from actual natural gas and electricity metering was 295ekWh/m^2. This is higher than the average energy intensity of 225eKwh/m^2 reported in another study of apartment buildings in Ontario (Natural Resources Canada 2008). Differing weather normalization techniques and focusing on MURBs in Toronto rather than all of Ontario may account for the higher energy intensity. As shown in Figure 1, the energy intensity varied widely within the data set from 88ekWh/m^2 to 520ekWh/m^2. The greenhouse gas emissions intensities were calculated by applying emissions factors to the energy intensity. The emission intensities were found to vary between 14.6ekgCO$_2$/m^2 and 93.3 ekgCO$_2$/m^2 with an average of 50.4ekgCO$_2$/m^2.

2.3 Preliminary Correlation Analysis

After determining the overall energy intensity of each building, characteristics such as building vintage, size and occupancy type were analyzed with the energy-use data to determine if any correlations exist. Conclusions were drawn from the data inventory and the correlation analysis.

Even when the buildings were categorized by either vintage or ownership type, the variation in energy intensities within each category remained large. Due to this significant variation, many of the correlations identified within the Meta-Analysis data set were weak.

The results of correlating energy intensity with building vintage showed the expected relationship: energy intensities decreased from older to younger buildings until the 1970s, when energy intensities started to increase slightly. The higher energy intensities of the oldest buildings in the data set could be due to the age of the mechanical systems and the condition of the building envelope. However, the increased energy use in newer buildings may be due to greater fenestration ratios typically seen in more modern buildings as curtain and window-wall construction became more prevalent.

No correlation could be found between energy intensity and gross floor area, number of suites or building height. Naturally, the total building energy use increases with size, however the correlation between energy intensity and building size is not strong enough to suggest a trend even when buildings are classified by vintage or ownership type. The lack of correlation is likely due to the significant variation of the energy intensity data that exists within the Meta-Analysis data set. This finding suggests that if policy makers want to set certain energy intensity benchmarks or energy performance standards, different benchmarks for high-rise, mid-rise, and low-rise MURBs may not be required. However, this finding differs from another study based on Canada-wide HiSTAR data only (Liu 2007) which showed that buildings between 7 and 20 stories were the most energy intensive group.

The Meta-Analysis also included an exploration of the relationship between ownership type and energy intensity. On a gross floor area basis, condominiums had the lowest average energy intensity, but on a per suite basis, they had the highest energy intensity. This variation in energy intensity depending on the normalization method (by suite or area) can be explained by considering a few different factors. First, condominium buildings typically have larger suite sizes and therefore presumably a lower occupant density which explains the lower area-based energy intensity. However, when viewed on the suite basis, the higher energy intensity can be attributed to generally higher incomes and therefore more household appliances and electronics. It can also be attributed to the greater common area loads often seen in condos such as pools and gyms. As well, with larger suites, common area energy use is spread over a smaller number of units. The energy intensity of the subsidized rental buildings on both the 'per area' and 'per suite' basis were lower compared to the other ownership types. This can perhaps be explained by restricted operating budgets and limited common areas, typical for this ownership type.

2.4 Meta-Analysis Conclusions

Generally the data analysis did not yield the strong correlations that were anticipated at the outset of this phase. Nevertheless, some interesting observations and conclusions were drawn:

1. The meta-analysis of MURB energy-use data presented here represents a reasonable sample size of the GTA MURB population;

2. The energy-intensity values determined from actual natural gas and electricity metering were higher than the published values from a similar study. The difference in the two values can be largely accounted for by different weather normalization practices. The Meta-Analysis data were normalized to a standard year which is colder than 2007, which is the year considered in the other study. The Canadian Weather for Energy Calculations (CWEC) standard weather year, used in this study, is based on the average weather data in Toronto for a 30-year time period from 1960-1989. The CWEC has over 20% more heating degree days than the average from 1990 to 2011 and 18% more heating degree days than the year 2007 specifically;

3. There was a wide range in the observed energy intensities. The lowest energy intensity was less than one fifth of the highest one. Given the weak correlations between building energy use and the building characteristics available, the range in energy intensity may be a result of other parameters which are harder to capture. These parameters include differences in the way the buildings are operated, differences in the efficiency of the major mechanical and electrical systems in the building, and differences in construction type. With respect to building operations in particular, this finding could also indicate that major improvements in energy efficiency are possible for many of the buildings in the dataset;

4. An examination of the relationship between energy intensity and gross floor area, number of suites, and building height, did not yield any strong correlations. This finding suggests that different policies directed at low-, mid- and high-rise buildings may not be required;

5. An examination of the relationship between weather–related energy intensity and year of construction revealed that energy intensity generally decreased until the 1970's. After the 1970's, intensities began to rise. This latter rise may be due to the energy-saving effects of better thermal insulation and air-tightness measures being offset by higher fenestration ratios. This hypothesis may explain the apparent paradox of the declining energy-efficiency of the more modern MURBs in the data set and points to a need for better building energy standards which is being addressed by codes and standards such as the Toronto Green Standard and 2012 Ontario Building Code requirements;

6. This Meta-Analysis also explored, in a preliminary way, the relationship between ownership type and energy intensity. Although condominiums had the lowest average energy intensity on a gross floor area basis, they had the highest energy intensity on a per suite basis. This is counter-intuitive unless the effects of household income and energy used in common areas are considered in the explanation.

The findings from the Meta-Analysis pointed to the need for more a detailed study of energy use and buildings characteristics beyond those considered as part of the Meta-Analysis. In order to determine the reasons behind the large variation in energy intensity, more detail about each building was required beyond the basic building size, vintage and ownership details.

The complete report from this study, "Meta-Analysis of Energy Consumption in Multi-Unit Residential Buildings in the Greater Toronto Area", includes a more detailed discussion of the data set characteristics, normalization procedures, assumptions and resulting correlations.

3 Refined Data Analysis Phase

The aim of this phase of the study was to address the data limitations of the Meta-Analysis Study by examining a refined data set composed of 40 buildings. More complete energy consumption data and information about building characteristics including parameters such as fenestration ratio, envelope thermal resistance and mechanical equipment efficiency were available for these buildings.

The complete report from this phase, "Energy Consumption Trends of Multi-Unit Residential Buildings in the City of Toronto", includes details of the data processing methodology including outlier determination, a more complete discussion of how load types and variables were derived as well as other assumptions, correlations and conclusions.

3.1 Data Collection and Characterization

The refined data set, consisting of 40 buildings, is composed of both newly acquired data as well as select data from the Meta-Analysis.

The 20 new buildings added to the data set include: two that were the focus of a study by Tzekova et al. (2011); three were the subject of a community energy plan for the City of Toronto (Arup, 2010); 15 were obtained from energy audit reports conducted by engineering consulting firms for projects being carried out by the City of Toronto's Tower Renewal Office.

Twenty of the buildings were from the original Meta-Analysis data set. Only five of the Green Condo Champions buildings were included because permission from each building was required in order to access electricity data. Fortunately, this data also included four years of monthly natural gas consumption information as well as energy audit reports for each building. The 15 remaining buildings were selected from the High Rise Building Statistically Representative (HiSTAR) buildings (Liu, 2007). Only HiSTAR buildings with the following characteristics were chosen: located in the City of Toronto; more than eight months of natural gas and electricity consumption data were available; a good correlation between primary heating energy use and heating degree days existed.

The refined data set of 40 buildings represents 1.9% of the entire mid- and high-rise population and 0.7% of the total MURB stock in Toronto. The buildings had construction dates ranging from 1960 to 2003 and ranged in height from five to 28 storeys. Each building had between 24 and 250 suites. Overall, the distribution of building height and age in the data set was comparable to the actual distribution of building height and age of Toronto mid- and high-rise MURBs except that the data set did not contain any buildings constructed prior to 1960 or any buildings taller than 28 storeys as shown in Figure 2 and Figure 3.

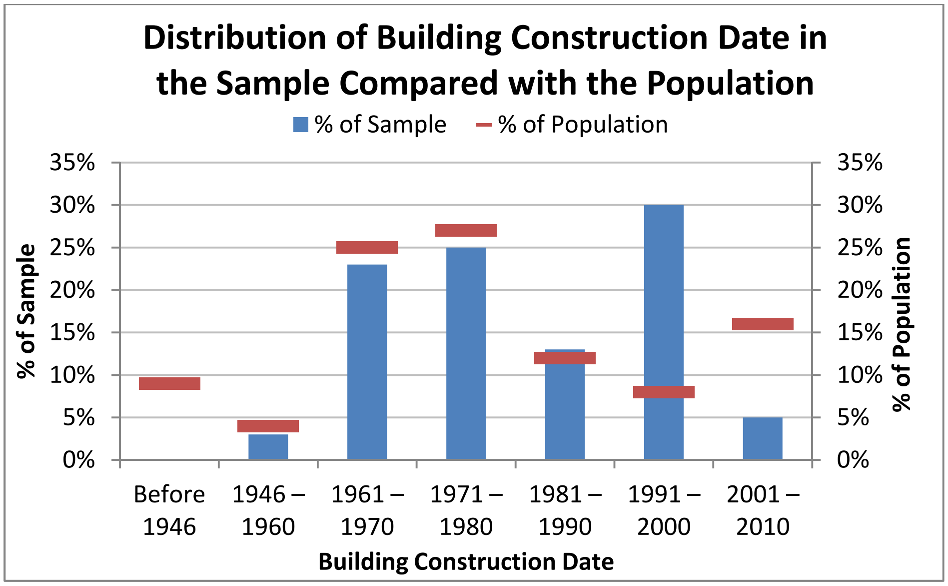

Figure 2: Distribution of Building Construction Date in the Sample Compared with the Population

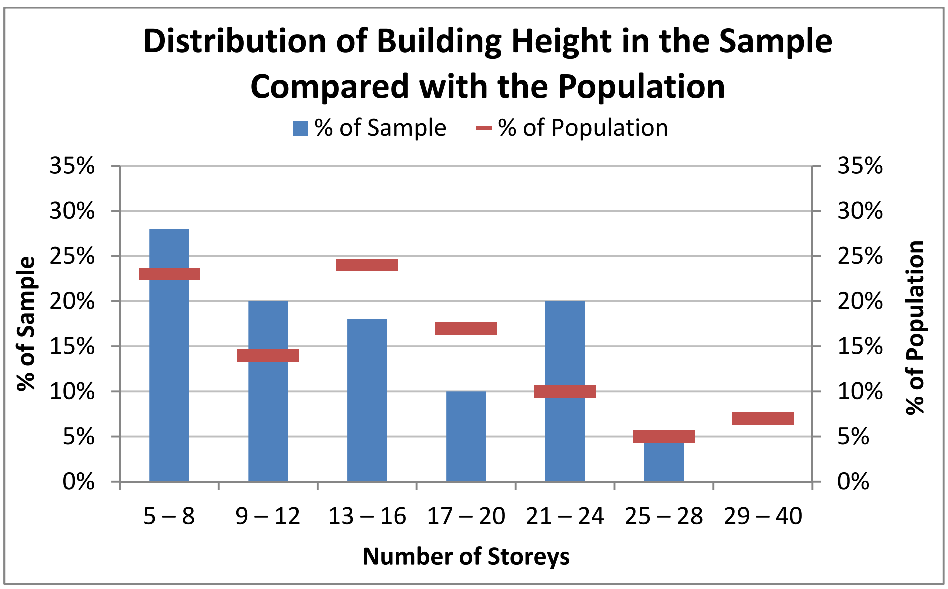

Figure 3: Distribution of Building Height in the Sample Compared with the Population

NOTE: "% of sample" means the number of buildings in the refined data set that fall within a given category divided by the total number of buildings in the refined data set. "% of population" means the number of buildings in Toronto that fall within a given category divided by the total number of buildings in Toronto. If the % of sample is larger, then that category is over-represented in the sample and if the % of sample is smaller, then that category is under-represented in the sample.

The limitations of the refined data set are discussed in Appendix B.

3.2 Refined Data Set Energy Intensity

For each of the 40 buildings, monthly natural gas and electricity data were weather normalized using a standard weather year as determined from CWEC. Following this normalization, the base component (weather independent) and the variable component (weather dependent) of the natural gas and electricity use were identified. The total weather-normalized energy intensities ranged from 90ekWh/m^2 up to 510ekWh/m^2 and averaged 292ekWh/m^2. The average energy mix of the data set is 33% electricity and 67% natural gas which is almost the same as the energy mix of apartment buildings in Ontario: 34% electricity and 66% natural gas (NRCan, 2008). The energy intensities for all 40 buildings split up by variable and base natural gas intensity are shown in Figure 4.

Similar to the Meta-Analysis, there is a great deal of variation in the energy intensities between the worst performing buildings (highest 10% of energy users) using more than three times the amount of energy consumed by the best performers (lowest 10% of energy users) as shown in Figure 4.

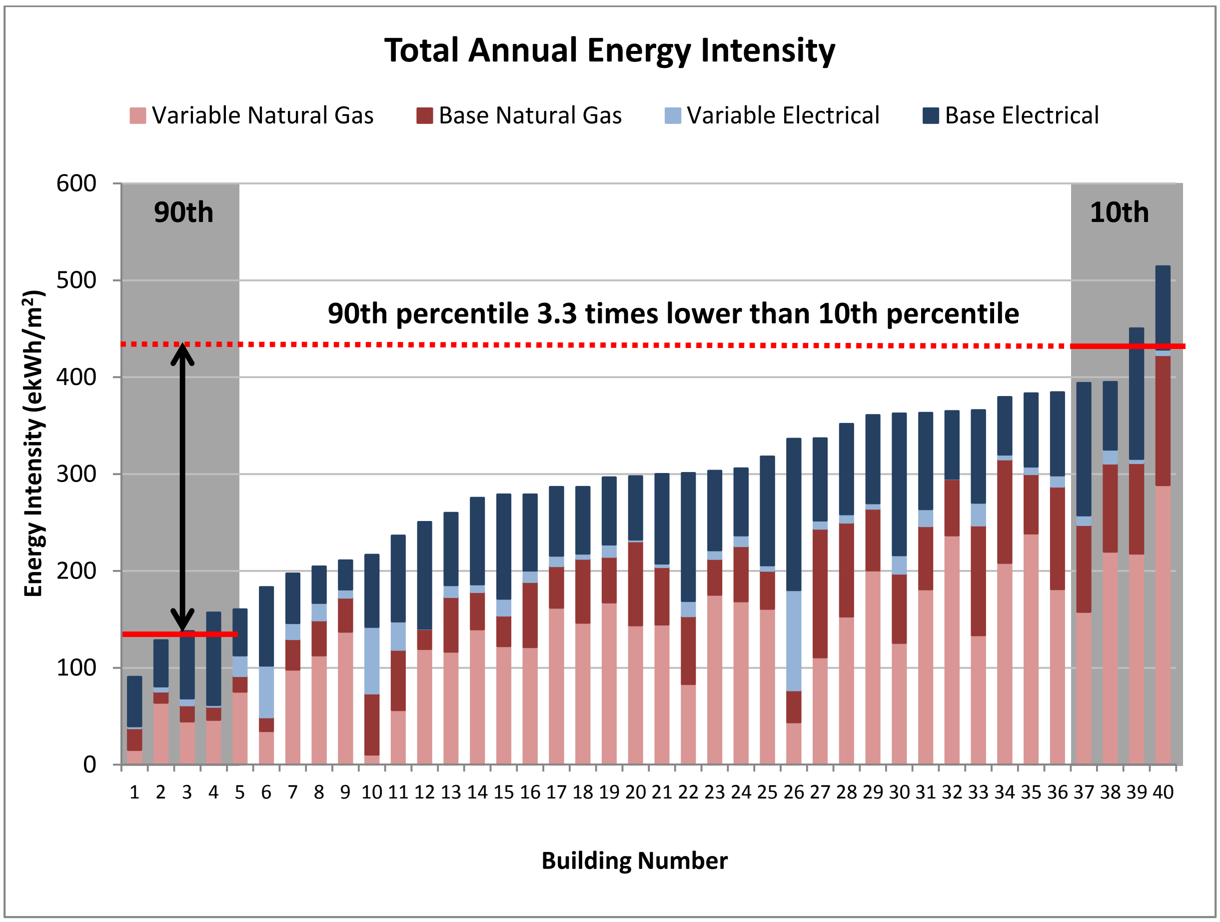

Figure 4: Energy Intensity from the Refined Data Set

As suggested by an energy benchmarking report about buildings in New York City (City of New York, August 2012), highly energy intensive buildings may be able to see significant reductions in energy use by simply adjusting controls, sensors and schedules for the mechanical equipment in the building. It follows that the buildings with the highest energy intensity may be able to achieve the median energy intensity, as shown in Figure 5, with relatively simple adjustments to existing systems. In order to estimate the impact of these types of adjustments, it has been assumed that the range and frequency of the energy intensity in the refined data set is representative of the population, based on the comparisons in Figure 2 and Figure 3. If this is the case, the resulting reduction in average energy intensity of the entire sample would be greater than 10%. However, if all buildings were able to achieve the energy intensity of the 75th percentile through a more comprehensive set of energy conservation measures, the resulting reduction in average energy intensity of the sample would be more than 35%.

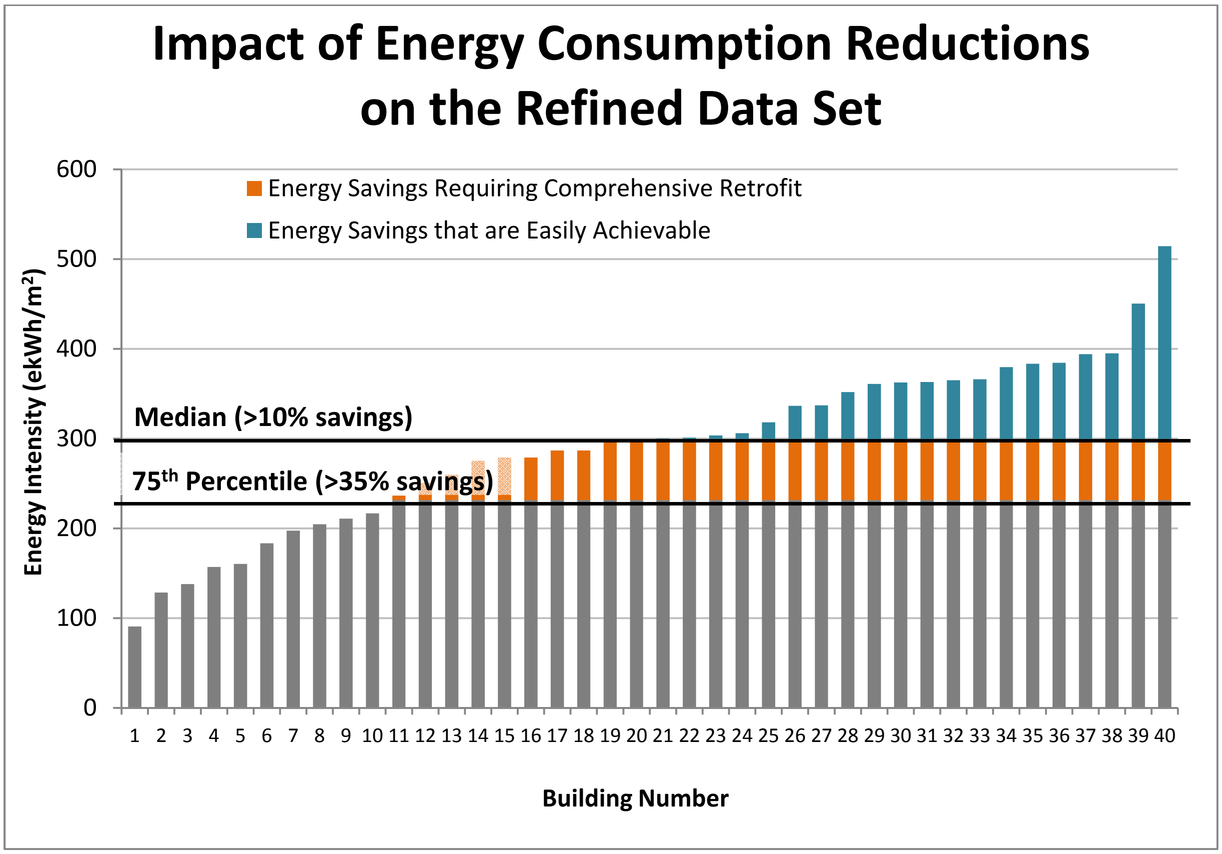

Figure 5: Impact of Energy Consumption Reductions on Refined Data Set

However, the total energy use for the lowest energy users (90th percentile) needs to be verified. It is possible that not all the components of building energy use were captured, resulting in an artificially low energy intensity.

The average energy intensities found in the Meta-Analysis and Refined Data Sets were compared with a number of other studies. The range of published energy intensity values varied widely due to variations in how the data were sourced (from consumers or suppliers and from what types of consumers) and processed (weather normalized or not and the floor area used to determine intensity). Generally, the energy intensities derived from the supplier-side studies tend to be lower than the average energy intensities from the consumer-side studies. As the data used in the Meta-Analysis and Refined Data Set studies were collected in a similar manner to the consumer-side studies, only consumer-side studies were used for comparison.

When compared with the average energy intensity from various consumer-side studies of energy use in Toronto and Ontario MURBs (305ekWh/m^2), the energy intensity in this study appears to be consistent. However, in the comparator consumer-side studies, there was no need to weather normalize the data because the buildings in each sample came from a similar time period. Thus, the energy intensities from these studies were understated relative to the weather-normalized data presented here since there was a lower demand for heating energy. This is because the standard weather year used here, CWEC, (Environment Canada, 2012) results in a greater heating demand than the years in the other studies. The CWEC data uses the 30-year period from 1960 to 1989 to create an 'average' or a 'standard weather year.' By using a standard weather year, direct comparisons can be made between various building energy studies that cover a wide range of years.

However, problems arise when the standard weather year is used to predict energy performance in a period when the climate or microclimate is changing. For example, the CWEC data provides a Heating Degree Day total of 4089°C-days for the standard weather year and yet in the 10-year period from 2002 to 2011, the actual average number of Heating Degree Days was only 3394°C-days. Thus, the climate-related demand for heating in Toronto was 17% less in the 10-year period ending 2011 than it was in the standard weather year.

To summarize, weather normalization is necessary to compare building data from different years. However, it is not possible to directly compare weather-normalized results to other non-weather-normalized studies. Further, energy predictions using weather-normalized data must be used with caution, particularly in periods where the climate or microclimate is changing. As well, the size and use of common areas and the attitude of the participant building owners and managers to energy-efficiency can also affect energy intensity calculations.

3.3 Correlation Analysis

Functional relationships between the normalized energy use and the variables relating to the mechanical and the electrical system, the building envelope, and the occupancy characteristics of the building were sought. These variables were tested against various measures of energy use to determine where correlations existed.

Prior to conducting the correlation analysis, predictions were made regarding the variables that were believed to have the most significant effect on different components of energy use. The variable (weather dependent) natural gas intensity was thought to be influenced by the thermal conductance of the glazing, the air-tightness of the glazing, the glazing area, the boiler age, and the boiler efficiency. In buildings with air conditioning, the variable electrical intensity was thought to be governed by the glazing characteristics listed above as well as the solar heat gain coefficient (SHGC) of the glazing and the cooling capacity of the air conditioning system. The base (weather independent) natural gas intensity was expected to be governed by the number of occupants; the base electrical intensity was expected to be related to the building age and the number of occupants. The two most important influences on energy use were found to be window and heating system characteristics.

3.3.1 Window Characteristics

Characteristics such as window area, air-tightness, thermal conductance, and SHGC of windows were expected to influence both heating and cooling loads.

Since the majority of heat loss and solar heat gain through the building envelope is often through the glazing, it was expected that the larger the fenestration ratio, the higher the heating and cooling loads will be. This relationship, with respect to natural gas consumption, was shown to be stronger in buildings with double-glazed windows when compared to those with single-glazed windows as shown in Figure 6.

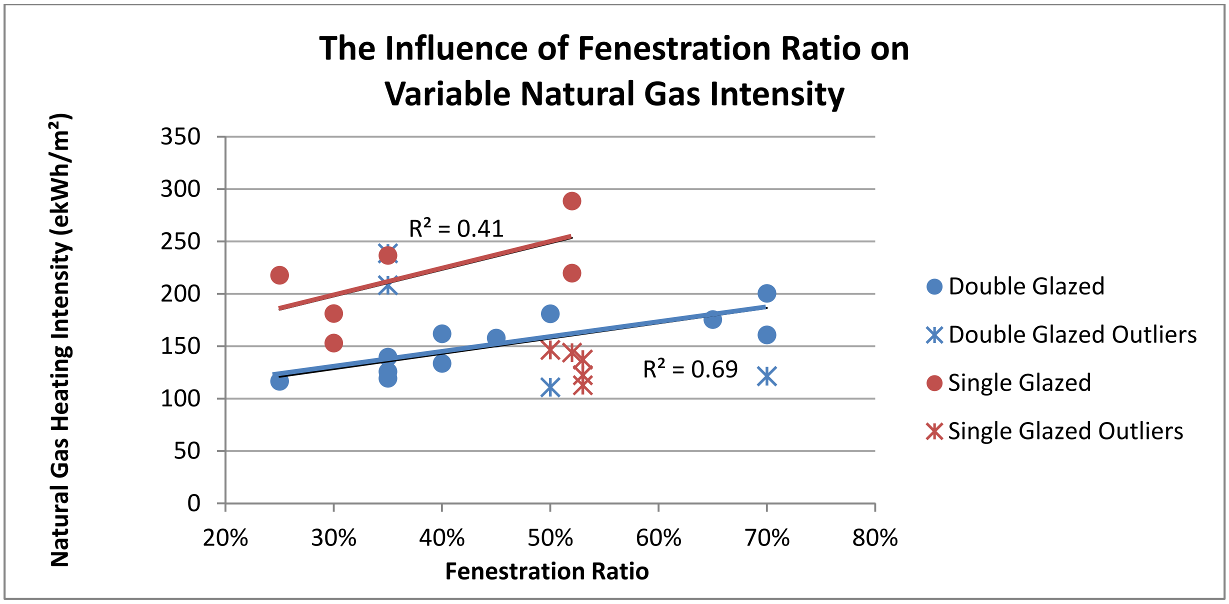

Figure 6: The Influence of Fenestration Ratio on Variable Natural Gas Intensity

One of the reasons that the correlation coefficient (R^2 value) for single glazed windows was lower than the R^2 value for double glazed was that the buildings with single-glazed windows are generally older and the glazing is in worse condition. Thus, the air-tightness of the glazing assemblies may be the factor that governs heat loss for these buildings, not just the fenestration ratio. Similarly, a higher fenestration ratio also leads to greater air conditioning loads (R^2 = 0.58 for variable electricity intensity versus fenestration ratio for double-glazed window). This is expected because of solar gains and conductive and convective heat gains from the outdoors during the summer.

Glazing thermal conductance (U-value) is another contributing factor to heating and cooling loads. Higher U-values mean that more heat transfer occurs and thus heating and cooling loads will presumably be higher. This hypothesis was confirmed for both heating and cooling albeit, the heating condition showed a weaker correlation. The stronger correlations shown with fenestration ratio suggest that glazing area has a greater effect on heating intensity than window thermal conductance.

3.3.2 Heating and Cooling Equipment

Another factor affecting building heating loads is the efficiency of the heating system. It was expected that the more efficient the heating system is, the lower the variable natural gas intensity will be. However, the relationship between variable natural gas intensity and boiler efficiency, as shown in Figure 7, was not as strong as expected. This may be due to the fact that the boiler efficiencies provided in the audit reports may not reflect the actual efficiency of the heating system. Therefore, while the approximate relationship is correct, the correlation could be stronger with more data that better reflects the actual performance of the system.

The provided system efficiencies are either rated or estimated efficiencies. The rated efficiency is the efficiency of the boiler when it was new, but this efficiency declines as the boiler ages. The rate of decline depends on maintenance practices, the boiler use patterns, the type of boiler, and the boiler and pipe configuration.

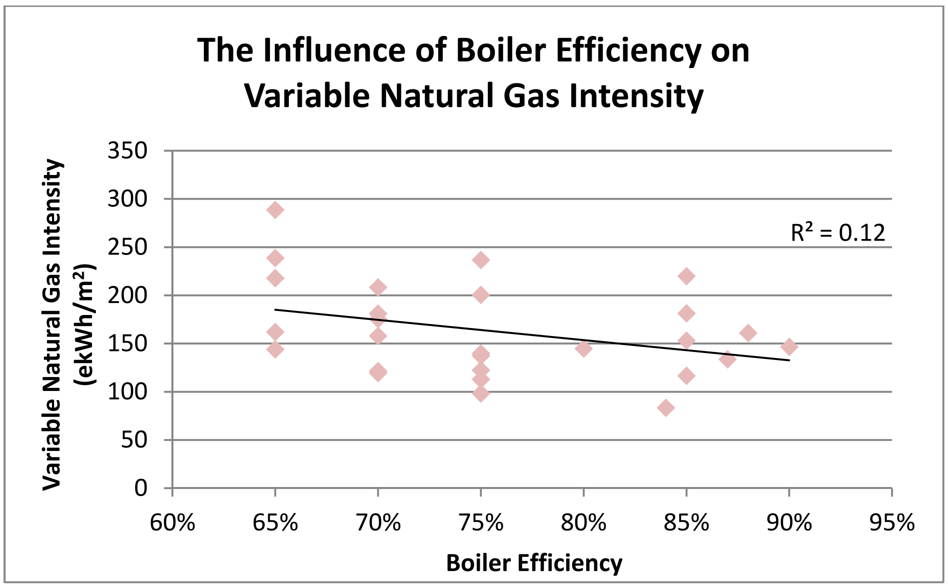

Figure 7: Variable Natural Gas Intensity versus Boiler Efficiency

The results of the correlation analysis revealed that many of the predictions of variables governing energy use held true. However, in most cases the correlations were weaker than expected. For some of the variables such as boiler efficiency and fenestration ratio, the R^2 was thought to be low because the data did not always reflect the actual conditions of the building as closely as required. For other variables such as the thermal conductance of the glazing, it was reasoned that another building characteristic, such as glazing air-tightness, governed the relationship. However, this hypothesis could not be tested since no data relating to glazing air-tightness were available.

