Meta-Analysis of Energy Consumption in Multi-Unit Residential Buildings in the Greater Toronto Area

For:

Toronto Atmospheric Fund

Submitted by:

Clarissa Binkley, University of Toronto

Marianne Touchie, University of Toronto

Professor Kim Pressnail, University of Toronto

Executive Summary

This study analyzes Multi Unit Residential Building (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. This 'meta-analysis' combines data from these three sources in order to better characterize the energy performance of Greater Toronto Area MURBs, and to understand the correlations between energy performance and various building characteristics. This research is motivated by the need to better understand the energy use of our building stock in order to support policy and programmatic interventions that are designed to achieve significant energy-use and greenhouse gas emissions reductions in existing buildings.

The energy-use data from the three databases were first normalized to account for variations arising from different weather conditions, and billing periods. The data were normalized so that it could be directly compared between the data sets. In the process of normalization, base loads and weather-dependent loads were also identified. Following the normalization process, an inventory of the data characteristics and range of values was taken and the data were analyzed for correlations between energy use and building age, size, and occupancy type. Conclusions were drawn from the data inventory and the correlation analysis.

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

The annual energy intensity of the buildings was calculated by dividing the total annual energy provided from both electric and natural gas sources, by the building's gross floor area (HiSTAR and Tower Renewal data only). This total energy intensity split out by natural gas and electricity consumption is shown in the figure below. The 42 Green Condo Champions buildings do not include electricity data, but were also included for reference.

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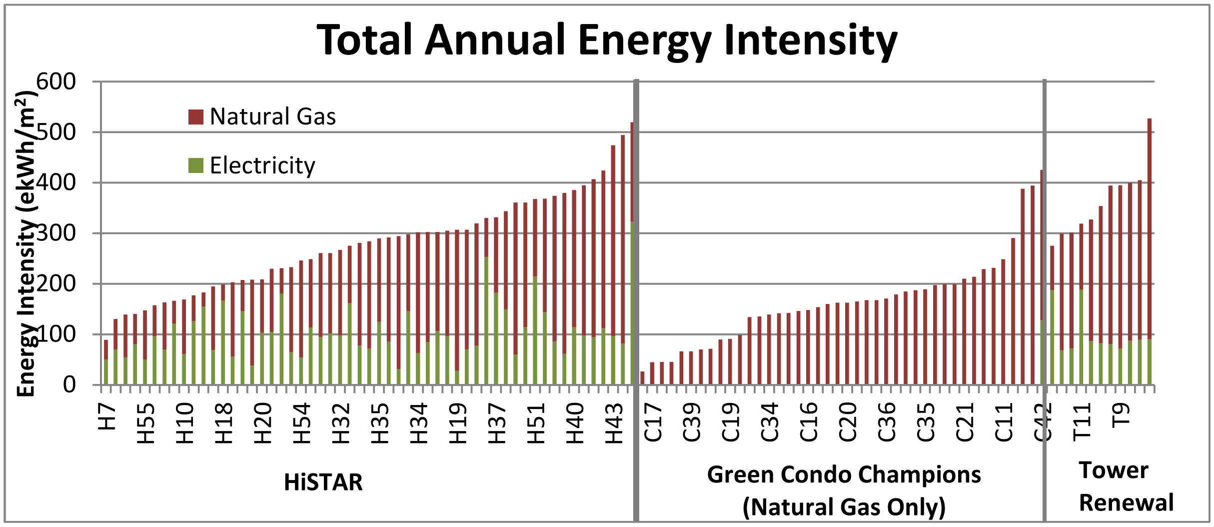
[1] The estimate of MURB population is based on the number of households in apartment buildings less than five stories and the number of households in apartment buildings with five stories or more from the 2006 Census. The number of apartment-based households combined with the median number of suites per building from this Meta-Analysis organized by floor were used to determine the MURB population estimate. For example: 380,000 households in buildings five stories or more divided by the median number of suites (181) in all Meta-Analysis buildings five stories or more results in approximately 2100 buildings that are five stories or more. Similarly there are an estimated 4000 buildings under five stories.



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 the figure above, the energy intensity varied widely within the data set from 88ekWh/m^2 to 520ekWh/m^2. Even when the buildings were categorized by age or ownership type, the range in energy intensities within each category remained large. Because of this significant variation, many of the correlations identified within the data were weak. The greenhouse gas emissions intensities, which were calculated by applying emissions factors to the energy intensity, varied between 16.5 ekgCO$_2$/m^2 and 96.6 ekgCO$_2$/m^2 and the average was 55.3ekgCO$_2$/m^2.

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-to-wall 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. Of course, total building energy 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 within 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-rise MURBs may not be required. However, this finding differs from another study based on HiSTAR data only (Liu 2007) and should be investigated further.

This study also includes a preliminary exploration of the relationship between ownership type and energy intensity. On a gross floor area basis, condominiums had the lowest average energy intensity, but yet 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 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 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. 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 could be explained by the tight operating budgets common in this ownership type and sparse common areas.

Given the findings of this meta-analysis, further study is necessary to determine the underlying reasons behind the correlations so that effective measures can be taken to reduce energy consumption in all MURB typologies.

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PART 1: STUDY BACKGROUND

Introduction

High rise multi-unit residential buildings house approximately one third of the population in the City of Toronto. Energy used in these buildings is responsible for over 40% of Toronto's residential sector greenhouse gas emissions. With the high-rise MURB sector totaling over 2000 buildings and MURBs with fewer than five stories totaling approximately 4000, this vast building stock represents a tremendous opportunity to reduce energy use and therefore greenhouse gas emissions. However, recognizing that there are limited economic and human resources, it is important to identify and prioritize the retrofit needs in this sector. Furthermore, policy-makers require a better understanding of MURB energy use in Toronto in order to design fair and effective policy interventions.

To carry out this benchmarking, a profile of energy use in existing buildings must be developed. Fortunately, many of these buildings are constructed similarly, and can potentially be grouped for the purposes of energy-use analysis. The aim of this study is to develop correlations between building typologies and energy use. These energy use patterns can then be used to prioritize the energy retrofit of certain typologies and so, inform policy makers.

There are multiple sources of MURB energy use data that have been collected by different parties. This study uses three different data sets, and presents a meta-analysis of these sources. By combining three data sets which include more than 100 buildings, more statistically significant relationships can found. Building age, ownership type, building size and energy use can all be considered and compared. This study also identifies gaps in the existing data and helps define future data collection needs.

Description of Data Sources

The three data sources accessed in this study included the HiSTAR database developed by the Canada Mortgage and Housing Corporation (CMHC) and two other data sets developed by the Toronto Atmospheric Fund (TAF) through the Green Condo Champions Project and the Tower Renewal Benchmarking Initiative.

To gain a better understanding of energy and water use in apartment buildings the High-Rise Statistically Representative (HiSTAR) database was developed by CMHC in partnership with Natural Resources Canada. Working with consulting firms across Canada, they gathered data from 81 buildings and assembled the information using Microsoft Access format (CMHC 2001). CMHC has very generously permitted the authors to access a modified version of this database that protects the anonymity of the building owners. Although the database contains information from buildings nationwide, only 55 buildings located in Southern Ontario were included in the meta-analysis since these buildings share a common climate. Buildings in this data set range in age from 1941 to 1994, and range in size from four to 35 storeys.

The second data set, TAF's Green Condo Champions data set, consists of energy audits of 50 condominium buildings in the Toronto area collected by Mann Engineering. Building directors from the participating condominiums attended training and engagement programs focused on cutting energy costs and reducing greenhouse gas emissions and received an audit report and recommendations for strategies to reduce the energy use in their buildings. Energy audits from 42 of the 50 buildings were used in this meta-analysis. The building construction dates range from 1971 to 2007 and they range in size from four to 46 storeys.

The third data set, originated from the Tower Renewal Benchmarking Initiative and run by the City Manager's Office, was partially funded by TAF. In this project, monthly energy consumption data were collected from 29 high-rise rental apartments by Enerlife Consulting. The purpose of the project was to begin an energy benchmarking system that could lead to improvements in energy performance. Of the 29 buildings, the annual energy consumption information for use in this meta-analysis was provided for 11 of the buildings. The buildings construction dates range from 1961 to 1978 and they range in size from nine to 33 storeys.

A summary of the data sets used for the meta-analysis of 108 buildings is presented in Table 1.

Table 1: Summary of Data Set 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 – Ont	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	42 - Toronto	2006 to 2010	NO	YES	3-4 years of data: monthly
Tower Renewal Benchmarking Initiative	11	11 - Toronto	2009	YES	YES	1 year of data: annual

Report Structure

Given the different data set characteristics shown in Table 1, it is evident that some data manipulation was required to be able to compare these three data sets directly. Part 2 of this report outlines the methodology and assumptions used to manipulate and analyze the data. Part 3 provides an inventory of the data and details the results of the correlation analysis, comparing building energy use with building characteristics such as date of construction and size. This section also includes a discussion of the limitations of the results. Part 4 summarizes the conclusions from this study and outlines the next steps required to improve the quality of the database. This includes conducting more in-depth data gathering and analysis in order to expand the preliminary results presented here.

PART 2: ANALYSIS PROCEDURE

This section begins with an over-all description of the approach used in the data analysis. This is followed by a detailed discussion of the normalization procedures including a description of the assumptions used during this process.

General Approach

From building to building, the energy data varied according to location, billing periods and billing years. Therefore normalization was required to account for these variations. The normalization process applied depended on the data characteristics and was different for each data set. The normalization methods applied to each data set have been summarized in Table 2 and the process and purpose of each of these normalizations has been described in the next section of this report.

Table 2: Energy-Use Data Normalization Summary

Processes Applied	HiSTAR	Green Condo Champions	Tower Renewal
Calendarization		✓	
Month-length Normalization	✓	✓	
Total Consumption Normalization	✓		
Linear Regression Weather Normalization	✓	✓	
Annual weather normalization			✓

Once the data were normalized, buildings were tabulated according to certain characteristics such as age, ownership type (rental or condominium) and size including gross floor area, number of suites and building height. Normalized energy use data were then examined for correlations with building age, size and ownership type to determine any trends. Where significant outliers appeared, they were removed and the results re-analyzed to determine if this changed the correlation. For some of the correlation analyses, the base load or non-weather dependent data were separated from the variable, weather-related data.

Before beginning an examination of the normalization procedures and assumptions, however, it is helpful to examine the limitations inherent in the data sets. Table 3 contains a summary of the issues that limited the usefulness of the data. Primary issues are issues that are expected to have the greatest effect on the data analysis, while secondary and tertiary issues, though important, are expected to have less effect on the outcome of the analysis. In a summary way, this table reveals imperfections inherent in the data. In the sections that follow, how these imperfections were managed will be revealed.

Table 3: Energy-Use Data Limitations

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.	

Normalization Analysis Decisions & Assumptions

This section outlines the various normalization procedures and identifies which data sets were analyzed. Weather data sources and the assumptions used to normalize the data will also be discussed and presented here.

Calendarization

Typically, energy billing cycles do not correspond to the beginning and end of the calendar month. These billing cycles also differ from building to building. In order to compare buildings directly, the associated energy use for each calendar month must be determined.

Fortunately the Green Condo Champions data contained meter reading dates. Meter reading dates were then used to apportion energy use to each month. The HiSTAR data were already allocated to particular months and did not contain billing dates. As such, it was assumed that the given consumption corresponded exactly with the month to which it was assigned. The Tower Renewal data were not calendarized because only annual consumption data were available.

Month-Length Normalization

As the number of days in each month varies throughout the year, the consumption data and heating degree days (HDD) had to be normalized to a standard month with a length of 30.42 days which corresponds to a non-leap year. This was done so that each data point would have “equal weighting” in the linear regression used for weather normalization. The total annual energy consumption and total HDD were kept the same, but divided proportionately among the “standard” months. This process was completed for the HiSTAR and Green Condo Champions data sets since both contained monthly data but it could not be used for the annual Tower Renewal data.

