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**Utility Benchmarking and Potential Savings of Multi-Unit Residential
Buildings (MURBs) in Toronto**

By

Mahssa Ghajarkhosravi

B.Sc. (Bachelor of Civil Engineering)

Ryerson University, 2010

A thesis

Presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Applied Science

in the program of

Civil Engineering

Toronto, Ontario, Canada, 2013

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Utility Benchmarking and Potential Savings of Multi-Unit Residential Buildings (MURBs) in Toronto MURBs

Mahssa Ghajarkhosravi

Master of Applied Science

Department of Civil Engineering

Ryerson University, Toronto, Ontario, Canada, 2013

Abstract

Building energy, water and solid waste benchmarking and developing meaningful performance indicators can help government and building owners to make effective decisions on improving their buildings' efficiency. For this study, information on 120 Multi-Unit Residential Buildings (MURBs) has been provided. The study entails the following steps: performing energy (weather normalized using the Princeton Scorekeeping Method (PRISM)), water, and solid waste benchmarking for the 120 MURBs, developing meaningful performance indicators; determining performance ranking; and estimating different levels of savings (energy, water, solid waste, cost, and GHG emissions). The most appropriate performance indicator and the benchmarking range for energy, water, and solid waste are as follows, energy consumption normalized by square metre, 141-580 kWh/m²; water consumption normalized by square metre, 1.06 - 4.19 m³/m²; solid waste benchmarking normalized by number of units, 1.58- 17.4 yd³/unit. Also, the MURBs domestic hot water system efficiencies are found to be very low (boiler efficiency of 35% to 45%).

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Nomenclatures

3Rs	Reducing, reusing, and recycling
A/C	Air conditioner
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEUTS	Building energy use tracking system
BMD	Building monitoring data
BU	Bottom-up model
BWOF	Building warrant of fitness
CaGBC	Canada Green building Council
CDD	Cooling Degree Days
CH ₄	Methane
CIBSE	Chartered Institution of Building Service Engineers
CIBSE	Chartered Institution of Building Service Engineers
CMHC	Canada Mortgage and Housing Corporation
CO	Cooling only
CO ₂ eq	Carbon dioxide equivalents
CREEM	Canadian Residential Energy End-use Model
DHW	Domestic hot water
DOC	Degradable organic carbon
DSWG	Disposal solid waste generation
ECC	Energy conservation cases
ekWh	Equivalent kilo Watthour
EPIs	Energy performance indicators
FTE	Full time equivalent
GDP	Gross domestic product
GHG	Greenhouse gas emission
GWP	Global warming potentials
HC	Heating and cooling
HDD	Heating degree days

HO	Heating only
HVAC	Heating, ventilation, and air conditioning
IEQ	Indoor environmental quality
ILI	Infrastructures leakage index
IWA	International water association
LEED	US. Green building council's leadership in energy and environmental design
MCF	Methane correction factor
MITACS	The Mathematics of Information Technology and Complex Systems
ML/D	Million litres per day
MSW	Municipal solid waste
Mt	Megatonnes
MURBs	Multi-unit residential buildings
MWWS	Municipal Water and Wastewater Survey
NAC	Normalized annual energy consumption
NCR	National capital region
NDA	Non-disclosure agreement
NEUD	National energy use database
NLA	Net lettable area
NRCan	Natural resources canada
NSWBI	National solid waste benchmarking initiative
OECD	The Organization for Economic Cooperation and Development
OEE	Office of Energy Efficiency
OHC	Ontario housing corporation
PJ	Petajoule
PMP	Performance Measurement Protocols for Commercial Buildings
PRISM	Princeton scorekeeping method
RU	Ryerson university
SHEU	Survey of Household Energy Use
STEP	Sustainable Towers, Engaged People program
SWANA	Solid Waste Association of America
TCHC	Toronto community housing corp

TCHC	Toronto community housing corp
TD	Top-down model
U.S EPA	U.S. environmental protection agency
UNEP	United nations environment programme
USGBC	U.S. green building council
WCI	Water consumption indicator
WDO	Waste diversion organization
WEP	Water efficiency program
WPTs	Water treatment plants
WRATE	Waste and Resources Assessment Tool for the Environment Software
Yd ³	Cubic yard

Chapter 1

Introduction

1.1 Energy Use in Canadian Multi-Unit Residential Buildings (MURBs)

The demands for energy are increasing everyday while the energy resources are limited. Figure 1.1 demonstrates the amount of resources available in the world at 2010.

Figure 1.1. World's various energy sources breakdown (Hodgson, 2010)

In 2001, around 31% of people in Canada lived in MURBs, and that accounted for 24% of annual energy consumption within the residential sector (Liu, 2007). On the other hand, the residential sector in Canada accounts for 15% of Canada's energy consumption (NRCan, 2011) in which space heating, water heating, major appliances, lighting, and space cooling were responsible for 63%, 18%, 13%, 4%, and 2% of this energy use respectively (NRCan, 2012). Figure 1.2 shows the year over year energy consumption by the residential sector in Canada. The energy consumption drop from 2008 to 2009 is as result of energy consumption decline within residential and agricultural sectors.

Figure 1.2. Residential secondary total energy use in Canada^I (NRCan, 2012)

An overview of rental MURBs (focus of this project) and their energy consumption shows that majority of rented buildings tend to be older and less energy efficient (Counihan & Nemtzow, 1980). In some MURBs the utility costs are included in their monthly rental payments. For this case improving energy efficiency is a challenge. Due to the fact that tenants, actual consumers, do not pay their own utility bills directly and they do not feel a sense of ownership, they are not so careful about the way energy has been used in their units, such as having an air conditioning system on while the windows are open in the summer; in the winter, although nobody is at home, the inside temperature is set high all day long, etc. On the other hand, owners do not invest much into their rental properties in terms of energy efficiency since they include the energy cost in the rent. That is the reason why the majority of rental buildings are older and less energy efficient (Counihan & Nemtzow, 1980).

I. Because a Joule is a relatively small amount of energy, energy consumption is discussed in terms of petajoule (1.0×10^{15} Joules) denoted by PJ here.

1.2 Water Use in Multi-Unit Residential Buildings (MURBs) in Canada

A large amount of water is used for generating energy, cooling nuclear power plants, etc. Water consumption by municipalities is the third largest water use in Canada as is shown in Figure 1.3.

Figure 1.3. Main gross water users in Canada (Environment Canada, 2012)

Basically, the energy sector is known as the largest water user in Canada (Mass, 2009). But since Canada has always been counted as a rich country in terms of water resources, it seems that the value of water has not been appreciated enough. Water consumption per person in Canada is relatively high compared to other countries, which could be a result of water being less costly compared to others. According to Environment Canada (2006), in Europe people pay four times more for water than Canadians. Also what Canadians pay for water is three quarters of what Americans pay at the domestic and industrial level. In other words, water has been underpriced in Canada. With the increase in water demand and the depletion of freshwater supplies, the cost of water use will increase and water scarcity is likely to be felt in Canada, as well as in many other countries such as Australia and the United States (REALpac, 2011). As is shown in Figure 1.4, residential sector in Canada is the largest user of municipal water.

Figure 1.4. Municipal water consumption breakdown within sectors in Canada, 2006 (Environment Canada, 2012)

Toronto is the most populated city in Canada. It is expected that stakeholders would be more concerned about developing better water management strategies to improve water efficiency and reduce excessive water use in MURBs in Toronto (Environment Canada, 2011).

1.3 Waste Generation in Multi-Unit Residential Buildings (MURBs) in Canada

Waste is the unwanted material of the producers (human and human activity), which can be solid, liquid or gaseous. Waste can be classified either by source of generation such as residential (single family, multi-family, high-rise and low-rise residences), commercial, institutional, and industrial or by composition such as organic waste, paper, glass, metal, and plastic. Statistics show that 65 percent of residential solid waste generated in Canada in 2002, came from Ontario and Quebec, when the residential sector by itself was responsible for 39 percent of the solid waste generation in Canada (Statistics Canada, 2005). In Canada the amount of municipal solid waste generated per person in 2008 was 777 kg per person (Statistics Canada, 2012). There are a lot of factors involved in the growing waste production, for instance, population size, incomes, society, etc (Statistics Canada, 2005). High income countries generate more waste than poor countries. In fact, one-quarter of the

world's municipal solid waste is generated by rich countries, which is just one-sixth of the world's population (Beede & Bloom, 1995).