3.4 Multi-variable Regression Analysis

In order to determine whether the correlations could be improved, a multi-variable linear regression analysis was conducted. This method of analysis considers correlations between more than one explanatory variable at a time. A stepwise forward-selection approach to maximize the adjusted R^2

value was used for each regression analysis. An additional approach, based on the presumed logic of which variables should govern each energy consumption component, was used to select the order in which variables were added for some of the regression analyses. The results of both types of regression analyses are shown in Appendix C. The multi-variable regression analysis procedures are described fully in the complete report for this phase of the study.

The variables used in the multi-variable regression analyses included those used for the correlation analyses. The multi-variable regression analyses revealed that some variables do not govern in equal proportions for all buildings. For example, the energy use of one building may be influenced more by air leakage, while the energy use of another building may be more significantly affected by an inefficient boiler.

The R^2 values remained low in the multi-variable linear regression models conducted for components of energy intensity. Similar to the correlation analysis, the multi-variable regression analysis was also limited by the type and quality of data available.

3.5 Investigation of Anomalies

Within the correlations analysis, a number of buildings were identified as "anomalies" either because they were outliers in the correlations charts or because they had abnormally high or low components of energy use. These buildings were subjected to a more detailed investigation in order to determine the reason for the anomalous energy use.

For example, anomalies in the correlations between base natural gas and number of occupants were explained by the type of housing provided by the building. The MURBs designated as seniors' homes tended to exhibit lower energy use while the MURBs designated as subsidized rental housing were above the line of best fit. The reason for this trend is probably because the estimate of the number of occupants in the building was not accurate. The number of occupants in each apartment is likely higher than the census average in subsidized housing and below the census average in senior housing. Other reasons for anomalous energy consumption included alternative heating systems and additional common area facilities. A complete discussion can be found in the full report for this earlier phase.

Overall, there was no particular factor that could account for the presence of a large group of anomalies. The anomalies were generally the result of a special circumstance that applied to one or two buildings in the data set.

3.6 Refined Data Set Conclusions and Recommendations

The refined data set was an improvement over the Meta-Analysis data set not only because it contained more complete energy consumption information and detailed building characteristics for all of the buildings, but also because it more closely reflected the population characteristics of Toronto mid- and high-rise MURBs in terms of the distribution of building ages and heights sampled and the split between electricity to natural gas use. The most important conclusions and resulting recommendations from this phase are presented here:

1. The average energy intensity of the buildings in this study was found to be 292ekWh/m^2. This finding is similar to that of the Meta-Analysis (295ekWh/m^2). The average energy mix of the refined data set is 33% electricity and 67% natural gas which is almost identical to the reported energy mix of apartment buildings in Ontario.

2. When making a comparison between energy intensity statistics, the data source and processing method must be identified before proceeding with a direct comparison.

3. The use of CWEC to normalize energy-use data overstates the actual energy intensity of the building stock. When using this information to make assessments about the impact of energy retrofits, the impacts of heating energy retrofits may be overstated while those affecting cooling loads may be understated.

4. The fenestration ratio was shown to affect energy use related to heating and cooling as expected. The correlation was shown to be stronger in buildings with double-glazed windows than in buildings with single-glazed windows. The considerable variation in the data correlating the glazing U-value with heating and cooling loads suggests that other window-related considerations such as air leakage rates and frame characteristics are affecting energy usage. This study also found that boiler efficiency and age estimates are not well correlated to variable natural gas use which is thought to be affected by other factors such as maintenance, operation, controls, configuration and the appropriateness of the system size. Conclusions for each variable tested are presented in Appendix D and the needs for additional data are discussed in Section 5.1 of this report.

5. The authors recommend that window air-leakage data should be collected along with detailed window characteristics. As well, more information should be collected about actual heating system performance. Once correlations have been developed between this more detailed data and building energy consumption, perhaps generalizations about window and boiler performance can be made based on a standard list of characteristics that can be observed on site during an audit.

6. The authors recommend that the actual number of building occupants be collected during an energy audit. This relatively easy step could be used to benchmark the efficiency of the DHW system against other buildings given the seemingly high correlation with base natural gas use.

7. The analysis of anomalies revealed that there was not one particular factor that could explain a large group of the anomalies. However, information on special facilities such as the existence of a swimming pool or daycare facility aided in the explanation of a number of the anomalies. Therefore, it is important to collected detailed information about these spaces such as area use, square footage, lighting intensity and equipment use during an audit.

8. The area of the parking garage in each building was not included in the gross floor area of the building. Ideally, parking garages should not be included in the gross floor area calculations because they are often not conditioned to the same extent as the rest of the building. However, if the energy use of this space is metered with the rest of the building, the total annual energy use must be reduced before calculating the energy intensity of the non-parking areas. Therefore, the authors recommended that parking garages and energy use should be dealt with in a standard way.

4 Overview of the Final Phase

This final phase of the project includes two major works: development of a database of MURB energy use, and detailed energy modelling of selected MURBs. This latter energy modelling was carried out in order to explore the impact of potential energy retrofit solutions.

Through the Meta-Analysis Study and the Refined Data Set phase of this project, it was clear that a more uniform and detailed data set was required to conduct the correlation analyses. To organize existing data and collect better quality data for future analysis, a MURB database and an accompanying Database Entry Tool were developed as described in Section 5.

In Section 6, four representative buildings were selected and a detailed energy model for each building was developed. These models were calibrated with actual building energy use. In an effort to generate typology-specific energy savings associated with certain retrofits, the calibrated models were used to determine the projected impact of potential retrofit strategies.

Finally, policy recommendations and suggestions for additional data collection procedures are made in Section 7.

5 Database Tool Development

The development of a database to manage Toronto MURB energy use and building characteristics is necessary to organize the existing data and allow expansion of the data collected for this study. This database tool also takes newly entered data, provides preliminary analysis and reports the results.

The tool was developed in two parts using Microsoft Excel: the “MURB Data Input Tool” and the “MURB Database”. First, a building-specific tool allows entry of raw electricity and natural gas use and prompts the user to enter other information about the building. The purpose of this tool is to ensure the same type of data is collected for each building and that energy-use data are normalized and processed in the same way. The output of the MURB Data Input Tool is one row summarizing the processed building energy-use data and other details for input into the MURB Database. The database houses all of these individual building summaries and provides some preliminary analysis as well as snapshots of the database population.

5.1 MURB Data Input Tool

For each building entered into the Database, one MURB Data Input Tool is required. Only one tab in the Tool requires user input. A screenshot of this tab, “Building Inputs”, is shown in Figure 8.

Building Inputs

Required Building Characteristics

Building Name	Year Built	Number of Floors	Gross Floor Area (m^2)	Number of Suites	Air Conditioning	Heating Source

Detailed Building Characteristics

First 3 Characters of Postal Code	Window U Value (W/m^2K)	Overall Building RSI (m^2K/W)	Height (m)	Occupancy Type	Fenestration Ratio (%)	Cooling Capacity (tonnes)	Space Heating Equipment Efficiency (%)	Mechanical Ventilation Rate (m^3/h)	Pool

Comprehensive Building Characteristics

Window Air Leakage* (m^3/m crack length per hour)	Building Air Leakage* (m^3/m^2 wall area per hour)	Air Conditioning SEER	Gross Floor Area of Common Space (m^2)	Heated Parking Garage Area (m^2)	Year Current Space Heating Equipment Installed	Year Current A/C Equipment Installed	Interior Temperature: Heating Season	Interior Temperature: Cooling Season	Number of 1 Bedroom Units	Number of Bedroom Units

* Report air leakage at a 75 Pa pressure differential

Electricity Consumption (Monthly Total in kWh)

	2020	2019	2018	2017	2016	2015	2014	2013	2012	20
January										
February										
March										
April										
May										
June										
July										
August										
September										
October										
November										
December										

Natural Gas Consumption (Monthly Total in m^3)

	2020	2019	2018	2017	2016	2015	2014	2013	2012	20
January										
February										
March										
April										
May										
June										
July										
August										
September										
October										
November										
December										

Total Water Consumption (Monthly Total in L)

	2020	2019	2018	2017	2016	2015	2014	2013	2012	20
January										
February										
March										
April										
May										
June										
July										
August										
September										
October										
November										
December										

Figure 8: Building Inputs Tab

The various building characteristic inputs are divided into three categories and grouped according to data importance and availability as shown in Table 2. The 'Required Building Characteristics' are considered necessary for even the most basic analysis such as the correlations in the Meta-Analysis but are relatively easy to acquire. The 'Detailed Building Characteristics' allows for a more detailed correlation analysis as included in the Refined Data Set phase. Most of this information can be obtained from building audit reports. The 'Comprehensive Building Characteristics' allows for a comprehensive energy-use investigation. This type of information can be used to investigate and explain anomalies that may be revealed in a correlation analysis. To gather this latter information, a site visit or testing may be required together with interviews with the building owner or manager, and/or a detailed drawing review.

Table 2: MURB Data Input Tool Contents

Input Category	Need and Accessibility	Category Items
Required Building Characteristics	Necessary; relatively easy to acquire	Building name Year built Number of storeys Gross floor area Number of suites Air conditioning (window/central/none) Heating source (natural gas/electricity/combo)
Detailed Building Characteristics	Allows for a more detailed correlation analysis; from audit reports	Postal code Window U-value Overall building RSI Height Occupant Type (rental/condo/coop/subsidized rent) Fenestration ratio Cooling capacity Space heating equipment efficiency Mechanical Ventilation Rate Pool (indoor/outdoor/none)
Comprehensive Building Characteristics	Allows for a comprehensive correlation analysis; may require site visit/testing, interview with building owner/manager, and/or detailed drawing review	Window air leakage Building air leakage Air conditioning SEER Gross floor area of common space Heating parking garage area Space heating equipment age Heating and cooling set point temperatures Number of 1, 2, 3+ bedroom suites
Monthly Electricity Consumption	Necessary; from utility bills	
Monthly Natural Gas Consumption	Necessary; from utility bills	
Monthly Water Consumption	Necessary; from utility bills	

The Building Inputs tab also requires monthly electricity and natural gas consumption data. Water consumption data are included in this tab as an optional input because, if energy use and building data are to be collected on a broad scale in the future, it would be worthwhile to input water consumption data from City records at the same time for possible future research. Although water consumption analysis has not been part of this study, analysis of the water consumption for a building could be indicative of the magnitude of the DHW load and attributed to some of the energy required for pump operation in the building.

In addition to user inputs, the Input Tool includes an explanation of the weather normalization procedure and illustrates the application of this procedure using the actual building data. A sample application is illustrated and shown in Figure 9 for the natural gas consumption normalization of a sample building.

Natural Gas Consumption

NO DATA ENTRY REQUIRED ON THIS TAB

Monthly Weather Normalized Natural Gas Consumption

Month	Standard HDD	Weather Normalized Consumption (kWh)
January	719.7	1,367,370
February	716.8	1,362,516
March	565.1	1,109,063
April	371.3	785,209
May	182.5	469,732
June	56.2	258,784
July	7.3	177,038
August	16.6	192,520
September	107.2	343,995
October	289.0	647,695
November	439.1	898,544
December	618.5	1,198,207
Total	**4,089**	**8,810,672**

Regression Results

Parameter	Value
Slope	1,671
Intercept	164,815.48
Coefficient of determination	0.97

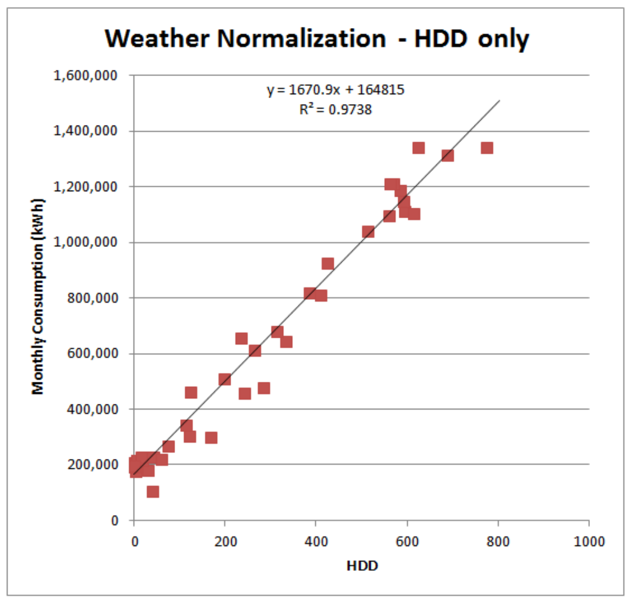

Figure 9: Natural Gas Weather Normalization in the Gas Consumption Tab

There is also a tab showing the historical heating and cooling degree day data for Toronto which can be expanded as new annual data becomes available. Finally, the “Data Summary” tab, shown in Figure 10, presents a one-row summary of all inputs and processed data for transfer to the “MURB Database” described in Section 5.2. Instructions on how to use the tool and a glossary defining all of the input fields are provided in the first and last tabs, respectively.

Data Summary

NO DATA ENTRY REQUIRED ON THIS TAB

	ENERGY DATA					REQUIRED BUILDING INPUTS						
Building Name	Total Annual Electricity (kWh)	Annual Base Gas (kWh)	Annual Variable Gas (kWh)	Total Annual Gas (kWh)	Total Annual Energy (kWh)	Year Built	Number of Storeys	Gross Floor Area (m^2)	Number of Suites	Air Conditioning	Heating Source	First 3 Characters of Postal Code
Building DD	3,577,731	1,977,786	6,832,886	8,810,672	12,388,403	2002	27	33776	Central	Natural Gas	no input	no input

This row is copied to the Database

Figure 10: Data Summary Tab

5.2 MURB Database

The output from the "MURB Data Input Tool", containing summarized data about a single building, is combined with data from other buildings in the "MURB Database". The "MURB Database" shows all of the data collected and processed by the "MURB Data Input Tool" for each building in the data set.

The "Database Summary" tab, shown in Figure 11, includes a comparison between the sample of buildings within the database and the estimated Toronto MURB population in terms of building height and vintage. The aim of this comparison is to demonstrate where the entered building data lie with respect to the MURB population. This tab also includes a summary of the energy and water use as well as GHG emissions and a few basic building characteristics. Finally, the summary tab shows how the buildings are broken down by heating and cooling system type.

Database Summary

Population of Database	39

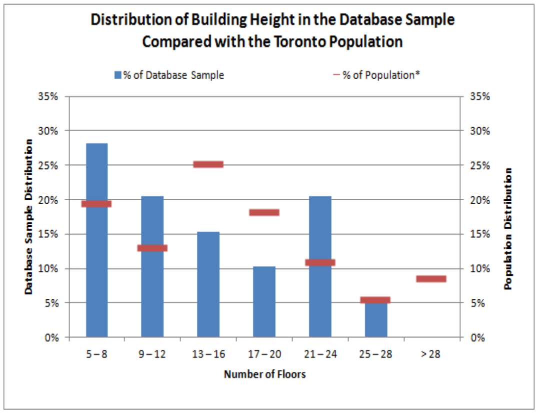

Figure 1: Distribution of Building Height in the Database Sample Compared with the Toronto Population

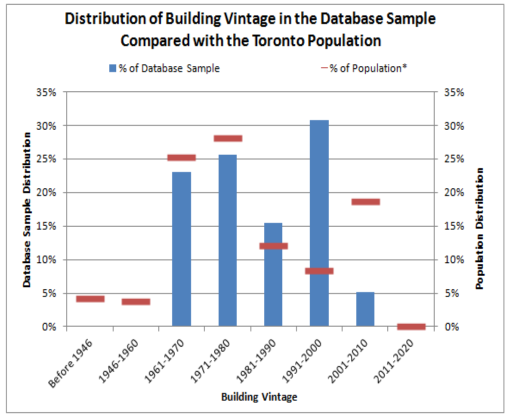

Figure 2: Distribution of Building Vintage in the Database Sample Compared with the Toronto Population

*population estimate is as of 2010 as described in "Energy Consumption Trends of Multi-Unit Residential Buildings in the City of Toronto"

Table 1: Summary MURB Database Statistics

ENERGY DATA	Minimum	Maximum	Mean	Median
Total Annual Energy (kWh)	1,080,488	26,212,862	6,065,400	3,768,127
Energy Intensity (kWh/m^2)	87	1,010	339	301
Total Annual Electricity (kWh)	393,198	7,224,742	1,655,217	1,409,565
Annual Base Natural Gas (ekWh)	136,286	7,361,484	1,264,721	755,126
Annual Variable Natural Gas (ekWh)	120,740	17,089,350	3,145,463	1,722,214
Total Annual Natural Gas (ekWh)	257,026	24,450,834	4,410,184	2,463,730
GHG EMISSIONS DATA**				
Total Annual GHG Emissions (tonnes CO^{2}e)	106	5,544	1,053	661
From Electricity (tonnes CO^{2}e)	59	1,084	248	211
From Natural Gas (tonnes CO^{2}e)	47	4,460	805	449
WATER DATA				
Total Annual Water Consumption (L)	0	0	#DIV/0!	#NUM!
DESCRIPTIVE BUILDING DATA				
Date of Construction	1963	2003	1981	1981
Number of Floors	5	28	14	13
Number of Suites	12	339	158	156
Gross Floor Area (m^2)	3,345	35,869	16,788	14,190
Attributed Suite Size (m^2)	279	106	106	91

**Emission Factors Used:			
	Electricity	0.15	kg/kWh
	Natural Gas	1.879	kg/m^3
	Natural Gas	0.182	kg/ekWh

Table 2: Building Count by Air Conditioning and Space Heating Type

Building Space Conditioning Category	Number of Buildings in Database
Primarily Natural Gas Heating	14
Primarily Electrical Heating	2
Combined Natural Gas and Electrical Heating	5
Undetermined Heating System	18
Central Air Conditioning	7
Window Units	8
No Air Conditioning	6
Undetermined Air Conditioning	18

Figure 11: Database Summary Tab

The last tab in this workbook, the "MURB Audit Datasheet", is a three-page document that can be printed out and taken to site to assist with data collection.

6 Evaluating Retrofit Measures Using Energy Modelling

This section describes the energy modelling of possible retrofit measures for four buildings that were selected for detailed study. After first examining the rationale for the selection of these buildings, detailed characteristics of the buildings are described. Next, apparent inconsistent energy intensity data for two of the buildings are presented. Then, a discussion of how the four buildings were modelled using an energy simulation software package is presented. An important step in the modelling process is to iteratively adjust the default or standard input variables so that the modelling results are similar to the observed energy use of the buildings. Once the model results are in close agreement with the actual energy usage observed, a base case model is established. Using this base case model, various retrofit measures are evaluated based on their energy performance. This section concludes with a summary of the most promising retrofit measures.

6.1 Selection of Modelled Buildings

Figure 2, reproduced here for convenience from page 7 of this report, shows how the data set in the Refined Data Analysis Phase compares with the Toronto MURB population.

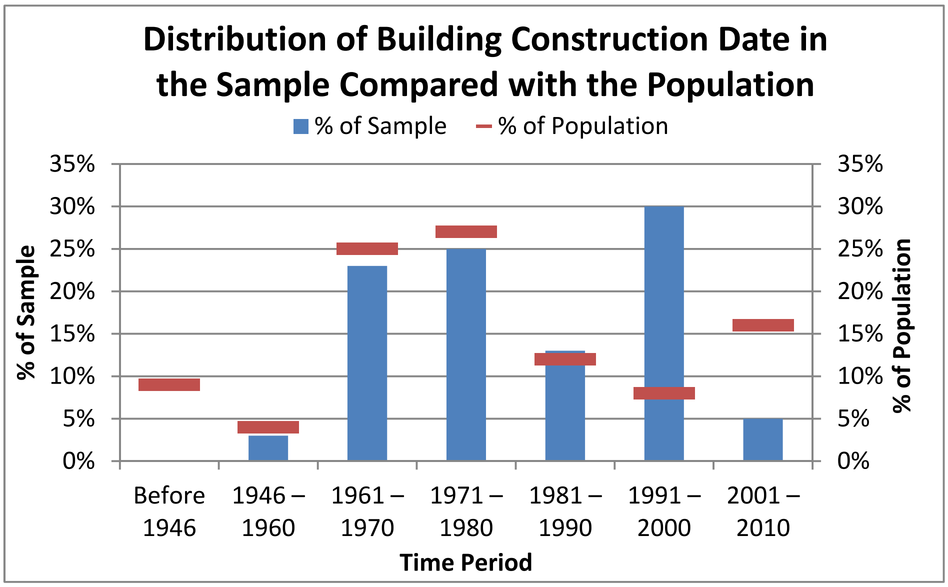

Figure 2 (Reproduced from page 7): Distribution of Building Construction Date in the Sample Compared with the Population

Of the four buildings selected, two are from the 1970's, as this vintage represents the largest proportion of buildings in the population. One building was included from the 1960's as this was the second largest group in both the sample and the population. The final building included in the detailed building energy modelling was from the 1980's. Based on their year of construction, these buildings have been labelled: 1960, 1970a, 1970b, and 1980.

Though buildings from the 2000's represent a greater proportion of the population than the 1980's buildings, they are under-represented in the sample. However, a 1980's building was chosen instead of a 2000's building because it was thought to have similar characteristics to the 1970's set and therefore, by using a 1980's building, it was possible to carry out a detailed retrofit analysis of a continuous 30-year block of buildings. Furthermore, buildings constructed from 1960 to 1989 are already candidates for significant retrofits to address issues such as water ingress and mechanical system inefficiencies. Opportunities for significant energy retrofits will present themselves as mechanical and envelope components reach the end of their respective service lives. Since it is unlikely that buildings from the 2000's would be undergoing such major retrofits this soon after construction, these buildings were not considered in this phase of the study.

The variables found to be most significant in the Refined Data Analysis Phase were the window and heating system characteristics. These two significant variables should be considered when selecting building typologies. The buildings selected have fenestration ratios ranging from 16% to 33%. Two of the buildings have single-glazed windows and two have double-glazed low-emissivity windows. Rated or estimated boiler efficiencies range from 70% to 85% and heating system types include fan coil units and hydronic baseboard radiators.

6.1.1 Data Collection

The most important criterion for selecting buildings to model, apart from the vintage grouping discussed above, was the availability of detailed building information and drawings. There were surprisingly few buildings in the data set that fell within the identified vintage category and for which detailed information about the building systems and accessible drawings were available. In order to model a 1980's building, information was gathered from outside of the original data set.

The data sources for each building are shown in Table 3.

Table 3: Building Data Sources

Building Name	Data Sources
1960	(ARUP, 2010)
1970a	(Tzekova, Pressnail, De Rose, & Day, 2011), Building drawings, Energy bills
1970b	(Mann Engineering, 2010), Building drawings, Energy bills
1980	Building drawings, Energy bills

In all cases, this data was supplemented with online research tools such Google Maps and Google Streetview. Building details such as the number of window air conditioners, the colour of the building envelope and the presence of exposed slab edges were verified. These resources were also used to verify that the drawings were in general conformance with the actual building.

6.1.2 Building Details

A summary of the basic building characteristics determined from drawings, audit reports and other sources is provided in Table 4.

Table 4: Building Characteristics

Name	Year Built	Size	Envelope	Heating	Cooling	Ventilation
1960	1967/ 1969	17 above ground (A/G) floors 192 units	Concrete masonry unit (CMU) with 1" exterior insulation, vented masonry facade	Hydronic Baseboard Radiators (2x3.5MBTU)	No central, data indicate some window A/C	Unconditioned make-up air (MAU)
1970a	1971	22 A/G floors 122 units	CMU with 2" EPS interior insulation, masonry facade	Hydronic Baseboard Radiators (1&1.5MBTU, η= 85%)	No central system on drawings, data indicate some A/C	Conditioned MAU
1970b	1977	25 A/G floors 193 units	Steel stud wall with 2" of insulation, metal cladding	Vertical Fan Coil Units (2x3MBTU, η= 70%)	Vertical Fan Coil Units	Conditioned MAU
1980	1984	4 A/G floors 71 units	Steel stud wall with brick veneer, no insulation indicated	Hydronic and Electric Baseboard Radiators	No central system on drawings, data indicate some A/C	Unconditioned MAU

More detailed information about each building modelled can be found in Appendix E. All building data provided were incorporated into the model with one exception. The drawings for Building 1980 did not indicate any insulation. The authors believed that this was unlikely and therefore the building was modelled with the same level of insulation found in the 1970's buildings. For some of the modelling software parameters, no building data were available. In these cases, the auto-sizing or default items were used. For example, no boiler information was provided for Building 1980 so the boiler was auto-sized and then the efficiency was determined during the natural gas calibration process described in the section below. Even if the boiler efficiency was available and used in the model, it is unlikely that this efficiency is the true efficiency of the heating system for reasons already discussed in this report. Only the audit report for Building 1970b included a rated efficiency and then an estimated current efficiency.

Unlike the other high-rise buildings selected, Building 1980 is a low-rise MURB. It was selected because it was the right vintage, and because of the timely availability of data for the building. Low-rise MURBs were included in the Meta-Analysis but were not used in the Refined Data Set Analysis in order to focus on mid- and high-rise MURBs. However, Building 1980 does provide an interesting contrast to other high-rise buildings because of its vastly different aspect ratio.

Most of the suites in each of these buildings were two-bedroom which is a common characteristic of buildings from this era that were designed with families in mind.

6.2 Energy Intensity Variations of the Modelled Buildings

Figure 12 shows the total annual energy intensity for each of the selected buildings along with the proportion of natural gas and electricity usage.

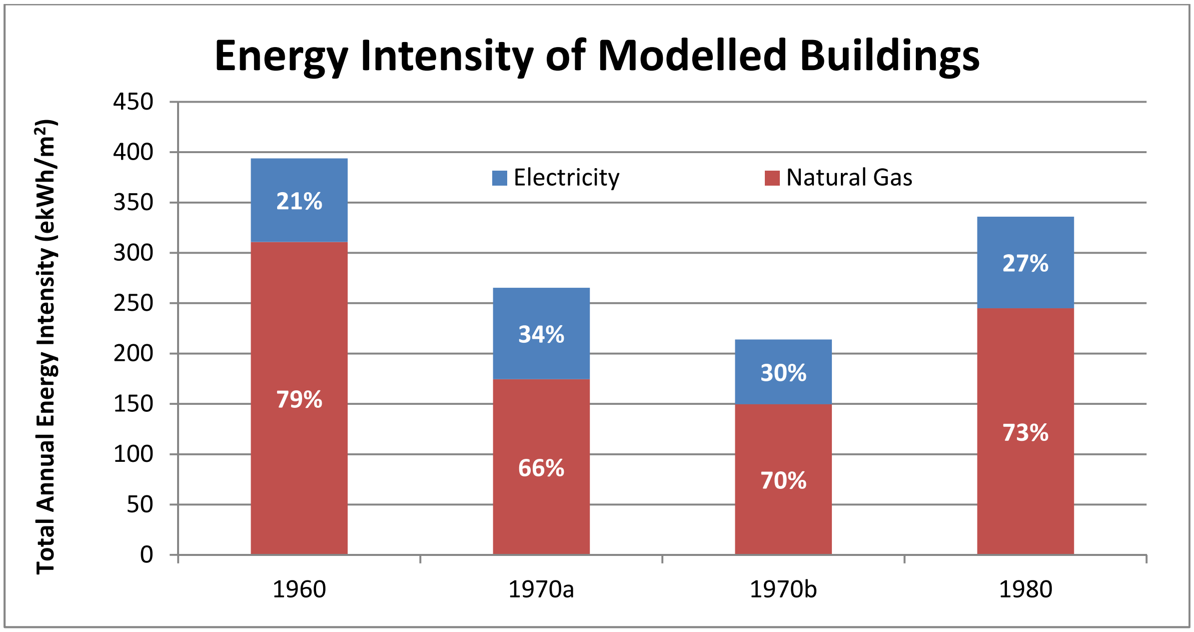

Figure 12: Annual Energy Intensity for Modelled Buildings

It is immediately noticeable that energy intensity varies significantly from building to building. The high proportion of natural gas consumption is also evident. Relative to the energy mix of apartment buildings in Ontario: 34% electricity and 66% natural gas (NRCan, 2008), the natural gas consumption of this small sample is higher (28% electricity and 72% natural gas). This could be due to the fact that all four buildings are heated primarily by natural gas.

The previous Meta-Analysis Study introduced a hypothesis that sought to explain the relationship between the year of construction and the energy intensity. It was thought that the reason for greater energy intensity in older buildings was due to aging, less efficient mechanical equipment and a deteriorating envelope. The reason given for the increasing energy intensity following the 1970's was thought to be due to the increasing fenestration ratios common in more modern construction.

Though perhaps coincidental, the relationship between vintage and energy intensity found in the four selected buildings is similar to the average energy intensity by vintage found for the 40 buildings in the Meta-Analysis Study as shown in Figure 13.