Total Consumption Normalization

This process was only completed on the HiSTAR data. The process was necessary because energy consumption was provided for the individual months along with the total annual energy consumption. The sum of the monthly consumption data did not always equal the annual energy consumption provided. In some cases, this discrepancy arose because energy consumption information was missing for one or more of the months. In addition, it is possible that the billing period did not match the actual month to which the energy was assigned. If, for example, some of the energy billed in January should have been assigned to the previous year, this would be reflected in the annual total, but not in the monthly data. A third possible source of discrepancies is the meter-reading practices of the utility. The utility companies will sometimes estimate the energy use based on historical use rather than reading the meter and then apply a correction for the estimate later. The correction would be reflected in the annual total, but not in the monthly data. To account for this latter discrepancy, normalization of the total energy consumption was carried out by determining the difference in the sum of the monthly consumption data and the annual data. This difference was then distributed evenly among the months before the weather normalization was completed.

Weather Normalization

The energy consumption data have been collected from a range of years and also for buildings in different locations. Weather conditions vary from year to year and city to city thereby influencing energy use. Thus, energy-use data must be weather normalized to a common year and location to allow comparison between buildings. Following completion of the normalizations above, weather normalization was carried out on the HiSTAR and Green Condo Champions data sets. Weather normalization involved the following steps:

1. The monthly HDD (X-axis) were plotted together with the monthly energy consumption (Y-axis) for all of the available months of data as shown in Figure 1.
2. Linear regression was then used to determine a line-of-best fit for the data.
3. The coefficient of determination or the "R^2 value" of the linear regression was determined. The significance of this term is described below.
4. The equation of the line of best fit was used to determine the energy consumption over a "standard weather year" as determined from the Canadian Weather for Energy Calculations (CWEC). This was done by inputting the monthly HDD calculated from the CWEC to determine the resulting standard monthly energy consumption. The sum of the monthly energy consumption became the weather normalized annual consumption value.

Figure 1 shows an example of the plots created to perform the weather normalization. This graph is for one of the buildings in the Green Condo Champions data set.

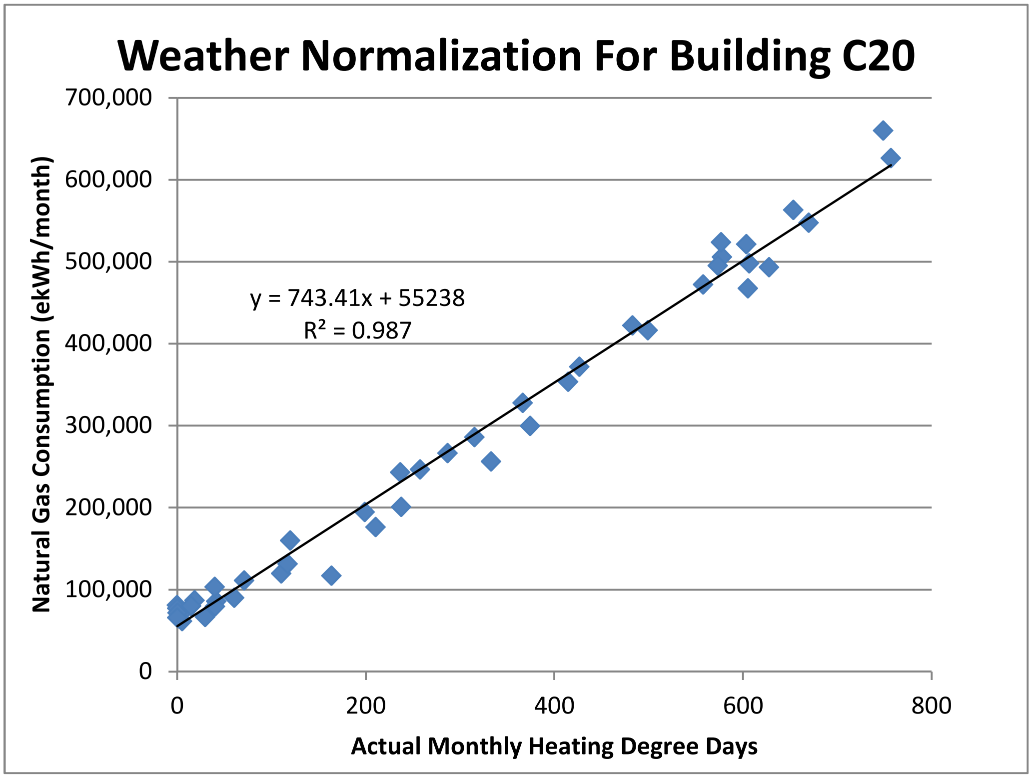

Figure 1: Sample Graph Used for Weather Normalization

Since no monthly data were available, this process could not be used to weather normalize the Tower Renewal data. Instead the data were normalized on an annual basis. The normalization assumed the same relationship as used in the monthly weather normalization:

$$\frac{Annual\ Variable\ Energy}{Actual\ Annual\ HDD} \propto \frac{Normalized\ Variable\ Energy}{Standard\ Annual\ HDD}$$

Weather data

Historical weather data were retrieved and associated with the energy consumption data. Monthly HDD and cooling degree day (CDD) data were obtained from Environment Canada for the applicable cities and years. For buildings located in and around Toronto including those in Mississauga, Scarborough, Brampton and Thornhill, data from the weather station in Toronto near the University of Toronto were used. For locations further afield such as Lindsay, Whitby, Ottawa, Peterborough and Windsor, city-specific weather data were applied.

The energy consumption data associated with this weather data were then normalized to HDD data using CWEC data, a 'standard year' of weather data provided by Environment Canada. A standard reference year such as this captures average weather over a long period of time. For example, the CWEC data used in this report were based on Toronto mean temperatures from 1960-1989. Finally, all HDD for both historical weather and the standard reference year were calculated with an 18°C base, based on the assumption that heating is not required until the exterior temperature falls below this base (Hutcheon and Handegord 1995).

Determination of Base Load

Energy consumption in buildings has both a fixed and variable component. The fixed base load includes end uses such as domestic hot water and appliance-use. The variable load is a result of changing exterior conditions such as heating and cooling.

For the HiSTAR and Green Condo Champions data sets, two methods were used to determine the base load. The first used the average of the two months of lowest energy consumption of each year to estimate the base load. For example, if three years of data were available, this method would yield an average of the six relevant months. If the building was air conditioned, the lowest consumption was typically in the shoulder months while buildings without air conditioning had the lowest consumption during the summer months. The second method used the Y-intercept value from the weather normalization procedure outlined above. The Y-intercept represents the energy used by the building when there are no HDDs or, in other words, when no heating is required. These methods and their respective results are compared below.

As the Tower Renewal data contained no monthly data, the base load determination methods outlined above were not applied. Fortunately, this data set already included separate base and variable loads. The method used to determine these loads is unknown but they are likely based on the average energy consumption in the summer months.

Coefficient of Determination (R^2 Values)

The coefficient of determination indicates how well the linear regression line explains the variation in the data. For example, how well the HDD correlates with the energy use of a building in the weather normalization process. An R^2 value close to one means that most of the variation is explained but a number close to zero means that most of the variation is unexplained.

R^2 values above 0.8 are considered acceptable in the context of weather normalization. If the R^2 value is between 0.6 and 0.8, the data were lacking a good correlation but the weather normalization is often still done. In practice, if the R^2 value is below 0.6 the weather normalization is typically not completed. In this analysis, 50% of the R^2 values were greater than 0.6, but only 20% of the buildings had a good correlation for both electricity and natural gas consumption with weather. The HiSTAR data yielded R^2 values that ranged from 0.0001 up to 0.99. The reasons for values below 0.6 will be discussed below. Nevertheless, the weather normalization was still completed so that the HiSTAR data could be compared with the other data sets.

Shared Gas Meters

Some of the buildings in the Green Condo Champions data set shared a gas meter between two buildings. In each case, the “twin” buildings had very similar physical characteristics. Therefore the natural gas consumption data were split proportionally by the gross area of each building. Though a reasonable approximation, it is likely that building operation and occupancy would likely make these numbers different.

Efficiency of Natural Gas Combustion

Even though the efficiencies of the natural gas boilers in each building were not known across all data sets, the energy consumption still needed to be compared.   Since the total fuel in-take was known with certainty some meaningful comparisons could still be made. In the analysis presented below, cubic metres of natural gas supplied were converted to equivalent kilowatt-hours without application of an efficiency factor. The actual efficiency and therefore the actual thermal energy made available to the building to meet the energy demand will depend on the age, type and inherent efficiency of the mechanical equipment. Efficiencies typically range between 60-90% but can sometimes be higher or lower. The thermal energy requirements of a building are a function of many parameters including building envelope, air tightness, orientation, occupancy and electrical load. A detailed study of these parameters is outside the scope of this study, but is an area for further investigation.

The conversion from cubic metres of natural gas supplied to equivalent kilowatt-hours of energy was based on a factor of $37.08 mJ/m^3$ or $10.3 kWh/m^3$.

PART 3: ANALYSIS RESULTS

An important part of the meta-analysis is generating a profile of the data after combining the three existing data sets. Any correlations must be viewed in the context of this inventory recognizing that some building types may be under or over represented. Where possible, these representations are highlighted based on other sources such as Canada Mortgage and Housing Corporation building stock statistics. The remainder of Part 3 shows the correlations between energy use and various building characteristics.

Data Inventory

This section summarizes the characteristics of the buildings in the data set by grouping similar buildings together. Energy performance is also presented by ranking the consumption of each building against one another.

Summary of Building Characteristics

The normalization process was completed on 108 buildings: 90 buildings were located in the City of Toronto and 8 were located around Toronto in the Cities of Thornhill, Mississauga, Scarborough and Brampton. The remaining 10 buildings were located in other cities around Southern Ontario including Whitby, Peterborough, Lindsay, Windsor and Ottawa. The sample represents approximately 1.8% of the total Toronto MURBs based on the estimation that Toronto has more than 6000 MURBs. If considering only buildings of five stories or more, the sample represents 4.8% of the mid to high-rise MURBs.

The Tower Renewal Guidelines (Kesik and Saleff 2009) define mid-rise buildings to be five to eight storeys and high-rise buildings to be greater than eight storeys. Based on these definitions, six of the buildings in the sample were low-rise, 22 were mid-rise and 80 were high-rise. The height was unknown for six of the buildings; however, the number of suites and the floor area suggest that all six of these were high-rise buildings consisting of at least 16 storeys based on an analysis of the height and floor area of the other buildings in the data set. The tallest high-rise was 46 stories; however, 80% of the high-rise buildings had less than 25 storeys. All six of the low-rise buildings had four storeys. The number of buildings of each height, represented in four storey increments, is shown in Figure 2.

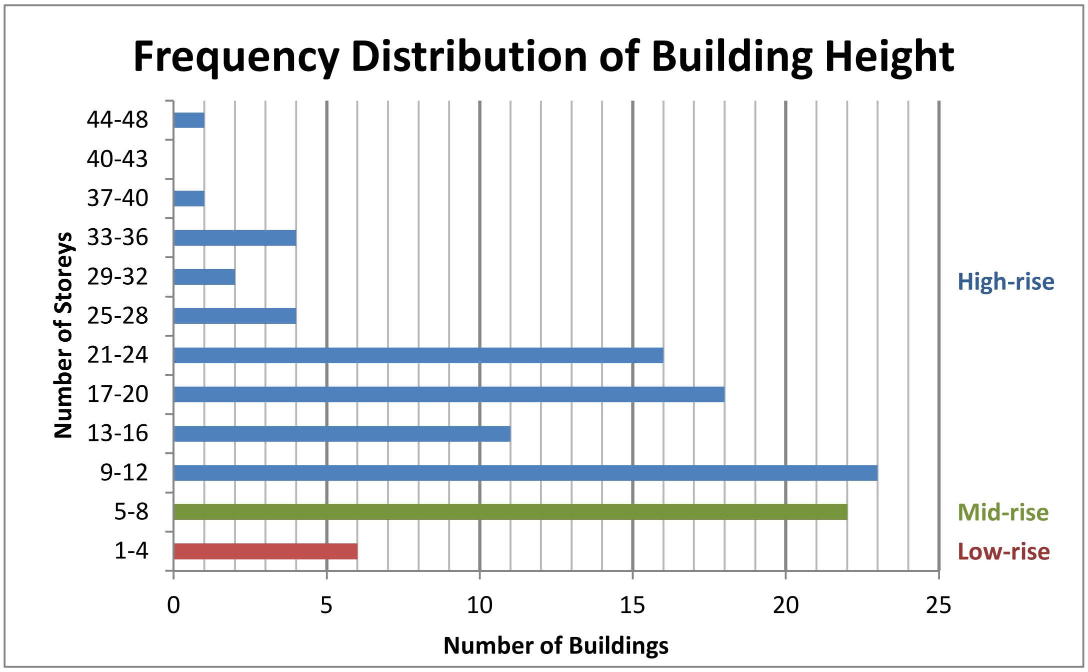

Figure 2: Frequency Distribution of Building Height in the Meta-Analysis Data Set

A comparison of a selection of the Meta-Analysis data with a recent study of Post-War Apartment buildings (Ministry of Infrastructure 2010) shows that there is a slightly larger proportion of high-rise buildings and a slightly small proportion of low rise buildings in the Meta-analysis set as shown in Figure 3. However, the magnitude of this difference is not expected to change the correlations significantly.