The importance of reducing the amount of waste being sent to landfill was sent by the Canadian Council of Ministers of the Environment, in 1989. All governments are challenged to reduce disposal wastes by 50% till the year 2000. Natural Resources Canada (NRCan) took the challenge and initialed a waste management program called “Waste Free”. The program started from NRCan facilities across Canada, and was expanded to the National Capital Region (NCR) and regional facilities. As a result, by year 1996, 60% reduction in amount waste transferring to landfill had been achieved (Forsyth, 2000).

The idea of how to manage waste has been an issue for thousands of years and reached a peak in the Industrial Revolution of the 19th century. But, it is only in the last few decades, due to the problem with landfill capacity and resulting pollution from landfill and incineration that governments and citizens have become concerned about this issue. Therefore, by initiating different waste minimization programs, regulations/ legislations by government and public effort in reducing and re-using, better waste management systems and waste reduction programs effects are being made (Statistics Canada, 2005).

1.4 Toronto Tower Renewal Program

There are 1,892 Multi-Unit Residential Buildings (MURBs) in the City of Toronto, which gives Toronto the second highest number of MURBs in North America (The City of Toronto, 2012).

One-third of Toronto's population lives in apartment buildings of five stories and above. The majority of the older MURBs in Toronto have low efficiency in terms of energy performance, and they are isolated from shopping centres and other services. In early 2009, the City of Toronto initiated the Tower Renewal program, whose focus is to make these aging MURBs economically and environmentally efficient by reducing the energy costs more than 50%, increasing water efficiency by more than 20% and making social improvements to the older MURBs and their neighbourhoods through job creations, safety improvements in MURBs and their neighbourhoods (The City of Toronto, 2011). Following that, a program

called the Step Program was introduced by the City of Toronto (The City of Toronto, 2012) to encourage building owners and property managers to reduce energy and water consumption of residential buildings. Toronto Hydro and Enbridge Gas are collaborating in this program by offering incentives to motivate building owners to evaluate their building performance (Audit Funding Program by Toronto Hydro) (Toronto Hydro, 2009) and make their buildings more energy efficient by implementing energy saving strategies (Energy Savings Incentives by Enbridge) (Enbridge Gas, 2011). In order to make any decision in applying any efficiency strategies to a building, it is necessary to know how the building performs comparing to other similar buildings. The goal of this project is to review and analyze the actual waste generation, energy and water consumption of the existing MURBs to estimate the different achievable level of savings (energy, water, solid waste, cost, and GHG emissions) according to best, 25th percentile, 50th percentile, 75th percentile will be part of the analysis. The outcomes can be utilized for developing better design and energy conservation strategies for both new and existing MURBs to reduce the greenhouse gas (GHG) emission.

1.5 Confidentiality

The dataset (billing information) used for this study was collected by Toronto Community Housing Corp. (TCHC), the City of Toronto, and some private sectors as part of the Tower Renewal program. For confidentiality reasons a non-disclosure agreement (NDA) has been signed and buildings used in this analysis are shown by building ID numbers. In terms of information exchange and confidentiality, the results of benchmarking analysis remain confidential and will not be shared outside the confines of the participants. The purpose of the study is for education and performance improvement of the individual utility and the participants' group. Therefore, in order to inform the individual participant' building owners about their building performance among the other similar buildings, separate building performance assessment reports have been sent to them. A sample report along with its detailed calculations are shown in Appendix B and Appendix A respectively.

1.6 Purpose of Research Motion the Grant

This project is sponsored by The Mathematics of Information Technology and Complex Systems (MITACS), The City of Toronto, Enbridge, CMHC, and the Provincial Government of Ontario to investigate the behaviour of aging MURBs in terms of energy performance, water consumption, and waste generation, and to discover solutions to make the poorly performing MURBs more efficient in cost-effective ways.

1.7 Scope of Research: What's Involved

The Tower Renewal project has been conducted as part of a major Ryerson University project under the Toronto Tower Renewal Initiative. This is a multi-disciplinary project, whose contains the following sub-projects:

1. Building-wide consumption data collection and analysis, benchmarking (energy, water and waste) and performance indicators
2. Building simulation and modeling
3. Analysis of various retrofit strategies
4. Occupant survey to determine behavioural patterns and indoor environment
5. Occupant engagement strategies

1.8 Objective of the Study

This thesis is to investigate the energy and water consumption and solid waste generation of number of aging MURBs in Toronto. The provided information is on the 120 rental MURBs, mainly social houses.

The objectives of this thesis research are as follows;

1. Data collecting and screening of provided monthly utility data (2 to 5 years gas, electricity, water consumption plus solid waste generation) from TCHC.
2. Performing energy (weather normalized for Toronto location using the Princeton Scorekeeping Method (PRISM) software), water, and solid waste benchmarking for the 120 data base size.

3. Investigating the influence of different factors, such as vintage, building size, number of unit, and number of occupants, etc., on MURBs' performance (in terms of energy, water, and waste) to developing the most meaningful performance indicators.
4. Determining performance ranking (identify the best, 25th percentile, 50th percentile, and worst performer of the dataset).
5. Estimating different levels of savings (energy, water, solid waste, cost, and GHG emissions) according to best, 25th percentile, 50th percentile, 75th percentile.
6. Investigating the correlation between water and gas consumption, to estimate the potential savings from water conservation methods.

1.9 Structure of the Thesis

The summary of the work carried out to form this thesis is outlined as follows with the contents of the individual chapters:

Chapter 1: Introduction on the background to the research and outline of the overall objectives of the study

Chapter 2: Literature review on energy, water, solid waste benchmarking

Chapter 3: Proposed weather normalized energy benchmarking, and water, solid waste benchmarking plus potential cost and GHG emission savings analysis

Chapter 4: Results and discussion on the benchmarking of the dataset, factors that influence the performance of the MURBs (in terms of energy, water, and solid waste), and estimated savings (consumption, cost, and GHG emission)

Chapter 5: Conclusion and recommendations

Chapter 2

Literature Review

2.1 Data Collection

The first step of benchmarking (energy, water and waste) is to collect useful data.

Depending on what information is necessary to collect, surveys have been developed for different benchmarking purposes.

A recent web-based benchmarking method has been deployed by the U.S. Environmental Protection Agency (EPA) called ENERGY STAR® Portfolio Manager. Water and energy consumption of over 200,000 buildings are tracked by using this tool around the world. Required data for the analysis are gathered using a data collection sheet (US. EPA, 2012). Required information, such as building address, year built, building characteristics (number of units, occupants, etc.), building fuel types, and utility bill (12 consecutive months) is asked in the survey.

Another study has been undertaken on developing energy performance benchmarks for primary schools in Ireland (Hernandez et al., 2008). Data collection was performed on 500 schools in Ireland. The gathered information is as follows;

1. General information such as name, address, gross floor area, and current number of people (students and staff)
2. The buildings' characteristics (details information of the building's envelope), which can be obtained from blueprints and drawings.
3. Information on mechanical systems such as type of heating system (both space and water), ventilation, and lighting.

Tower Renewal program released a data collection survey called Sustainable Towers, Engaged People (STEP) program. The purpose is to both collect the necessary information for energy, water and waste benchmarking for MURBs (private for-profit and non-profit) located in Toronto and encourage building owners to implement cost effective and

necessary retrofits to their buildings (The City of Toronto, 2012). The prepared survey contains the following sections:

1. Foundation stage: general information such as the building address, building size, unit types, number of stories, etc. plus utility bills (electricity, gas, water, and waste) are collected.
2. Learning and planning: learn and gather the basic and essential information about the buildings to develop a future plans, such as running audits (energy, water), data collection and customizing training sessions for tenets.
3. Implementation: introducing simple retrofits/improvements (those having less than a five-years pay back) for all three sections, energy, water and waste, such as changing shower heads to low flow shower heads, installing high efficiency light bulbs, and employing better recycling methods.
4. High performance: inform the building owners on the greater benefit that they can achieve from investing in a major retrofit to achieve a comprehensive improvement in the building such as changing heating and/or cooling system to the efficiency system.
5. Leadership: promoting the new technology, for which the building owner can be the best person to act as a leader to explain how these new technologies and/or strategies can make a substantial improvements to the building and the community.