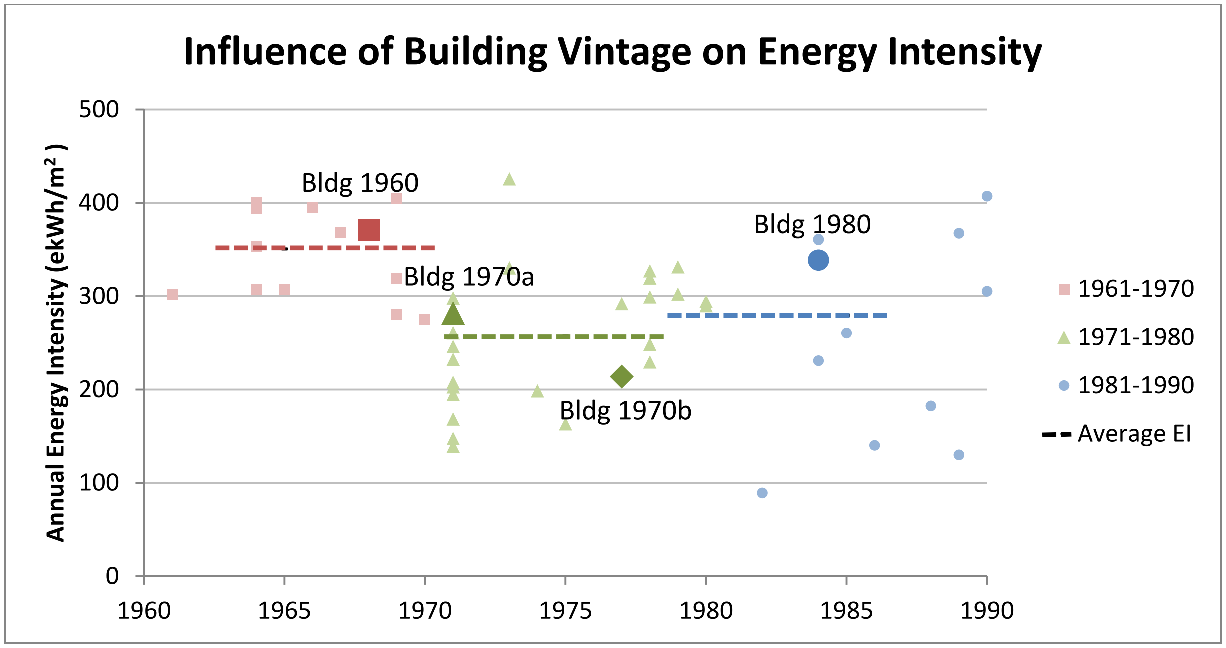

Figure 13: Energy Intensity of Modelled Buildings Compared with Meta-Analysis Buildings

It is particularly interesting to note that Building 1970b has a lower natural gas intensity than Building 1970a. Though Building 1970b has similar wall insulation levels and infiltration rates, it also has older single-glazed windows, a less efficient boiler and a higher fenestration ratio than the 1970a building. Taken together, Building 1970b should use more energy than Building 1970a. A few differences that may explain the lower energy intensity of the Building 1970b include the building shape and occupants. The floor area of Building 1970b is almost three times larger than the floor area of 1970a but the surface area-to-volume ratio of Building 1970b is about 20% lower, meaning 1970b has a more compact, and therefore more energy-efficient form. Aside from the poor windows, when normalized by floor area the roof, wall and infiltration losses are less in Building 1970b. Building 1970b is also occupied predominantly by senior citizens, which is likely one of the major reasons for the lower DHW load in this building.

The preceding discussion illustrates the point that there are many reasons why similar buildings will have different energy intensities. While such variations make predicting energy savings due to retrofit measures challenging, as shown in the sections that follow, reasonable model predictions of the incremental savings can still be made so long as models are properly calibrated using actual energy consumption.

Based on the energy intensities presented in Figure 13, it illustrative to also examine the emission intensity of the four selected buildings, as shown in Figure 14.

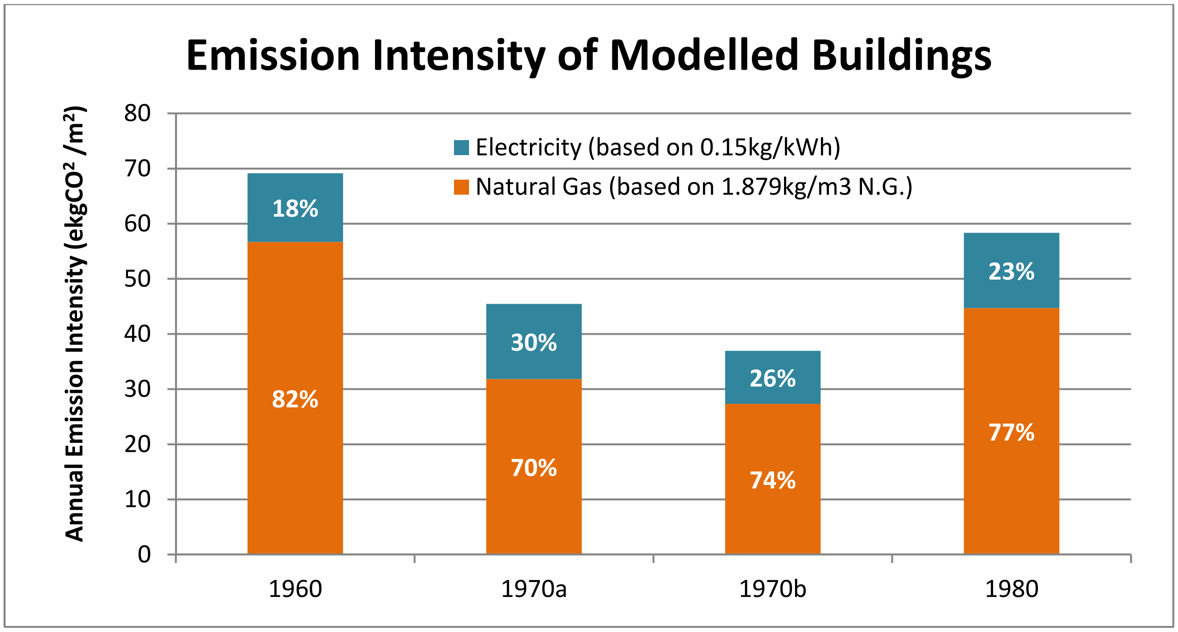

Figure 14: Annual Emission Intensity for Modelled Buildings

Assuming one cubic metre of natural gas yields 10.3kWh of energy, on a per kilowatt-hour basis, the use of natural gas is more emission intensive than electricity. Given the high proportion of natural gas consumption in these buildings, it is evident that, in order to significantly reduce the CO_2 emissions associated with building operation, natural gas savings measures should be targeted.

6.3 Model Setup

This section begins by examining how the modelling software was selected. Next the energy model is calibrated for the four selected buildings. The calibration method is outlined as the building input variables are adjusted until the model results are in close agreement with the actual energy usage. At this point, a Base Case energy model exists which can be subsequently varied to evaluate the energy savings potential of various retrofit measures.

6.3.1 Software Selection

The Quick Energy Simulation Tool (eQUEST), developed by the U.S. Department of Energy (DOE), was used to model the energy performance of the MURBs in this study. eQUEST is a free building energy simulation software available for download online that is commonly used in industry. eQUEST was chosen because it is a whole-building energy simulation program that can easily adapt to different levels of input detail (in the schematic and detailed modes) depending upon the level of detail of the building information available in this study. eQUEST is also easy to use and has “wizards” and help menus that assist the modeller (U.S. Department of Energy, 2011). For these reasons and the disadvantages of other programs discussed below, eQUEST was chosen to model the buildings in this study.

EE4 is another commonly used program for building energy analysis offered by Natural Resources Canada’s Office of Energy Efficiency. It automatically generates a base building to verify compliance with the Canadian Model National Energy Code for Buildings (MNECB), which was not required for this study. EE4 is a simple program that is limited since it cannot model all mechanical system types. Advanced modelling know-how is required to work around these limitations.

EnergyPlus is another DOE program widely used for energy consumption analysis. However, it was not chosen for this study because it is too complex for the limited information gathered on the buildings sampled.

TRNSYS is another program that was considered for use in this study but like EnergyPlus, inputs are very detailed and require more information about the buildings than was available. Another disadvantage of using TRNSYS is its relatively high cost.

6.3.2 Base Case Energy Model Generation

Having chosen to use the eQUEST software, a base case model for each building was developed. This was accomplished by refining the input variables in eQUEST until the model output closely agreed with the actual energy use. This step is commonly referred to as 'calibration.'

Any energy model is only an estimate of how energy is being consumed in a building. Schedules and loads vary from day to day and, without detailed sub-metering, it is impossible to know how each end-use is contributing to the overall energy load. However, all available data were incorporated into the model. Next, unknown items were estimated from drawings, photos and other sources, where applicable. While, eQUEST default values were used for all remaining unknown parameters. The model was then run using the CWEC file for Toronto and the results were compared with the weather-normalized actual energy data before any further changes to the model were made. The goal was to adjust the unknown parameters iteratively and systematically until the model energy use was in close agreement with the actual energy use.

Three of the four buildings were modelled using the simpler schematic mode in eQUEST. Given the complexity of the HVAC system in Building 1970a, the detailed mode had to be used. The modelling and calibration procedures are outlined below.

The first step was to weather normalize the energy-use data. All four buildings had natural gas heating as the primary system, so the natural gas data were normalized to the standard weather year using heating degree days (HDD) with a base of 18°C. Electricity consumption can be related to air conditioning loads as well as heating loads which, in the case of these buildings, would be supplementary electric resistance heating. Building 1980 was the only building with some electric baseboard heaters installed in addition to hydronic radiators. However, the electricity profiles of some of the other buildings indicated that supplementary electric heating was likely used by some of the residents.

Therefore, electricity use data were weather normalized considering both HDDs and cooling degree days (CDDs). Three weather normalization processes were completed on the electricity data. One normalization process used HDDs only, one normalization process used CDDs only, and one normalization process used HDDs for the winter months (October to March) and CDDs for the summer months (April to September). The normalization process that yielded the highest coefficient of determination (R^2 value) was the normalization process that was selected for the particular building.

Due to the nature of the electrical loads in the each building, the selected normalization process was different for each building as shown in Table 5. The electricity normalization is described more fully in the procedure outlined in the Data Input Tool (Section 5.1) and in the full report from the Refined Data Set phase.

Table 5: Weather Normalization Processes for Electricity Loads

Building Name	Electricity Weather Normalization Process
1960	12 months normalized to HDD
1970a	Oct to Mar normalized to HDD, Apr to Sept averaged electricity use
1970b	Oct to Mar normalized to HDD, Apr to Sept normalized to CDD
1980	Oct to Mar normalized to HDD, Apr to Sept normalized to CDD

A sensitivity analysis of the weather normalization processes selected is shown in Appendix F in order to show the impact of comparing buildings that have been normalized differently.

6.3.3 Modelling of Natural Gas Load

The procedure for calibrating the model-generated base natural gas use with the actual base natural gas use began with adjusting the magnitude of the modelled domestic hot water load (DHW) load per person so that the model value output agreed with the average of the actual July and August natural gas load. The model DHW value for each building was compared with other sources to ensure that it was reasonable. It was found that, in order to match average July and August consumption, the modelled loads varied from 37 to 80 US gallons (USG) per capita per day with an average of 50 USG. Two studies cited (Aguilar, White, & Ryan, 2005) found average consumption values of 25 and 55 USG per capita per day but recognized that a number of factors affect the DHW load such as occupancy type, household income, water pipe leakage, water heating equipment and laundry appliances to name a few. Given the many factors affecting variability, the range found in the modelled size of the DHW load seems reasonable.

Variable or space heating natural gas consumption model output was then matched with the actual variable natural gas consumption. Where boiler size and efficiency were provided, the perimeter air-tightness value was adjusted to match the modelled natural gas profile to the actual profile. When only the boiler size was provided, both the efficiency and perimeter air-tightness were adjusted to fit the model. For Building 1980, no boiler information was available. In this case, the boilers were auto-sized and then the efficiency and perimeter air-tightness were adjusted. The resulting perimeter air-tightness values from each building were compared with experimental studies (Hanam, Finch, & Hepting, n.d.) to ensure the resulting value was within a reasonable range, as shown in Table 6.

Table 6: Modelled Envelope Air-tightness

Experimental Studies		Building Model	Modelled air-tightness values at ambient pressure
Air-tightness values from Hanam et al. (@ 5Pa)	**Level of Air Tightness**		
0.40 cfm/ft^2	Very Leaky	1960	0.40 cfm/ft^2
		1980	0.30 cfm/ft^2
0.20 cfm/ft^2	Leaky		
0.15 cfm/ft^2	Tight – High Average	1970a	0.135 cfm/ft^2
		1970b	0.13 cfm/ft^2
0.10 cfm/ft^2	Tight – Average		
0.05 cfm/ft^2	Tight – Low Average		
0.02 cfm/ft^2	Very Tight		

All building air leakage rates fell within the spectrum between “tight” and “very leaky” with Buildings 1960 and 1980 being more air-leaky than the 1970’s buildings.

It is important to note that there is a high level of uncertainty associated with these values, particularly where limited boiler information was available. Even boiler efficiency data taken from an audit report, as discovered in the Refined Data Set phase of this study, may not be indicative of the true efficiency of the heating system. In terms of the model, it is possible to increase the boiler efficiency while increasing the perimeter air leakage and then end up with a similar annual natural gas profile. Buildings 1960 and 1970b were the base case models with the highest and lowest air leakage rates, respectively. Figure 15 shows the base case model boiler efficiency and air-leakage rate for these buildings. Additional models were run with varying air leakage rates and then boiler efficiencies were used to calibrate natural gas use. Two alternative models for each building are also presented in Figure 15. The shaded band shows the resulting sensitivity of boiler efficiency to changing air leakage rates assuming that these rates are between the “Tight-Average” and “Very Leaky” ranges as shown in Table 6.

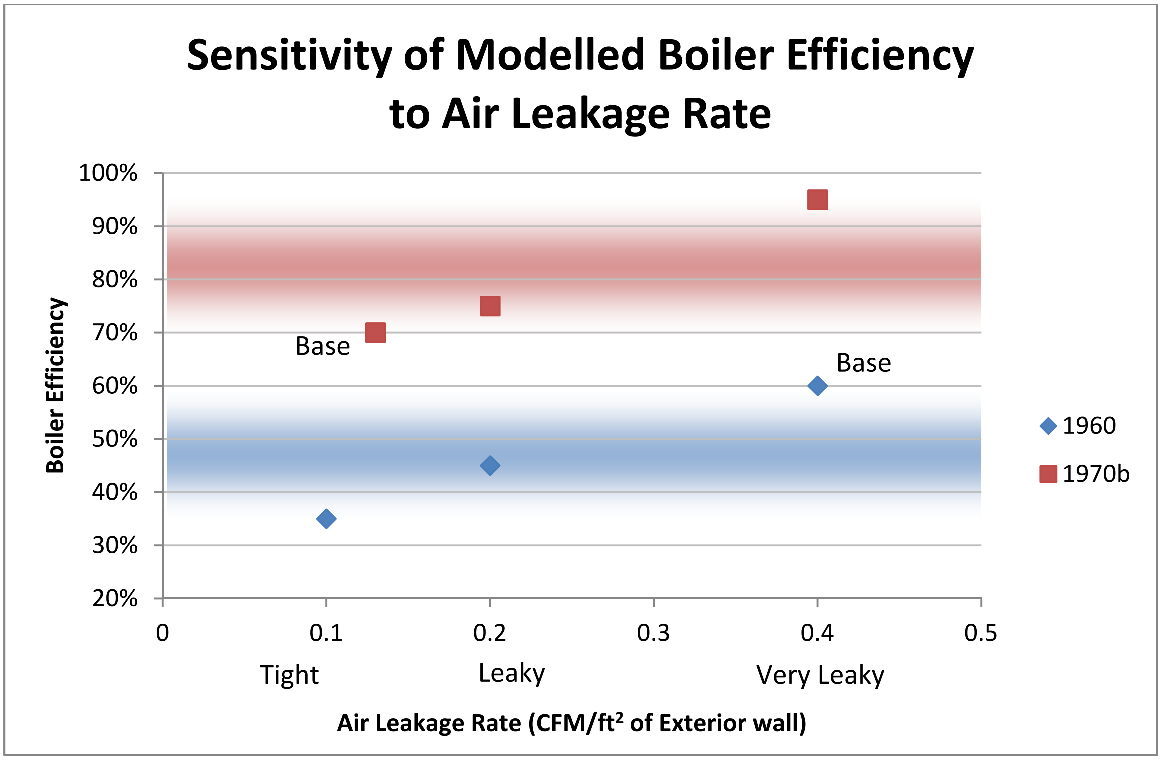

Figure 15: Sensitivity of Boiler Efficiency to Air Leakage Rate

Of course, the aim of this modelling exercise is to get the component heat losses in the model to match as close as possible with the actual energy use data. Once this is accomplished, energy savings associated with various retrofit measures can be reasonably predicted.

The resulting total modelled natural gas intensity for each building compared to the total actual natural gas intensity is shown in Figure 16. These graphs, along with tables of the monthly consumption values are shown in Appendix G. For each building, the absolute value of the monthly errors is averaged and is shown along with the total annual error or the difference between the total modelled consumption and the total actual consumption. On an annual basis, the models for Buildings 1960, 1970a and 1970b slightly underestimate the actual natural gas consumption of each building. This underestimate will likely make the variable natural gas retrofit savings estimates slightly conservative. The annual error for Building 1980 was 0%.

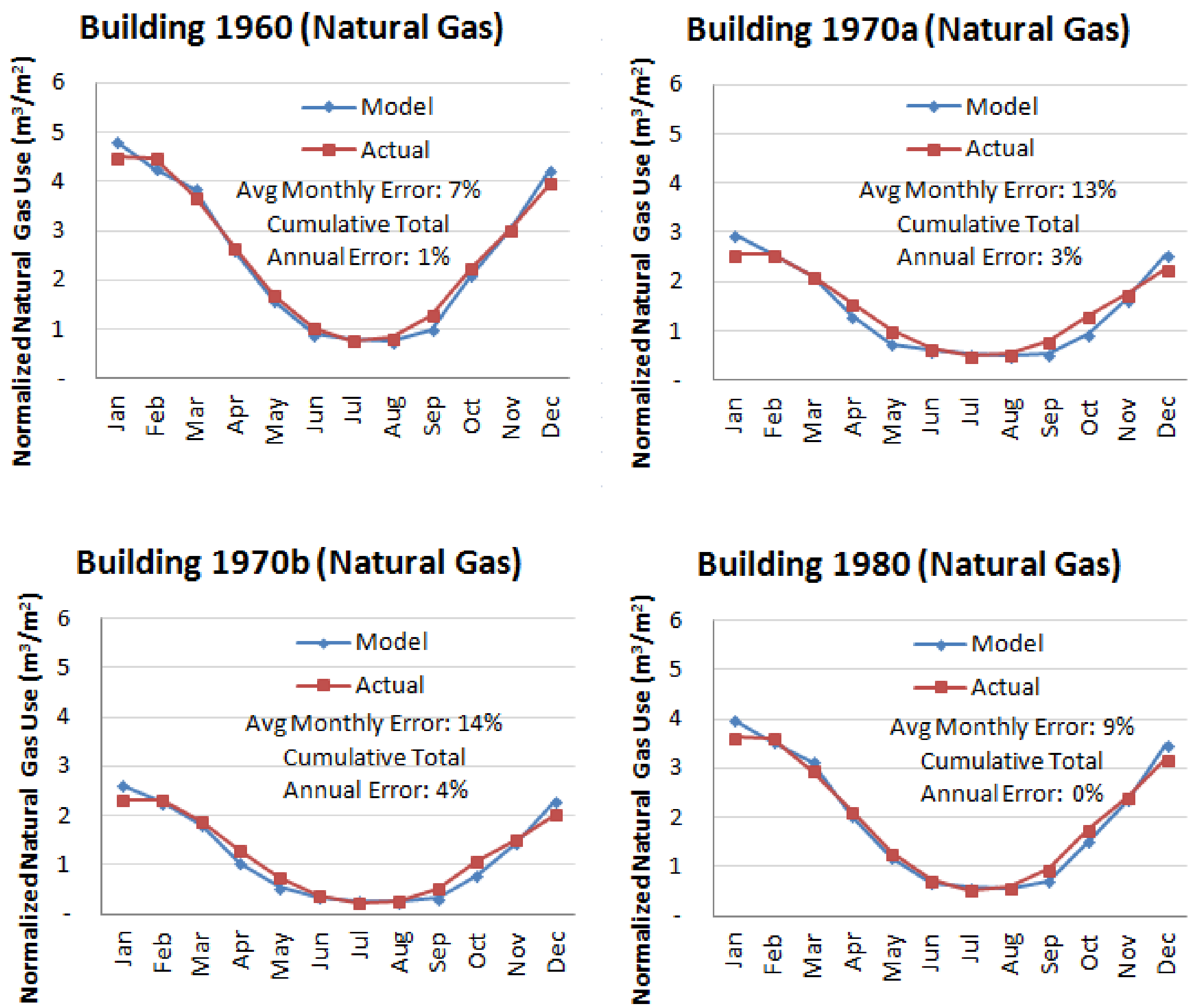

Figure 16: Comparison between Actual and Modelled Natural Gas Intensity

The modelled natural gas used agrees reasonably well with the actual energy use for each building. However, one source of error common to all of the models is that natural gas use is slightly over-estimated by the model in January and December. In some buildings there is also a slight underestimation of natural gas consumption in the shoulder seasons. This underestimation and the winter over-estimate could be due to differences between how the building operator and the model control the HVAC system. On average, the absolute value of the monthly error produced by modelling for the four buildings was 11%. The average annual cumulative error across the four modelled buildings was 2%.

6.3.4 Modelling of Electrical Load

Electrical plug loads are highly variable and difficult to separate out from whole-building electricity use. Through sensitivity testing, it was determined that the "daytime unoccupied" schedule allowed for better calibration of the models as opposed to the "24-hour operation" schedule. This is reasonable for residential apartment buildings, because the selected "day-time unoccupied" schedule lowers some of the occupant-driven loads during the daytime hours when occupants would be at work or school. This schedule type might not be the most appropriate for a building occupied predominantly by seniors such as Building 1970b but because plug load reductions are not the main focus of this exercise, the same schedule was used across all four buildings for consistency.

Default electrical and lighting loads from eQUEST were used for the most part except where explicit information was available about a building that allowed for a truer representation of the specific building. For example, Building 1970a has undergone an in-suite lighting retrofit so the loads in this particular building were reduced to account for the transition from incandescent to compact fluorescent lighting. The only other exception to the use of default electrical loads was higher miscellaneous loads in the apartment zone of Building 1980 which was done for calibration purposes.

The total monthly electrical load profile for each building is shown in Figure 17. These graphs, along with tables of the monthly consumption values are shown in Appendix G.

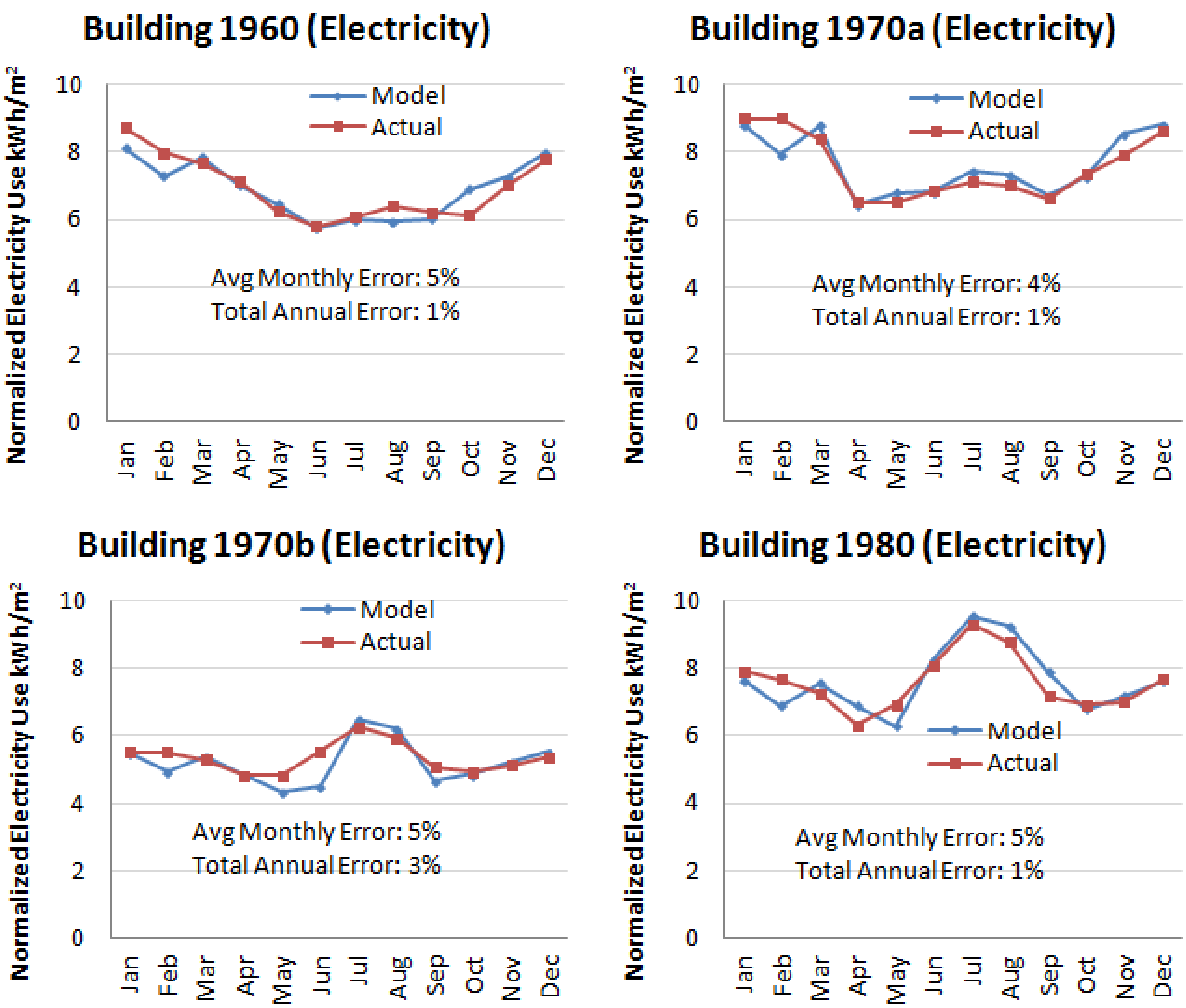

Figure 17: Comparison between Actual and Modelled Electricity Intensity

If the electricity profiles above resembled straight horizontal lines, this would mean that the electricity load for each building is independent of the changing weather throughout the year. Instead, all of the buildings exhibited some proportion of variable electricity load in the winter and/or summer months.

Some of the winter-time electricity consumption can be attributed to increased lighting load during the shorter periods of daylight. However, this weather-sensitive load can also indicate the presence of supplementary electric resistance heating in the winter and window air conditioning units in the summer. Buildings 1960 and 1970a both exhibit some variable load in the winter. It was possible to incorporate electric resistance heating in the model for Building 1960 but not for Building 1970a because of the HVAC system configuration. Therefore, cooking loads were used to increase the electricity load in the model in order to account for electric resistance heating in Building 1970a. The cooking load schedules were then modified so that the loads were minimized during the summer months, moderate during the shoulder season and maximized during the winter months until the modelled electricity profile was close to the actual usage. A discussion of the magnitude of the electric resistance heating loads is presented in Appendix H.

For Building 1970b, the only building with a central cooling system, the variable electricity is primarily related to cooling. As the electricity consumption of Building 1980 exhibits both cooling and electric heating, both were modelled.

6.3.5 Model Energy End-Use and Heat Loss Components

None of the building data included information about sub-metered energy use. Some energy end-use figures such as the contribution of domestic hot water load to total natural gas load can be estimated by examining the usage patterns throughout the year. But, with so many end-uses contributing to electricity consumption, it is difficult to estimate the contribution of individual end-uses without more detailed information being available.

It is important to have a reasonable energy end-use breakdown reflected by the models because each of the retrofit scenarios affects end-uses differently. So, in addition to the model calibration performed above, a breakdown of the energy end-use was carried out for each of the models, as shown in Figure 18.

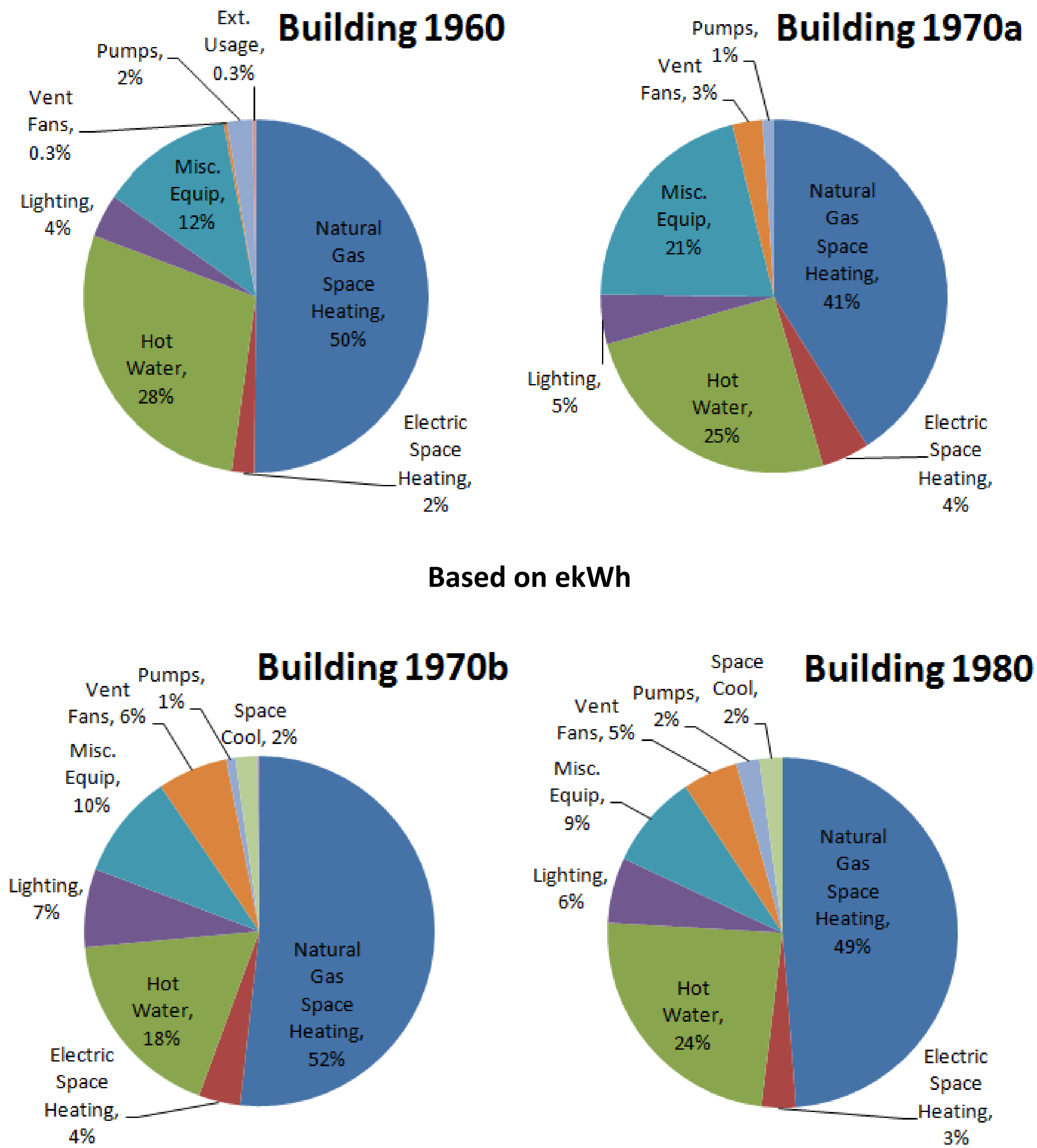

Figure 18: Energy End-Use Breakdown for Each Model

The breakdowns shown in Figure 18 compare favourably with the national data provided by Natural Resources Canada (2012) as shown in shown in Figure 19. From Figure 19, it is clear that the proportional split between energy end-uses is reasonable compared with data available on a national scale.