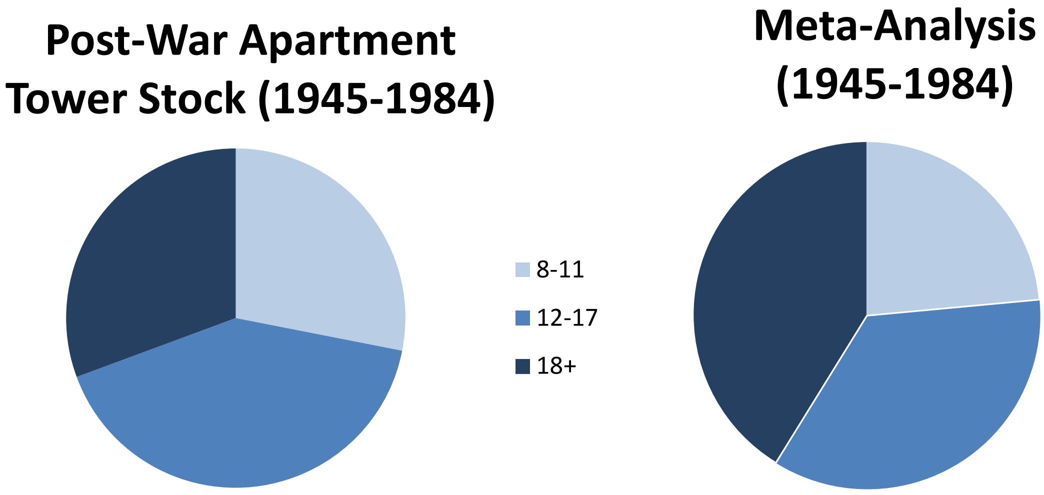

Figure 3: Comparison of Building Heights from two data sets by Number of Storeys

The number of suites in each building ranged from 14 to 714. The number of suites was unspecified for one of the buildings and was estimated to be 80 suites based on the building area. Forty of the buildings had between 101 and 200 suites and more than 80% of the buildings in the sample had fewer than 300 suites. The number of suites in each building, categorized into ranges by hundreds of suites, is shown in Figure 4.

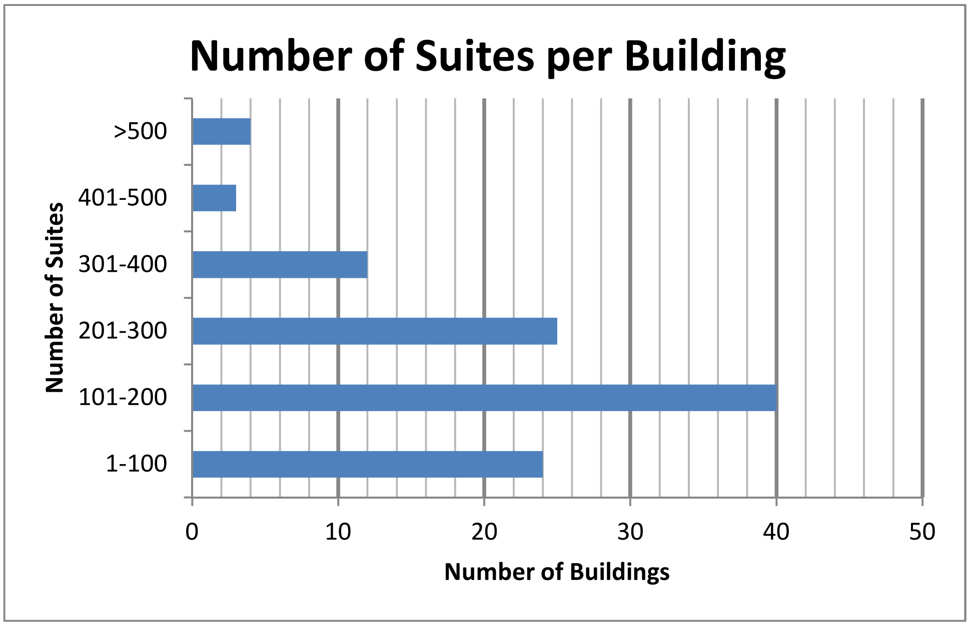

Figure 4: Number of Suites per Building

The total building floor areas ranged 2,000m^2 to 101,700m^2. Thirty-eight of the buildings had floor areas between 10,000m^2 and 20,000m^2 and more than 75% of the buildings had floor areas below 30,000m^2. Figure 5 shows the floor areas of the buildings split up in increments of ten thousand square metres.

The gross floor area represents the total area containing residential suites, lobby, common areas, and any conditioned recreational areas. It typically does not include underground parking areas even though this space is conditioned in many buildings. It is important to note that the method used to obtain the gross floor area reported in the Meta-Analysis data sets is not known. Often, the gross floor area is estimated from floor plans of the building, from physical measurements of the building, or from values obtained from real estate information. These methods may not net highly accurate measurements of total floor area. The most accurate gross floor area information is likely to exist for condominiums since this information is used to subdivide ownership of the building.

Errors in the estimated gross floor area may affect other results presented in this report, in particular the energy intensity values as well as the average attributed suite floor area described below. Also if the underground parking area is conditioned but not included in the gross floor area, the energy intensity based on the occupied space of the building will be overestimated. The effect of an inaccurate estimation of the floor area of conditioned space will be diminished with a larger data set as errors off-set one another but more detailed data are required on whether parking garages are included in the gross floor area an whether these spaces are conditioned.

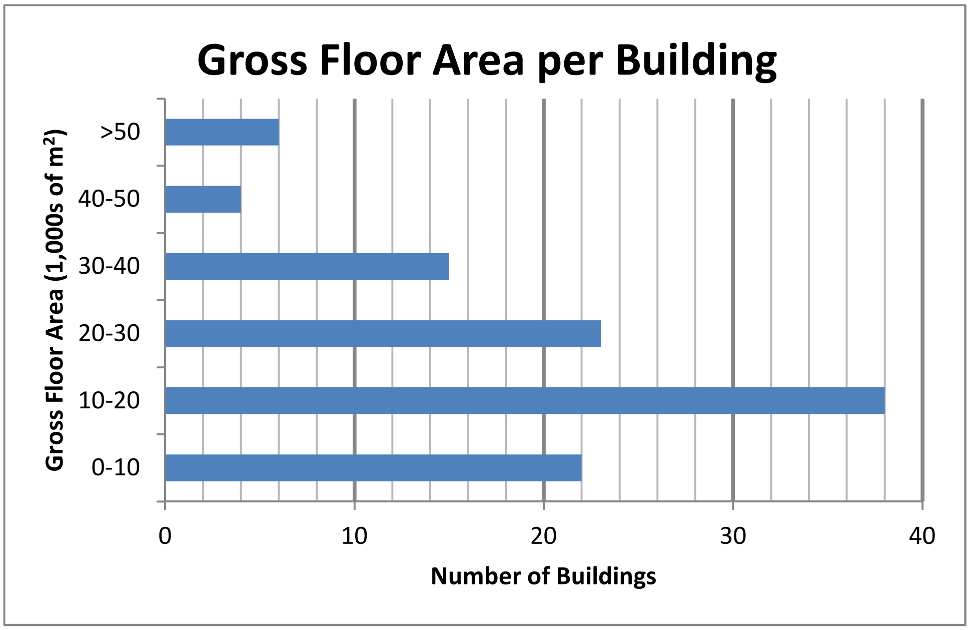

Figure 5: Gross Floor Area per Building

The gross floor area divided by the number of suites provides an approximation of the average suite size. Note that this average ‘attributed’ suite area will be larger than the actual suite size because it also includes a proportion of the common areas. The attributed suite areas ranged from 42m^2 to 280m^2 but just under half of the suites were between 50m^2 to 100m^2 as shown in Figure 6. The average suite size was about 115m^2. The number of bedrooms in each suite was specified for 19 of the buildings in the Meta-Analysis data set. Based on the average of these 19 buildings, 3% of the suites were threebedroom suites and the remaining 97% of the suites were split evenly between one-bedroom and two-bedroom suites.

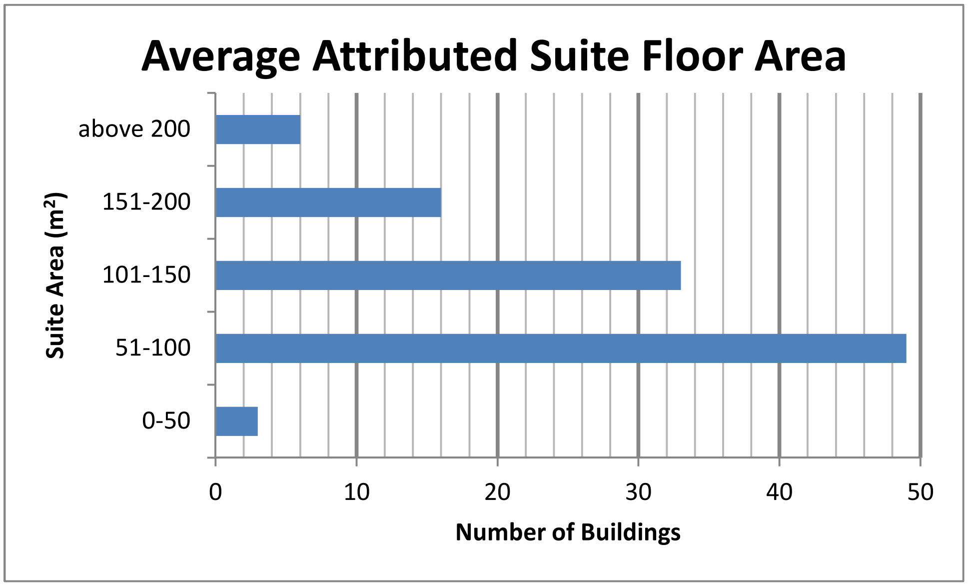

Figure 6: Frequency Distribution of the Average Attributed Suite Floor Area

The date of construction in the Meta-Analysis data set ranges from 1941 to 2009. Three buildings did not have a date of construction and it could not be estimated based on the general building characteristics. Therefore, only 105 buildings of 108 were included in Figure 7 below. This figure shows how many buildings fall into each of the 10 to 15 years construction date periods taken from the Tower Renewal Guidelines (Kesik and Saleff 2009). Most of the buildings, 31, were constructed between 1971 and 1980 and only one building in the Meta-Analysis set was constructed between 1946 and 1960.