A survey method has been used for collecting data for a study done in New Zealand on water benchmarking within commercial office buildings (Bint et al., 2010). In order to gather all required information for the analysis five steps have been set for the survey, which are as follows:

1. Building warrant of fitness (BWOFF): it is a legal document, including information on building legal description, ownership/management, age, floor area, maximum number of occupants, fire hazard categories, number of stories, etc.
2. Consent: this step involves getting approval from building owners or building managers to gather information from the first stage (BWOFF); and continue to the next level, which is getting utility bills (in this case historical buildings, water consumption).

3. Information sheet: the detailed information such as net lettable area (NLA), total number of occupants or occupancy rate, any changes that have been made over the past five years, whether or not the building has sub-metering and an air conditioning system (central or window air conditioner (A/C)), etc.
4. Billing data: billing data are included in the information sheet provided by the building owner, which helps to achieve better understanding of the water consumption.
5. Site survey: detailed information that cannot be achieved through the information sheet and utility bills can be collected from site surveys, such as type of fixtures (regular or low-flow fixtures) and kitchen facilities (regular or water efficient appliances), types of cooling systems in the building, etc.

The insights from the above mentioned literatures were implemented into the current study to gather the minimum useful information for the benchmarking.

2.2 Energy

2.2.1 Overview of the energy consumption in residential sector

Ontario has the second highest ratio of new construction to stock removal (about 5.4^{II}) among all provinces in Canada, which is higher than the ratio at the national level (4.0). For this reason, energy conservation and management have become important topics in the province (Canadian Home Builders' Association, 2011).

Energy consumption growth within the building sector is one of the fastest among all the sectors (Rey, Velasco, & Varela, 2007). The fluctuation of the overall residential sector energy consumption over the years (1990-2008), with having year 1990 as a reference, is shown in Figure 2.1.

II. This addition/removal ratio calculation has been done for the time period of 1990 to 2008.

Figure 2.1. Energy use trend of the Canadian residential sector normalized by unit area and housing unit (Canadian Home Builders' Association, 2011)

Throughout the period, the energy consumption was improved by 14.1% per housing unit and 21.4% per square metre, while the total secondary energy use, total number of households units, and total floor area increased 14.3%, 33.0%, and 45.5% respectively. The energy consumption improvement over the years is mainly due to the climate change (warmer weather) and partially as a result of energy efficiency improvement within the residential sector (Canadian Home Builders' Association, 2011).

The United Nations Environment Programme (UNEP) declares that buildings are responsible for almost 40% of the energy used globally (UNEP, 2007). The residential sector of Canada by itself accounts for 17% of national energy consumption (Cuddihy, Kennedy, & Byer, 2005), of which residential apartment buildings contributed 18% of the total residential sector's energy consumption (NRCan, 2011). Figure 2.2 demonstrates the energy consumption within different sectors in Canada.

Figure 2.2. Energy consumption breakdown within the sectors in Canada, 2009 (NRCan, 2011)

Within the Canadian provinces, Ontario, Alberta and Quebec are the major energy consumers; according to Statistics Canada (2012), they were responsible for 73.5% of total energy consumption in the country in 2010. In Canada, the energy consumption in Ontario and British Columbia increases mainly as a result of population growth (Ménard, 2005).

Natural gas and electricity are the major sources of energy in Canada (Statistics Canada, 2010). Figure 2.3 compares energy consumptions of natural gas and electricity per household within different regions in Canada.

Figure 2.3. Average Canadian household energy use for households using the specified type of fuel, 2007 (Statistics Canada, 2010)

The rate of population growth is higher than energy consumption in Ontario. Observing Ontario's energy consumption trends/fluctuations has proved the above-mentioned fact; for instance, Ontario has experienced years of having an incremental energy consumption increase (year by year) while having a reduction in energy consumption per person for the same period of time (Ménard, 2005). Due to an ongoing population increase, having an increase in the number of buildings in Canada, and having energy intensive older MURBs, more than 20 years ago NRCan and Canada's residential construction industry developed a standard called R2000 (a standard to improve the energy efficiency within homes). The Office of Energy Efficiency (OEE) declares houses built according to R2000 standards tend to consume around 30% less than other traditionally built houses (Ménard, 2005).

On the other hand, increasing the energy efficiency of the buildings is not always the best and only effective way of conserving energy. A recent study shows that the best level of energy savings cannot always be achieved by just implementing energy saving technologies. In fact, applying energy management can be more effective than applying energy saving technologies in facilitating energy conservation (Choi, Cho, & Kim, 2012).

Therefore, energy benchmarking needs to be done before any energy saving strategies and/or energy management implementation can be applied for energy

consumption reduction within the MURBs. This makes building owners aware of their buildings' energy performance level among the other similar MURBs in the same climate area. And then a reasonable level of savings can be achieved accordingly.

2.2.2 Energy benchmarking

It is important to understand the difference between energy benchmarking and energy baselining. Energy baselining refers to a comparison of the past and current energy performance of a building (Federspiel et al., 2002), while the term "building energy benchmarking" refers to the energy consumption comparison of the buildings having similar characteristics. Energy benchmarking was introduced in the 1990s (Lombard et al., 2009). A comprehensive benchmarking can give an insight to building users/owners where their buildings stand among similar buildings in terms of energy performance. Action can be taken to reduce energy consumption when the subject building has been identified as the one that consumes more than other similar buildings (Chung, 2010) since applying retrofit strategies to the existing residential buildings could result in significant improvements in their energy efficiency (Cuddihy et al., 2005). This is the way to encourage owners of poorly performing buildings to improve their performance according to benchmarking results (Chung, 2010). From the broader perspective, developing any energy efficiency standard, policy, and regulation for MURBs requires an understanding of the existing energy consumption level of MURBs (having similar characteristics within the same climate condition) and the target reduction, which both are achievable by building energy benchmarking.

In New York City, buildings (all types, such as residential, commercial, hospitals, etc.) having total floor area greater than 100,000 sq ft, have to contribute to the city energy (weather normalized), water, and GHG emission benchmarking by-law. Individual buildings' energy and water consumption for years 2009 and 2010 have to be measured by their owners and reported to the city. The benchmarks (median) of the data set for multifamily and office buildings are found to be 417 (kWh/m²/yr) and 673 (kWh/m²/yr) respectively. More outcomes of the benchmarking are as follows. First, the most energy intensive buildings consume around three to five times more than the least energy intensive buildings. Second, inefficient buildings' energy consumptions and GHG emissions can be

reduced up to 18% and 20% respectively, if those inefficient buildings achieve the median level of energy consumption and GHG emissions of the data set. Third, 31% and 33% energy use and GHG emission reduction can be achieved by improving all buildings within the data set to 75th percentile level energy consumption and GHG emission. Fourth, although energy consumption per square footage by itself cannot be a reliable factor to evaluate the energy performance of the buildings, newer office buildings use more energy per square footage than older ones, which it could be as a result of newer buildings having larger surface glazing. Last, unlike the larger office building that consumes more energy than smaller office buildings, larger multifamily buildings consume less energy per square foot than smaller multifamily buildings (The City of New York, 2012).

Performance Measurement Protocols for Commercial Buildings (PMP) have been developed by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the U.S. Green Building Council (USGBC), and the Chartered Institution of Building Service Engineers (CIBSE). The ASHRAE Headquarters building located in Atlanta has been used as a test building for the energy, water, and indoor environmental quality (IEQ) benchmarking (not weather normalized) of commercial buildings to increase the efficiency to satisfy the same level of need. The building has gone through a renovation in 2009 and 2010. The building's energy intensity before the renovation (September 2006) was 243kWh/m² and it decreased to 128kWh/m² after renovation (47% savings achieved) (Hunn et al., 2012).

Moreover, the National Energy Use Database (NEUD), which is a survey-based data collection, has been deployed to analyze energy consumed by different types of residential apartments. The survey is not sensitive to building type; therefore, broad types of buildings such as high-rise, mid-rise and low-rise, residential, and non-residential have been included in the survey. The energy consumption by kWh/m² and by households residing in apartments in 2009 is 197 kWh/m² and 17,222 kWh/household, respectively (Natural Resources Canada, 2011).