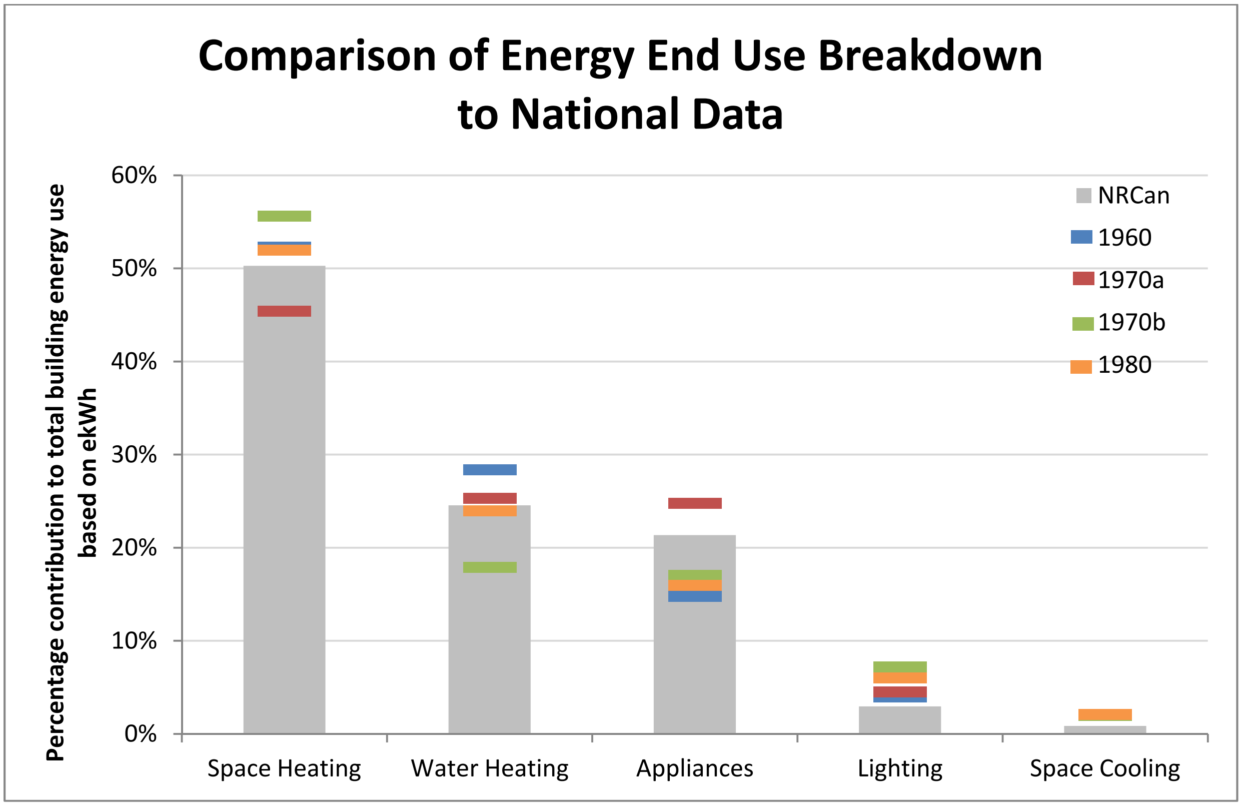

Figure 19: Contribution of End-Use Energy to Total Building Energy Use

It is also important to ensure the model is assigning energy losses to building components and systems in a way that is reasonable with regard to the characteristics of these components and systems. Figure 20 shows the percentage contribution of each building component and system to total building heat losses. The total heat losses are equal to the total energy input including natural gas and electricity, as well as solar, infiltration and occupancy gains. Thus, the percentage contribution of DHW load in Figure 18 is different from the DHW load shown in Figure 20. In other words, the total energy use in Figure 18 is based on only utility consumption while the total energy use in Figure 20 is based on utility consumption in addition to solar, infiltration and occupant gains. Envelope component losses, infiltration and DHW losses were determined from the eQuest simulation reports. Ventilation losses were estimated as the total energy input minus the envelope, infiltration and DHW losses.

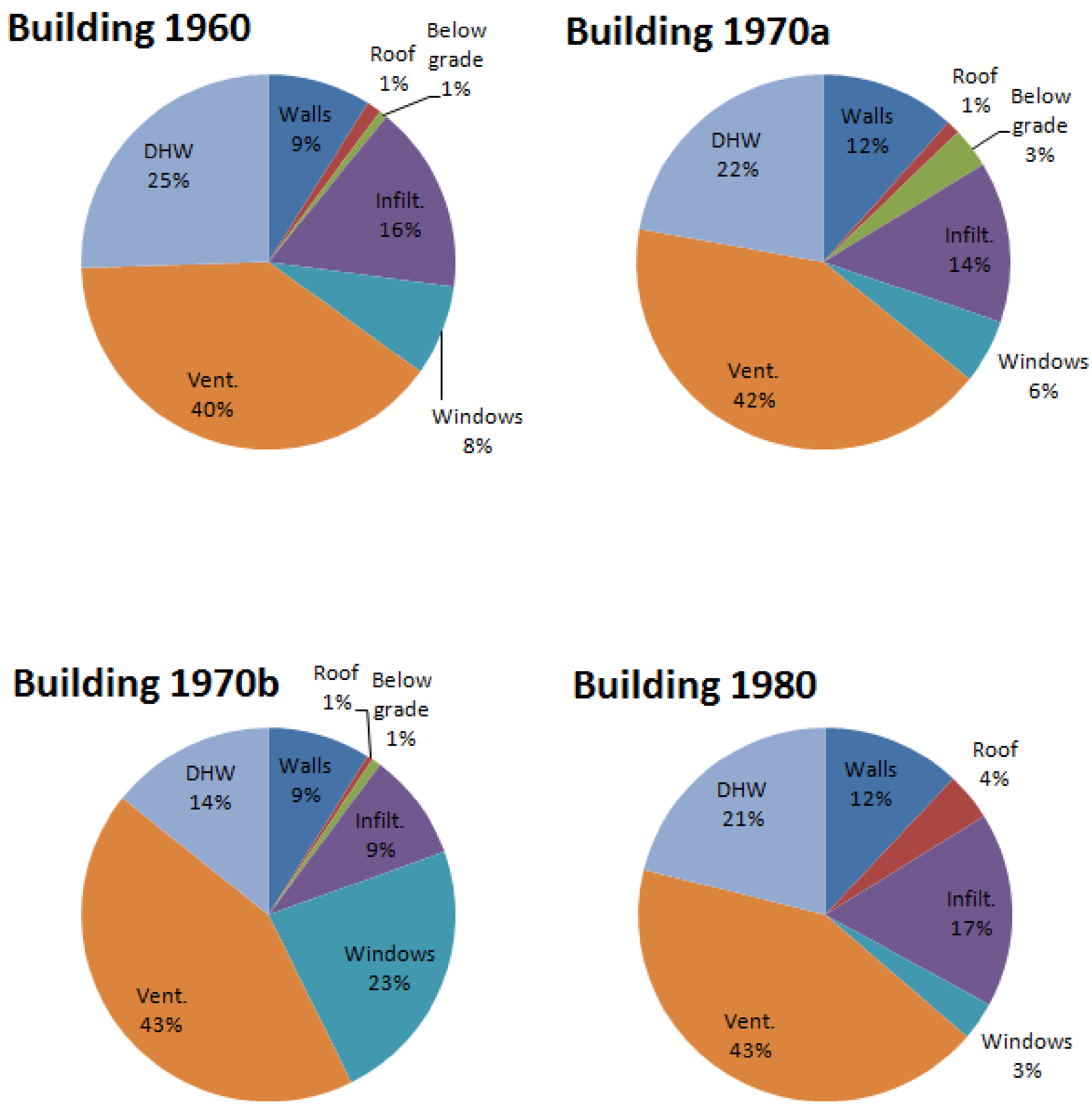

Figure 20: Contribution of Building Components and Systems to Total Building Heat Loss

As shown in Appendix E, Building 1980 has a rather complex form which was not possible to model in the schematic mode of eQuest. Therefore, an "equivalent" building was generated with similar envelope area components, orientation and volume. A consequence of this equivalent building is that the model does not include a below-grade wall. From the drawings, this would have been about half of one storey but putting an entire storey underground to account for this would have underestimated the above grade wall losses. Thus, a conservative approach was used where the above grade heat loss is slightly overestimated for this particular model.

6.4 Retrofit Measure Selection

The retrofits chosen can be grouped into three categories: improvements or changes in operation of the HVAC system, envelope improvements and reductions in electrical loads. The specific retrofit measures in each category were determined by reviewing of published reports on MURB retrofits, [including (ARUP, 2010), (Genge & Rousseau, 1996) (Canada Mortgage and Housing Corporation)] and the options within eQUEST. Where particular values had to be selected such as air-tightness and boiler efficiency, additional research sources were sought to determine appropriate values for model input. Table 7 shows a list of all of the retrofit measures tested.

Table 7: Retrofit Measures Tested

Category	Element Retrofit	Base Case	Retrofit Range
HVAC	Corridor supply air temperature	Heating 68F, Cooling 78F	Heating 64F, Cooling 82F Heating 60F, Cooling 86F
	Boiler efficiency	60-85%	65%, 70%, 75%, 80%, 85%, 90%, 95%
	Fan type	Constant	Variable Speed
	Fan efficiency	Standard or High	Premium
	Pump efficiency	Standard or High	Premium
Building Envelope	Air-tightness of envelope	0.13-0.4 cfm/ft^2	0.05,0.10, 0.15, 0.20, 0.30 cfm/ft^2
	Windows	Single-glazed clear, Double-glazed low-e	Double-glazed low-e Triple-glazed low-e
	Exterior insulation	1-2” polystyrene with exposed slab edge	2-3” polystyrene with insulated slab edge
	Roof insulation	1-3” polystyrene	2-4” polystyrene
Electrical Loads	Common area lighting	T12 (40W)	T8 (32W)
	Suite lighting and plug loads	Mostly default loads	Reduce by 10-30%

6.5 Retrofit Measure Modelling

The following sections detail how each retrofit measure was modelled and the resulting predicted energy-use of the four buildings. Modelling results are presented in terms of energy intensity so that the buildings can be directly compared. Further, electricity and natural gas intensities are separated so that the impact of a retrofit measure on a particular utility can be determined. In the figures that follow, a percentage reduction relative to the base case energy consumption for each retrofit measure has been presented.

In most cases, the “base case” used in making retrofit comparisons is the calibrated energy model presented in Sections 6.3.3 and 6.3.4. For some buildings that have already undergone retrofits of certain components, a “reverse retrofit” scenario was modelled for illustrative purposes only. For these cases, the calibrated base case and the reverse retrofit are indicated on the relevant graphs. For all other cases, the base case is the model version with the highest energy intensity. Accordingly, in most cases, the legend on each graph begins with the base case and progresses to the most energy-efficient retrofit scenario.

Only the retrofit measures that impacted total building energy intensity by more than 1% are presented here in detail. The retrofit measures from Table 7 which impacted the building energy-use by less than 1% are discussed briefly at the end of the section.

6.5.1 Boiler Efficiency

The natural gas heating systems originally installed in many of the buildings in this study were conventional gas-fired boilers. Conventionally-vented gas boilers are less efficient than today's high-efficiency condensing or near-condensing gas boilers because they recover less heat following the combustion process; thus the naturally-vented flue gases are hotter. This means that more heat is wasted as hotter flue gases and dilution air leaves the building.

The audit reports from some of the buildings indicate that boilers have been replaced since construction but also indicate that all of the boilers are currently natural draft. New non-condensing boilers have rated efficiencies typically in the range of 70-85% while the actual efficiencies of the original boilers found in some of these buildings can be much lower (Natural Resources Canada, 2009). The rated efficiency is the efficiency of the boiler when it was new and if it was operating under optimal conditions but the efficiency declines as the boiler ages. The rate of efficiency decline depends on maintenance practices, boiler use patterns, the type of boiler and the boiler system configuration. It is not known whether the boiler efficiencies provided for each building are rated or estimated. Due to the uncertainty surrounding actual heating system efficiency, it is important to determine the actual performance of the system before deciding on retrofit options.

A boiler "tune-up" could be a reasonable first step to efficiency improvements before complete replacement. This tune-up of the existing system can involve: adjusting the air-fuel mixture for safer and more efficient combustion (Environmental Protection Agency); reducing stack temperatures (Lobenstein, Hewett, & Katrakis, 2010); cleaning the heat transfer surfaces for more efficient heat transfer (Harrell); and adjustments to cycle and reset controls (Lobenstein et al., 2010). Savings from a tune-up have been estimated at 4-5% of heating energy-use (Lobenstein et al., 2010).

To estimate the reduction in natural gas use due to improvements in the efficiency of natural draft boilers, the baseline models with boiler efficiencies lower than 85% were modelled using boiler efficiencies in increments of 5%. The resulting total natural gas savings and space heating natural gas savings are shown in Figure 21 and Figure 22.

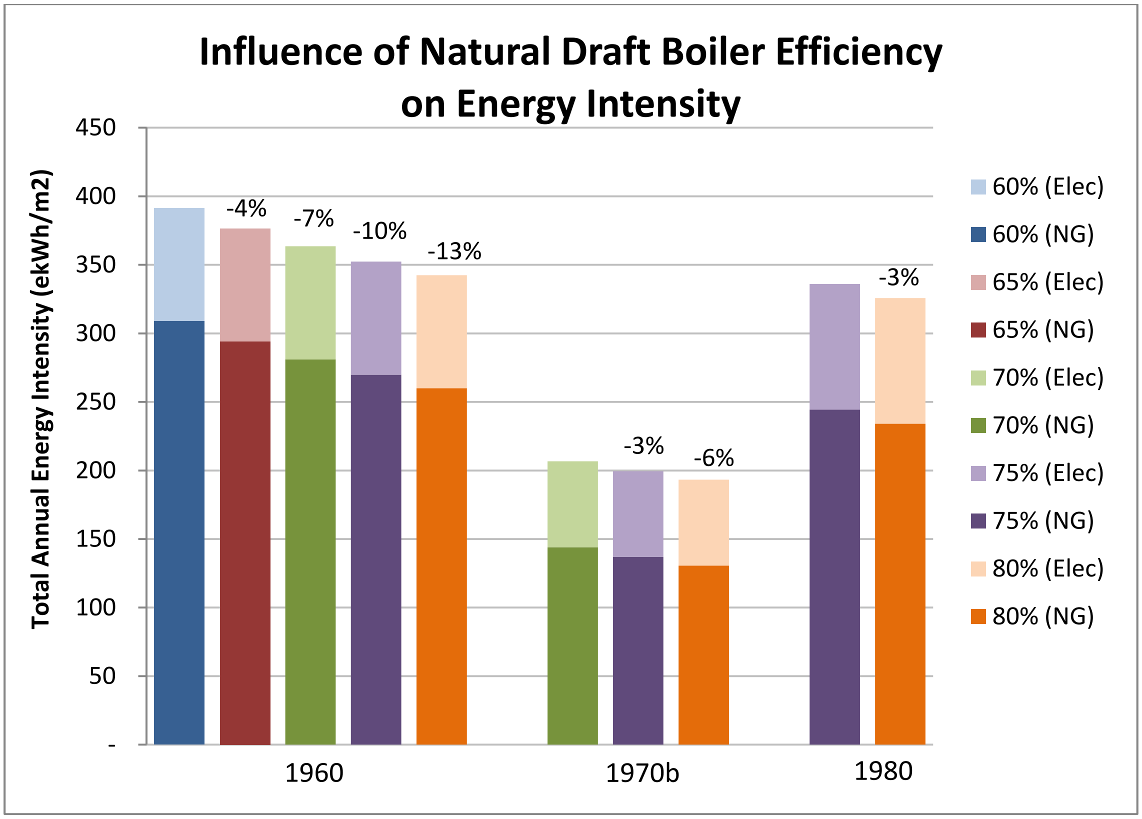

Figure 21: Influence of Natural Draft Boiler Efficiency on Energy Intensity

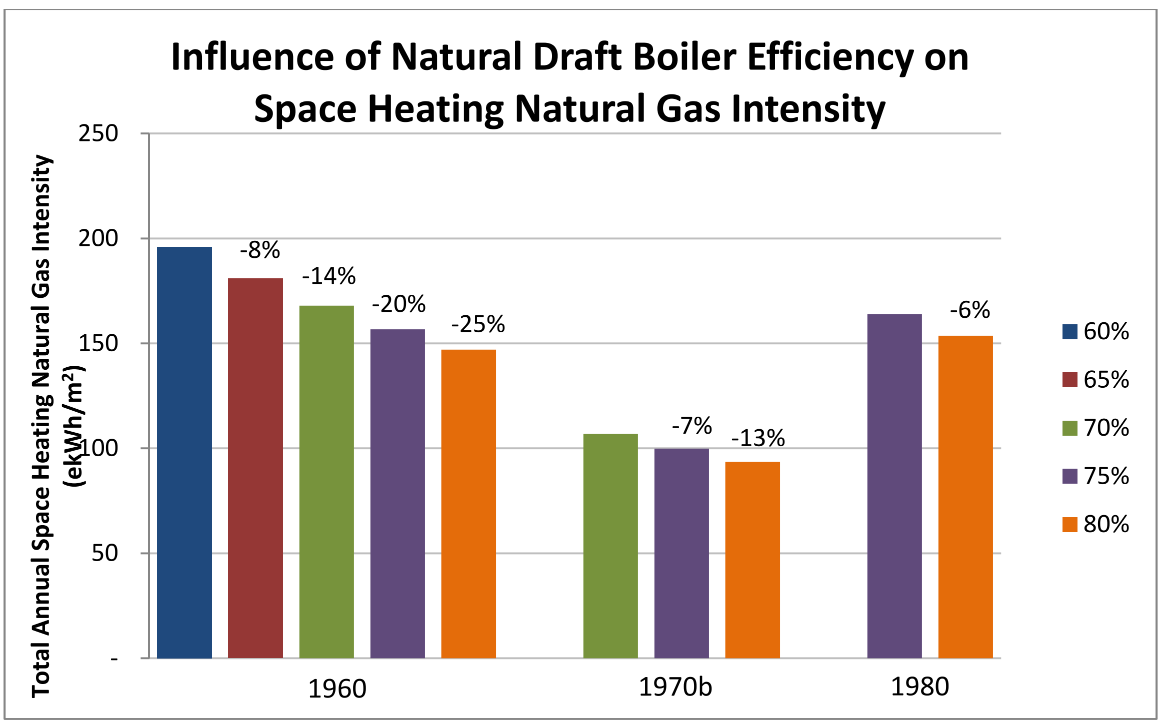

Figure 22: Influence of Natural Draft Boiler Efficiency on Space Heating Natural Gas Intensity

As introduced above, once source notes that the efficiency gains from a boiler tune-up could result in up to a 5% reduction in space heating natural gas use. As shown in Figure 22, an incremental improvement in boiler efficiency of 5% would have a similar percentage reduction in terms of space heating natural gas use in the model. For Building 1960, it is unlikely that changes to the existing system could achieve the greatest efficiency gains shown in Figure 21 and Figure 22 but the higher efficiencies were shown here to allow comparison with Buildings 1970b and 1980.

High-efficiency condensing gas systems are more efficient than conventional systems because they extract more heat from the combustion gases by cooling the combustion gases to the point where some of the combustion products such as moisture, actually condense. Since these high-efficiency systems have cooler flue gases, an electric powered fan is used to directly vent the combustion gases. As a venter motor controls the flow of combustion air through the burner, high-efficiency systems no longer require an atmospheric damper. This means that there are no longer any dilution air heat losses. These condensing boilers can have efficiencies ranging up to 95% (Durkin, 2006). Such boilers are typically used for retrofits today.

In eQUEST, boiler efficiency is defined as the total heat input to the boiler less the heat lost with the flue gases (U.S. Department of Energy, 2010). Accordingly, regardless of whether the boiler is modelled as a natural draft or a condensing type, for a given efficiency, the modelled energy-use should be the same given this definition as shown in Figure 23.

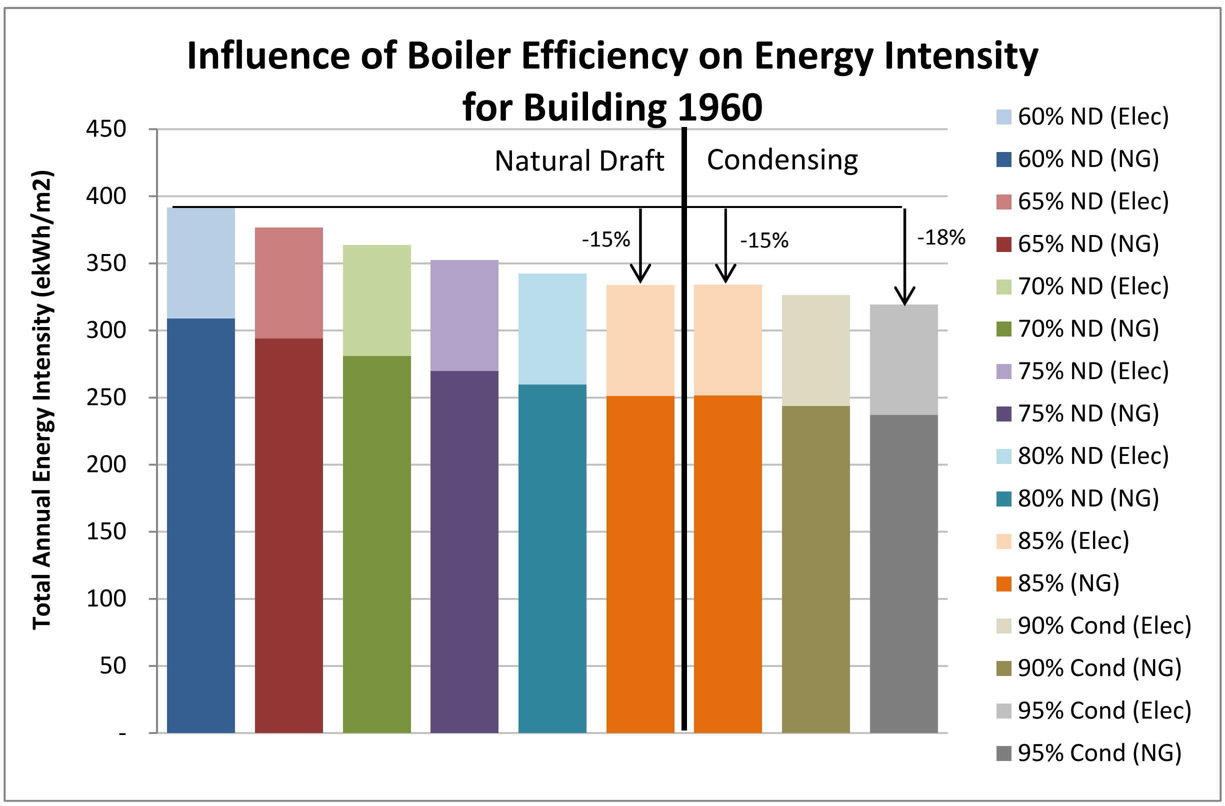

Figure 23: Influence of Boiler Efficiency on Energy Intensity for Building 1960

Beyond a tune-up or when the boiler has reached the end of the service life, boiler replacement is an option. The need for a boiler retrofit should be carefully assessed on a case-by-case basis. To examine the potential impact of this type of retrofit on the four buildings, the condensing gas boiler efficiencies in the models were varied between 85% and 95%. Figure 24 shows the energy intensity associated with the original base case natural draft (ND) boiler efficiency and the three condensing boiler scenarios.

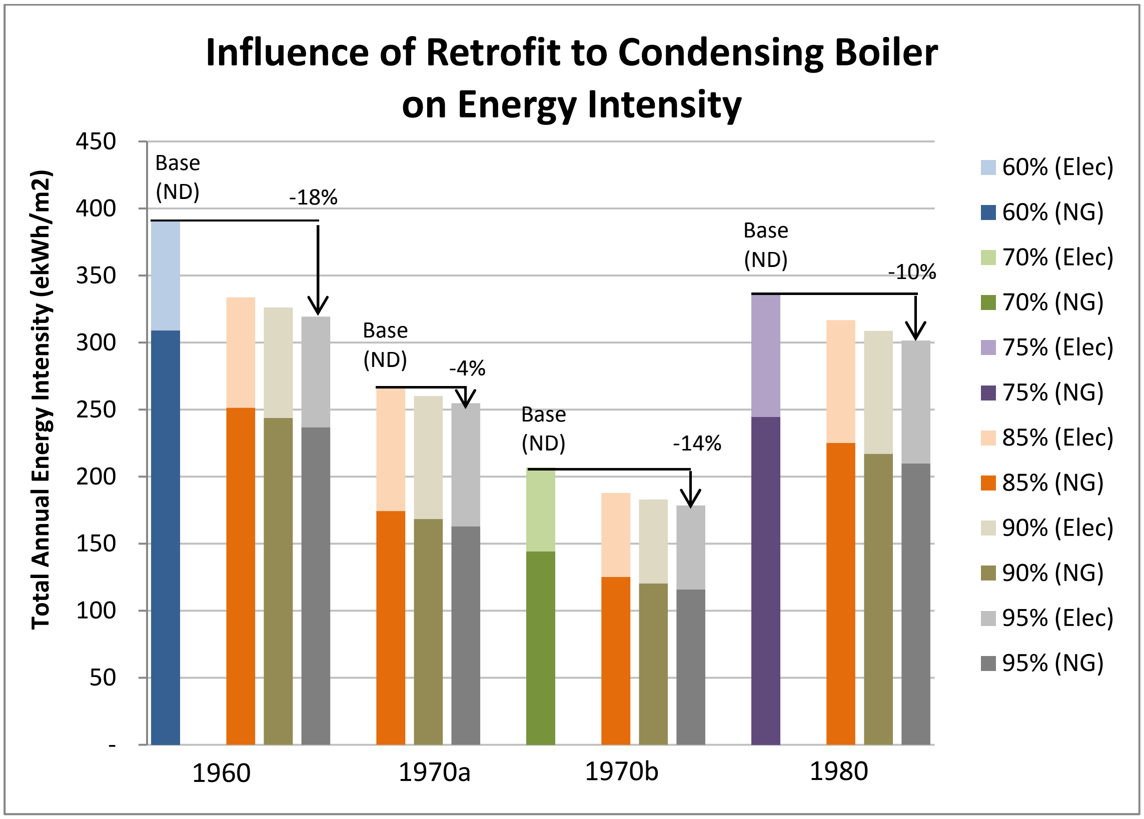

Figure 24: Influence of Retrofit to Condensing Boiler on Energy Intensity

Buildings with the least efficient boilers would see the greatest reductions in natural gas use by switching to a higher efficiency boiler. However, greater reductions may be possible if the original boiler efficiency estimate was higher than the actual efficiency or if the act of retrofitting the boiler leads to other adjustments and changes in controls that reduce natural gas use. It is also possible that an efficiency gain may not result in natural gas savings as expected if boiler operation is not optimized. The charts above provide an indication of improvements in total energy intensities and natural gas intensities when boiler efficiencies are improved. However, an accurate assessment of heating system performance is essential in order to determine a meaningful estimate of the impact of a contemplated boiler retrofit.

6.5.2 Envelope Air Leakage

The air-tightness of a building envelope can have a significant influence on energy use. Particularly in high-rise MURBs, air-tightness is very important because large differential air pressures occur across the envelope due to stack effect. Stack effect is driven by the buoyancy of air and stack pressure differences are a function of building height and the magnitude of the difference in temperature between the inside and outside temperatures. For example, on a winter day, warm air inside the building rises and escapes through cracks and openings near the top of the building. This air is replaced by cold air infiltrating near the bottom of the building. While stack pressure differences can be reasonably estimated and even measured, it is the area of the envelope leakage openings that are difficult to estimate. Field testing is the most effective way to estimate the area and location of leakage openings in a MURB envelope, but field testing is difficult and expensive to conduct. During the natural gas calibration process, the envelope air leakage rate was adjusted to align the modelled variable natural gas consumption with the actual consumption. The resulting modelled air leakage values are shown in Table 8 along with boiler efficiencies and glazing type. Some illustrative calibration decisions using these parameters will be discussed below.

Table 8: Modelled Air Leakage Compared with Other Building Characteristics

Building	Modelled Air Leakage	Qualitative level of air-tightness	Boiler Efficiency	Boiler efficiency Source	Glazing
1960	0.40 cfm/ft^2	Very Leaky	60%	Calibration	Single
1970a	0.135 cfm/ft^2	Tight – High Average	85%	Audit	Double
1970b	0.13 cfm/ft^2	Tight – High Average	70%	Audit	Single
1980	0.30 cfm/ft^2	Leaky to Very Leaky	75%	Calibration	Double

The air leakage rate included in the Building 1960 model seems reasonable given the age of the building and the existence of single-glazed window units. As well, the calibrated boiler efficiency is relatively low, which means that both the boiler and the air leakage are contributing to the variable natural gas component of energy use. For example, if the unknown boiler efficiency was modelled as 85%, then the air leakage rate would have to be disproportionally high to account for the natural gas use. Since neither piece of data is known with certainty, both were chosen to be within the reasonable range expected for this type of building.

The provided boiler efficiency for Building 1970a was included in the model and therefore, only the air leakage rate was adjusted to fit the modelled natural gas curve to the actual gas usage. The resulting air leakage rate that was found, is typical of a fairly tight building. This is reasonable because Building 1970a is the only building that has undergone air sealing measures. Measures undertaken at Building 1970a include separation of the parking garage from the remainder of the building; sealing all doors to the exterior and vertical chases through the buildings such as garbage chutes, stairwell and fire/electrical cabinets (Tzekova, Pressnail, De Rose, & Day, 2011). This building also underwent window replacement which can affect air-tightness as well.