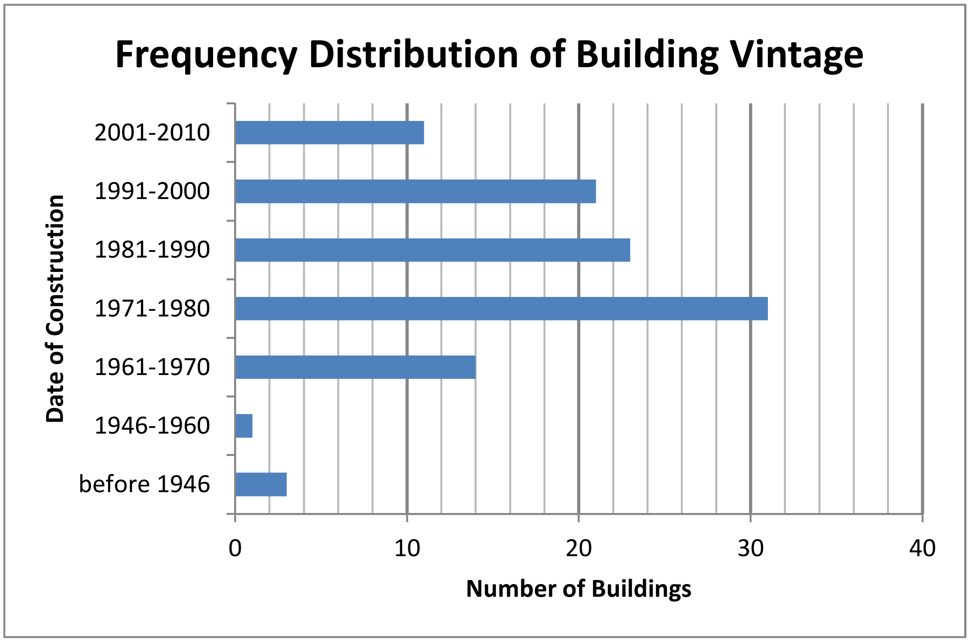

Figure 7: Frequency Distribution of Building Vintage

The Meta-Analysis set in Figure 7 appears to correlate reasonably well with the much larger sample from the CMHC's historical housing starts shown in Figure 8 below. The most significant discrepancy appears to be between the 1960's and 1970's. The Meta-Analysis set has approximately double the number of buildings constructed from 1971 to 1980 as compared to those built in 1961 to 1970. Though the area under the graph below is smaller in the 1960's than the 1970's, it is not half the size. Part of the reason for this discrepancy could be that four of the HiSTAR buildings were assigned construction dates with a range (1970-1972). These were allocated to the 1971-1980 range, increasing the number of buildings in this bin.

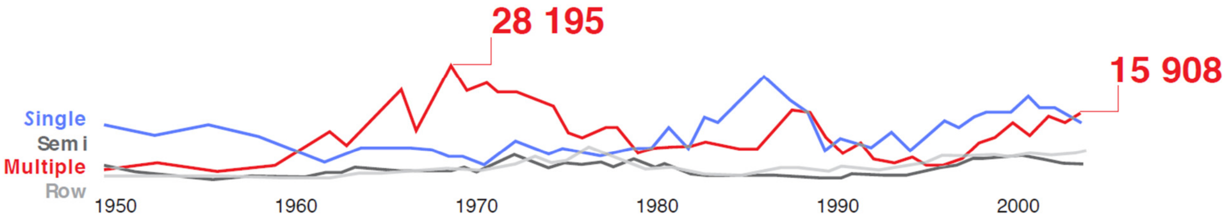

Figure 8: Housing Starts in GTA 1950-2005 from CMHC

Source: Kesik and Salef 2009

The buildings in the sample set also represent different types of ownership. For 22 of the buildings, the type of ownership was not specified and is unknown. Of the remaining buildings, 52 of the buildings were condominiums, five were co-operatives, 15 were non-profit, eight were social housing and six were private rental. These categorizations were taken from the original data sources; however, no definition of these categorizations was provided so actually distinguishing between various ownership forms may be difficult. Table 4 summarizes the ownership types based on the criteria of rented or owned units and subsidized or un-subsidized units.

Table 4: Building Ownership Distribution

	Subsidized	Un-subsidized	TOTAL
Rental Unit	Social (8) Non-profit (15)	Private rental (6)	29
Owned Unit	Co-operative (5)	Condominium (52)	57
TOTAL	28	58	86

Summary of Energy Consumption

The annual energy intensity of the buildings was based on the total annual energy provided from both electric and natural gas sources divided by the building's gross floor area (HiSTAR and Tower Renewal data only). This total energy intensity split out by natural gas and electricity consumption is shown in Figure 9. The 42 Green Condo Champions buildings did not include electricity data, but the natural gas data were presented for reference purposes in the Figure 9. The total energy intensity values vary widely from 88 ekWh/m^2 to 520 ekWh/m^2 with an average of 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). The main reason the Meta-Analysis data set has a higher energy intensity may be because of different weather normalization practices. Since the Natural Resources Canada data was based on the 2007 Survey of Household Energy Use and all of the data came from the same year, it did not have to be weather normalized to the CWEC standard weather year, while the Meta-Analysis data did. Based on the Meta-Analysis data set, energy consumption normalized to the standard weather year is 25% higher on average than energy consumption in the year 2007.

The average energy mix of the Meta-Analysis data set is 38% electricity and 62% natural gas which is also slightly different from the published energy mix of apartment buildings in Ontario: 34% electricity and 66% natural gas (NRCan 2008).

Typically, natural gas provides most of the energy required for the building but in a few of the buildings, electricity is the primary heating source. Presumably these buildings use electric space heating and natural gas or electricity for domestic hot water heating, but further investigation would be required to confirm this.

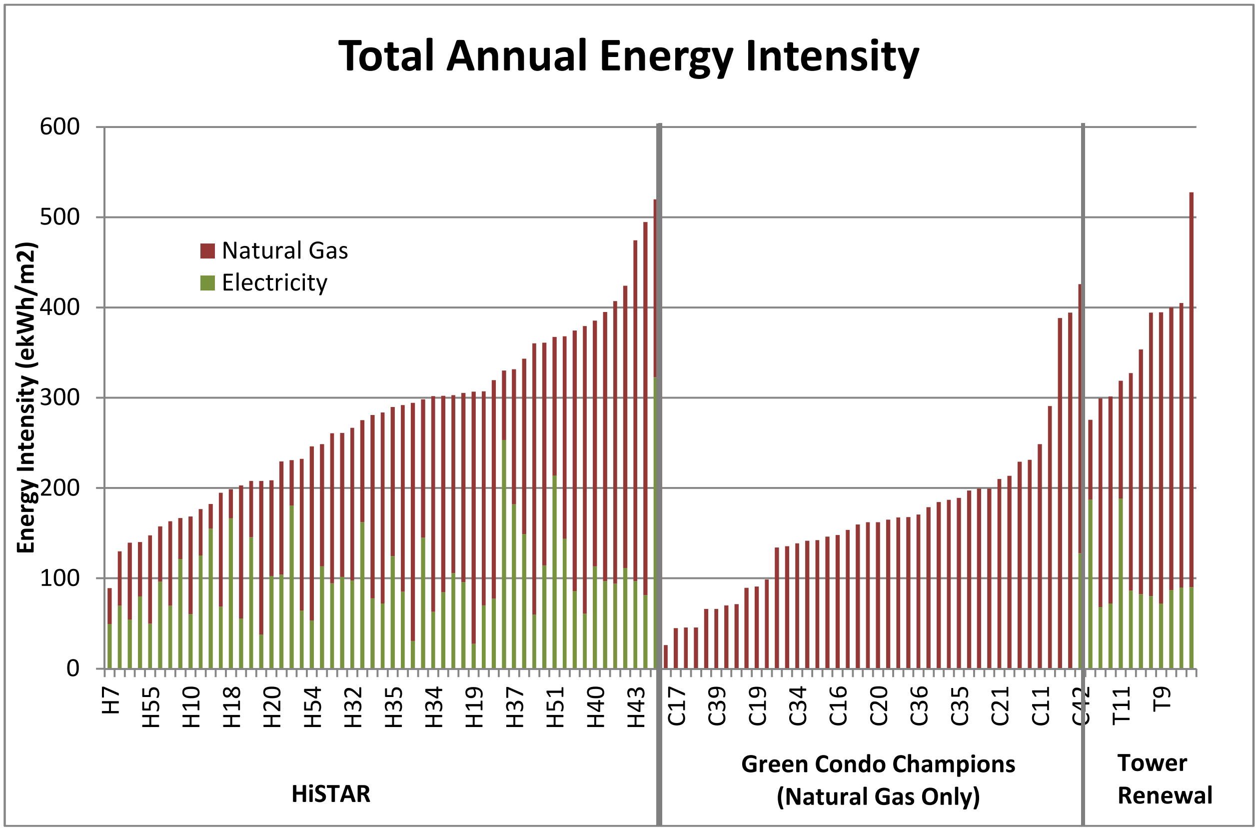

Figure 9: Total Annual Energy Intensity

The annual natural gas energy intensity is shown separately from electricity use for the 108 buildings in Figure 10. The natural gas energy intensity is in equivalent kilowatt-hours per square metre and ranges from 26 ekWh/m^2 to 447 ekWh/m^2. The yellow bars included in Figure 10 show the range of potential thermal energy intensities for each building as the thermal energy intensity is a function of the boiler efficiency. Boiler efficiency can vary from about 60% up to almost 100%, hence the 40% range in Figure 10. Therefore, it is expected that the actual thermal energy intensity required to meet the building demand lies somewhere within the range represented by the yellow bar.

The buildings with the highest natural gas energy intensity values could be good candidates for new boilers with higher efficiencies. The yellow bars essentially show the range of energy intensity reductions which could potentially be achieved by installing more efficient boilers though it is important to note the numerous other factors affecting these systems such as operating and maintenance items. Regardless of boiler efficiency or operation, the buildings will still demand the same amount of heat energy, but having a more efficient boiler system means that more of the energy delivered to the building becomes usable heat directed to occupied spaces. In other words, less natural gas is required to produce the same amount of usable heat.

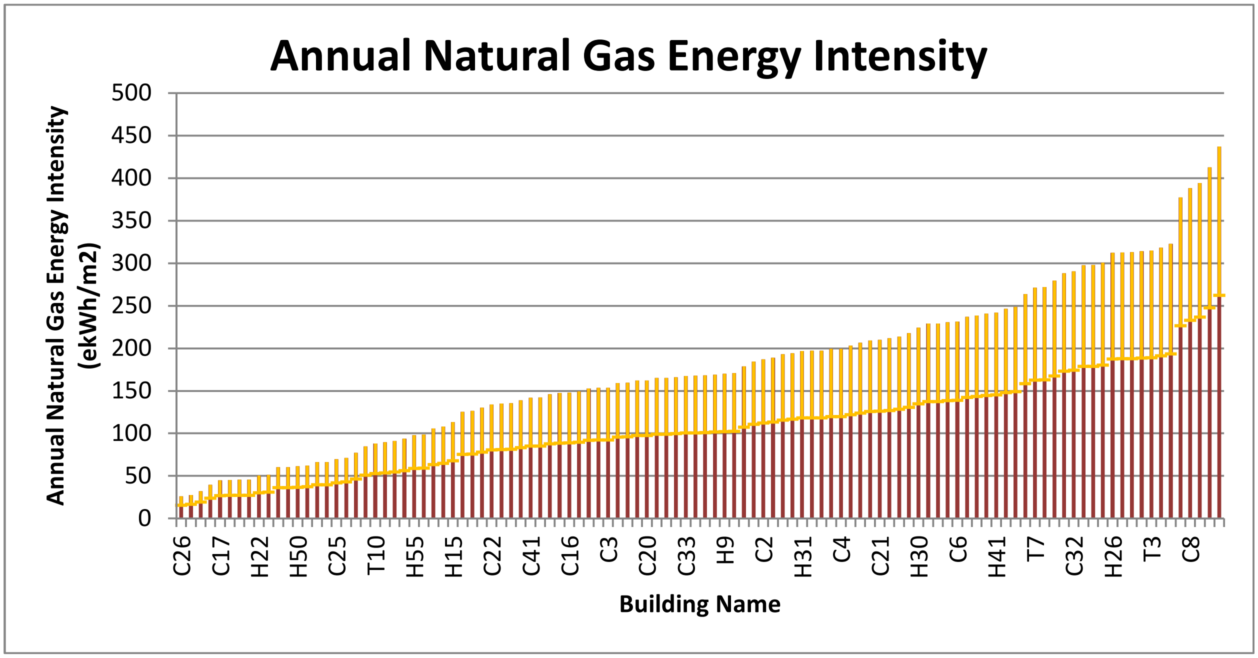

Figure 10: Annual Natural Gas Intensity of each Building

The total energy use per suite is based on the total energy provided from electric and natural gas sources divided by the number of suites in the building (HiSTAR and Tower Renewal data only). Figure 11 shows that the total annual energy use on a per suite basis ranges from 6,270 ekWh/suite to 58,480 ekWh/suite with an average of 25,100ekWh/suite. The Green Condo Champions data has been excluded from Figure 11 because this building set contains natural gas data only.