There are not a lot of resources/datasets on MURBs energy intensity in Canada. Two datasets with different classifications have been introduced in the literature: the Survey of Household Energy Use (SHEU) and the National Energy Use Database (NEUD). For the

purpose of encouraging energy conservation and energy efficiency OEE conducts surveys on a regular basis to track and assess the energy used by households, residential houses and residential buildings including high-rise residential buildings (buildings greater than five storeys) across Canada. The SHEU uses building type for classification including single detached, double/row houses, apartment and mobile homes. The most recent SHEU survey, the fourth one, has conducted for the year 2007(SHEU-2007), and provides information on 12.9 million households across Canada. Results show that newer buildings (built after 1969) consume more energy than those built from 1946 to 1969, due to the increase in the buildings' sizes and heated areas. On the other hand, energy consumption per square metre is lower for mid-and high-residential buildings than for single detached and mobile homes. Results from SHEU -2007 data show that high-rise residential buildings are responsible for using 128 kWh/m² and 12,222 kWh/household, which are both the lowest among the other types of buildings. Another finding is the inverse relationship between heated area and energy intensity within each category of building (NRCan, 2010).

A smaller scale dataset, HiSTAR, developed by Canada Mortgage and Housing Corporation (CMHC) in 1999 analyzed energy and water consumption within MURBs across Canada. The database size is limited to 40 buildings, six to 26 stories, built from 1920 to 1993, and with a total of 27 to 400 suites per building. Energy consumption has been calculated by converting annual electricity, gas, oil, etc. to the equivalent kilowatt hours. From the results, average annual energy consumption is found to be 279 ekWh/m²; and buildings built from 1981 and after are more energy efficient (33 percent less energy per square metre while the amount per suite is constant) than those built before 1980. The other outcome is that condominiums (buildings having private ownership) consume 20 percent more energy than social/non-profit buildings. By and large, a larger dataset sample is required in order to achieve more accurate results (Enermodal Engineering Ltd, 2001).

Another study has been done by the Ontario Housing Corporation (OHC) on energy consumption of eighty-eight building (all types of buildings) located in different regions in Canada. The dataset characteristics are as follows: eighty-eight buildings of one to 23 stories, which were built from 1960 to 1989 and having mixed occupancy of both seniors and family. The average energy intensity of the sample was found to be 232 ekWh/m². Also, according to this study energy intensity has been found to have a strong relationship with

the building age and a poor correlation or even inverse trend with degree-days. Family-type buildings consume more energy than seniors' houses per unit floor area (due to higher occupant densities); Toronto has a higher number of family-type buildings, and this makes it one of the most energy intense provinces even though it is warmer than other provinces (CMHC, 2007).

The energy consumption of thirty-nine buildings (mix of mid and high rise residential buildings) located in Lower Mainland of British Columbia has been studied by Finch et al (2009). Almost 10 years of billing data (1998 to 2008) have been observed to understand the outside weather effect on energy consumption (the energy has not been weather normalized for this study). The range and average energy intensity (kWh/m^2) of the selected dataset has been found to be from 144 to 299 kWh/m^2 and 213 kWh/m^2 , respectively. Also, the energy consumption has been normalized by the number of suites, and the range and average energy consumption per suite has been found to be from 11,566 to 34,812 kWh/suite and 21,962 kWh/suite respectively (Finch et al., 2009).

Outside weather temperature has significant influence on buildings' energy consumption, which has been ignored in the majority of the above-mentioned studies. The energy consumption was not been normalized to a common base, and the methodologies used are not consistent. Therefore, appropriate comparisons cannot be made.

2.2.3 Overview of Residential Sector Energy Modeling Approaches

There are two widely-used modeling approaches for energy policy making, top-down (TD) or bottom-up (BU) (Bohringer et al., 2008). TD models evaluate energy consumption at an aggregated level; on the other hand, BU models evaluate energy on a disaggregated level, which requires a large set of experimental data (Kavgic et al., 2010).

BU methods investigate the individual components' influences on energy usage, for example, how the energy is being used in a building for different purposes. This information is vital, especially for savings potentials. The required information for BU analysis, such as monthly billing data and comprehensive information on all energy end-users is collected either by running a survey and/or installing sub-metering (Wilson & Swisher, 1993). An

example of the BU method is SHEU-2007, which has used the survey for data collection on tenants' demographics, appliances possessed and schedule of use (Kavgic et al., 2010).

The Canadian Residential Energy End-use Model (CREEM) has been developed using the BU method by Farahbakhsh et al. (1998) using HOT2000 energy simulation software to assess different measures/scenarios that can be implemented to reduce energy consumption and its associated GHG emissions within the residential sector (low-rise and single family dwellings) across Canada. Data from SUEU-1993, the modified STAR-HOUSING database (Statistically Representative HOUSING Stock), and the 200-House Audit Project Database have been used for the analysis (Fung et al., 2000).

Unlike BU methods that require detailed information on energy end-users, TD methods do not require that much detailed information. Data such as total utility bills (historical bills) and single or multiple measures are used for these methods. Measures such as outdoor dry-bulb temperature^{III}, humidity and/or building characteristics are used depending on the type of expected outcome from researches.

The TD method has been used in the study done by Reddy & Claridge (1994) for comparing the daily energy use of large institutional buildings located in four parts of the U.S having different climate conditions. Factors such as outdoor dry-bulb temperature, humidity and horizontal solar radiation have been used as multiple measures for developing a linear model.

Some of the challenges of using BU methods included obtaining energy consumption by end-uses from surveys because answers are not fully reliable, energy conservation measures cannot be quantify by using this methods, the method requires a high level of expertise (Kavgic, et al., 2010), and the process of gathering the information takes a lot of time and cost (Nikolaou et al., 2011). Therefore, the TD model has been chosen for this study, since the received information included historical billing information and general building characteristics (but not enough detailed information for implementing the bottom-up method).

III. The dry bulb refers to air temperature indicated by a thermometer without being moistened.

2.2.4 Energy Benchmarking Methods

There are four different benchmarking methods. First is the statistical analysis (also known as Regression Model-Based) benchmarking method. In this method, energy performance intensity (EPIs) of the subjected building will be compared to a large data set (reasonable size) of buildings having similar characteristics. The combinations of variables (usually expressed as a ratio) that result in meaningful interpretation of energy consumption within buildings are called EPIs. An example of this method is ENERGY STAR® Building Label, which was developed for office buildings in the U.S. A large data set was developed using the CBECS survey. Based on linear regression, factors having strong correlations with energy use have been identified such as floor area, number of occupants, connected load, type of occupancy, and hours operated per week. The influence of outside weather temperature (weather normalization) on buildings' energy consumption was studied also (Sartor et al., 2000). Second is a method called the points-based rating system that unlike the previous method (Statistical Analysis), provides guidelines and standards to measure the efficiency level of a building, comparing it to the best practice standard, rather than doing the comparison within the dataset. An example is the US. Green Building Council's Leadership in Energy and Environmental Design (LEED) Rating System (Sartor et al., 2000). Third is the simulation model-based benchmarking (Sartor et al., 2000). Federspiel et al. (1999) do not fully agree with using statistical analysis for building benchmarking since, they believe that buildings cannot be compared with each other unless they are similar and the selected data set population may not be efficient. In simulation model-based benchmarking buildings are modeled in the building energy simulations, such as DOE-2 and benchmarks are calculated according to the idealized model. A shortcoming point of simulation results can be the fact that benchmarks resulting from the simulation model may not be close and/or calibrated to the actual consumption (Sartor et al., 2000). Fourth is another method for benchmarking called hierarchal and end-use metrics. A set of hierarchical and end-use performance metrics are developed, which starts at the highest (whole-building) level and moves down to the underlying system performance data (Sartor et al., 2000).

The statistical analysis method has been chosen for this study. According to the study done on energy benchmarking on commercial buildings done by Sharp (1996),

different approaches that are usually used for energy benchmarking includes averaging, median, simple ranking, and normalized ranking (Sharp, 1996).

Averaging is a straightforward benchmark. It is a quick and simple method to compare similar buildings based on their energy efficiency. For small samples of buildings with high energy consumption, using the average is not a reliable approach since the average can be influenced by buildings having extreme energy intensities (both low and high) and it may increase the average drastically (Xuchao, Priyadarsini, & Eang, 2010; Sharp, 1996).