The boiler efficiency provided for Building 1970b was also included in the model but the resulting air leakage rate seems relatively low considering the window characteristics and the results from Building 1970a. However, while both values are highly uncertain, both values fall within a reasonable range.

Similar to Building 1960, there was no information available about boiler efficiency in Building 1980 so both efficiency and air leakage were used to calibrate the modelled natural gas profile to the actual profile. The resulting boiler efficiency was moderate and the resulting envelope was found to be leaky.

These values seem reasonable because there were no known retrofit measures related to either of these components.

Figure 25 shows the base case energy intensity as well as the difference in energy intensity between the base case and the retrofit cases.

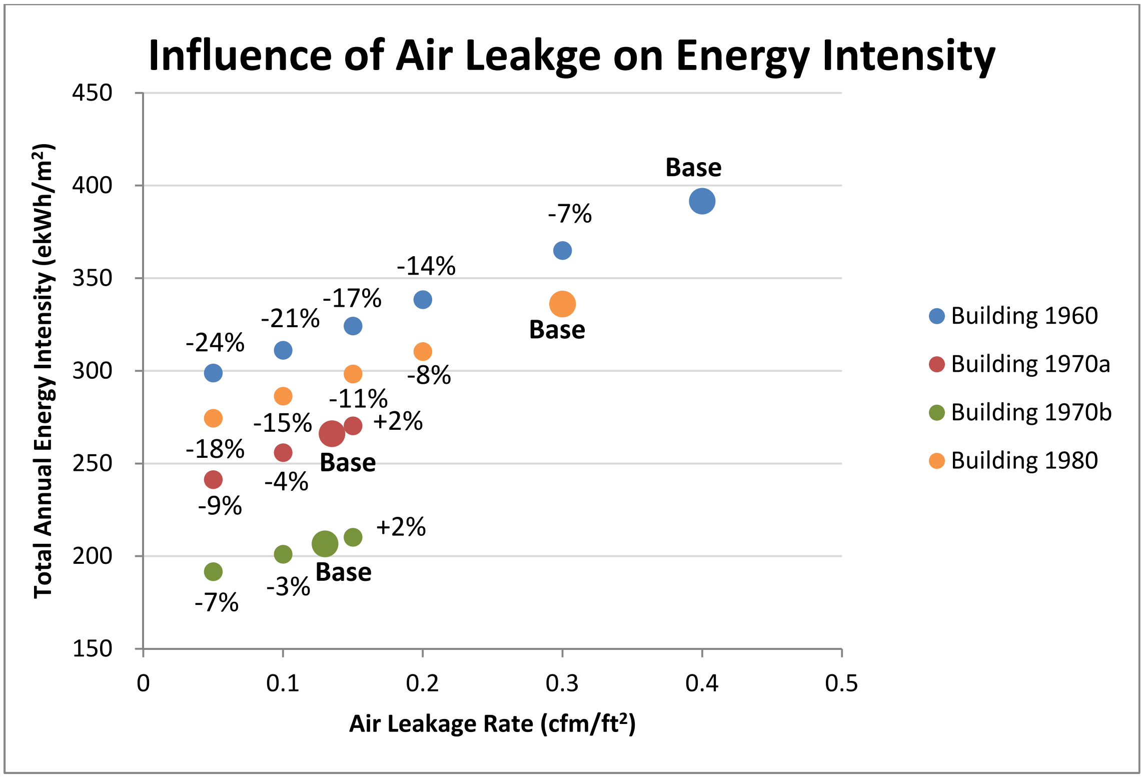

Figure 25: Influence of Air Leakage on Energy Intensity

As shown in Figure 25, reducing air leakage across the building envelope can significantly reduce energy use. The majority of the energy savings is due to reduced natural gas consumption for space heating although there is also a small net decrease in electricity consumption. This can, perhaps, be attributed to a decrease in fan energy required to distribute the conditioned air. The electricity use associated with cooling actually increased slightly. This possibly occurs because some natural ventilation through a leaky envelope could be beneficial in maintaining comfortable temperatures during the warmer months. As the envelope is made more air-tight, the effects of natural ventilation become diminished, and therefore, more air cooling is required.

A tighter envelope can be achieved in several ways. When replacing envelope components such as windows or over-cladding, a building often becomes more air-tight. These measures are not likely to be chosen for the sole reason of improving air-tightness. However, improved air-tightness can be a co-benefit of these retrofit measures even though they were likely chosen for other reasons. As well, a tighter envelope can be achieved by applying air sealing products to existing components for a relatively inexpensive energy retrofit. In order to be cost effective, the potential for improved air-tightness and thus the associated natural gas and electricity cost savings must be significant enough to offset the capital cost of the air sealing. A detailed on-site assessment, perhaps including blower-door testing, would be required to determine whether air sealing measures could be cost effective.

6.5.3 Window Retrofit

Two of the buildings in this study have single glazed windows (1960 and 1970b) and two have double-glazed low-emissivity windows (1970a and 1980). Double-glazed windows are now the minimum standard used in construction today. Although less common, the use of triple-glazed windows is becoming more prevalent in cold climates (Gustafsson & Karlsson, 1991) particularly as energy prices rise and the payback period on the incremental cost decreases. Double- and triple-glazed windows were modelled for the single-glazed base case and triple-glazed windows were modelled for the double-glazed base case along with a “reverse retrofit” single-glazed case for comparison purposes. The energy intensities associated with each of these cases along with the fenestration ratio (FR) of the four modelled buildings are presented in Figure 26.

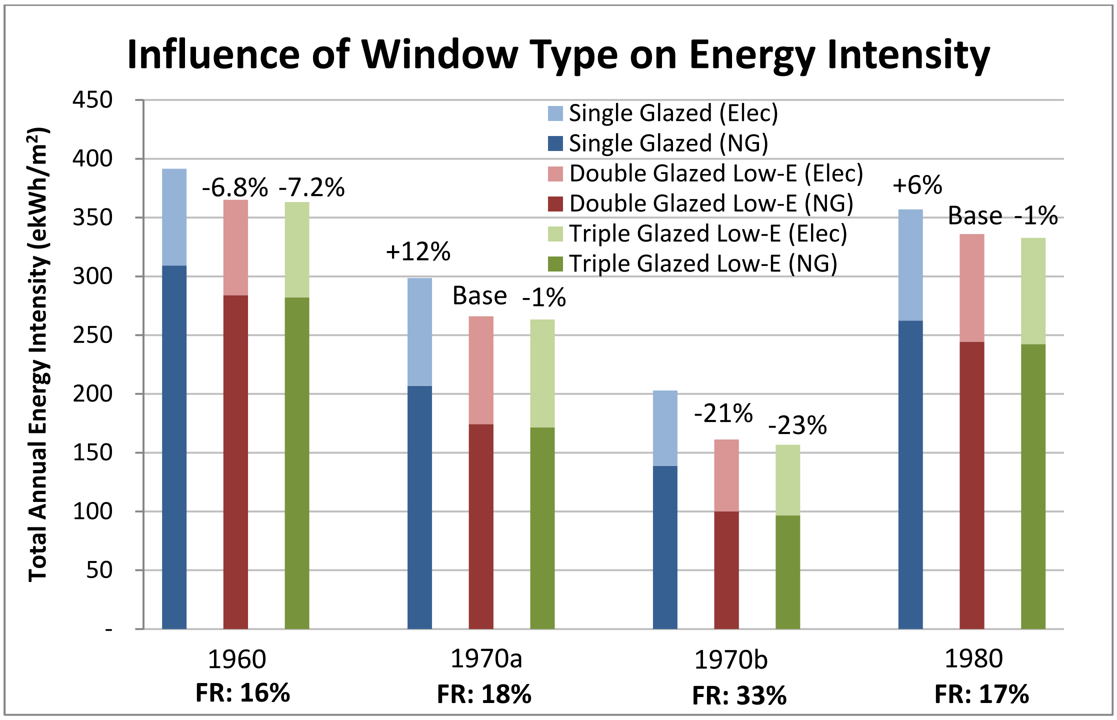

Figure 26: Influence of Window Type on Energy Intensity

As shown in Figure 26, a window retrofit can have a significant impact on energy use particularly if the windows were single-glazed. The energy saving percentages associated with the two single-glazed buildings modelled as double-glazed are reasonable because the fenestration ratio of Building 1970b is just over two times that of Building 1960. As shown in Figure 20 of Section 6.3.5, windows account for 23% of the total heat losses in Building 1970b while windows account for only 8% of the total heat losses in Building 1960. Thus, improving windows in Building 1970b compared to Building 1960 will have a greater effect on the overall building heat loss. This percentage difference in energy savings is revealed in Figure 26 as expected. This demonstrates the importance of evaluating the detailed energy performance and heat loss components on a case-by-case basis before considering retrofit options. It would be natural to assume that a building with a higher energy intensity would benefit more from an envelope retrofit than a low energy intensity building. However, the model indicates that window heat loss is more significant in Building 1970b than window heat loss in Building 1960. Therefore, on the basis of energy use alone, Building 1970b might be the better candidate for a window retrofit.

The incremental difference in energy use between double and triple-glazed windows is rather small. Although triple-glazed windows have a greater thermal resistance to heat loss, they also admit less solar radiation than double-glazed windows. These effects are off-setting. However, even though the energy savings benefits of triple-glazed windows may not be as compelling as the transition from single- to double-glazed, there are other non-energy related benefits. Thermal comfort for the occupants is improved during the colder months because the triple-glazed window surface temperature on the interior is higher than with a double-glazed window. This warmer surface temperature also means reduced condensation potential. As well, triple-glazed windows have a lower sound transmission coefficient so the suites are quieter, and by admitting less solar gain, they are also cooler in the summer.

The window types modelled here have been standardized across all four buildings so that savings could be directly compared to window area and orientation. In reality, there are a wide range of window types available with different frames, spacers, coatings, tints and inert gas fills. Each of these possible window choices needs to be evaluated in an actual retrofit situation because all of these characteristics affect the overall energy transmission of a window unit. It may even be appropriate to specify different windows on different orientations of the same building.

Typically a window retrofit also improves the air-tightness of the building envelope. However, the savings shown above resulted from changing only the window characteristics. The resulting magnitude of the improvement in air-tightness is highly uncertain and was not been considered in the models when the windows were upgraded. Thus, the energy savings due to window retrofits shown in Figure 26 are likely underestimated.

To illustrate the potential savings associated with the combined effects of improved window thermal resistance and a reduction in air leakage, as series of incremental improvements of both window and air leakage rates were modelled using Building 1960. The results are shown in Figure 27 and reveal that window upgrades which can lead to improved air-tightness, can significantly reduce building energy intensity.

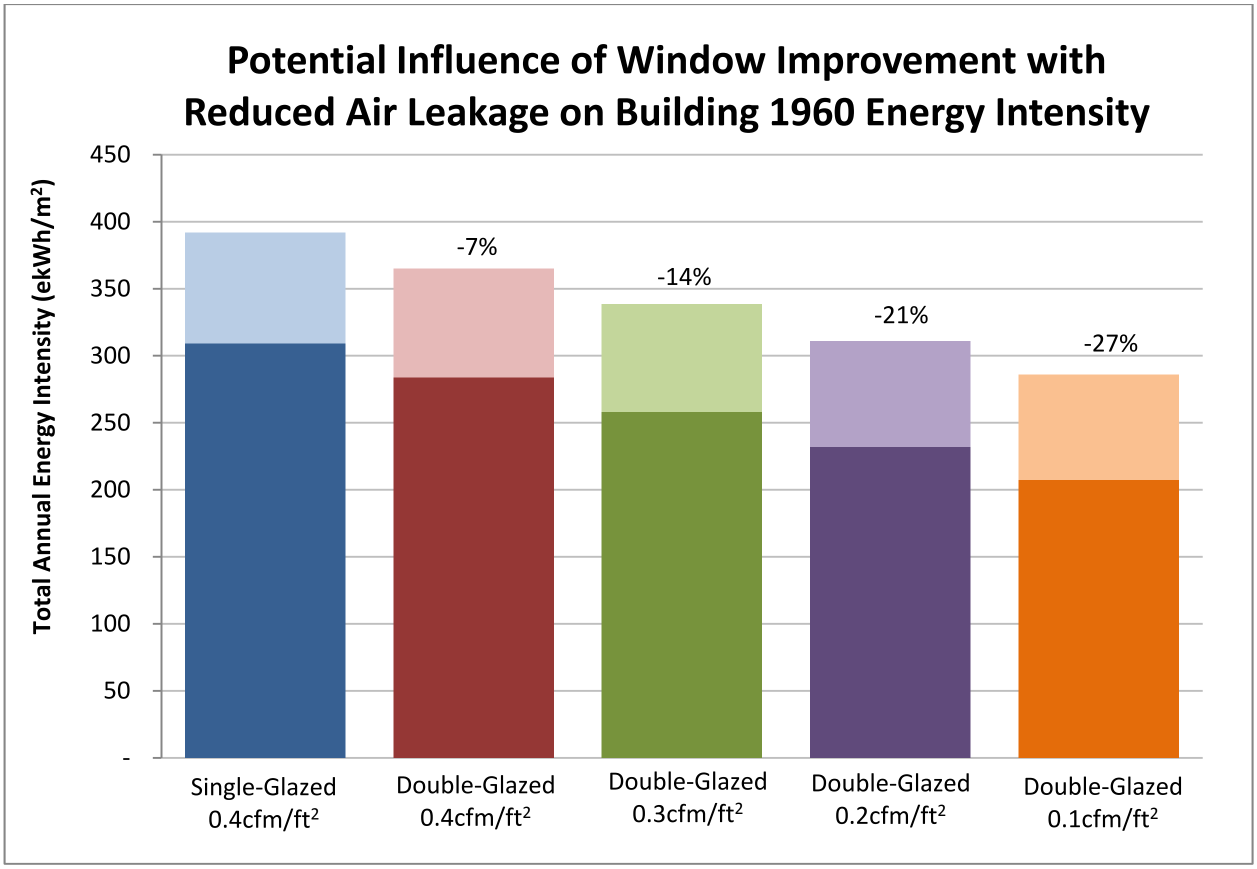

Figure 27: Illustrating the Potential Influence of Decreasing Air-Leakage Rates and Window Improvement on Building 1960 Energy Intensity

A range of potential air-leakage rates have been presented in Figure 27 due to the uncertainty in air leakage rates already addressed.

6.5.4 Exterior Insulation

The opportunity to add exterior insulation can arise when an over-cladding retrofit for rain penetration is being considered (Selby, Seskus, Pressnail, & Timusk, 1988). Applying exterior insulation to the building envelope is often a less intrusive means of improving envelope thermal resistance compared with insulating from the interior in an existing building. The use of mechanical fasteners is required to attach the insulation to the exterior and this limits the overall insulation thickness that can be applied as a retrofit measure (Plaston, n.d.). Accordingly, the insulation thickness for the retrofit models was varied from 1-inch thick (R-4) to a maximum of 3-inch thick (R-12). Three of the buildings have existing insulation but with exposed slab edges. The drawings for Building 1980 did not include insulation as part of the envelope, but it is likely that some insulation was actually installed. It was assumed that insulation levels would have been the same or greater than the 1970's buildings. As such, despite the drawings, it was assumed that Building 1980 had two inches (R-8) of wall insulation.

Figure 28 shows the impact of increasing exterior wall insulation on energy intensity. So as not to overstate the estimated savings from retrofit scenarios, each of the base cases in Figure 28 includes slab-edge insulation equal to the base case insulation level. The exposed slab edges are addressed below.

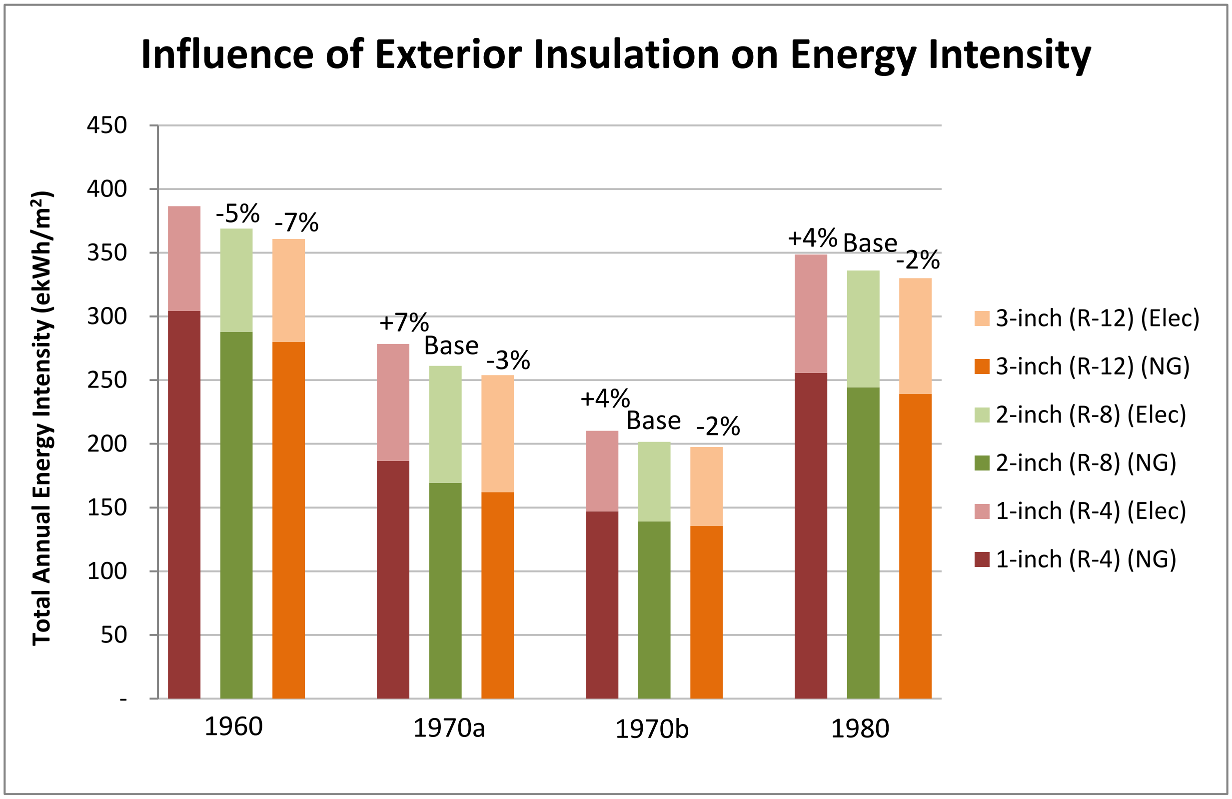

Figure 28: Influence of Exterior Insulation on Energy Intensity

Most of the energy savings shown in Figure 28 can be attributed to a reduction in natural gas space heating. However, there is also some electricity savings associated with reduced electric space heating and cooling.

It is evident in Figure 28 that there are diminishing returns associated with continuing to add more wall insulation. Therefore, the greatest energy savings occur in Building 1960 which had the lowest level of insulation.

In Buildings 1960, 1970a and 1970b exposed slab edges were observed. In addition to the exploration of the impact of exterior insulation retrofits discussed above, these buildings were modelled with and without exposed slab edges. Insulating only the slab edges would not be considered a typical retrofit but the associated energy intensity reductions are included in Figure 29, below, for illustrative purposes to show the effect eliminating slab-edge thermal bridges. The different levels of insulation between Building 1960 and the 1970's buildings are due to the base case condition.

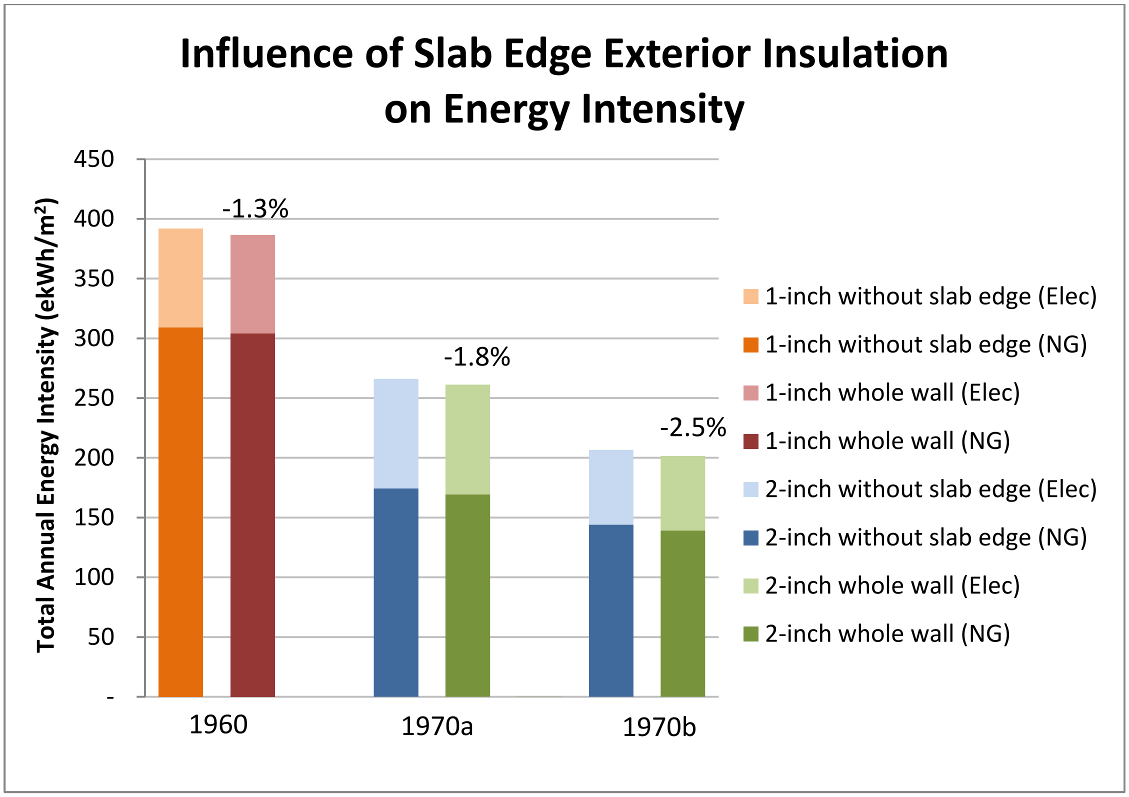

Figure 29: Influence of Slab-Edge Exterior Insulation on Energy Intensity

Although the savings associated with slab-edge insulation are minor, Figure 29 demonstrates how thermal bridges are significant components of building heat loss. Assuming the slab edge makes up an estimated 6% of the wall area, by adding one inch of insulation to the slab edges of Building 1960, a 1% reduction in total building heat loss results. This is significant considering that the impact of adding one inch of insulation to the entire wall area resulted in energy savings of 5% for Building 1960.

It is also important to note that an over-cladding retrofit will also improve air-tightness, but a window retrofit may be more effective at reducing air leakage. A sensitivity analysis of the possible impact of a window retrofit on air-tightness has already been presented for Building 1960 in Figure 27.

6.5.5 Roof Insulation

A roof will likely be replaced several times during the life of a building. Each replacement presents an opportunity to improve the energy performance of this part of the building envelope by adding insulation.

Building 1960 had one inch of roof insulation; Building 1970a had 1.5 inches and Building 1970b had three inches. Building 1980 had no insulation specified in the drawings but two inches was the assumed insulation level given the roof assemblies of the 1970 buildings. These base cases along with a series of roof insulation retrofits ranging from 2-inches (R-8) to a maximum of 4-inches (R-16) were modelled in order to determine the effect on energy intensity as shown in Figure 30.

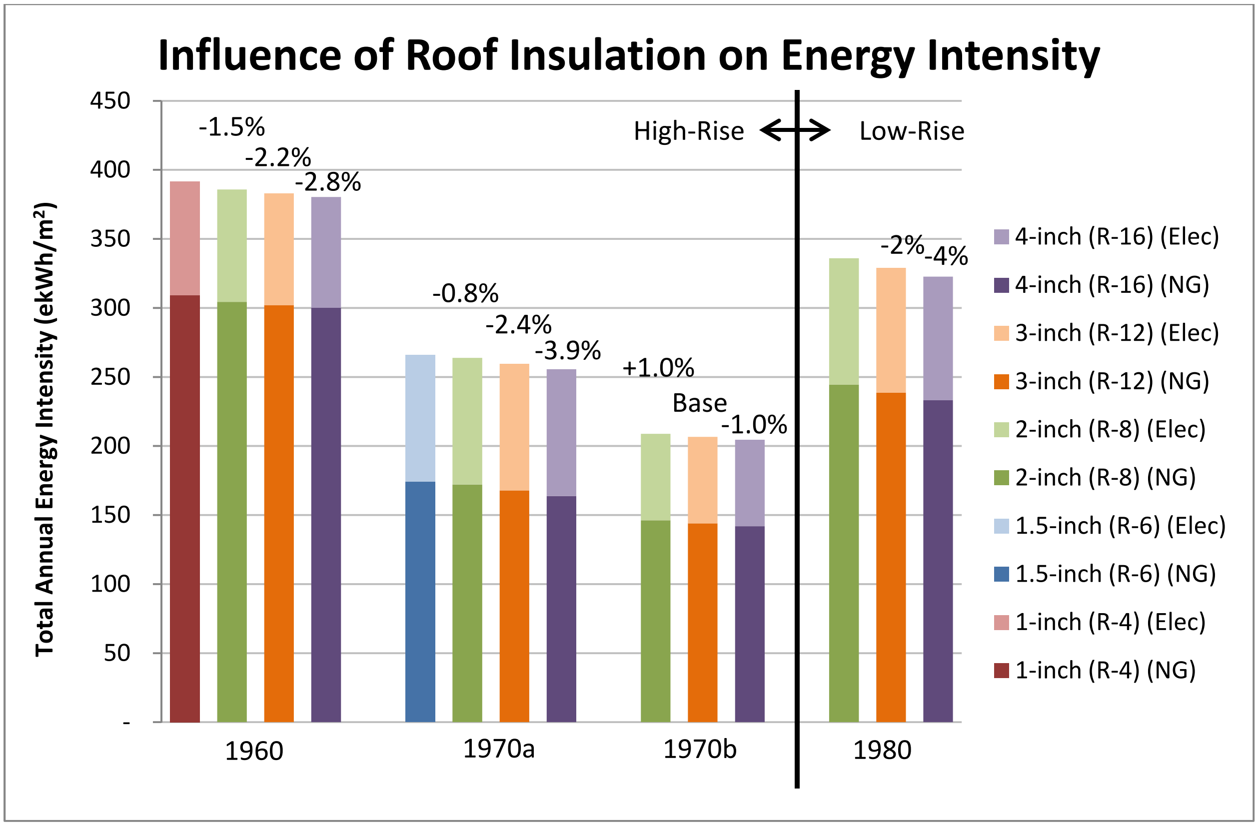

Figure 30: Influence of Roof Insulation on Energy Intensity

Incremental improvements between the three high-rises (Buildings 1960, 1970a and 1970b) with increased insulation levels are similar but this retrofit measure obviously has a larger impact on the lower-rise, Building 1980, where the roof makes up a much greater proportion of the building envelope area.

The impact between 2-inches and 4-inches is considered here, as this interval is common to all buildings. The difference in the incremental energy-use reductions between Building 1960 and 1970a is about three times. This is reasonable because the roof area of 1970a (5,600ft^2) is about one-third that of 1960 (14,000ft^2) even though the roof heat losses (1.2%) as a proportion of total heat loss is identical in the base case of the two buildings. Though the roof size of Building 1970b (12,000ft^2) is about the same as Building 1960, Building 1970b sees a smaller incremental improvement because roof heat losses make up a smaller proportion (0.5%) of the total building heat losses in the base case. Finally, as discussed above, the large roof size of Building 1980 and high proportion of total heat losses associated with roof heat loss in the base case (4%), result in the larger roofing retrofit impact shown in Figure 30.

Since the roof will have to be replaced several times, only the incremental cost of additional insulation during the replacement should be considered against the projected energy savings, not the total roof replacement cost.

6.5.6 Suite Lighting and Plug Loads

MURB occupants without electrical sub-metering tend to use more electricity than those who are sub-metered. The cost of electricity is often hidden in fixed costs like rent or condominium fees, while the actual electricity cost per suite varies according to fluctuations in energy use. Individual sub-metering ensures occupants are aware of their energy consumption. Then to manage energy costs, occupants have the option to reduce their in-suite appliance use and lighting. One study has found that occupants of MURBs can reduce their electricity consumption by up to 50% without significantly changing their lifestyle (Rich, 1985). In this study, a more conservative range of between 10% and 30% reductions in suite appliance and lighting use is evaluated to determine the effects on overall building energy consumption. These electricity reductions are shown in Figure 31.

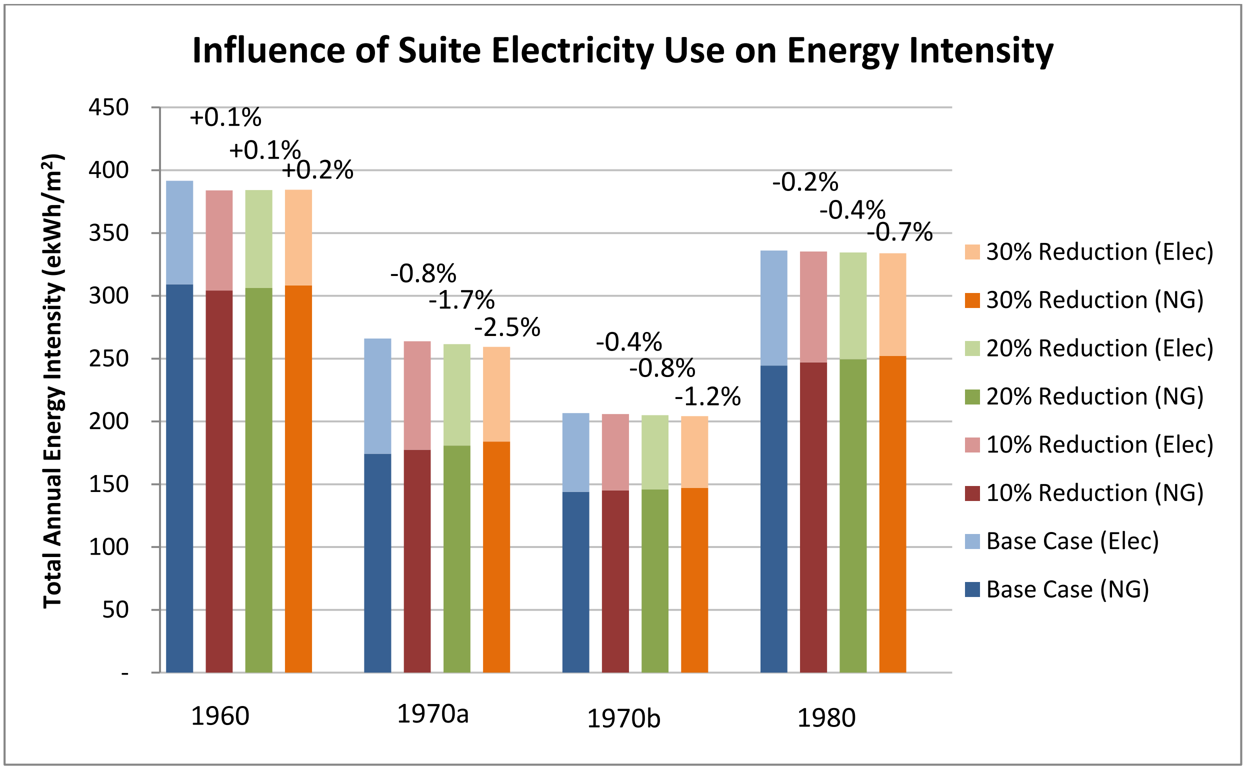

Figure 31: Influence of Suite Electricity Use on Energy Intensity

The small magnitude of the effect on energy use is related in part to the natural gas and electricity mix. As shown in Figure 31, the impact of electricity savings is smaller in buildings with a higher natural gas intensity.