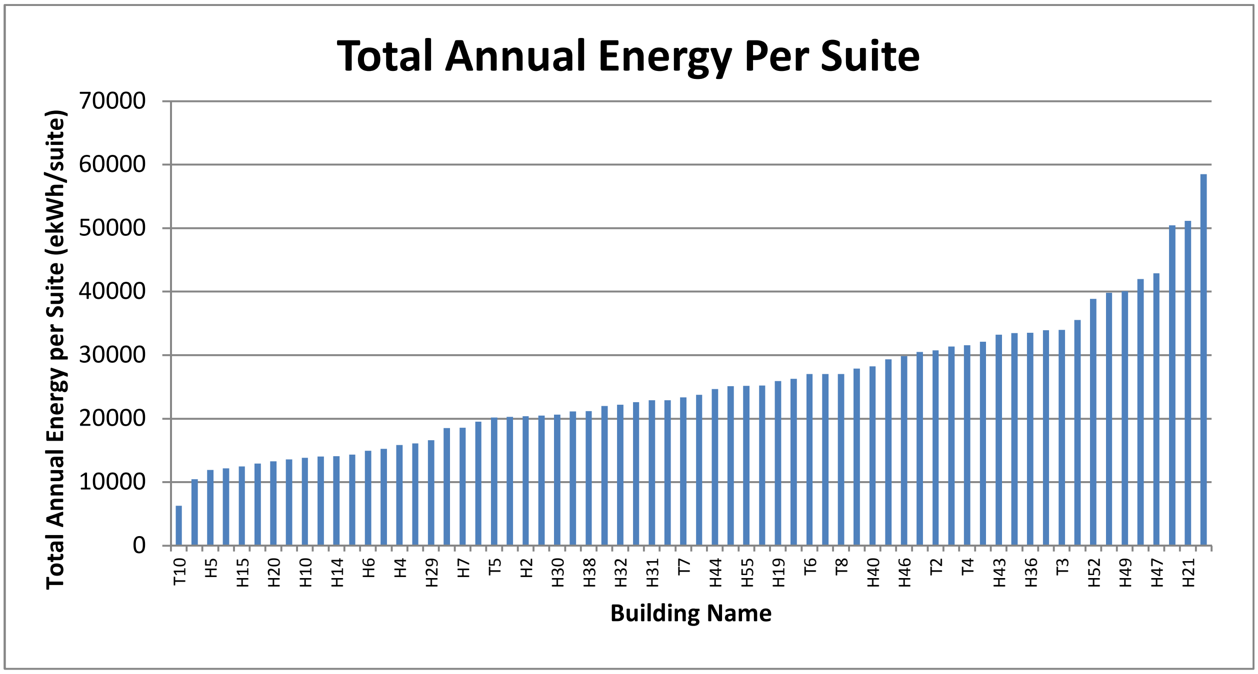

Figure 11: Total Annual Energy Use per Suite

Summary of Greenhouse Gas Emissions

The greenhouse gas (GHG) emissions due to electricity and natural gas consumption in MURBs were calculated by applying emissions factors. The emissions factors have been expressed in terms of equivalent kilograms of carbon dioxide (ekg CO_2). The emissions factor for electricity was 0.187ekgCO_2/kWh and the emissions factor for natural gas was 1.879ekgCO_2/m^3 (TAF, 2011).

Figure 12 shows the annual GHG emissions from each building per square metre. Similar to Figure 10, Figure 12 splits up the GHG emissions so that emissions due to electricity and natural gas are shown separately. The buildings from the Green Condo Champions data set only show emissions due to natural gas because no electricity data was available.

The total annual GHG emissions intensities range from 16.6ekgCO_2/m^2 up to 96.6ekgCO_2/m^2 and the average was 55.3kgCO_2/m^2. Since the GHG emissions intensities are a directly related to the energy intensities, the GHG emissions intensities show the same wide variation within the data sets.

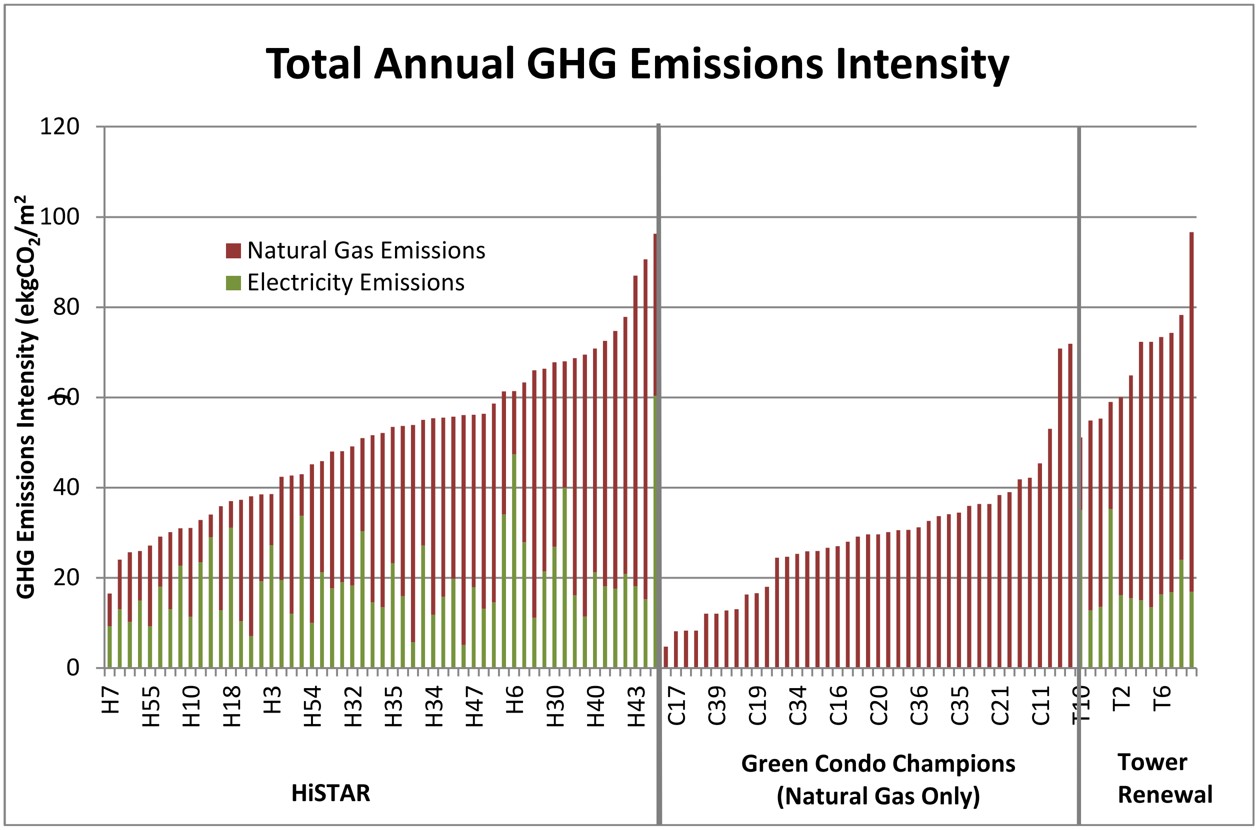

Figure 12: Total Annual GHG Emissions Intensity

Base Load Determination

As explained in Part II of this report, two methods were used to determine the base load from the electrical and natural gas energy consumption data. The first method used the Y-intercept from the weather normalization and the second method used the average between the two lowest months of energy consumption. Figures 12 and 13 show comparisons of the base load calculation methods for electricity and natural gas respectively.

There is good agreement between the results of the two methods used for electric base load derivation. This could be because most of the buildings are heated with natural gas and electricity load variation is relatively constant throughout the year. The Y-intercept method was preferred for the normalization calculations because of the greater number of data points on which it is based. However, for buildings exhibiting a relatively low R^2 value or those with a correlation between CDD and electricity load, the Low Average Method was preferred.

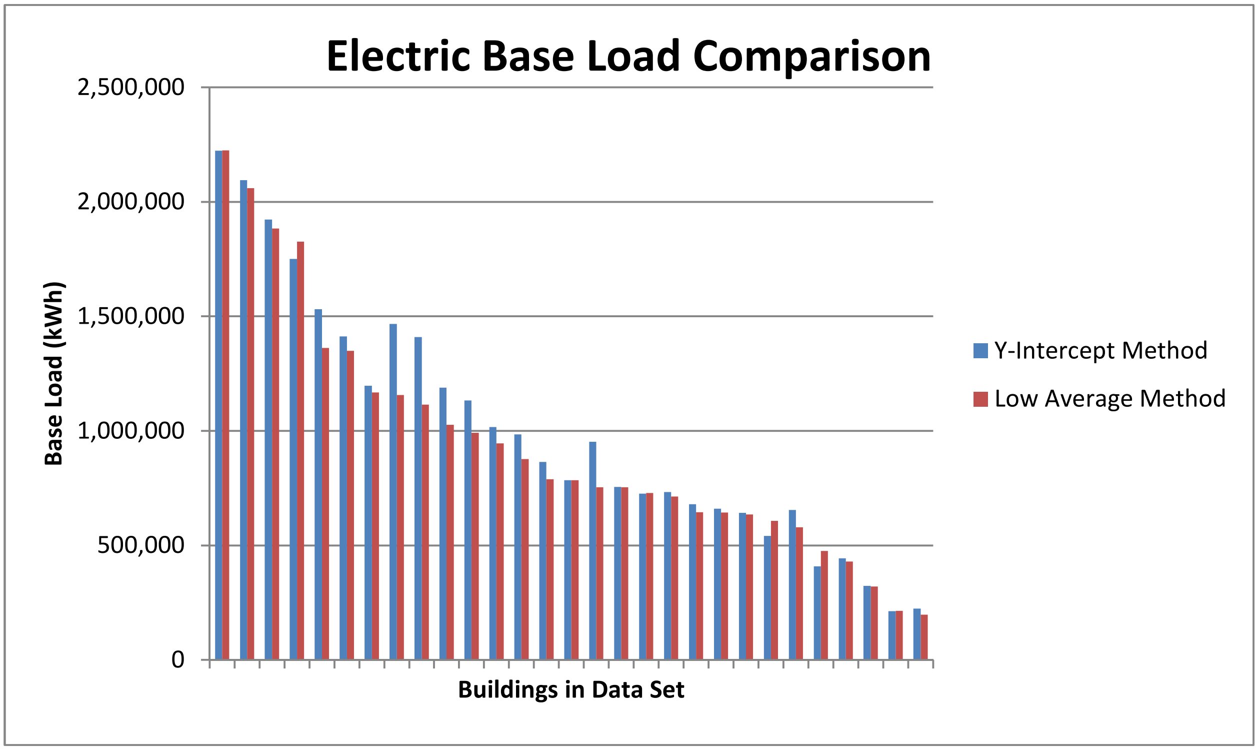

Figure 13: Comparison of Base Load Calculation Methods for Electricity

There is more variation between the results of the two methods used for natural gas base load derivation presumably because of the great reliance on natural gas for weather-related energy use. This annual variation makes it more difficult to strip out the base load, including domestic hot water. Once again, the Y-intercept method was generally preferred but the Low Average Method was used for buildings exhibiting a relatively low R^2 value.