Medians, similar to averages, are more reliable than averages (less sensitive to extremes). Energy efficiency of each building is either above or below the benchmark (Xuchao et al., 2010). Another drawback of using median as a benchmark is that EPIs distributions generally are not normal; and it makes this method an unreliable benchmarking (Kinney & Piette, 2002).

Simple ranking is a more informative benchmark than averages and medians. Buildings are ranked based on their EPIs among a whole group of similar buildings. The ranking is presented in a cumulative distribution curve. The problem with this method is that some operational and functional characteristics of the buildings cannot be made known and compared, which results in diminishing some buildings without any good reason and giving undeserved high grades to some other buildings (for instance, a building with high occupancy will be ranked lower if directly compared to a building with much lower occupancy). Therefore, in order to make a more sensible and reasonable comparisons between buildings, factors need to be normalized (Normalized ranking method) (Xuchao et al., 2010).

Normalized ranking is a method that enables comparison of energy performance of buildings with similar and dissimilar features and functional requirements. Several different factors affect building energy performance, such as weather condition, physical characteristics like age, number of floors, occupancy rate, occupants' behaviour. The actual energy consumption of reference buildings needs to be normalized to the above-mentioned factors. Therefore, by implementing normalized results, buildings can be ranked based on their energy use performance (Xuchao et al., 2010).

2.2.5 Energy benchmarking using weather normalization

There are a lot of factors affecting the energy consumption within MURBs, factor such as buildings characteristics, buildings' mechanical system, tenants' behaviour, and natural conditions (climate) (Fels, 1986). The outside weather temperature has the greatest influence on MURBs energy consumption (short term), while fuel prices, household income, and the number of households have a long term effect on the MURBs energy use (Hirst & Goeltz, 1986). For instance, in a gas-based heating system building, when the outside temperature decreases, the gas consumption increases to heat up the building and keep the indoor temperature at a satisfying level (Xuchao et al., 2010).

Estimating building energy consumption using dry-bulb temperature is called weather normalization (Fels, 1986). Weather normalization usually applies for building energy benchmarking to analyze energy performance of buildings exposed to different outside temperatures (Xuchao et al., 2010). There are two factors called Heating Degree Days (HDD) and Cooling Degree Days (CDD) that play major roles in energy benchmarking using weather normalization. HDD reflects the weather condition in winter. HDD is the summation of difference (in degree) between outside weather temperatures when it drops lower than a specific temperature (reference temperature) (Fung et al., 2013). Figure 2.4 demonstrates HDD fluctuation (18°C reference temperature) or the winter weather pattern of Canada and Ontario.

Figure 2.4. HDD trend in Canada and Ontario for the period of 1990 to 2008 (Canadian Home Builders' Association, 2011)

As is shown in the Figure 2.4, effect of global warming trend can be seen in the HDD trend. The HDDs for warmer winters are lower than the colder winters.

On the other hand, CDD reflects the average weather condition in summer and space cooling. CDD is the summation of difference (in degree) between outside weather temperature when it gets higher than a base/reference temperature (Fung et al., 2013). Figure 2.5 demonstrates CDD fluctuation or the summer weather pattern of Canada and Ontario for the period of 1990 to 2008.

Figure 2.5. CDD trend in Canada and Ontario for the period of 1990 to 2008 (Canadian Home Builders' Association, 2011)

As is shown in the Figure 2.5, majority of annual CDDs is well above the average CDD. This indicates that summers are getting warmer throughout the years in Canada (the higher the CDD, the warmer the summer).

According to Rachlin et al. (1986), base/reference temperature is the temperature at which neither cooling nor heating is required in a building. Depending on types of tenants (tenants' behaviours), building characteristics, and appliances, reference temperature is different from building to building (Rachlin et al., 1986). According to ASHRAE (2009), the acceptable range is from 50 to 65 degrees Fahrenheit (10 to 18 degrees Celsius). HDD has a linear relationship with space heating (Fels, 1986) and is used for calculating energy consumption needed in cooler season to heat the buildings; and CDD is used for calculating the energy consumption needed in warmer seasons to cool the building (Fung et al., 2013).

Canada is classified as a cold climate country. It has been divided into four climate zone^{IV}(A,B,C, and D) based on HDD. Zone A represents areas having mild climate and zone D those having the coldest climate in Canada (NRCan, 2011).

Figure 2.6. Different climate zones in Canada (NRCan, 2011)

Toronto is located in zone B. A big portion of energy consumption is used by space heating in a cold climate. According to NRCan (2012), a large portion of energy is used by space heating in cold climate provinces; for instance, 63% of secondary energy was used for space heating by the residential sector in Canada in 2009. Due to this reason, weather normalization has been chosen for energy benchmarking in this study using the Princeton Scorekeeping Method (PRISM) (Fels, 1986).

2.2.6 PRInceton Scorekeeping Method (PRISM) overview

Due to the need of having a reliable method to evaluate the effectiveness of retrofits or energy conservation methods implemented to the buildings in United States, Princeton University designed and introduced the PRInceton Scorekeeping Method (PRISM) in 1984 (Fels, 1986). In order to make the best use of available utility data, some improvements were made to the original PRISM later. Features such as heating-and-cooling model, a

IV. Zone A (mild zone): ≤ 3500 HDDs, Zone B: > 3500 to ≤ 5500 HDDs, Zone C: > 5500 to ≤ 8000 HDDs, Zone D (coldest zone): > 8000 HDDs

robust model, an aggregate version, and an automated data correction/ outlier detection (for reliability enhancement) were added (Fels et al., 1995).

PRISM is a regression-based model (statistical procedure), in which outdoor weather temperature (extracts from the nearest weather station) and monthly energy consumption (obtained from utility bills) are the inputs to estimate normalized annual energy consumption (NAC), base load, heating/cooling slope (heat-loss/heat gain rate of a building), and reference temperature of a building (Fels, 1986). PRISM estimates individual buildings' reference temperature according to optimized linear regression (Fels, 1986).

Results from three different data sets in the New York city, including 71 multi-family buildings from the Building Energy Use Tracking System (BEUTS), 30 oil heated multi-family buildings from Building Monitoring Data (BMD) project, and some from Energy Conservation Cases (ECC), found that by using the PRISM method energy conservation can be successfully monitored and reliable NAC can be estimated both for oil and gas heated large multi-family buildings (Fels & Reynolds, 1992). Also, the PRISM method has been used for analyzing energy consumption (gas related) for space and water heating in multifamily buildings (Decicco et al., 1986).

Energy analysis of 16 buildings at Ryerson University (RU), which represent about 86% of RU's total area, has been successfully studied using PRISM method. PRISM results have been compared to the actual utility bills. The comparison shows 2.7% and 6.4% discrepancy for hydro and steam consumption respectively, which this makes PRISM results generally stable, and reliable (Fung et al., 2013).

Another study done in New Jersey investigating the effectiveness of the PRISM models for selected dataset of electric-heated houses (with and without electric cooling system) shows that PRISM can provide a reliable NAC index even for buildings using electricity as their heating source. The estimated cooling reference temperature was found to be within the range of 21 to 29 degrees Celsius. Also, since research showed that the electric cooling demand is more related to occupant's behavior than to outside temperature, the estimated NAC of the buildings having smaller demand for cooling tends to be more reliable (Stram & Fels, 1986). Since Canada is a cold climate country, which

means heating seasons are longer (more energy is required for space heating) than cooling seasons PRISM is found to be suitable for this study.

There are some advantages and disadvantages in using PRISM. The advantage of using PRISM is being able to estimate energy savings after retrofits and describe the energy consumption of the studied building over time. Feeding twelve consecutive monthly data to PRISM will result in the most reliable outcome (NAC) (Rachlin et al., 1986). Limitations of using PRISM are not being able to predict the building future energy consumption and breakdown detailed energy uses. According to Rachlin et al (1986), in order to achieve a reliable estimate for base load, heating slope, and reference temperature, summer data, winter data, and both summer and winter data are needed respectively.

2.2.7 Developing Energy Performance Indicators

Energy consumption of different buildings (different size, height, etc.) cannot be compared according to their absolute values. In order to compare a building's energy consumption to a population of similar buildings, energy use need to be normalized to common factors, which results in EPIs (Filippn, 2000). It is very important in building energy benchmarking process to derive the most meaningful EPIs.