Although the energy savings from reduced suite electricity loads are small, the analysis of this measure was included here to show the effect of load shifting between energy types. The energy savings from a suite-based load reduction are only seen in electricity use. But this decrease in electricity use results in a reduction in the waste heat produced by the lighting and appliances. During the heating season, this heat energy will be provided by natural gas instead of the waste heat from electricity use. Thus, during the winter, the net impact to building energy consumption is minimal. During the summer these reduced electrical loads and associated waste heat can reduce cooling loads thereby saving even more electricity. As discussed in Section 6.3.2, the energy use for each building was weather normalized to CWEC prior to base model generation. As CWEC was recognized as having a higher number of heating degree days than the year from which the energy data was taken, the winter effect of natural gas offsetting electricity use will be slightly larger in these models than it would be in reality.

As shown, the net impact of reducing suite-based electrical loads is minor when viewed in terms of total building energy use. To determine if the magnitude of the savings generated by the models was reasonable, the influence of suite electricity use reductions on electricity intensity was calculated and is presented in Figure 32.

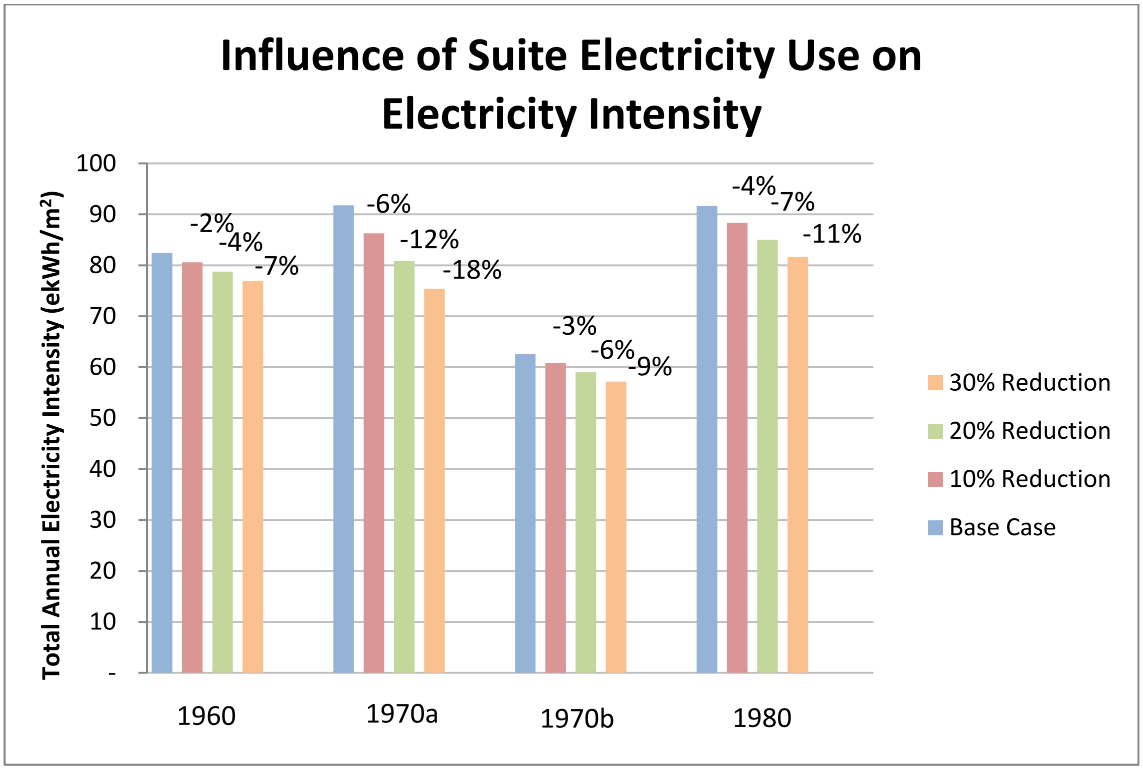

Figure 32: Influence of Suite Electricity Use on Electricity Intensity

The energy end-use breakdowns presented in Figure 18 in Section 6.3.5 shows that the miscellaneous and lighting loads together account for between 15% to 26% of total energy use and 37% to 50% of total electricity use. Based on the model inputs, the proportion of this load allocated to suites is about two-thirds. Therefore, with a 30% reduction in suite electricity consumption, the savings presented in Figure 32 appear to be reasonable.

Occupant education programs can be a low-cost strategy for reducing suite-based loads but the degree of success may be limited. On the other hand, sub-metering, which has been shown to reduce suite-based energy use, is more costly to install and to administer, but it is more effective.

6.5.7 Other Retrofit Measures

Other retrofit measures tested included corridor temperature adjustments, changing fan type and efficiency, improving pump efficiency and upgrading common area lighting. Although these measures did not affect the overall building energy use by more than a fraction of a percent, they are all relatively low cost items that are easily implemented and so could be considered “low-hanging fruit”. Retrofits such as these can be combined with the larger more capital-intensive measures described above, to reduce the blended payback period of a comprehensive energy retrofit program.

6.6 Impact of Modelled Retrofits on Greenhouse Gas Emissions

Generally, the results from the energy modelling were as expected. The largest impact measures included improving boiler efficiencies, reducing air leakage and improving of the thermal resistance of the envelope through window retrofits, over-cladding and roof insulation. This section will summarize the energy savings associated with each of these measures and present the associated greenhouse gas (GHG) emissions reductions. The GHG emission calculations are based on the following factors (City of Toronto, 2012):

- Electricity: 0.15kg/kWh
- Natural gas: 1.879kg/m^3

The energy content of natural gas was assumed to be 10.3ekWh/m^3 resulting in a natural gas emissions factor of 0.182kg/ekWh.

The modelled impact of a boiler “tune-up”, which improved the performance of a natural draft boiler from 75% to 80% reduced the total energy use by 3% and natural gas use by 5-6% in the three buildings that tested this improvement. The resulting CO_2 emission reductions range from 10 to 40 tonnes depending on the building. The modelled impact of a mid- (85%) to high-efficiency (95%) boiler retrofit reduced total energy use by between 3 and 5% for each of the four buildings. The resulting annual reduction in CO_2 emissions ranged between 15 and 60 tonnes depending on the building.

Improving air-tightness from a relatively loose envelope (0.2cfm/ft^2) to a relatively tight envelope (0.1cfm/ft^2) resulted in a 7% total energy savings for the more air leaky buildings 1960 and 1980. This impacts CO_2 reductions by about 24 to 114 tonnes annually for each of the buildings. The reason for the large range is because Building 1960 is more than four times larger than Building 1980. Reducing the air leakage rate of the 1970’s buildings to 0.1cfm/ft^2, from the base case air leakage rates of 0.13cfm/ft^2 and 0.135cfm/ft^2, has less of an impact (20 to 30 tonnes). Air leakage reductions affect primarily natural gas use and to a lesser degree, electricity use.

The transition from single- to double-glazed units resulted in total energy savings of 7% for Building 1960 and 21% for Building 1970b. The annual CO_2 emission reductions associated with these two buildings were estimated to be 110 and 230 tonnes, respectively. The modelled energy savings for Buildings 1970a and 1980, transitioning from double- to triple-glazed, resulted in savings of five and three tonnes, respectively.

For Building 1960, the impact of adding two inches of exterior insulation (from the existing one inch with exposed slab edges to a total of three inches) during an over-cladding retrofit, resulted in a 7% reduction in total annual energy use. The associated emissions reduction is estimated at 128 tonnes. Adding an additional inch of insulation to the 1970's buildings (from existing two inches with exposed slab edges to three inches total) resulted in emissions reductions of 24 to 50 tonnes depending on the size of the building. In Building 1980, which did not appear to have exposed slab edges, the emissions reduction associated with the transition from two to three inches of insulation was estimated at six tonnes. If the building has minimal wall insulation, the case for improving the thermal resistance of the walls is even more compelling when GHG emissions reductions are considered.

Due to the original insulation level and the size of the roof area as shown in Table 9, adding up to 4-inches of roof insulation to all of the buildings resulted in varying emissions reductions. The savings shown here are comparable to the impacts of a boiler tune-up or minor air leakage reduction.

Table 9: Emission Reductions Associated with Addition of Roof Insulation

Building	Base Case Insulation	Retrofit Case Insulation	Emission Reduction (tonnes eCO_2)
1960	1-inch	4-inch	45
1970a	1.5-inch		21
1970b	3-inch		12
1980	2-inch		13

Reducing suite-based electrical loads by 30% decreases the total building electricity use but it also leads to an increase in the natural gas heating load for the building during the winter as discussed in Section 6.5.6. Thus, the net energy-use impact is small. However, the shift of this proportion of energy from electricity to natural gas combusted on-site results in varying impacts on CO_2 emissions as shown in Figure 33.

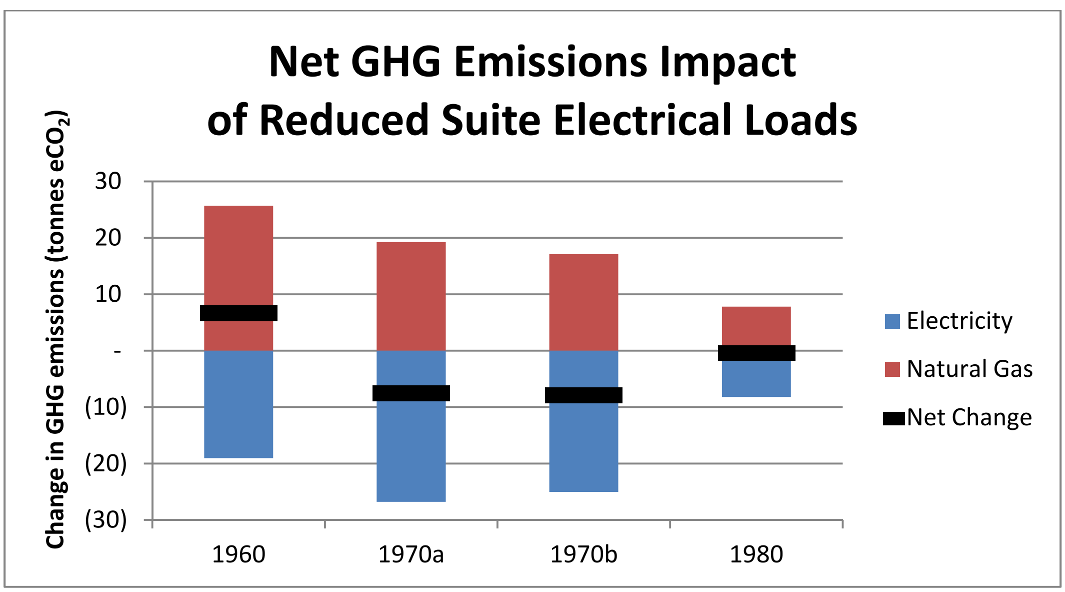

Figure 33: Net GHG Emissions Impact of Reduced Electrical Loads

Depending upon the building, a shift from electricity to natural gas may result in an increase, a decrease or even no change in emissions as shown in Figure 33. Some of the reasons for this difference in impact could include the performance of the building envelope. Emissions from Building 1960, for example, are negatively affected by a reduction in suite-based electrical loads. The fact that Building 1960 has the envelope with the lowest thermal resistance and highest air leakage rate of the four buildings studied may be the cause of this regressive outcome. A detailed investigation of the reasons for this regressive emissions outcome should be conducted in the future.

Given the current cost of electricity versus natural gas, the reduction in electricity use makes economic sense. However, from a GHG emissions perspective, reduction of suite electricity loads should be examined on a case-by-case basis to determine all of the projected impacts.

6.7 Summary of Retrofit Measure Impacts

Table 10 summarizes three energy retrofit measures for each building which have the greatest effect on reducing modelled energy consumption. These three measures have been presented and ranked in order of significance. Only retrofit measures that are considered possible for each particular building have been included in the summary below. Improvements in air-tightness have been limited to a maximum of 0.1cfm/ft^2 ("Tight-Average") and retrofits for single-glazed windows have been limited to double-glazed windows.

It is interesting to note that for all buildings, boiler efficiency improvements and improved air-tightness were among the most significant contributors to reduced energy consumption. The remaining measure for all of the buildings involved improvements to envelope thermal resistance.

Table 10: Summary of Retrofit Measure Impacts

Order of Significance			Building: 1960	Building: 1970a	Building: 1970b	Building: 1980
1	Measure		Significant improvement in air-tightness (0.4cfm/ft^2 to 0.1cfm/ft^2)	Boiler Refurbishment or Replacement (85% to 95%)	Window Replacement (SG to DG)	Improvement in air-tightness (0.3cfm/ft^2 to 0.1cfm/ft^2)
	Annual Reductions	Electricity	4%	0%	5%	6%
		Natural Gas	25%	6%	28%	18%
		Total Energy	21% 1,850eMWh	4% 120eMWh	21% 1,280eMWh	15% 170eMWh
		Total GHG Emissions	335 tonnes	22 tonnes	220 tonnes	31 tonnes
2	Measure		Boiler Replacement (60% to 95%)	Addition of Roof Insulation (1.5" to 4")	Boiler Replacement (70% to 95%)	Boiler Replacement (75% to 95%)
	Annual Reductions	Electricity	0%	0%	0%	0%
		Natural Gas	23%	6%	20%	14%
		Total Energy	18% 1,700eMWh	4% 115eMWh	14% 860eMWh	10% 190eMWh
		Total GHG Emissions	300 tonnes	21 tonnes	160 tonnes	34 tonnes
3	Measure		Addition of Exterior Wall Insulation (1" to 3")	Improvement in air-tightness (0.135cfm/ft^2 to 0.1cfm/ft^2)	Improvement in air-tightness (0.13cfm/ft^2 to 0.1cfm/ft^2)	Addition of Roof Insulation (2" to 4")
	Annual Reductions	Electricity	2%	0%	0%	2%
		Natural Gas	9%	6%	4%	5%
		Total Energy	8% 700eMWh	4% 110eMWh	3% 170eMWh	4% 73eMWh
		Total GHG Emissions	128 tonnes	20 tonnes	31 tonnes	13 tonnes

7 Policy Suggestions and Recommendations

Throughout the three phases of this study, numerous attempts have been made to draw correlations between building vintage and energy use. Though the difference in energy intensity between the vintages of the four modelled buildings is similar to the difference in energy intensity between the vintage categories from the Meta-Analysis Study, the correlation between building vintage and energy-use is not strong enough to focus policy recommendations on particular vintage groups.

The Refined Dataset phase found that window and heating system characteristics should be considered when selecting building typologies. However, similar to the Meta-Analysis, there was no correlation between particular characteristics in the four modelled buildings and their vintages.

The findings of the previous study and earlier phase indicate that designing policies to target specific MURB typologies is not appropriate as generalizations about buildings characteristics have not been found. Therefore, policies designed to target MURB energy use, must recognize the diversity within the existing building stock.

However, one common feature to most Toronto MURBs is a significantly higher natural gas intensity compared with electricity intensity. Thus, the majority of emissions from this sector are due to natural gas consumption. In order to significantly reduce the CO_2 emissions associated with MURB sector, natural gas savings measures should be promoted. The final phase of the study was able to show the potential impacts of various retrofit measures on the energy consumption in the four modelled buildings. These results can be used to determine reasonable energy-use reduction goals for existing MURBs, depending on the type of retrofit measures selected.

This section will include recommendations for a number of areas. In order to supplement the data collected in this study, methods to gather more information on building characteristics, energy use and cost of retrofits are proposed. Where possible, this report will show how the proposed data collection methods could be incorporated into existing administrative procedures. Next, opportunities to encourage MURB energy retrofits within existing municipal regulations, such as the City of Toronto's Official Plan, are presented. Looking further afield, an example of municipal policy in New York City is also presented as a potential model for Toronto. Finally, recommendations related to the use of CWEC are proposed.

7.1 Cost

The cost of these retrofit measures has not been examined since cost evaluations were outside of the scope of this study. In general terms, the higher impact retrofits summarized in Sections 6.5.1 to 6.5.5 typically involve a higher capital cost than the lower impact measures mentioned in Section 6.5.7. However, opportunities to incorporate some of these measures into regular building retrofits necessitate only the incremental cost of the energy saving component to be justified by energy cost savings. For example, roof replacements occur several times during the life of the building, but the incremental cost of adding insulation during a retrofit that is already scheduled could be minor compared with the potential energy cost savings. A similar opportunity exists with boilers that have to be replaced. The incremental cost of upgrading to higher performance equipment can represent only a small portion of the overall retrofit investment, but the potential energy savings can be significant.

Less capital-intensive retrofit opportunities could target air leakage and occupant energy use. While air leakage reduction can be achieved effectively through costly window replacements and over-cladding, air leakage products applied to the existing envelope can also be effective but for a lower upfront cost. Occupant energy-use reduction also presents an opportunity for energy savings with minimal investment if approached from the perspective of occupant education.

Beyond very general discussion, such as this, it is not possible to estimate the cost to implement the measures investigated in this study. Replacement costs for envelope components, in particular, can be two to three times the cost of the original installation (or more), not accounting for inflation. This might suggest the need for a robust database of publicly accessible actual retrofit cost data to provide price ranges for certain retrofit projects like roof, window and boiler replacements. Unfortunately, the existing databases containing this type of information are usually proprietary. Even if access to this data was provided, it would be necessary to extract the true incremental cost of the energy reduction component such as the roof insulation or the difference in cost between a standard and high performance window in order to properly assess the value of the energy upgrade. To build on the work presented here, a detailed analysis of actual costs from numerous energy retrofit projects must be conducted in the future.

7.2 Data Collection

One of the major challenges faced during this study was data collection. It was often impossible to collect uniform, detailed information on the characteristics and energy performance for each MURB. This made it difficult to draw comparisons and develop correlations between energy use and building characteristics. It is also challenging to make policy recommendations on retrofits when the availability of data is inconsistent. Accordingly, a number of mechanisms to ensure consistent baseline data are collected are presented here, categorized by housing tenure.

7.2.1 Affordable Housing

There are several affordable housing programs administered by the City of Toronto, many of which rely on federal and/or provincial funding schemes. A number of these programs could apply to the MURBs in this study. Leveraging City involvement in these programs could help improve the amount and quality of data available for building performance analysis.

In April 2013, the City will begin administering an affordable housing program with Federal and Provincial funding called Toronto Renovates (City of Toronto). The "Rental Renovations" component of the program will supply 600 forgivable loans to eligible landlords of up to $24,000 per unit for renovations to private rental buildings with low- to moderate-income tenants.

Through Housing Connections, a subsidiary of Toronto Community Housing Corporation, the City administers about 2,900 rent supplements (Housing Connections). These supplements are paid directly to landlords and are based on a tenant's income. Rent supplement units are scattered throughout the City, and Housing Connections fills the units on behalf of 130 private market landlords.

In order to expand the amount of data collected, the City could consider mandating that all building owners successful in either receiving money from Toronto Renovates or rent supplements provide access to utility bills and information about basic building characteristics such as those suggested in Table 2 of this report. Actual retrofit cost data should also be provided upon completion of the Toronto Renovates projects. MURBs that undergo energy retrofits funded by Toronto Renovates could provide pre- and post-retrofit utility data, while utility data from rent supplement units (i.e. buildings that have not been renovated) could be used to supplement the benchmark data. Rather than building owners and managers providing utility consumption data directly, they could simply grant permission for the City to access this information directly from the utility provider. This approach was used to gather some portions of the data in this study. Allowing access to utility data is not a cumbersome process for building owners and managers, and would provide the City, as well as researchers, with very useful information. Sharing this data (with building identifiers removed) on the City's Open Data portal would also ensure the information is accessible to the public.

7.2.2 Private Rental Buildings

In the United Kingdom, when a building is sold or rented, an energy performance certificate (EPC) is required (The National Archives, 2007). This certificate includes a rating of the energy-efficiency of the building, according to a standard methodology, and suggested improvements to reduce energy use. Through the UK’s Carbon Emissions Reduction Target (CERT) program, installers of energy-efficient retrofits must be accredited and provide certain building data after the installation (Office for Gas and Electricity Markets, 2012). The government collects this data and uses it to gain a better understanding of the energy performance of their building stock.

This type of assessment program is triggered by the sale of a building and could be implemented in Toronto when private rental apartment buildings change hands. It does not have to be onerous, as building condition assessments are often part of the divestiture process. Apartment owners could then share their building condition reports with local municipal building departments or the provincial Ministry of Municipal Affairs and Housing, allowing policymakers and government officials to make more definitive assessments on the condition of its housing stock. As a first step toward encouraging energy conservation and extending the life of buildings, mandatory reporting of building condition assessments upon divestiture could be mandated. Such a step would be helpful in assessing the performance of the existing buildings.

7.2.3 Condominiums

Condominiums are subject to regular Reserve Fund Studies, which often encompass building audits (Government of Ontario, 2011).

There are three classes of Reserve Fund Studies:

- Class I is a comprehensive study;
- Class II is an update of an existing Reserve Fund Study with a site visit; and
- Class III is an update without a site visit.

New condominiums are subject to a Class I Reserve Fund Study within the first year of registration. This applies to both standard condominiums and conversions from existing rental buildings. According to the Condominium Act (Section 94), a condominium corporation must carry out a Reserve Fund Study every three years, alternating between a Class II and a Class III Study. The Studies contain information on the current condition of all common elements, such as external walls, windows, stairwells, common corridors, elevators, sanitary systems, and the roof.

This valuable building condition data provides insight into the quality of a region's housing stock and would help governments develop stronger public policy. Therefore, to coincide with the current review of the Condominium Act by the Ontario Ministry of Consumer Services, it is recommended that the Ministry require condominium corporations to file their Reserve Fund Studies with the appropriate ministries or local governments. Because these studies are already occurring, it would be relatively easy for condominium boards to simply forward the results to appropriate authorities. It might also be worthwhile to modify Part IV Section 29 of the Ontario Regulation 48/01 of the Condominium Act to include detail on precisely how some of the information should be presented (to allow easy integration into a database) and to include some assessment of building energy performance.

7.2.4 Utility Companies

In order for utility companies to share utility usage data, building owners or condominium board representatives must sign an agreement granting permission to release this data. This is sometimes a difficult process that could be simplified if utility companies agreed to share anonymous usage information with governments or institutions for research purposes. Building specifics such as height, number of suites and vintage should also be provided for standardization. To avoid sharing addresses or other private information, buildings could be coded with protected identification numbers. Local utility companies could develop a portal similar to Open Data, or collaborate with an existing website, and upload utility data of buildings for public use. In Ontario, the conversion to 'smart meters' provides an excellent opportunity for automating data base entries of electrical use. Further, the use of 'smart meters' eliminates the need for billing adjustments or corrections due to estimated meter readings which serves to make electrical-use data more accurate.

The recommendations above would ensure the City and/or the Province has access to a more comprehensive range of data on MURBs. However, it would also be valuable for existing privately-run building programs to undertake data sharing and/or collection. This may include the Certified Rental Building (CRB) Program, a quality assurance certification program administered by the Federation of Rental-Housing Providers of Ontario (FRPO). In lieu of providing data to governments, building owners or managers could instead share utility data with the CRB program.

Generally, any data collection initiatives should incorporate as many of the building characteristics from the Data Input Tool, described in Section 5.1, as possible. As more data are collected about particular building characteristics, buildings requiring higher priority retrofits can be identified and mapped. Using census data such as average income or other socioeconomic factors with this location-specific building data, policies directed at certain MURB tenure groups can be developed.

7.3 City of Toronto's Official Plan

The City of Toronto's Official Plan is under review in 2012 and 2013, so it is an appropriate time to consider updating the contents to reflect the needs of Toronto's aging MURBs. There are two relevant sections of the City's Official Plan that could be applied to MURB energy retrofits (City of Toronto, 2010) are commented on here:

In Section 2.3.1, Healthy Neighbourhoods acknowledges that Apartment Neighbourhoods should be improved through environmental sustainability by investing in energy-efficient measures, among other things. However, prescribing what this means in more detail would ensure that building owners are more aware of their responsibilities. It is therefore recommended that this section of the Official Plan outline specific energy saving methodologies, such as suggested building retrofits or operational changes.

In Section 3.2.1, Housing Policies mandates that rental housing must be preserved, and the existing stock maintained and replenished. This statement, in point 2 of the section, could go further by encouraging MURB owners to not only maintain their buildings but improve energy performance in the process. Point 4 discusses the provision of municipal assistance in order to provide affordable housing. Energy savings and therefore energy cost reductions can ensure affordability in the long term, despite rising energy prices. Perhaps the loans and grants referred to here can be directed to energy-efficient retrofits, in particular, those that reduce natural gas consumption.

In order to meet the goals of the two sections above, an analysis of the typical maintenance and retrofit items in MURBs could be conducted and then be supplemented by the energy savings opportunities identified in this report. It is especially important to recognize energy saving opportunities whenever other retrofit projects are being considered. The incremental cost of adding an energy reduction component is much less than the cost that would be incurred if energy reduction was approached as a separate element.

7.4 New York City Local Laws 84 and 85

In 2009, New York City introduced Local Law 84 (LL84). This Local Law requires owners of all large privately-owned buildings to report annual energy and water consumption (City of New York, August 2012) and to carry out an energy audit and retro-commissioning every 10 years (New York City Mayor's Office of Long-Term Planning and Sustainability, 2012). In August 2012, the first benchmarking report of data collected since the introduction of LL84 was released and included data on almost 6000 MURB properties (City of New York, August 2012). Fines of up to $2,000 annually are issued for properties which do not comply with energy and water consumption data reporting requirements.

As well, in 2009, the New York City Energy Conservation Code, or Local Law 85, came into effect (City of New York, 2009). Local Law 85 requires any building renovation or alteration to meet the current code. Prior to the introduction of this law, only projects where more than 50% of the building was affected by the renovation were required to upgrade to the current code.

With LL84, NYC officials are starting to collect standardized data from the majority of the building stock and, with LL85, they are using building renovations as an opportunity to require reductions in energy consumption through the application of new code requirements to existing buildings.

As a first step, legislation similar to LL84 could be introduced in the City of Toronto. As indicated throughout this study, the correlation analyses would benefit from a much larger sample size and more detailed information about building characteristics. Along with the energy and water consumption data collected annually, a profile containing detailed building characteristics, such as those presented in the Building Input Tool, could also be created for each property. If linked to the building permit approval process, alterations to the property could alert City officials to the need for an update to the building characteristics profile. This type of data could be used to determine the real impact of retrofit measures because the building profile would include pre- and post-retrofit energy and water consumption data along with details of how the building characteristics changed during the retrofit. Furthermore, fines for non-compliance could be used to fund the maintenance and analysis of the database.

With a clearer picture of the energy use of this sector, legislation similar to, or more stringent than, LL85 could be introduced. Since LL85 is triggered by a renovation or alteration to the property, City officials can use this opportunity to highlight possible energy reductions specific to the proposed building retrofits. Retrofit impact models such as those presented in this report can be used to estimate the associated energy savings and justify the incremental cost of the energy saving component of the retrofit. In turn, as more data is collected from the post-retrofit operation under LL84-style legislation, more robust estimates of energy reduction impacts can be made for specific retrofit scenarios. This data will be particularly helpful in estimating the combined effects of multi-faceted retrofit approaches. For example, the co-benefits of retrofits such as window replacements and over-cladding with respect to conduction and air leakage energy losses can be ascertained.

7.5 Data Weather Normalization

As noted in Section 3.2, using a ‘standard weather year’ is a rational way of making energy comparisons between various building studies. Since researchers and consultants have already relied heavily on the use of the CWEC standard weather year, there are compelling reasons for continuing this approach of weather normalization. However, using the standard weather year to predict energy savings from retrofit measures may lead to erroneous results in periods of changing climate or microclimate. What is needed is a better way of making energy predictions, by using the standard weather year, not by abandoning it.

One approach would be to create Climate Indices that are referenced to the standard weather year. The standard weather year could be referenced much the way the Consumer Price Index is referenced to the year 1970. An Index Value 1.0 could be assigned to the CWEC standard weather year, and other weather periods could be assigned a corresponding Index Value. A Heating Climate Index (HCI) and a Cooling Climate Index (CCI) could be created for a given reference period. Table 11 shows the respective Heating and Cooling Index Values for the 5 and 10 year periods ending in 2011.

Table 11: Sample Heating and Cooling Climate Indices

Indices for periods ending in 2011	5-year period	10-year period
Heating Index Values	$HCI5_{2011}$=0.69	$HCI10_{2011}$=0.84
Cooling Index Values	$CCI5_{2011}$=1.19	$CCI10_{2011}$=1.72

For example, the Heating Climate Index value for the 10-year period ending in 2011 ($HCI10_{2011}$) was found to be 0.84. This means that using an HCI of 0.84, the predicted energy use in the year 2012 would be 84% of the energy that would be expected to be used in the standard weather year.

An example of the application of these heating and Cooling Climate Indices ($CI10_{2011}$) has been applied to Building 1960 as shown in Figure 34.