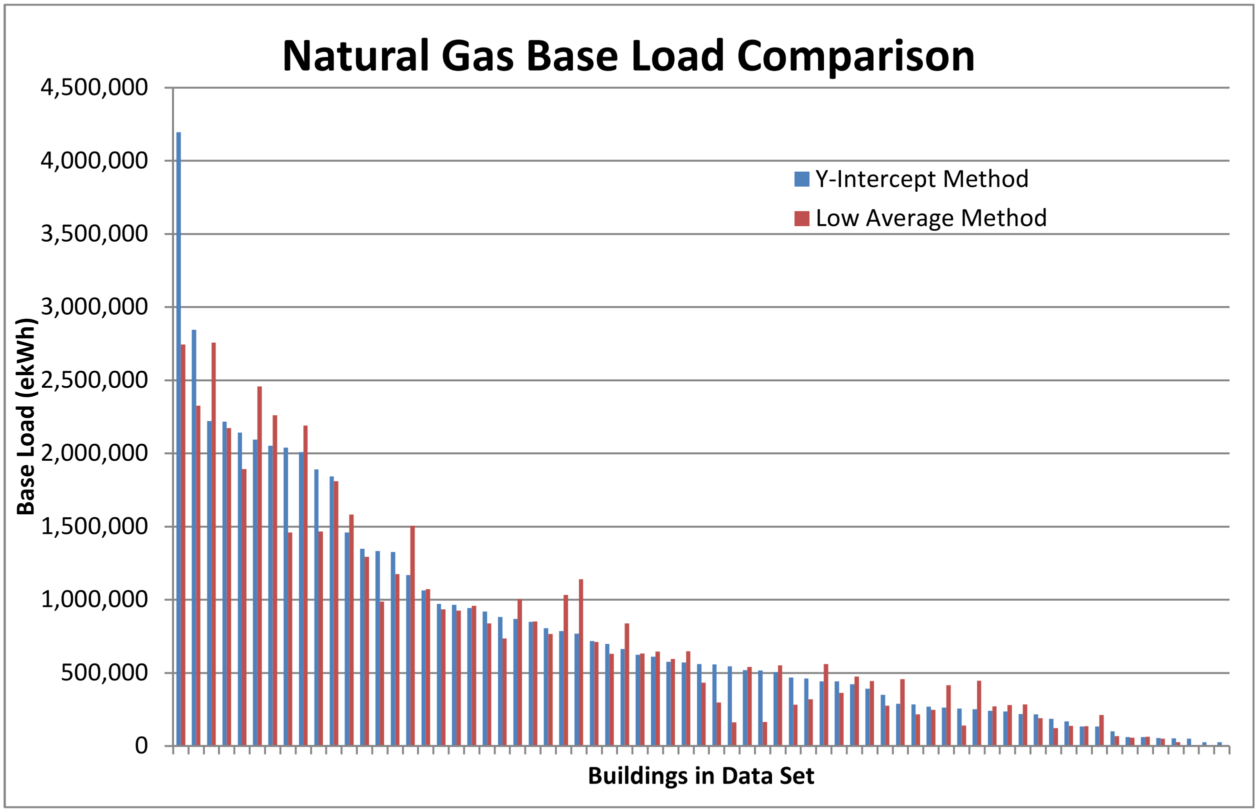

Figure 14: Comparison of Base Load Calculation Methods for Natural Gas

Summary of Weather Normalization

Part 2 included a discussion of the importance of R^2 values and the typical 'acceptable range.' Figure 15 shows the range of R^2 values achieved during the weather normalization process of the HiSTAR building data. Only 20% were considered to have a reliable correlation between energy use and weather for both natural gas and electricity use. However, an analysis of the correlations below showed that buildings with a poor R^2 value were not typically the outliers, so the effects of the low R^2 value should not skew the correlations significantly. The Green Condo Champions natural gas consumption data generally showed very good correlation with an average R^2 value of 0.91. The annual Tower Renewal data did not have associated R^2 values.

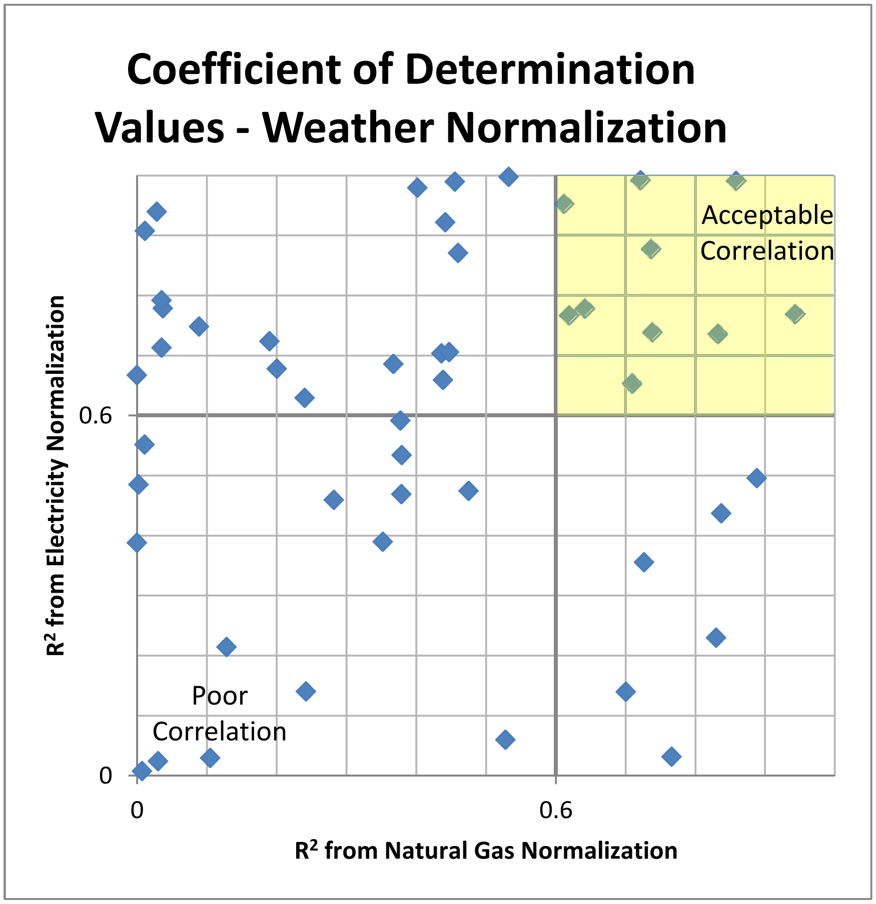

Figure 15: Coefficient of Determination Values from Weather Normalization

Correlation Analysis Results

Once the data were inventoried, the energy consumption of each building (both total and per square metre) were plotted against a range of parameters to identify any correlations.

Date of Construction

There is generally a negative correlation between energy intensity and building age as shown in Figure 16. Up until the 1970's, energy intensity of the older buildings was found to be somewhat higher than the newer buildings. The average energy intensity of buildings constructed in the 1980's and 1990's was slightly higher than those constructed in the 1970's. The higher energy intensity of the oldest buildings in the data set could be due to the age of the mechanical systems and condition of the building envelope. However the increase in energy use in newer buildings may be due to increased fenestration-to-wall ratios typically seen in more modern buildings as curtain wall construction became more prevalent. Further analysis of the building characteristics of each building is required to verify this hypothesis.

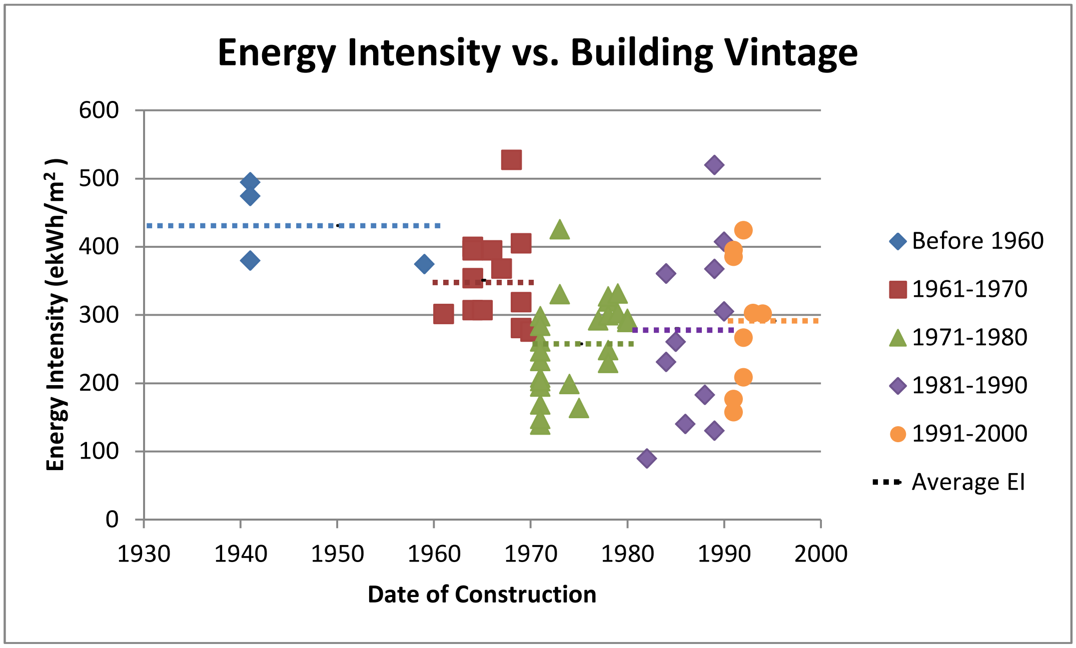

Figure 16: Energy Intensity vs. Building Vintage

Building Height

Total energy use should increase with building height and therefore overall building size. However, the lack of an excellent correlation in Figure 17 demonstrates that there are other factors besides building size contributing to energy use. As such, Figure 18 shows no correlation between energy intensity and number of storeys.