The EPIs are important factors in building energy benchmarking (Sharp, 1996). They reflect the rate of energy use (Sharp, 1996), plus they play a major role in choosing energy efficient technologies when it comes to the design stage (Nikolaou et al., 2011). EPI is the most common energy performance metric for building energy benchmarking applications. Usually EPI refers to the annual building energy consumption normalized by floor area (kWh/m^2). Choosing the simple EPI (kWh/m^2) can be misleading, because it can mask some inefficient systems or components. Therefore, many authors have introduced other factors, such as building parameters, heating, ventilation, and air conditioning (HVAC) system, climate and envelope parameters (Nikolaou et al., 2011).

Forty buildings across the Canada have been involved in energy benchmarking done by CMHC. Their energy consumption has been normalized by the factors such as, floor area (ekWh/m^2), floor area per HDD ($\text{ekWh/m}^2/\text{HDD}$), number of suites (ekWh/suite), and number of suites per HDD (ekWh/Suite/HDD) (Enermodal Engineering Ltd, 2001). In another study in

Singapore the energy performance of 29 hotels has been normalized by floor area (primary normalization variable due to having the highest R^2 in regression analysis), number of guest rooms, occupancy rate, and number of workers (Xuchao, Priyadarsini, & Eang, 2010). Also, energy consumption has been normalized by floor area in another study done by Filippin (2000) on energy and GHG emission benchmarking of schools in Argentina. In a more recent study done in the New York City, the weather normalized method has been used for comprehensive building (all types) energy, water and GHG emission benchmarking. Factors such as energy, water consumption and GHG emissions have been normalized by building size (square footage) (The City of New York, 2012).

The outcomes of a study done by Sharp (1996) on energy benchmarking for commercial office buildings in the United States using simple regression modeling showed factors such as the number of workers, number of personal computers, owner-occupancy, operating hours, and having an economizer or chiller have a significant relationship (statistically) with EPI (kWh/sq ft).

Using only one type of EPIs, for instance kWh/m², for comparing the MURBs' energy performances within a sample dataset (energy benchmarking), it will not result in an efficient comparison. Due to the fact that, inefficient systems or components can be masked and that could easily cause misinterpret comparison (Sartor et al., 2000). Occupants have influence on energy consumption. Occupant-related indicators, such as energy use per occupant per square metre (kWh/capita/m²), and numbers of occupants per unit (kWh/capita/unit) have been ignored in the studies done on energy benchmarking.

2.2.8 Energy Consumption and Greenhouse Gas Emission: The Link

Canada has one of the highest levels of energy consumption per capita in the world (Parker et al., 2001). Due to the daily increase of energy consumption/demand around the world (countries become more industrialized) and the limited amount of energy sources, energy conservation and management has become quite an important topic (Rahman, 2010).

According to Environment Canada, GHG emissions resulting from the residential sector, which are by-product of energy consumption, can reach up to 46 (Mt CO₂,eq) by

2020. But it is important to keep in mind that predicting the accurate future amount of GHG emission is not possible, since the fluctuation in GHG emissions over time is influenced by factors such as energy price, energy policy, gross domestic product (GDP), etc. Figure 2.7 presents different levels of GHG emissions by year 2020 based on different scenarios (economic drivers). The sensitivity range of GHG emission for the chosen scenarios, low GDP (low world oil prices), high GDP (high world oil Prices), and baseline are from 716 to 775 Mt CO₂e for year 2015 and from 747 to 839 Mt CO₂e for year the 2020 (NRCan, 2011).

Figure 2.7. Future estimation of GHG emissions under alternative economic assumptions (NRCan, 2011)

Even though newer buildings are more energy efficient than those built in the past, but still energy demand and GHG emissions keep increasing due to the direct and indirect energy use of the residential sector. For example, population growth, and larger size houses, which tend to require larger cooling and heating loads (Parker et al., 2001). According to a study done by Haggag (2011) on the Canadian industrial sector, energy consumption and GHG emission are in positive correlation; which is for each 1% increase in energy consumption, GHG emission increases by 0.82%.

The City of Toronto has committed to achieve 30% GHG emission reduction by 2020 and 80% by 2050 (based on GHG emission level of the year 1990). And since the residential sector is the third highest GHG emitter in Toronto (25% of overall GHG emissions), it is important to look into the current level of GHG emissions resulting from the residential sector, and try to deploy GHG emission reduction strategies in order to achieve the target reductions of 2020 and 2050 (The City of Toronto, 2012). According to UNEP (2007), by and

large, the building sector is capable of reducing GHG emission in a short period of time by enhancing energy efficiency in buildings. By implementing energy conservation programs and alternative generation solutions, energy reduction of 30% to 50% in both existing and newly built buildings can be achieved by 2020 (UNEP, 2007).

Experimental investigation on energy consumption and GHG emissions of high and low residential density developments in North America showed that the most effective way of achieving the target level of energy consumption and GHG emissions reduction is to aim at building operation systems (Norman et al., 2006).

2.3 Water

2.3.1 Overview of Water Consumption in the Canadian Residential Sector

Even though Canada is a rich country in terms of fresh water, supplying 3,472 km³ of water annually (Statistics Canada, 2012), whether Canada is able to meet future water needs with the existing situation is still questionable (REIC Consultants Ltd, 1999). Twelve percent of Canada's land is covered by water (surface water) (Statistics Canada, 2012), which is the main source of the Canadian water supply for municipalities (88.5% from surface water) (Environment Canada, 2010). Domestic uses have accounted for almost 40% of all municipal water consumption in Canada (REIC Consultants Ltd, 1999). CMHC (2007) declares that 75 teralitres (75 km³) of water would be consumed by the Canadian residential sector between 2004 and 2025, which has been found to be almost the same amount of water as one year of water flowing over Niagara Falls. Figure 2.8 shows the water consumption breakdown in the Canadian residential sector.

Figure 2.8. Water consumption breakdown in residential buildings (The City of Toronto, 2010)

The residential sector is responsible for almost 52% of overall water consumption in Toronto. The water use comparison within the seasons shows that the peak water demand occurs in summer (May to September), and is 80% more than in winter (October to April) (The City of Toronto, 2012). To prevent wasting water, a water efficiency program (WEP) was initiated by the City of Toronto in 2003 to set the target reduction level for water consumption within MURBs. Cash incentives are allocated to those commercial and institutional buildings that contributed to the physical and operational changes that can reduce water consumption. Two of the water consumption targets for MURBs were replacing toilets and installing clothes washer program to conserve 55.1 million litres per day (ML/D) and 8.5 (ML/D) water use reduction by 2011 (The City of Toronto, 2011).

Installing water meters has been found to be an effective way to reduce water consumption. In this regard, in one of the case studies done by the US-EPA in New York City, 20 to 40% water and wastewater reduction were achieved by sub-metering repair, leak detection, and toilet replacement (EPA, 2002). The City of Toronto is making regulations to deploy a mandatory water meter program. This makes individuals responsible for their water use (The City of Toronto, 2010).

Beside the issue of leaky fixtures and water leakages throughout the buildings, it is noteworthy to mention that around 13% of water is being wasted through the distribution system in Canada (Environment Canada, 2010). Water leakage in Toronto's infrastructures

has been assessed using International Water Association (IWA) water audit methodology. The average infrastructures leakage index (ILI) in Toronto was found to be 4.2 (4.2 times of water losses of what can be technically achieved). Toronto has been ranked 10 within North America's municipalities and 16 at the international level for ILI comparison. Therefore, ILI of 2.5 has been set as a feasible target point for Toronto (The City of Toronto, 2011).

Canada experienced a 16% drop in water consumption per capita from 2006 to 2009. The reason may be due to the climate changes, sub-metering installation, water prices, etc. According to the 2009 Municipal Water and Wastewater Survey (MWWS), water consumption per capita for both single family and multi-family dwellings in Ontario was found to be 255 (liters per capita per day) (Environment Canada, 2011).

Residential sources have contributed to almost 65% of the overall wastewater flow in Canada in 2006. And the estimated average daily wastewater flow per capita in 2006 was 668 liters (served by sanitary sewers) (Environment Canada, 2010). In Figure 2.9 different sources of wastewater flows in Canada was shown.