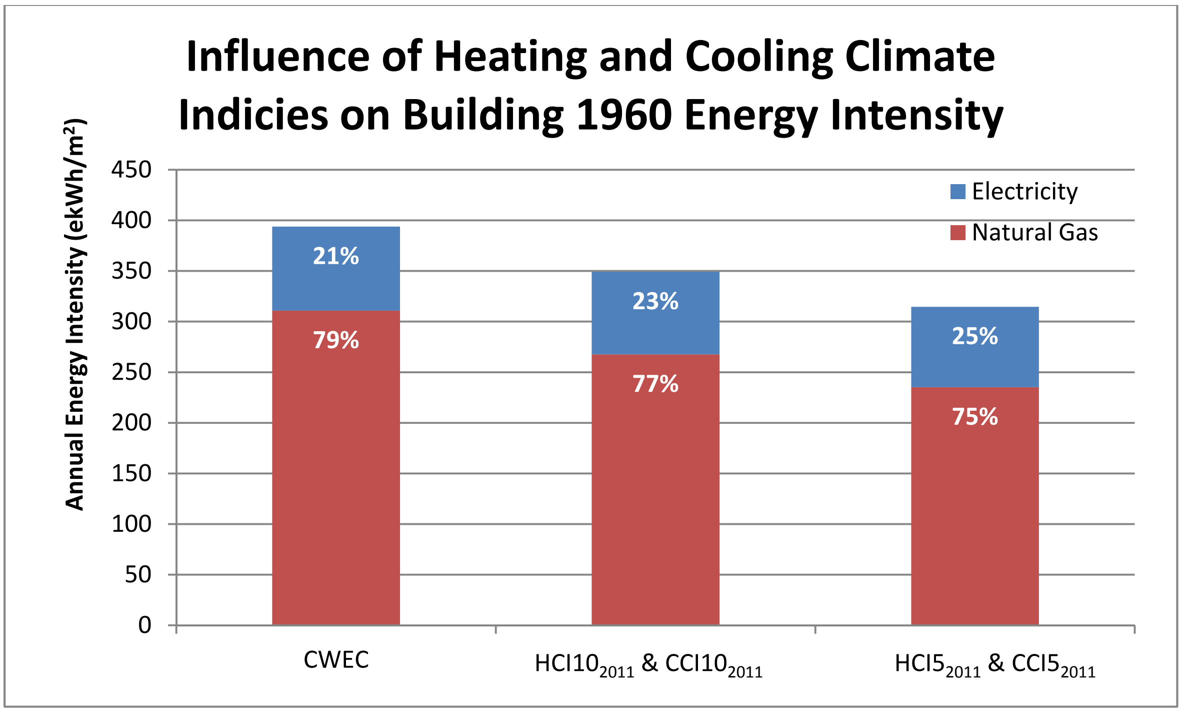

Figure 34: Influence of Heating and Cooling Climate Indices on Building 1960 Energy Intensity

It is interesting to note that with milder winters and warmer summers, there is a noticeable increase in electricity use as a percentage of the total building energy use. This is due to two factors: the reduced heating load associated with milder winters and the increased cooling loads with warmer summers.

When considering retrofit decisions and the associated paybacks due to energy savings, it is important to consider these investments in terms of the current warming climate by using a method such as Climate Indices presented here. Depending upon the researchers' or consultants' needs, a shorter or longer data index period could be used. The use of such a Climate Index system would allow researchers and consultants to retain the benefits of having a standard weather year, while allowing better energy-use predictions to be made.

8 Conclusions

This report concludes a three-part study in which the energy use of MURBs in Toronto was investigated and potential building retrofit measures for reducing energy consumption were explored. In the first phase, several existing databases were utilized in an attempt to correlate energy use with a selection of basic building characteristics including building vintage and height. Large variations in energy intensity were found in the building data set. It was concluded that relatively weak correlations existed. More detailed building data was needed in order to explain the wide variations in energy use.

The second part of the study sought to explain why energy use varied so widely. Thus, more detailed building information was collected. With this new information, a refined data set was created and new correlations were sought between building characteristics and building energy use. It was concluded that window characteristics along with heating system efficiencies were the two factors that could be most closely linked to building energy use. Once again, it was further concluded that additional data was needed.

The third and final part of the study consisted of three main components: the first component was the creation of a database of MURB energy use and building characteristics in order to better manage the information collected to date and allow for expansion; the second component was the exploration of the impact of various retrofit measures on the energy-use intensity of the buildings through numerical modelling; the third component was the identification of opportunities to develop both existing and new policies in order to promote viable energy retrofits.

A MURB database was developed to gather, normalize and analyze energy-use data. This database is an effective way of addressing the need for more uniform and consistent MURB data. As each new building is added, the database document updates a dashboard tab summarizing the ranges of energy performance and basic characteristics of the data set buildings. Further, a comparison between the data set sample and the estimated MURB population is also made. Capable of continuous updating, this tool can be made available for future research and benchmarking exercises.

In addition to developing a MURB database, a detailed study of four buildings was carried out. Buildings from the 1960's, 70's and 80's were chosen and it was found that these buildings had energy intensities similar to the vintage groups reported in the first part of the study. After establishing a calibrated model of the existing building using actual energy-use data, a series of retrofit measures were modelled and the resulting energy savings estimated.

It was concluded that the energy savings resulting from the retrofits were as expected. It was also concluded that the retrofits with the highest impact in terms of energy savings were improved boiler efficiency, reduced air leakage, and improved envelope thermal resistance through added insulation and window replacement.

It was also found that suite electricity load reduction had very little impact on overall energy use in terms of equivalent kilowatt-hours and a positive, neutral or negative impact on carbon emissions depending on the building. Other retrofit measures, such as improved fan and pump efficiencies, as well as common area lighting and reduced corridor supply air temperatures in winter all contributed to energy savings in a minor way.

Though the incremental impact of each retrofit type can be shown through this modelling, the synergies and secondary effects of some measures may not have been accounted for here. For example, when windows are replaced, air leakage rates often decline because the installed window assembly is more airtight than the previous window. These synergies could be verified in future by calibrating an energy model to a monitored building undergoing phased energy retrofits in order to determine the true impact of each retrofit.

The final part of this study considered ways in which the energy saving retrofits proposed could be implemented on a broad scale and how to expand and improve the quality of the data on which policy decisions are based. To assist in gathering more comprehensive MURB data, it was concluded that existing programs and procedures could be modified so as to require more data disclosure. The recent introduction of two local laws in New York City appears to be an effective strategy for both gathering energy consumption data and promoting energy retrofits. It was also concluded that the Official Plan was another means of raising the profile of energy retrofits when considering other scheduled maintenance or non-energy-related retrofits.

Recommendations about use of the standard weather year, CWEC, were also made. The importance of a standard weather year for comparing building energy performance between studies that span differing years was acknowledged. However, concerns were raised about the using the standard weather year to predict reductions in energy consumption. The concept of Heating and Cooling Climate Indices was introduced as a means of resolving this issue.

Though this study did not yield the expected correlations between energy use and building characteristics to allow for typology-specific retrofit measures, it has highlighted the variability of the energy performance in our existing MURB stock and the urgent need for energy retrofits in the highest intensity buildings. Accordingly, any policy approaches undertaken must recognize the diversity that exists in the MURB building stock while encouraging energy retrofits that are so essential to reducing the energy and thus environmental burden of this sector.

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Appendix A: Limitations of the Meta-Analysis Energy-Use Data

Name of Data Set	Primary Issue	Secondary Issue	Tertiary Issue
HiSTAR	Actual monthly use may not match with the month to which it had been assigned. This affected the weather normalization (especially the R-squared values)	No mechanical efficiencies have been applied, which made the meta-analysis figures difficult to compare with other studies. Values for mechanical efficiencies were available, but are unreliable. It is unknown whether the values were assumed, residual or actual.	The "data year" was uncertain. Electricity and natural gas information was often incomplete. The data overall were not reliable.
Green Condo Champions	Data set only included natural gas data. No electricity data were available.	No mechanical efficiencies have been applied, which made the meta-analysis figures difficult to compare with other studies. Values for mechanical efficiencies were generally available in the audit reports.	
Tower Renewal	Only one year of annual data was available. This was challenging to properly weather normalize.	No mechanical efficiencies have been applied, which made the meta-analysis figures difficult to compare with other studies. No values for mechanical efficiencies were available.	

Appendix B: Limitations of the Refined Data Set

Most of the building characteristics used in the correlation analysis come from information collected in building energy audit reports for each building. Building information was collected by at least 12 different individuals as part of at least seven different engineering consulting firms. The practices and the assumptions made by each firm vary, and the judgment of each individual may contribute to inconsistencies and variability in the data. Since the energy audits were not collected specifically for this study and since information was not necessarily recorded with the aim of being directly comparable with other data sources, the data must be scrutinized for inconsistencies. It appears that data were often estimated; however, no distinction is made between data actually observed and estimated data in the audit reports. Therefore it is difficult to distinguish reliable data from less reliable data.

Photographs of the buildings obtained from the audit reports and internet searches were used to improve the consistency of information such as the fenestration ratio, the presence of balconies and through-wall slabs, the general type of wall construction and the number of floors. Photographs were also used to confirm the presence of window unit air conditioners and roof equipment such as make-up air units. Searches on the building address were used to obtain more information about the ownership type (seniors' home, hospice, co-operative housing organization) and the presence of amenities such as a pool or fitness facilities. Finally, census information combined with the number of suites was used to estimate the number of occupants. The effect of the limitations of the data is discussed further in the full report for this phase: "Energy Consumption Trends of Multi-Unit Residential Buildings in the City of Toronto."

Appendix C: Summary of Regression Analyses Undertaken

	Component of Energy Consumption	Stepwise Forward-Selection		Logical Approach	
		Variables Selected	Adjusted R^2 Value	Variables Selected	Adjusted R^2 Value
Annual Energy Consumption	Total Annual Energy Consumption	Boiler Efficiency MAU ventilation capacity Gross Floor Area Balconies and Floor Slabs	0.85		
	Annual Variable Natural Gas Consumption	Wall R-value Gross Floor Area MAU Ventilation Capacity	0.81		
	Annual Base Natural Gas Consumption	DHW Boiler Efficiency Gross Floor Area	0.17		
	Annual Variable Electricity Consumption	No variables selected	All R^2 values were less than 0.1		
	Annual Base Electricity Consumption	MAU Ventilation Capacity Gross Floor Area Cooling Capacity	0.67		
Annual Energy Intensity	Total Annual Energy Intensity	Fenestration Ratio MAU Ventilation Capacity Number of Suites Year Built Wall R Number of Floors	0.57	Glazing U-value	0.10
	Annual Variable Natural Gas Intensity	Glazing U-value Boiler Capacity Number of Suites	0.19	Glazing U-value Boiler Capacity	0.18

Appendix D: Conclusions Related to the Variables Examined in the Refined Data Set

Variable	Conclusion
Fenestration Ratio	The fenestration ratio was shown to affect energy use related to heating and cooling as predicted. The correlation was shown to be stronger in buildings with double-glazed windows than in buildings with single-glazed windows leading to a hypothesis that window air leakage may also be a significant contributor.
Air Leakage	Air leakage is predicted to have an impact on energy use related to heating and cooling, especially in buildings with single-glazing. This suggestion could not be tested since no data on window air-tightness were available.
Glazing U-Value	The considerable variation in the data correlating the glazing U-value with heating and cooling loads suggest that glazing U-value affects heating and cooling loads but may not be a governing variable.
Boiler Efficiency	The expected relationship between boiler efficiency and variable natural gas intensity was found. However, the R^2 value was lower than expected. This was because the data on boiler efficiency was not comprehensive enough to accurately project actual boiler plant efficiencies.
Cooling Capacity	The relationship between cooling capacity and electrical intensity in air conditioned buildings provided the strongest relationship in the analysis.
Number of Occupants	The number of occupants was shown to be the governing variable related to base natural gas consumption; however, this result was based on an estimate of the number of occupants. The multi-variable regression analysis also suggested that the number of occupants may influence variable natural gas intensity since the number of occupants can contribute to internal heat gain.
Common Areas and Special Facilities	The analysis of anomalies revealed that although there was not one particular factor that could explain a large group of the anomalies, information on the special facilities included in the buildings aided in the explanation of a number of the anomalies.

Appendix E: Detailed Summary of Modelled Building Characteristics

Description of Building 1960

Building 1960 is a rental building located in East Toronto and, given conflicting dates listed, was constructed in either 1967 or 1969. The building represents the "flying-form" construction typical of 1970s high-rise buildings in Toronto and has 17 above grade floors and 2 below grade parking garage levels. Common areas are located on the first floor and include a lobby, laundry facilities and two daycare spaces. There is additional building operations space on this floor, including the electrical room, compactor room, boiler room, moving room and maintenance/storage areas. There are no apartment units on the first floor.

In total, the building houses almost 700 residents in 192 apartment units. Of these units, 33% are one bedroom, 50% are two bedroom and 17% are three bedroom units.

All building characteristics and energy data were sourced from an in-depth study done by ARUP Canada Incorporated as part of their Mayor's Tower Renewal study in April 2010. This study included detailed HVAC and building envelope descriptions, floor plans, temperature set points, information on electrical loads and residential behaviour.

Building Envelope

As there were no architectural drawings available for the wall sections, ARUP estimated the wall components with input from the building operations manager. The building has exposed slab edges, as shown in Figure E35, with a Concrete Masonry Unit (CMU) back-up wall. An estimated 1-inch insulation board is applied to the exterior followed by a waterproofing membrane, an air gap and a white brick façade. To the interior of the CMU is lath and plaster.

Figure E35: Exterior of Building 1960

Image Source: (ARUP, 2010)

HVAC System

The building is heated with hot water radiators. Two 3.5 MMBTU capacity boilers are used to provide hot water for space heating and DHW. The heating system for the building is complex, as shown in Figure E36, because it has been retrofitted since the original construction. For the purposes of energy modelling the system was simplified as shown in Figure E37.

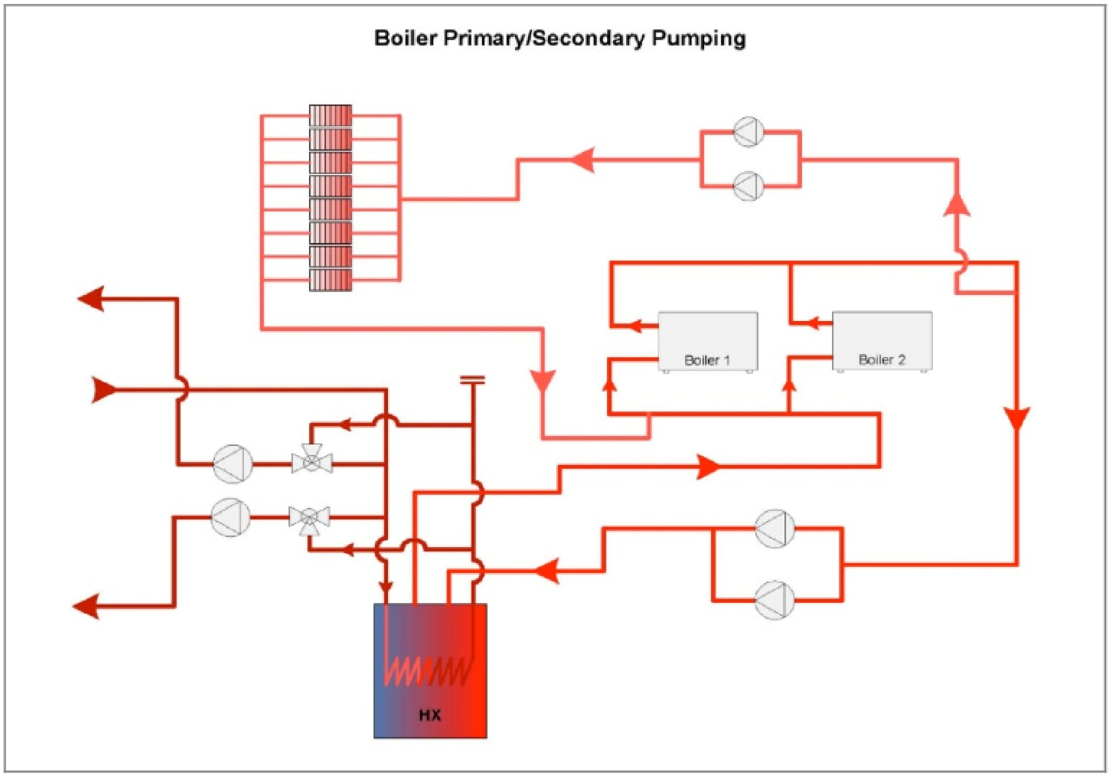

Figure E36: Building 1960 Existing Heating System

Image Source: (ARUP, 2010)

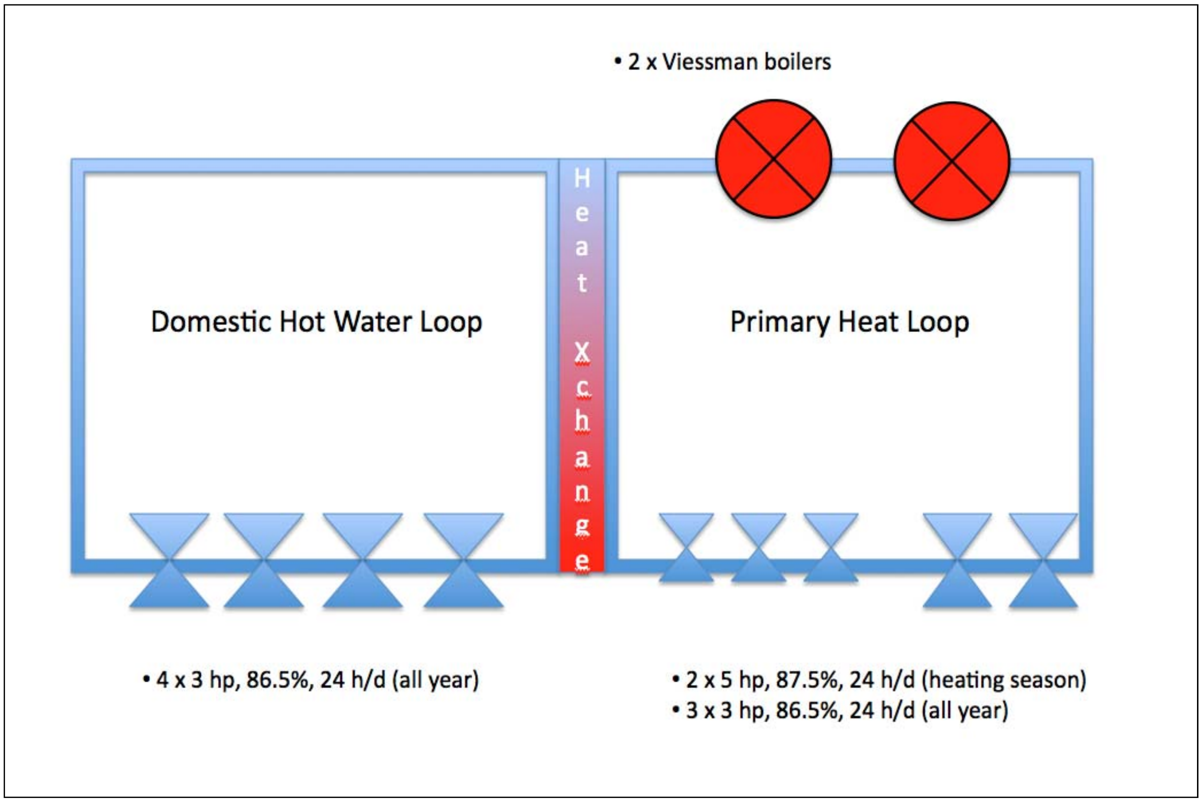

Figure E37: Building 1960 Simplified Heating System

Essentially, the simplified system consists of a primary heat loop with five pumps and two boilers. Through a heat exchanger, this loop feeds the domestic hot water loop which has four pumps to deliver the hot water to units radiators.

The building does not appear to have conditioned ventilation air. Two fresh air fans (each 2 hp) deliver fresh air to pressurize the corridors. Additionally, bathrooms are ventilated with ten exhaust fans of 1 hp each.

The building does not have a built in cooling system.

Lighting

Default settings have been used for the interior of the building. However a separate lighting load was added for exterior lights because the building contains an estimated 20 150W lights in the garage which are on 24 hours per day and six 150W lights on the grounds.

Previous Retrofits

The building has undergone some retrofits since construction including:

- Lights upgraded to CFLs, with a CFL incentive program for private units
- T8 ballasts installed in hallways and common areas
- Low flow showerheads and low flush toilets
- Boiler replacement

The building envelope has had no known upgrades.

Description of Building 1970a

Building 1970a, constructed in 1971, is believed to be a rental building and is located at downtown Toronto. The building has 22 floors above grade and one storey of underground parking that is about seven times larger than the ground floor area.

The ground floor consists of mostly the common areas including the lobby, laundry facilities and mechanical room as well as two residential suites. The entire second floor is dedicated to locker room storage. Each floor starting from the third floor consists of six suites with a total of 122 apartment units in the building. Of these units, 33% are one-bedroom and 67% are two-bedroom.

Building Envelope

The roof was assumed to be four-ply felt and gravel on 1.5-inch rigid insulation on the concrete slab. The exterior wall is composed of 4-inch brick with a 4-inch concrete block backer wall. There is 2-inch EPS insulation inboard of the masonry and then a plaster interior finish. The balconies surround the building and consist of exposed concrete slabs as shown in Figure E38.

Figure E38: Exterior of Building 1970a

The single-glazed, aluminium frame windows were all replaced in April 2008 with fixed units over 4-sash sliders containing sealed double-glazing with low-emissivity coating, argon infill, warm edge spacers, and thermally broken aluminum frames. A solar control, sputtered (soft) low-emissivity coating was used on the south elevation, while a regular pyrolitic low-emissivity coating was used on the other facades. The infiltration rate in the energy model was set at 0.11 CFM/ft^2 of exterior wall. Since air sealing measures had been undertaken, it was assumed that the infiltration was lower than the other buildings being modelled.

HVAC System

The building is heated with hot water radiators. A series of heating system retrofits were completed between November 2003 and May 2008. A building automation system (BAS) was installed to monitor and control the boilers, pumps, inside and outside air sensors, make-up-air (MUA) systems, domestic hot water (DHW) systems, exhaust fans, and garage temperature.

The BAS system install also involved boiler reconfiguration. Instead of having dedicated DHW boilers and separate boilers for the parking garage, all boilers are now integrated and provide hot water where needed on demand. This demand is now supplied by one 1.5MBTU and one 1.0MBTU boiler, both rated at 85% efficiency. A glycol heating loop, new heating loop, new heating coils and variable frequency fans were also installed.

The eQUEST model consists of a primary heat loop which serves the hot water radiator system, a glycol loop for pre-heating MUA, a domestic hot water loop and two boilers.

According to the electricity usage data analysis, it is believed that some of the suites in the building use supplementary electric heaters.

The hallways are provided with conditioned fresh air from a make-up air unit (MUA) which is pre-heated by the glycol loop in the winter months.

The building does not have a central cooling system.

Lighting

Default settings have been used for the interior of the building, with the exception of residential lighting intensity, which is about 65% of the default values, following the replacement of suite-based incandescent light bulbs with compact fluorescents.

Previous Retrofits

The building has had some upgrades to components including:

- Lights upgraded to CFLs, with a CFL incentive program for private units
- New glycol heating loops installed for MUA
- Boiler replacement
- Building air sealing measures
- Window replacement

Description of Building 1970b

Building 1970b is a condominium that was built in 1977 and located in the west end of Toronto. The building has 25 above grade floors and two below grade floors for the parking garage. Building common areas are located on the first floor and include a lobby, storage rooms, a recreation room, a card room and offices.

In total, the building houses 193 suites: 145 two bedroom apartments and 48 three bedroom apartments. Although this building is not a seniors' home, it has been noted that many retired people live in the building.

All building information came from a building energy audit completed by Mann Engineering (2010) as well as building floor plans that were obtained from the City of Toronto's Buildings Office.

Building Envelope

The building is constructed primarily with 8-inch concrete slabs and shear walls with glazing and brown metal spandrel panels forming the exterior walls. The spandrel panels are filled with two inches of insulation. The windows are single-glazed and have a reflective coating. Balconies surround the building and consist of through-the-wall concrete slabs as shown in Figure E39. The roof is insulated with three inches of insulation. Interior walls are finished with drywall.

Figure E39: Exterior of Building 1970b

An infiltration rate of was 0.279CFM/ft^2 was used to calibrate the natural gas use in the energy model.

HVAC System

The building is heated primarily with a hydronic circulation loop connected to vertical fan coils installed in each tenant suite. The water is heated with two 3.5MMBTU gas-fired natural draft boilers. These boilers are more than 15 years old and their efficiency had been estimated to be less than 70%. The water is circulated through the hydronic circulation loop with two pumps located in the penthouse mechanical room and water is circulated through the boiler loop with another two pumps.

Additionally, electric baseboard heaters are used in entrance vestibules and common areas for supplementary heating. The total capacity of these electric baseboards is estimated at 60kW. Based on the auto-sizing feature in eQUEST, the heating boilers used in this building have been undersized. Therefore, tenants may also be using plug in electrical space heaters to make up for heating needs.

The building is centrally cooled by a screw chiller and a cooling tower, which were installed in the building in 2005. The cooled water is circulated using one pump and delivered to the fan coil in the individual suites. The system has a 400ton cooling capacity.

The hallways are provided with conditioned fresh air from two identical MAUs. Each MAU is equipped with a heating coil for winter and a heat exchanger for cooling in the summer. The MAUs are each associated with a 5HP supply fan. Additionally, kitchen and bathroom fans are installed and controlled by an on/off switch.

Lighting

Default settings have been used for the interior of the building. Most common area lighting for the building is considered relatively efficient, utilizing fluorescent T9 fixtures and compact fluorescent light bulbs. In-suite lighting is very tenant specific.

Domestic Hot Water

The domestic hot water system that serves the building consists of two 0.75MMBTU boilers. Water is stored in a 1,000 gal tank and circulated with one pump. Compared with the eQUEST boiler auto-sizing estimate, the domestic hot water boilers are significantly under sized. This may be the reason why the domestic hot water energy usage had to be calibrated to match the actual usage. Additionally, the building has an older population, which often results in a lower occupant density in each suite and lower domestic hot water use.

Description of Building 1980

Building 1980 is a rental apartment building located in Aurora, Ontario. Built in 1984, it is a 4-5 split-storey building. In addition to residential units, the building also includes a pre-school.

The ground floor and second floor are considered 'part floors'. This is due to the west side of the building being one floor level taller than the east side. These two floors contain the building common area, including the lobby, daycare, garbage and mechanical rooms, as well as some apartment suites. The upper floors are mostly suites. In total, there are 71 units made up of 21 one-bedroom, 45 two-bedroom and five three-bedroom units.

Building Layout and Envelope

Building 1980 has a Z-shaped layout as shown in Figure E40 and ranges from five to four to three storeys moving from east to west as shown in Figure E41 (image contrast has been increased to maintain confidentiality).

Figure E40: Building 1980 Footprint

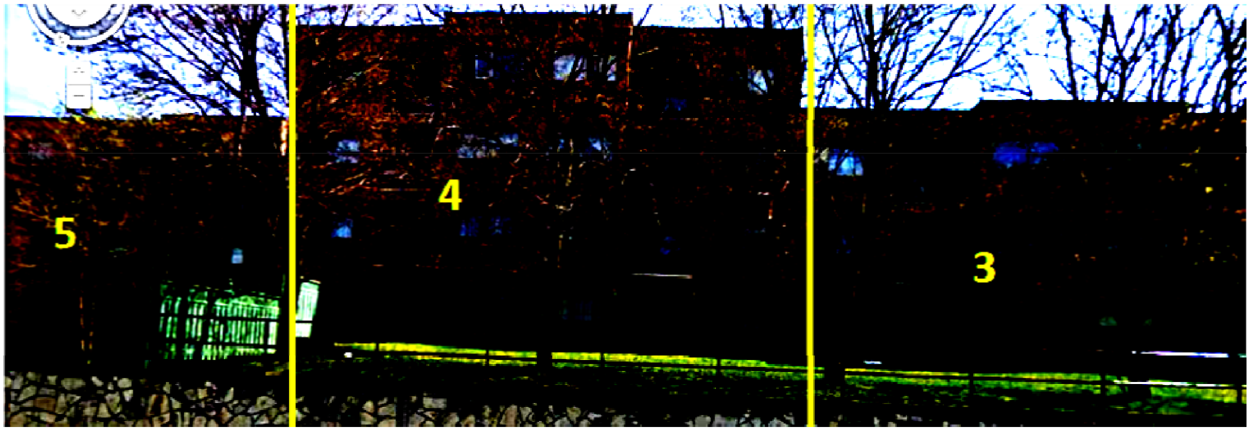

Figure E41: Building 1980 Elevation

The roof of this building is estimated as 4-inch concrete with a gravel finish. Above grade exterior walls consist of a steel frame with red brick veneer, as shown in the architectural drawings.

Although several types of windows are found in the building, the majority are double glazed, two-pane units of 8.2 ft wide and 3.6 ft tall. The North and South facades were estimated to have 31% windows by area while the East and West facades had minimal window areas. This was confirmed by Google Street View for the East face of the building and assumed to be the same for the West face which was not visible from Street View.

HVAC System

The building is heated with a combination of hot water radiators and electric baseboards. The hot water system uses three boilers fueled by natural gas. As boiler capacity information was not available, boilers were first auto-sized by eQUEST and then, in order to calibrate the natural gas usage, the boiler capacity was reduced forcing the electric heaters to make up the difference. The boiler capacity was adjusted until the consumption of both electricity and natural gas matched the utility data. The resulting boiler capacity was 0.2MMTBU. Two pumps serve the hot water heating system.

The built-in electric heaters were modelled as a second system. As the hot water baseboards are the main heating source, they were allocated to the perimeter while the electric heaters were allocated to the core. It should be noted that this does not reflect their physical location in the actual building however this was necessary in order to force eQUEST to incorporate electric heaters as supplementary to the boiler system. In order to obtain the correct proportion of space heating going to electric heaters, the perimeter zone was changed from the default 25 ft deep to 27.5 ft from the exterior of the building in order to model the two heating systems, electric and hydronic, in the correct proportion.