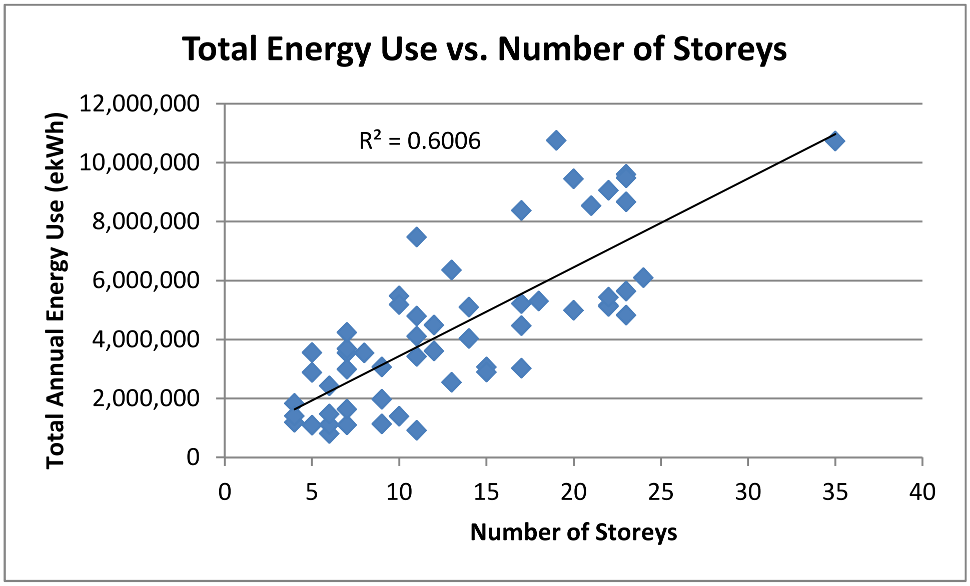

Figure 17: Total Energy Use vs. Number of Storeys

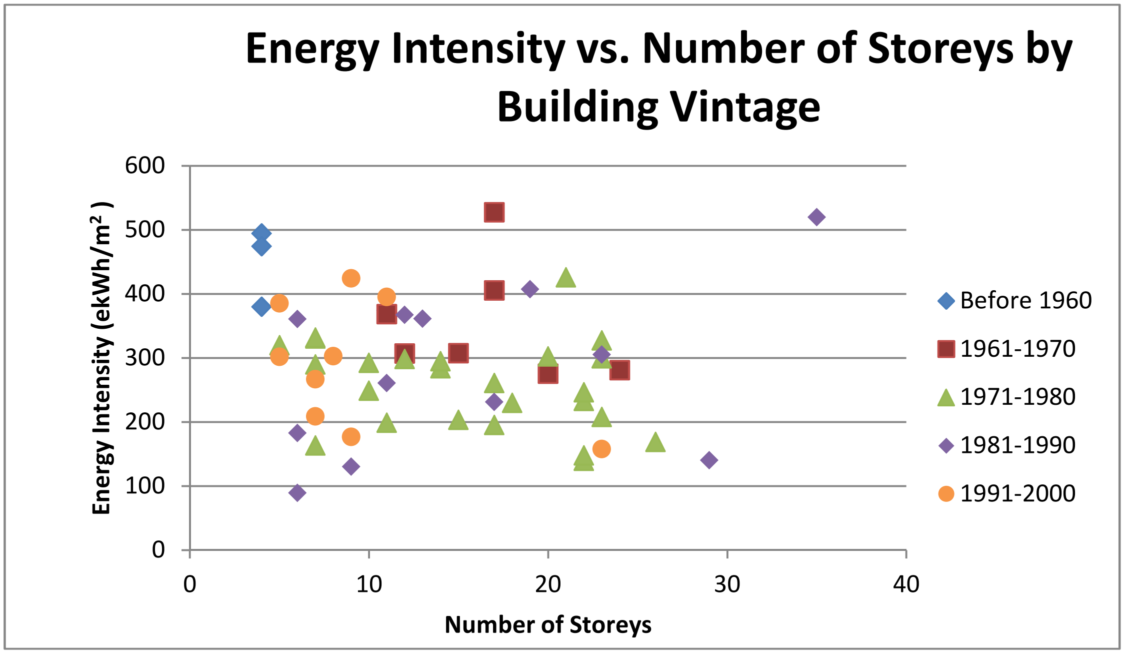

Figure 18: Energy Intensity versus Building Height

Number and Size of Suites

Similarly, as the number of suites increase, energy use increases as expected as shown in Figure 19. But, once again, the reasonable correlation in Figure 19 and lack of correlation between energy intensity and number of suites in Figure 20 mean there are other parameters that need to be considered.

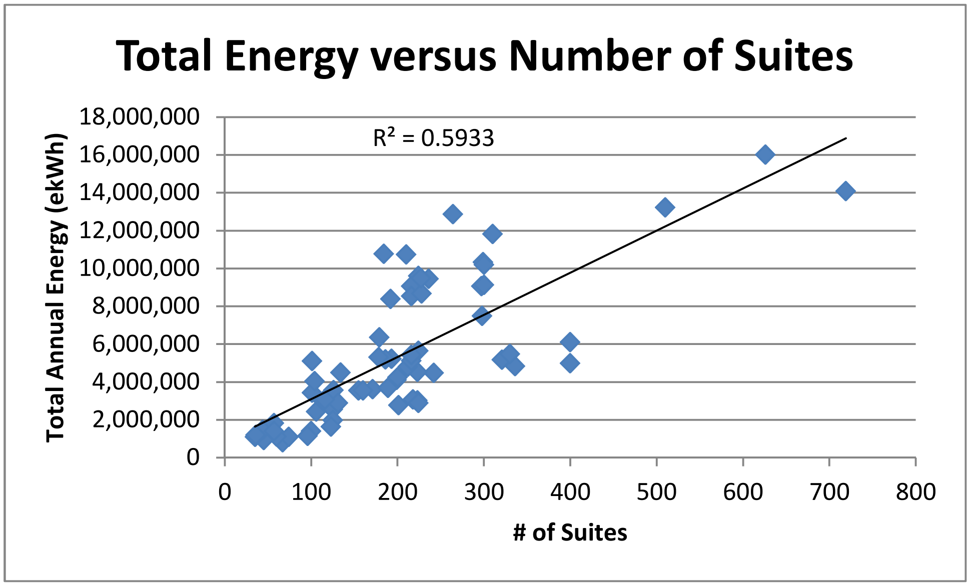

Figure 19: Total Energy Use vs. Number of Suites

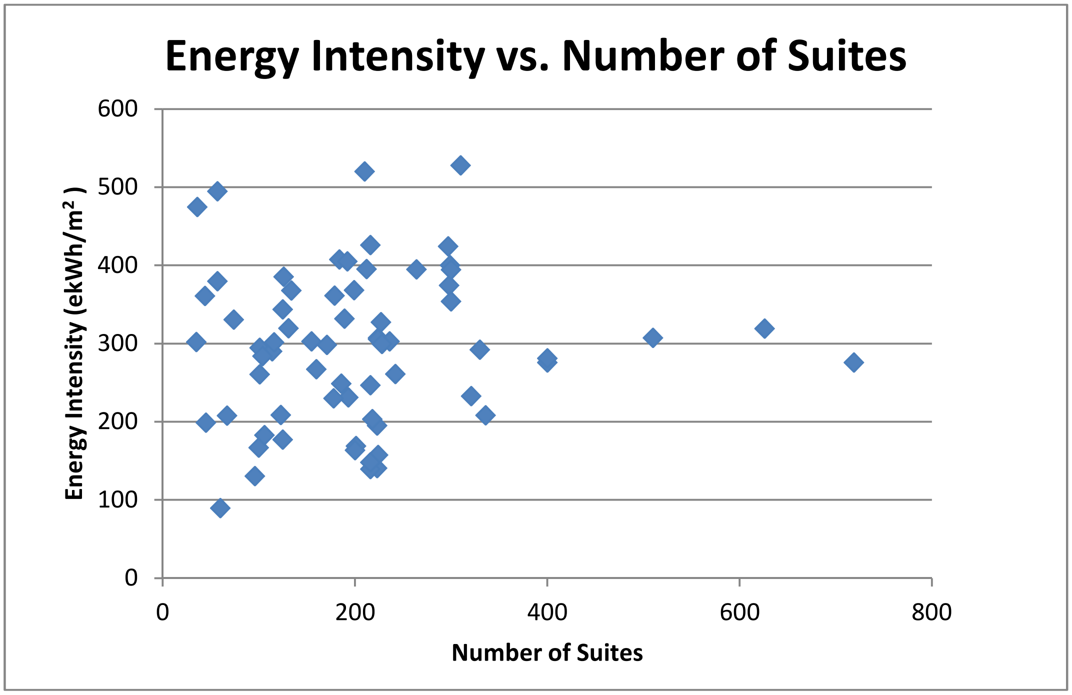

Figure 20: Energy Intensity vs. Number of Suites

Figure 21 shows a plot of the attributed suite size versus construction date. From the oldest buildings in the data set to the 1980's, the average attributed suite size increased. In recent years, the data reveal the prevalence of smaller suite sizes. This could be influenced by the size of common area spaces or the actual suite sizes. Larger suites could house more people which would likely result in higher energy use, but this is not reflected in the energy intensity by vintage shown in Figure 16 above. As such, the average number of people per suite may have remained the same over a period of increasing attributed suite sizes but occupancy information is required to verify this.

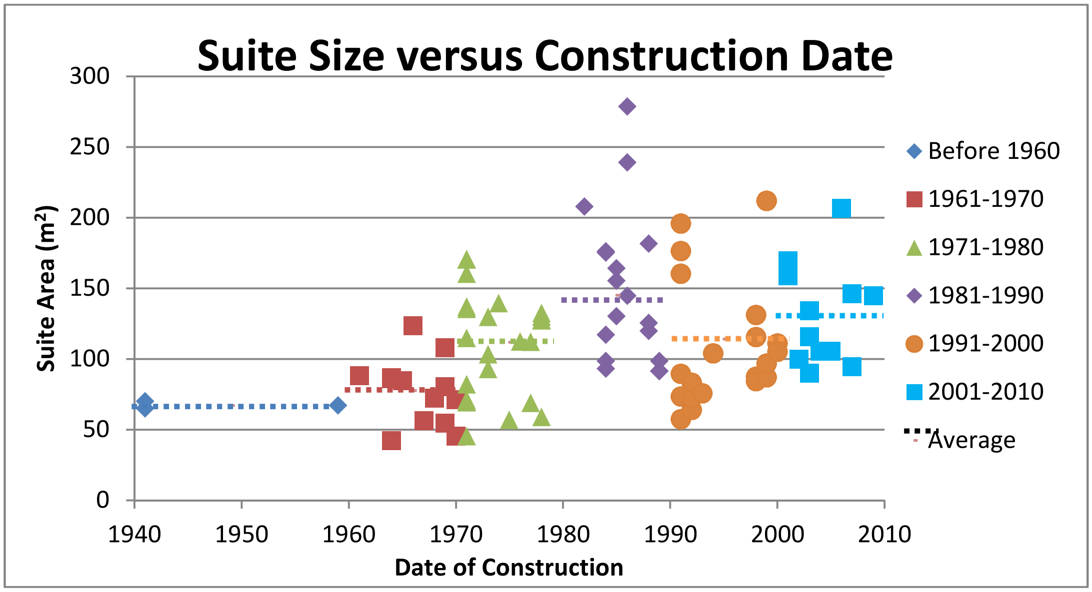

Figure 21: Suite Size vs. Date of Construction

Ownership Type

Figures 21 and 22 show the energy use per area and per suite for different types of building ownership. This was investigated because energy use is often a function of responsibility for payment. Generally speaking, condominium owners are more likely to be sub-metered than renters and therefore condo owners may use less energy because they are directly responsible for the cost. This hypothesis is supported in Figure 22, which shows that condos have the lowest average energy intensity. However, Figure 23 shows that condos have the highest energy use per suite, which simultaneously negates the hypothesis. Evidently, other factors besides the ownership type play a role here. Household income may be one of these factors. It is reasonable to assume that condo owners would have a higher income than renters or those in subsidized housing. With a higher income, the condo owners are more likely to have larger suites with more appliances and electronics that consume energy. Another explanation for having the lowest energy intensity but the highest per suite energy consumption could be due to the common areas. Condominiums often have larger common areas including a lobby, exercise rooms, pools, party rooms and board rooms. Since the total building energy divided by the number of suites is being measured and not the actual energy consumption per suite, this could be another explanation of the results.

The energy intensity of the subsidized rental on both the 'per area' and 'per suite' basis are lower compared to the other ownership types. This could be because in these particular buildings, owners are typically working with very tight operating budgets and may see energy efficiency as a means of controlling this budget. Owners of rental properties also typically have more control over the types of lighting and appliances in the building perhaps allowing them the ability to better control energy use. Finally, the common areas in these buildings are typically less extensive than a condominium, which could contribute to lower energy use on a per suite basis.