Figure 2.9. Wastewater sewer flows breakdown by sources, 2006 (Environment Canada, 2010)

Another finding was that wastewater flow per person does not follow a consistent trend as municipality size gets larger (Environment Canada, 2010). Within the smaller communities, the major source of wastewater is from the residential sector, and as the

community's size gets bigger the residential wastewater share becomes less (Statistics Canada, 2012).

Municipal wastewater can fit into two categories sewage from homes, institutions, businesses and industries, which is called sanitary sewage. Wastewater from rain and melting snow, etc. is known as stormwater (Statistics Canada, 2012). According to Statistics Canada (2012) sewer system is being widely used in within Canadian dwellings (almost 82%), and a small percentage of buildings, 13% and 1% use private and communal septic system respectively.

Wastewater treatments are applied to the wastewater before it is released to the environment. There are various degrees for wastewater treatment in Canada, such as preliminary treatment, primary, waste stabilization ponds, secondary mechanical, and tertiary or advanced treatment. Larger particles are removed at preliminary treatment level (grit removal). Primary treatment is treatment in which larger and insoluble matter are removed from the wastewater (Environment Canada, 2010). Secondary treatment, which it has been widely used in Canada, by about 79% of the population (Statistics Canada, 2012), is known as a level of wastewater treatment in which biological contaminations from water treated at the primary level are removed (significant amount of biochemical oxygen demand and suspended solids reductions are achieved). Advanced or tertiary treatment is an advanced treatment, in which nutrients and chemical contaminants remain from the secondary treatment, such as phosphorus and nitrogen, are removed from wastewater and may not be satisfactorily reduced from conventional secondary treatment (Environment Canada, 2010).

2.3.2 Water Benchmarking

In order to make effective policies for water conservation and set a proper water consumption reduction target for MURBs, it is important to have a clear understanding of water consumption, which can be inferred from proper benchmarking. The water consumption trend in the Canadian residential sector shows that the 2009 total annual water consumption was 100 m³/capita (Environment Canada, 2011).

With the aim of making improvements in both energy and environmental aspects of commercial buildings, the Canada Green Building Council (CaGBC) initiated a program called Green UP. Using this program allows building owners/managers to measure their buildings' water, energy^V consumption, and GHG emissions. Also, estimating cost savings and target reduction goals according to the top performer (top performer of all water, energy use and GHG emissions) is another feature of the program. Performances of the buildings are compared to the national online database of similar buildings included in the program (CaGBC, 2012).

Due to the high water consumption in American healthcare buildings and having limited information on their water uses on the other hand, Mazzetti Nash Lipsey Burch (M+NLB) recently launched a free water benchmarking tool called Watermark. This allows building owners and managers to track and measure their buildings' water consumption by just inputting a minimum of 12 months' water consumption data. The outputs are the absolute annual water consumption (gallons) per square feet and daily water consumption per bed. The studied buildings are compared to the other similar buildings with the data set (a nationwide database) (Mazzetti Nash Lipsey Burch, 2012).

The ENERGY STAR Portfolio Manager is another web-based energy and water benchmarking tool introduced by EPA. This program enables users (building owners and managers) to track and evaluate their buildings' consumption by entering the buildings' monthly utility consumptions, location of the building, and some buildings' characteristics and specifications. Subjected buildings' performances (in terms of both water and energy) are rated according to a scale of 1 to 100 relative to similar buildings^{VI} at the national level (U.S EPA, 2012).

The water consumption of eighty-eight buildings from the OHC has been evaluated. Broad types of buildings, from one to 23 stories and having 10 to 489 units with mixed occupancy (seniors and family), were selected as the data set of this study. The annual water consumption range was from 0.26 to 3.83 m³/m² and the average was 1.91 m³/m²

V. Energy consumption has been weather normalized for this program.

VI. Note: Energy and water consumption of the buildings are compared to the statistical national survey-based data set known as the Commercial Building Energy Consumption Survey (CBECS), which is conducted every four years.

(Enermodal Engineering Limited, 2007). In another study done on the HiSTAR data set (CMHC high-rise buildings), average water consumption was found to be $1.85 \text{ m}^3/\text{m}^2$ (Enermodal Engineering Ltd, 2000).

The energy and water consumption of thirty-four Canadian MURBs (data source: OZZ Corporation) have been analyzed by CMHC. The buildings in the data set are located in the GTA and the number of units varies from 69 to 473. The water consumption has been normalized by number of units. To this end, annual water consumption range was found to be from 92 to $313 \text{ m}^3/\text{unit}$ and the average was $209 \text{ m}^3/\text{unit}$ (CMHC, 2005).

Water consumption (pre and post renovation) of the ASHRAE headquarters building located in Atlanta has been analyzed by ASHRAE, USGBC, and CIBSE. Annual water consumption has been normalized by numbers of floors and occupants. The annual water consumption per person before retrofit (August 2007) was found to be $20.86 \text{ (m}^3/\text{capita)}$ and the consumption reduced to $6.9 \text{ (m}^3/\text{capita)}$ after applying water conservation methods on October 2010 (67% savings achieved) (Hunn et al., 2012).

Another study has been undertaken in New Zealand on water benchmarking of forty-four selected commercial buildings. The building survey, water consumption data (the past five years to date of the utility bills) plus observations achieved through onsite investigations of the buildings have been used for establishing the water consumption baseline. The median (fiftieth percentile) of the dataset has been used as a benchmark, which is $1.17 \text{ m}^3/\text{m}^2/\text{yr}$ (Bint et al., 2010).

Water benchmarking has been done by Exergy (2005) on behalf of the Australian Government Department of the Environment and Heritage on office and public buildings. The benchmark for public buildings has been found to be $3.34 \text{ m}^3/\text{m}^2/\text{yr}$ (Bannister et al., 2005).

All above-mentioned studies either studied the water consumption within commercial, institutional, and office buildings (not residential) or within the residential sector with mixed categories, such as different types of buildings and different types of occupants. It is important to compare the water consumption of similar buildings, in terms of building type, occupancy type, size, etc., with each other to perform an accurate benchmarking.

2.3.3 Developing Water Consumption Indicators

Water is consumed in a variety of ways in residential buildings, such as the mechanical system (cooling and heating systems), domestic uses (toilets and sinks) irrigation, and a building's amenities (swimming pool, etc.). In general, water consumption in buildings can be affected by building size and occupant behaviour, etc. Factors affecting water consumption within the residential sector were identified as temperature and precipitation level, occupant's behaviour, water rate, demand management tools and technology (Environment Canada, 2010). Water consumption per unit area in residential buildings is higher than in office building (Statistics Canada, 2005).

According to research done by Enermodal Engineering Limited research group (2007), fuel type is the only factor that showed considerable correlation to water consumption (gas-heated buildings tend to use more water than electric heated buildings). Poor relationships have been found between the water consumption indicator (WCI) and factors such as occupant type, outside weather temperature (HDD), building age, number of floors, building size, and region.

In the analysis done on water consumption of the MURBs in the CHMC HiSTAR dataset, the water consumption has been normalized by the number of units and building size. And, fluctuation of outside weather temperature (HDD) was found not to have any correlation with water consumption within MURBs (Enermodal Engineering Ltd, 2000). Unlike the finding by Enermodal Engineering Ltd (2000), investigations done by the City of Toronto on MURBs (2011) show that water consumption is significantly influenced by weather condition and seasonality.

The results of water benchmarking done by Exergy on office and public buildings show that total water consumption has a linear relationship with floor area and cooling degree days in office buildings (Bannister et al., 2005).

The water consumption of commercial buildings in New Zealand has been benchmarked. Water consumption has been normalized by net lettable area (NLA), full time equivalent (FTE) occupants and type of buildings, etc. in order to conduct a comparison between similar buildings. The inferences from the analysis showed NLA and FTE have a strong relationship with water consumption (R^2 of 0.61 for NLA and 0.59 for FTE). NLA has

been chosen by the author as the most steadfast normalization measure, since keeping track of the number of FTE occupants is too difficult and unreliable (Bint, Isaacs, & Vale, 2010).

In the study done in Atlanta on how water was being consumed within residential and non-residential buildings, gallons per household per day had been chosen as a WCI (Turner & Cosgriff, 1997).