Although not specified in the drawings, the utility data clearly illustrate that a cooling system is present in the building. It is possible that this is from window units in the suites. Regardless of how the units are cooled, the peak in summer electricity usage, closely related to summer CDD, clearly indicates large scale air conditioning exists in the building.

This cooling system was modelled as a typical DX coil system with the smallest possible units providing the cooling (<65 kBtuh) with an air cooled condenser.

The building contains a force flow fan on the second floor and a rooftop make-up air unit to bring in fresh air.

Lighting

Default settings have been used for the interior of the building as there was no explicit information about this included in the drawings.

Appendix F: Weather Normalization of Electricity Consumption

The MURB Data Input Tool tests three different weather normalization strategies for the electricity use of a building in order to determine the best fit:

- 12-month HDD for buildings with a significant amount of electric resistance heating and little or no cooling
- 12-month CDD for buildings with a significant amount of cooling and a small proportion of electric resistance heating
- Composite 6-month HDD and 6-month CDD for buildings with both electric resistance heating and cooling.

The data presented in Figure F42 includes the electricity normalization process selected by the MURB Data Input Tool based on the highest R^2 value (labelled as "Best Fit"), the process with the second highest R^2 value (Composite or 12-month HDD) and the average actual electricity and total energy consumption data. Buildings 1960 and 1970b will be discussed here because of the different electricity normalization techniques selected for these buildings based on the R^2 values in the Data Input Tool.

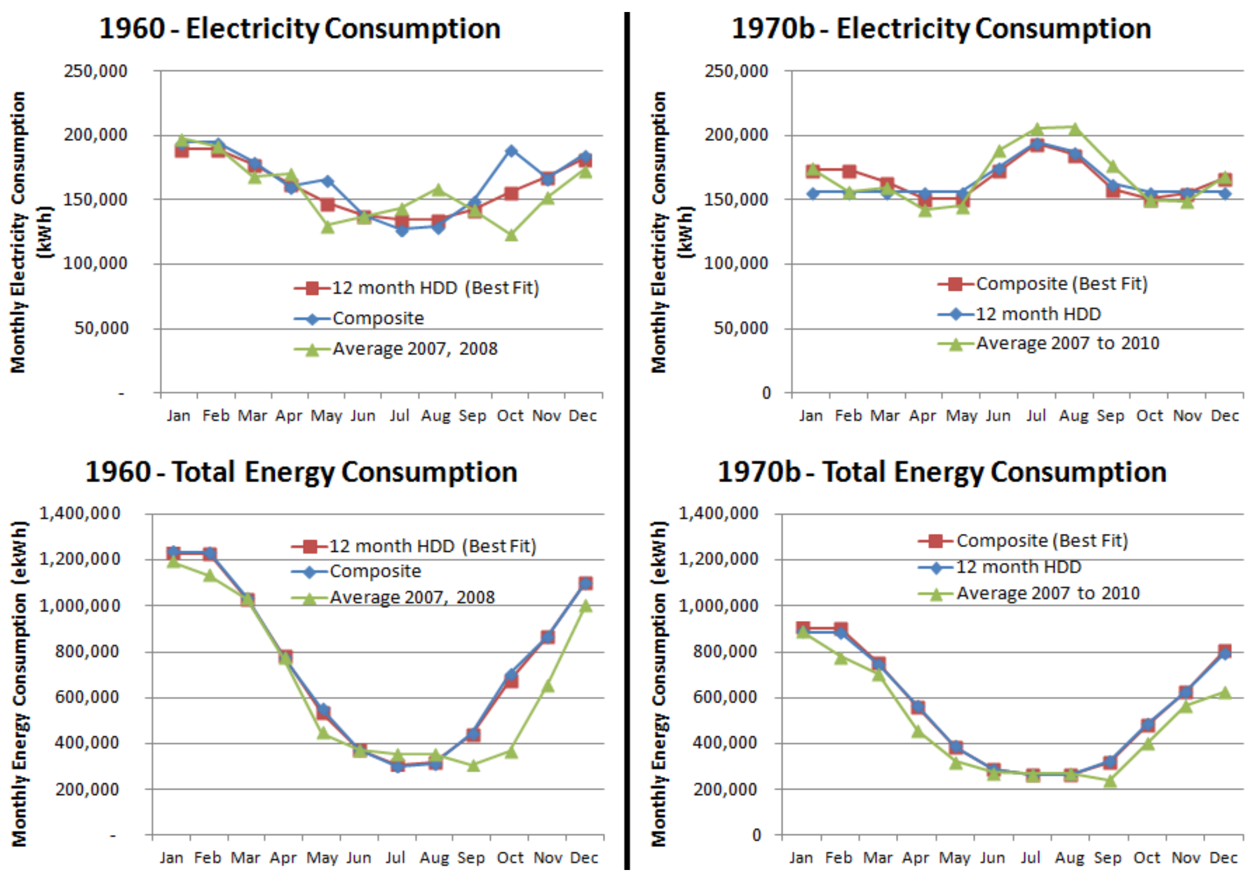

Figure F42: Comparison of Alternate Electricity Normalization Techniques for Buildings 1960 & 1970b

When examining the entire year of data, it is evident that Building 1970b has consistently higher cooling loads compared with Building 1960. However, Building 1970b also has some weather-sensitive electricity loads in the winter so the composite selection of six months of HDD and six months of CDD seems reasonable.

This data has also been presented to demonstrate the magnitude of the error associated with selecting a particular normalization process. The drawbacks associated with weather normalization to CWEC have already been discussed in Section 3.2. It could be argued that it is not valid to compare four buildings that have been normalized using different processes. However, the difference in electricity and total energy consumption between the two normalization processes shown in Figure F42 is minimal. Examining electricity consumption, the difference between the normalization processes is 3% and 1% for Buildings 1960 and 1970b, respectively. The difference in total energy consumption is 1% and 0.4% for Buildings 1960 and 1970b, respectively.

The purpose of the normalization procedure in this exercise is to best model the way that each building would respond to various climatic loads. With respect to comparing energy intensities and the impact of retrofit measures between buildings that have been normalized using different electricity weather normalization processes, the effect different weather normalization processes is truly minimal.

Appendix G: Comparison Between Actual and Modelled Energy Use

For each of the buildings the weather-normalized actual energy use was compared with the modelled energy use on a monthly and annual basis. This information is presented both numerically and graphically.

Energy Use of Building 1960

Table G12 and Figure G43 show the modelled electricity consumption and the actual consumption of Building 1960.

Table G12: Modelled and Actual Electricity Consumption for Building 1960

Electric Consumption (kWh x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	186.7	167.1	179.8	161.5	148.7	131.8	137.8	136.3	137.9	158.3	166.8	183.3	1895.8
Actual	200.6	183.3	176.2	163.5	143.4	133.3	139.3	147.3	142.7	140.6	161.3	178.9	1910.4
% Difference	7%	9%	2%	1%	4%	1%	1%	7%	3%	13%	3%	2%	1%

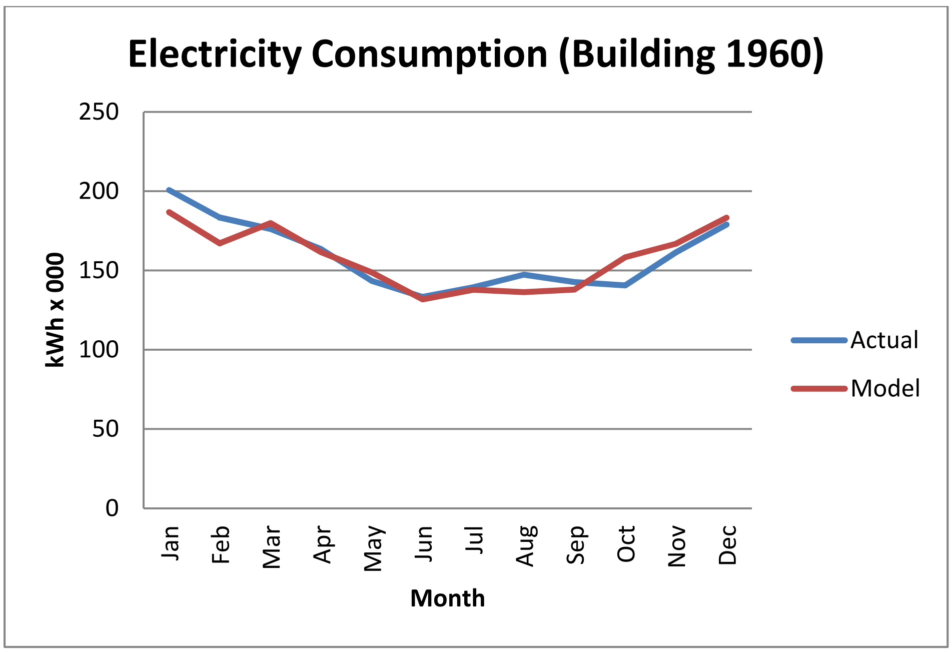

Figure G43: Electricity Consumption for Building 1960

Table G13 and Figure G44 show the modelled and actual natural gas consumption for Building 1960.

Table G13: Modelled and Actual Natural Gas Consumption for Building 1960

Natural Gas Consumption (m3 x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	111	98	89	60	36	21	18	17	22	48	70	98	689
Actual	103.3	103.0	84.8	61.5	38.8	23.7	17.8	18.9	29.8	51.6	69.6	91.2	694.0
% Difference	7%	5%	5%	2%	6%	12%	2%	8%	25%	7%	1%	7%	1%

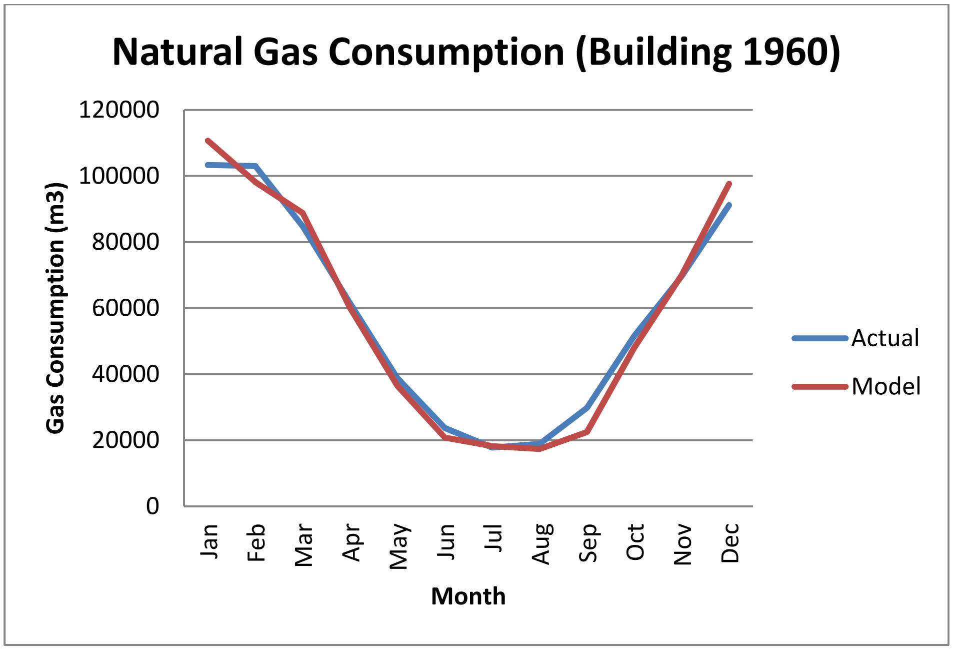

Figure G44: Natural Gas Consumption for Building 1960

Energy Use of Building 1970a

Table G14 and Figure G45 show the modelled and actual electricity consumption of Building 1970a.

Table G14: Modelled and Actual Electricity Consumption for Building 1970a

Electric Consumption (kWh x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	96.0	86.6	95.8	70.0	74.1	74.6	80.9	80.1	73.4	79.5	93.0	95.8	999.6
Actual	98.0	97.8	91.4	70.8	70.8	74.2	77.6	76.1	72.0	79.8	86.1	93.7	988.4
% Difference	2%	11%	5%	1%	5%	0%	4%	5%	2%	0%	8%	2%	1%

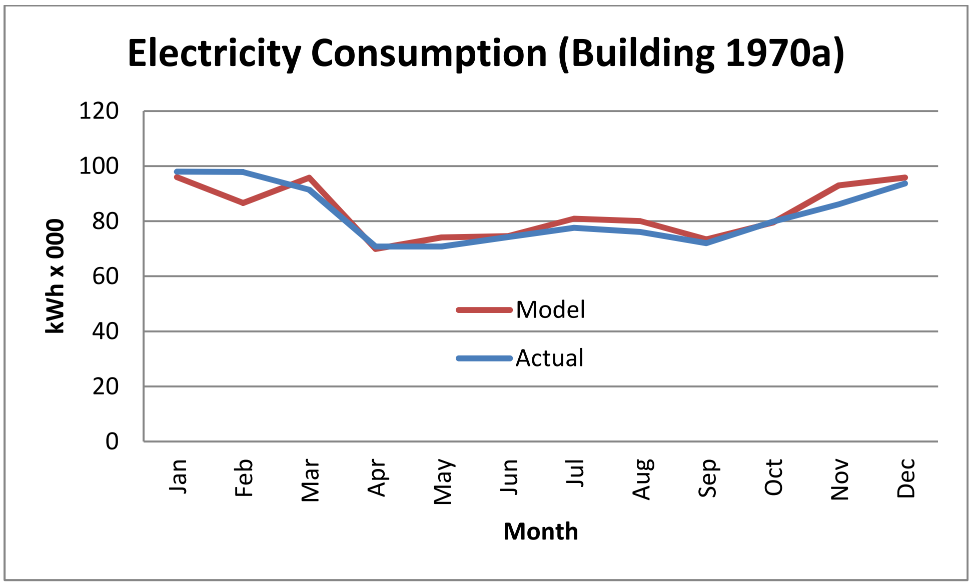

Figure G45: Electrical Consumption for Building 1970a

Table G15 and Figure G46 show the modelled and actual natural gas consumption of Building 1970a.

Table G15: Modelled and Actual Natural Gas Consumption for Building 1970a

Natural Gas Consumption (m3 x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	32.2	27.9	23.0	14.2	8.0	6.5	5.7	5.4	5.7	10.2	17.9	27.9	184.7
Actual	27.9	27.8	23.0	16.9	10.9	7.0	5.4	5.7	8.6	14.3	19.0	24.7	191.2
% Difference	15%	0%	0%	16%	27%	6%	5%	6%	34%	28%	6%	13%	3%

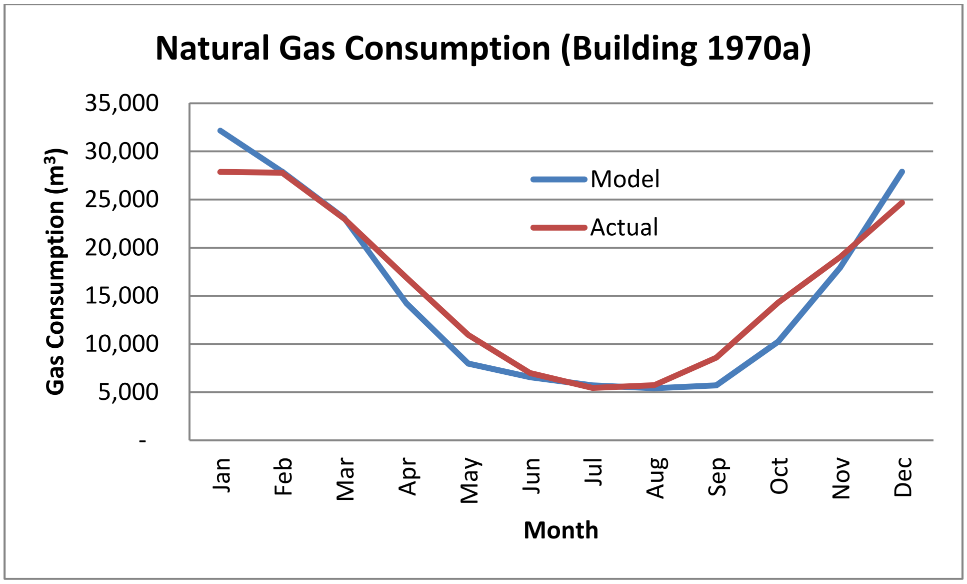

Figure G46: Natural Gas Consumption for Building 1970a

Energy Use of Building 1970b

Table G16 and Figure G47 show the modelled and actual electrical consumption of Building 1970b.

Table G16: Modelled and Actual Electricity Consumption for Building 1970b

Electric Consumption (kWh x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	169.7	152.6	165.4	148.9	133.6	138.7	199.5	190.8	143.1	149.5	161.0	169.8	1922.6
Actual	169.2	169.1	162.8	148.3	148.4	170.4	191.9	182.5	156.0	151.3	157.6	165.0	1972.6
% Difference	0%	10%	2%	0%	10%	19%	4%	5%	8%	1%	2%	3%	3%

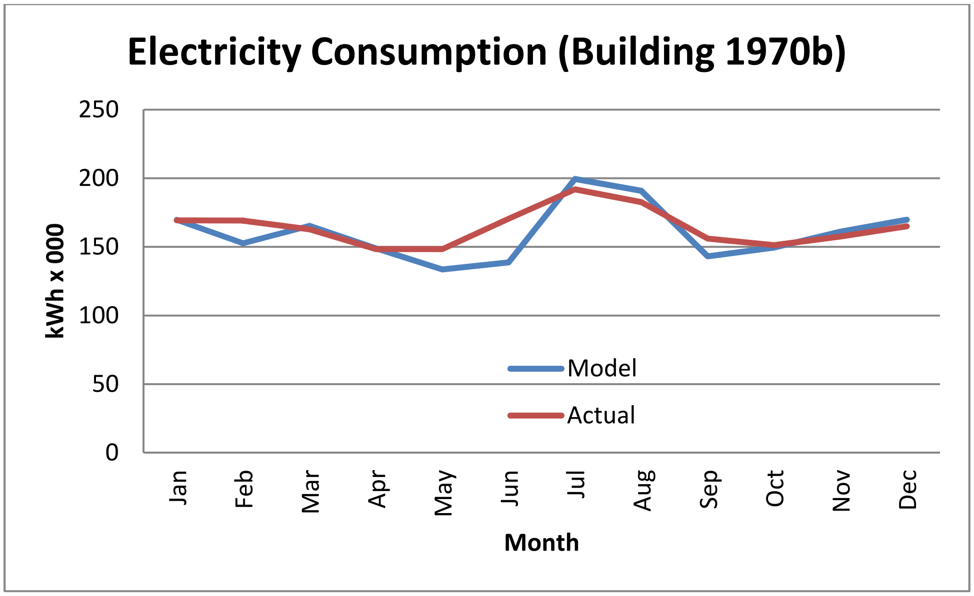

Figure G47: Electrical Consumption for Building 1970b

Table G17 and Figure G48 show the modelled and actual natural gas consumption of Building 1970b.

Table G17: Modelled and Actual Natural Gas Consumption for Building 1970b

Natural Gas Consumption (m3 x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	80.5	69.7	55.8	31.6	16.5	10.5	8.0	7.7	10.0	24.2	44.1	70.8	429.4
Actual	71.4	71.1	57.4	40.0	22.9	11.5	7.1	8.0	16.1	32.5	46.1	62.3	446.4
% Difference	13%	2%	3%	21%	28%	9%	12%	3%	38%	26%	4%	14%	4%

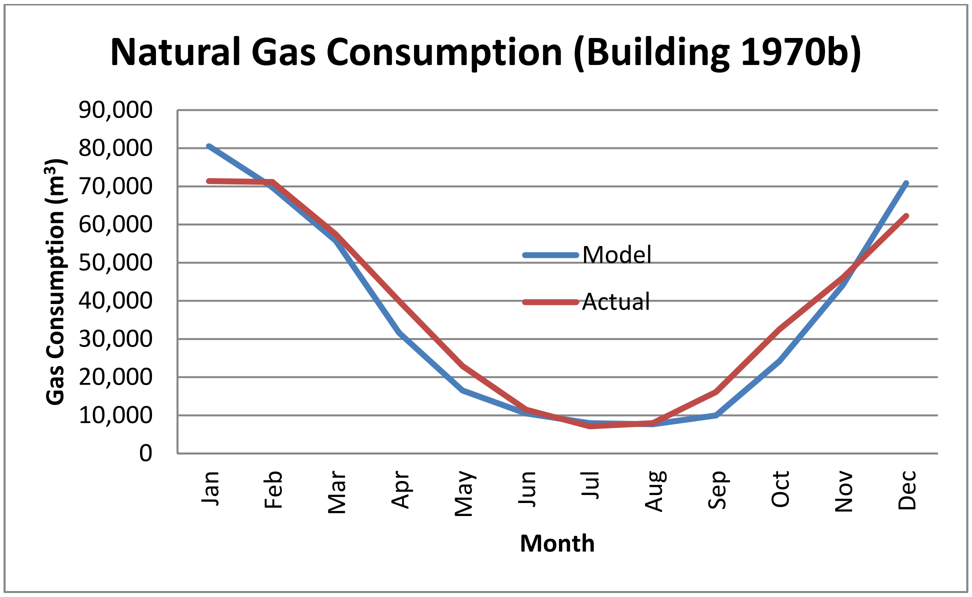

Figure G48: Natural Gas Consumption for Building 1970b

The modelled consumption slopes more steeply in the winter and flattens out more in the summer than the actual consumption; however the consumption of the model is reasonably similar to the actual consumption.

Energy Use of Building 1980

Table G18 and Figure G49 show the modelled and actual electrical consumption of Building 1980.

Table G18: Modelled and Actual Electricity Consumption for Building 1980

Electric Consumption (kWh x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	41.7	37.6	41.2	37.6	34.4	45.0	52.1	50.4	43.0	37.0	39.1	41.5	500.6
Actual	43.3	41.9	39.6	34.5	37.8	44.1	50.7	47.9	39.2	37.8	38.2	41.8	496.8
% Difference	4%	10%	4%	9%	9%	2%	3%	5%	10%	2%	2%	1%	1%

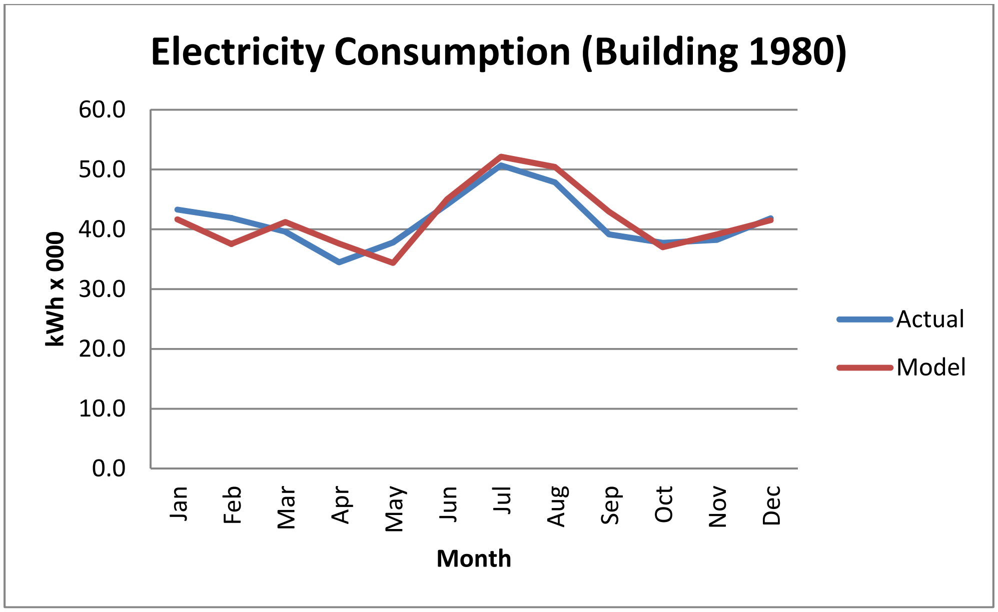

Figure G49: Electrical Consumption for Building 1980

Table G19 and Figure G50 show the modelled and actual natural gas consumption of Building 1980.

Table G19: Modelled and Actual Natural Gas Consumption for Building 1980

Natural Gas Consumption (m3 x 000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Model	21.7	19.3	17.1	11.1	6.4	3.7	3.1	3.0	3.8	8.3	12.9	19.0	129.6
Actual	19.8	19.8	16.2	11.6	7.1	4.1	2.9	3.1	5.3	9.6	13.2	17.4	129.9
% Difference	10%	2%	6%	4%	10%	10%	8%	4%	27%	13%	2%	9%	0%

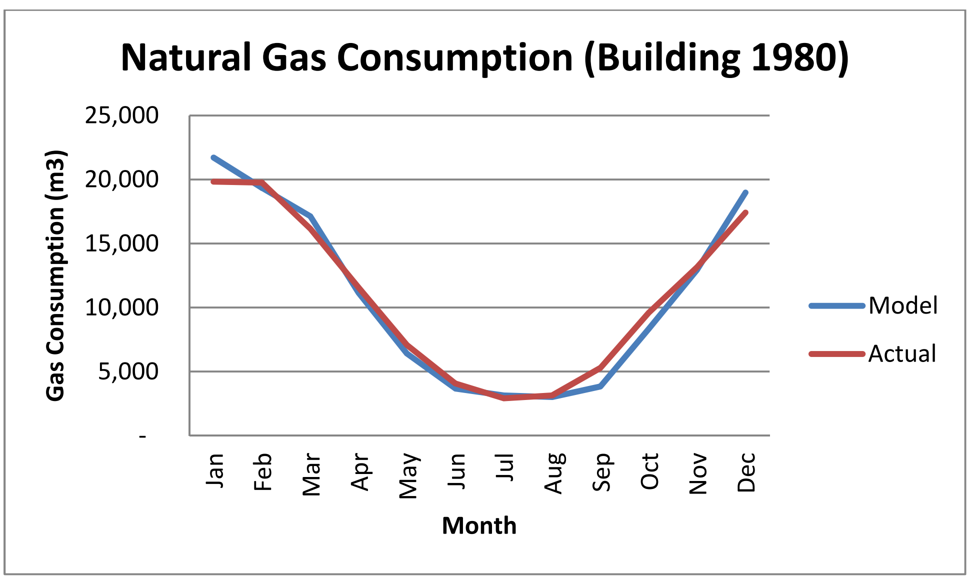

Figure G50: Natural Gas Consumption for Building 1980

Appendix H: Supplementary Electric Resistance Heating

To determine if the modelled electric heating loads were reasonable, an estimated heating capacity and number of hours of operation were used to determine how many suites might be using supplementary heating. Assuming a 1.5kW heater in each suite operating for 10 hours each day, the equivalent percentage of suites in each building operating supplementary electric heating is shown in Figure H51.

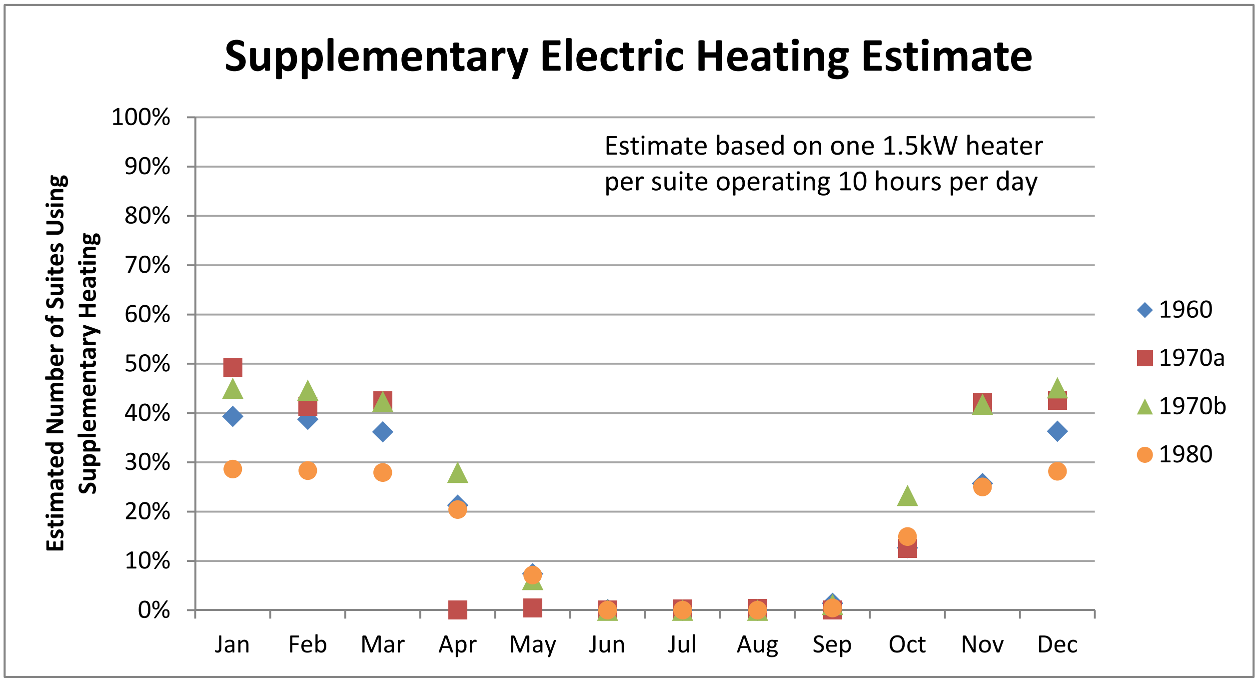

Figure H51: Estimated Percentage of Suites Operating Supplementary Electric Resistance Heaters

As long as the estimated percentage of suites was significantly less than 100%, as shown, the electricity load assigned to supplementary space heating was deemed reasonable. The binary nature of the supplementary suite heating estimate (e.g. all on or all off) in Building 1970a is due to the way in which the loads were scheduled, as described above. A check of the zone temperatures was also done to ensure zones were not being over-heated.

During the retrofit analysis that is presented in Section 6.5, the electrical heating loads were maintained in each model. This would lead to slightly overstated natural gas reductions from some retrofit measures. Due to the existing uncertainties in the model and the small contribution of electric heating energy to total energy use, this slight overstatement was deemed acceptable. It is impossible to know what proportion of electric heating would be required following each retrofit because the actual energy data for each hypothetical retrofit case is not available to calibrate the model.