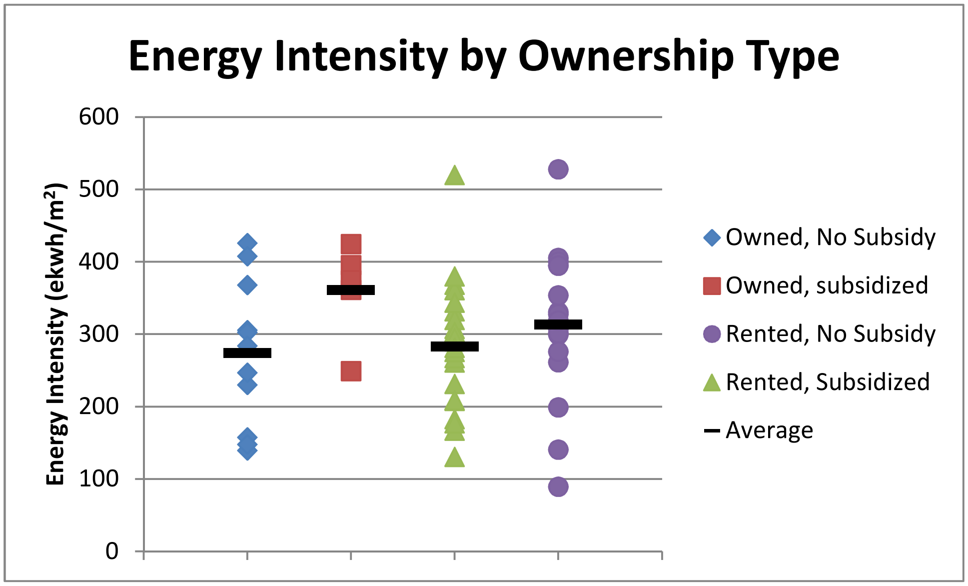

Figure 22: Total Energy Intensity by Area for each Type of Building Ownership

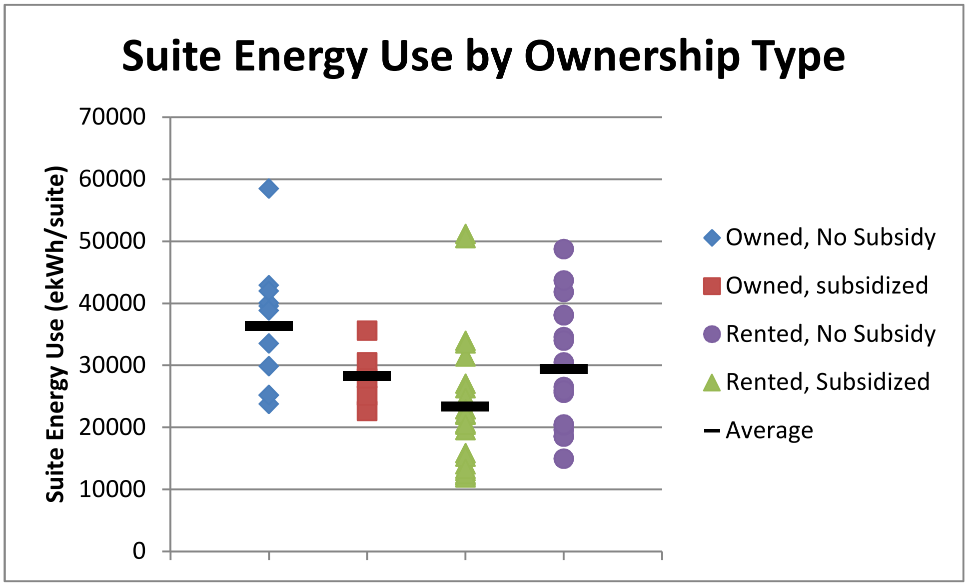

Figure 23: Total Energy Intensity by Suite for each Type of Building Ownership

Suite size is also worth investigating because this affects energy intensity and occupancy. However, without occupancy data, it is not possible to analyze this particular correlation further.

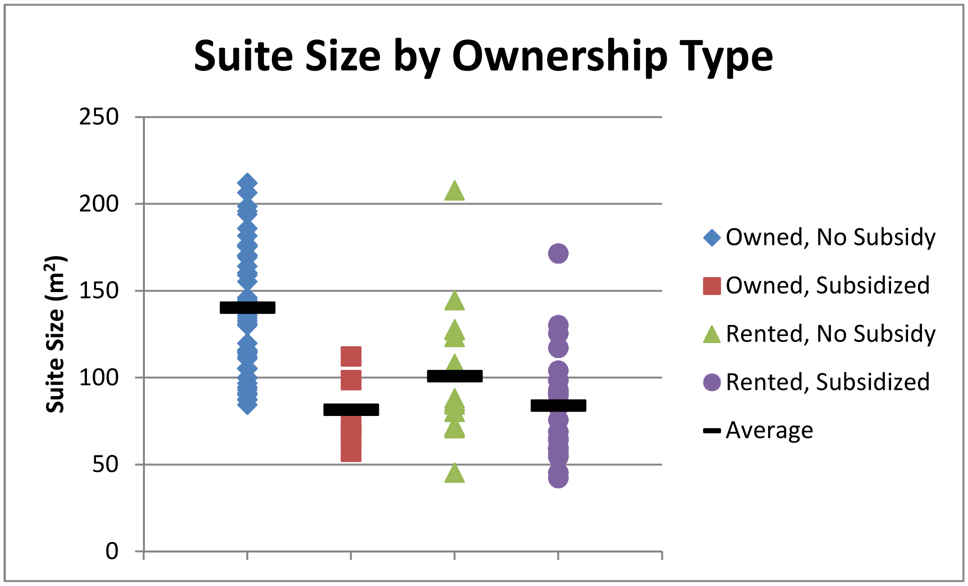

Figure 24: Suite Size vs. Building Ownership Type

Weather-Related Loads

After determining the base loads for each building as described above, these loads were deducted from the total energy consumption to determine the weather-related load. Figure 25 shows this variable, weather-related load plotted against the building vintages. There is a downward trend in weather-related energy intensity from the older buildings to the newer buildings presumably because of improvements in building envelope technology with time. Improvements such as increased air tightness and thermal resistance make the interior environment of the building less subjective to the exterior conditions, presumably improving energy performance as well.

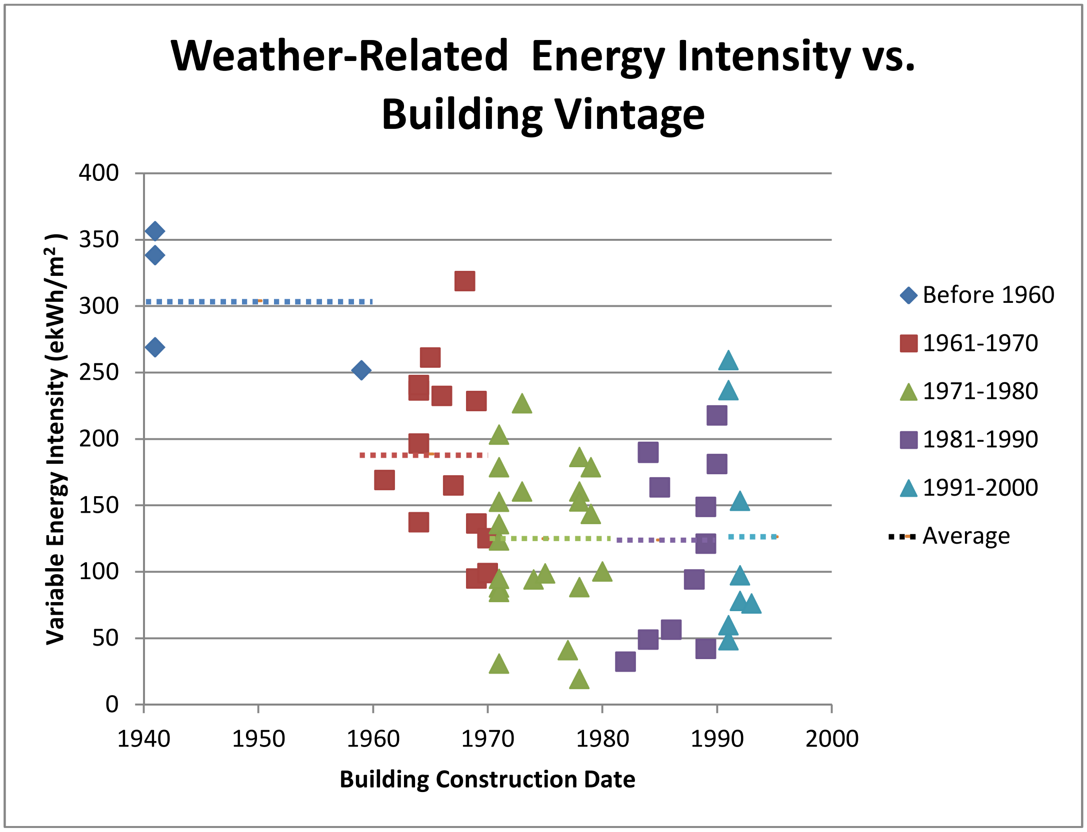

Figure 25: Weather-Related Loads vs. Building Vintage

PART 4: CONCLUSIONS AND NEXT STEPS

This section will discuss some conclusions that can be drawn from the correlation analysis above as well as outline steps for improving and building on this Meta-Analysis data set in future.

Conclusions

Generally the data analysis did not yield the strong correlations that were anticipated at the outset of the study. However, considering the limitations of the data as described above, there are some interesting observations and conclusions that can be drawn.

1. The meta-analysis of MURB energy-use data presented here represents a reasonable sample size. Energy-use data representing approximately 1.8% of the total MURB stock and 4.8% of the mid to high-rise MURB stock in the City of Toronto were analyzed in this study across all vintages of buildings.

2. The energy-intensity values determined from actual natural gas and electricity metering were higher than the published values from a similar study. An average intensity of 295ekWh/m^2 was found, which is higher than the average energy intensity of 225eKwh/m^2 reported in one other study of apartment buildings in Ontario (Natural Resources Canada 2008). The difference in the two values can be mostly accounted for by different weather normalization practices. The

Meta-Analysis data was normalized to a standard year which is colder than 2007, which is the year considered in other study.

3. There was a wide range in the observed energy intensities with the lowest energy intensity less than one fifth of the highest one. Even within each age class, there was significant variation in energy intensity. The range in energy intensity may reflect a variety of factors including differences in the way the buildings are operated, differences in the efficiency of the buildings major mechanical and electrical systems, and differences in construction type. The data suggest that many buildings could realize significant improvements in energy performance, although further research is needed to validate this hypothesis. This wide range may explain the lack of any correlation between building size and energy use so this should be investigated further to determine if the simplified policy conclusions can be drawn.

   Since no reliable data on the efficiencies of the natural gas burning appliances were available for this study, thermal energy intensities could only be bracketed assuming that efficiencies could be as low as 60% but no more than 100%. If further investigation were to reveal these efficiencies as well as the operating and maintenance condition of the boilers, conclusions could be drawn about whether envelope retrofits, mechanical retrofits or both would be the best energy reduction strategy.

4. An examination of the relationship between weather–related energy intensity and year of construction as shown in Figure 24 reveals 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 combined effects of better thermal insulation and air tightness measures being off-set by higher fenestration-to-wall 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.

5. This study 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 to intuition unless the effect of household income and energy used in common areas are considered in the explanation. Further study is necessary so that the underlying reasons can be more clearly identified and effective measures taken to reduce energy consumption in all MURBs.

Next Steps

The Meta-Analysis presented here, which combines three existing data sources, provides an important first step towards a better understanding of energy use in Toronto area MURBs. Development of a more comprehensive and complete data set can allow this preliminary analysis to be extended. The Green Condo Champions data set has the greatest potential for extension given the detailed condo audit studies that accompany it. However, to take full advantage of this information, historical electricity consumption must be sought and obtained.

Generally, investigating the building envelope and mechanical systems can lead to an improvement in the granularity of the typology divisions beyond building age ranges used in this report. Building envelope characteristics should include an estimate of thermal resistance and window-to-wall ratio. Information is also needed about the mechanical equipment including the efficiency of natural gas combustion equipment and heating fuel type.

By expanding this study to include this more detailed analysis, perhaps a narrower band of energy performance will emerge from more specific building typologies allowing for prioritization of energy retrofit efforts.

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Glossary

Heating Degree Day (HDD) – Represents the amount of heating energy required during the heating season. It is measured by the difference between the base temperature of 18°C and the mean temperature for a particular day. (Source: Natural Resources Canada)

Sub-Metering – The individual metering of utilities at the unit level in a multi-unit residential building. Each household can then be responsible for their own energy costs as opposed to splitting the energy bill for the entire building equally among all occupants. (Source: New York City Department of Housing Preservation and Development)

Weather Normalization – A mathematical process that adjusts actual energy usage so that it represents energy typically used in an average year for the same location. This accounts for weather differences from year to year that may result in abnormally high or low energy consumption. (Source: ENERGY STAR)