The investigations done on water consumption of 60 residential apartment buildings in Hong Kong demonstrate a correlation between annual domestic water consumption and number of occupants (Wong & Mui, 2008). Also water consumption has been normalized per capita for the analysis done by the City of Toronto in WEP, and it is said to be the best way of representing water conservation effects. The annual water consumption per capita was found to be 60 m³/capita in 2003 and the total of 14.5% reduction was achieved by 2010 (The City of Toronto, 2011).

Due to the diversity of opinion on the best WCI within the MURBs, investigating the most meaningful water consumption performances for MURBs has been chosen as one of the objectives of this study.

2.3.4 Water Consumption and Greenhouse Gas Emission: The Link

According to the Organization for Economic Cooperation and Development (OECD), Canada is ranked 28 among 29 countries for annual water consumption per person. Statistics show that the amount of water used per person in Canada is 1,600 m³, which is 65% more than the OECD average (Boyd, 2001). Also, NRCan (2004) stated that after thermal power generation and manufacturing, Canadian municipalities had the highest percentage of water use, about 11%, in the year 2000.

Energy consumed by the water sector is increasing (Rothausen & Conway, 2011). Forty percent of energy consumption in Ontario comes from the residential sector, in which heating water accounts as the second major source of energy use (20%) in buildings (SeeLine, 2005). In terms of water consumption, as is shown in Figure 2.10, Ontario by itself has the highest water consumption among the regions in Canada.

Figure 2.10. Municipal water consumption within different regions in Canada, 2006 (Environment Canada, 2012)

A study in the UK shows that within the cycle of water in the UK (supply, use and disposal), a big portion of the resulting GHG emissions (89% of overall GHG emissions produced by water cycle) comes from in-home water uses and water heating (Reffold et al., 2008) and pressurizing (Berkeley Law & UCLA Law, 2011), excluding space heating. A significant amount of carbon footprint reduction besides energy and water reduction can be achieved by reducing hot water consumption (Reffold et al., 2008).

There are number of studies that have been done on the water and energy consumption relationship such as, Cheng (2002), who investigates the inter-relationship between water use and energy conservation for a building; and Cohen et al. (2004) analyzed the hidden costs of California's water supply; and Mass (2009), studied the energy associated Energy associated with the water use cycle (indirect, direct energy)

Energy associated with the water use cycle can fit into three categories, indirect, direct energy, and embedded energy required to manufactures chemicals

Indirect energy: municipal water services such as pumping, extracting, and treating the water for consumers' use and wastewater plant treatment operation consume energy, release GHG emission, and contribute to global warming and climate change. This is called indirect energy. Major indirect energy consumption of water production comes from pumping the water. Therefore, the assumption has been made that total water production

energy consumption is equivalent to the energy usually consumed for water pumping (Mass, 2009). Water and wastewater treatment/facilities are responsible for a third to a half of a municipality's electricity consumption, double the consumption for street lighting (PAGI, 2008). According to the City of Toronto, the Region of Peel and the City of Guelph, water and wastewater facilities consumed 25 to 60% of the total municipal electricity usage (Farbridge, 2008; Harrison, 2007).

Direct energy: there is another type of water related energy consumption called direct energy. It is the energy consumed directly by end-users (households); for example, using hot water, water softening, etc. Studies have shown that the amount of GHG emission (volumetric basis) associated with water heating (direct energy) is much higher than water distribution (indirect) (Mass, 2009). A life cycle assessment study done in the United States on water consumption and its impact on energy resources of four different types of buildings (an apartment building, college dormitory, a motel, and an office building), proved the above-mentioned fact, which is water consumed in the buildings (direct energy) results in more energy consumption than water and wastewater treatment (indirect). Also, water and wastewater related energy consumption of apartment buildings, such as water heating and treating residential wastewater, is the highest among the all four types of buildings; and for office buildings it is the lowest (Arpke & Hutzler, 2006).

Embedded energy was required to manufacture chemicals: water and wastewater contain some disinfected chemicals such as chlorine gas, sodium hypochlorite, etc. and some coagulation and flocculation chemicals such as alum, ferric, etc. at the preliminary stage that requires some treatment. Chemical manufacturing consumes energy and produces GHG emissions. This type of energy is called embedded energy (Mass, 2009).

As is shown in Figure 2.11, natural gas related-energy consumption was the highest, for both 1990 and 2008. Also, the Canadian residential sector has experienced a higher increase in the share of natural gas consumption from 1990 to 2008 (14%) compared to the other energy sources (excluding wood-based fuels, since their contribution is not that significant comparing to natural gas and electricity).

Figure 2.11. Compare the gradual shift of energy sources used in the residential sector from 1990 to 2008 (Canadian Home Builders' Association, 2011)

Greenhouse gas emissions result from energy consumption. After space heating, domestic hot water systems consume the most energy (gas consumption). And since water and energy consumptions have been found to have a strong relationship with each other, it would be vital to investigate the potential energy and GHG savings that can be achieved from applying water conservation strategies.

2.4 Solid Waste Management

2.4.1 Municipal Solid Waste Management in Canada

Statistics (waste management survey) show that 13.4 million tonnes of waste have been generated by Canadian households in 2004, of which 78% was transformed to landfill and the rest was recycled (Babooram & Wang, 2008). Mainly due to the population growth, waste generation increased about 19%, equivalent to 2.1 million tonnes, within the Canadian residential sector from the year 2000 to 2004. Also, for the same period of time, the amount of recycled waste increased by 58%, in which the largest portion (22%) was organic waste (Babooram & Wang, 2008). Figure 2.12 demonstrates the latest statistics on the amount of disposal solid waste for both the residential and non-residential sector.

Figure 2.12. Amount of disposal solid waste per person within Canadian provinces, 2008 (Statistics Canada, 2010)

Also, Figure 2.13 demonstrates the percentage of increase/decrease of waste generation between 2006 and 2008 in different provinces.

Figure 2.13. Total solid waste fluctuation from 2006 to 2008 with Canadian provinces (Statistics Canada, 2010)

The amount of waste generated by the residential sector was found to be the third largest compared to other sectors in Canada in 2008 (Statistics Canada, 2012). In 2011, twenty-two percent waste diversion were achieved in MURBs according to the City of Toronto (2011). Investigations show that MURBs in Toronto are performing poorly in terms of recycling and waste diversion (13- 15 % waste diversion). The City of Toronto states that

there are a lot of opportunities for improvement in waste diversion in Toronto (GENIVAR Consultants LP, 2010).

In order to improve the existing waste management system or reduce the amount of waste being sent to landfills, it is important to have a clear understanding of the current waste management system. Figure 2.14 is the scheme of how generated waste is being managed (from generation to disposal).

Figure 2.14. Waste management diagram (Sabbasa et al., 2003)

As is shown in Figure 2.14, generated waste (from industrial activities, residential, etc.) first goes through the source separation process called waste collection. Second, the collected waste is sorted out in order to be prepared for recycling, reusing, or disposal, which is called processing. Third is recycling, in which materials such as paper, glass, etc. are produced from the waste. Fourth is implementing different technologies to those types of wastes needing treatment, such as hazardous waste. The last step is waste utilization and landfilling. Waste utilization includes all options of waste after processing, such as use of treated bottom ash (non-combustible and unburned organic material) for road construction,

compost for agricultural applications, etc. Those types of wastes that are not useful for any purpose are sent to landfills. But what kind of short and long term impacts disposal wastes can have on the environment definitely have to be considered (Sabbasa et al., 2003).

In 2004, TCHC initiated a plan called the Green Plan; in which waste management recycling was one of the commitments. The commitments were to reduce the amount of waste going to landfills by implementing 3 Rs (reducing, reusing, and recycling) (TCHC, 2006).

According to the data collection performed by Waste Diversion Organization (WDO), there are almost 1,225,000 multi-unit households (dwellings with six or more that are located in a municipality with a population of 5,000 or more) in Ontario (RCO, 2000). Within the Province of Ontario, recycling is mandatory for MURBs (RCO, 2000), and materials such as aluminum, glass, newspaper, and plastic have to be source separated for recycling under supervision of building owners (Ontario Ministry of the Environment, 2007). Carts/rollout containers are the most common municipal separation systems used in Ontario (about 65%) (RCO, 2000). Depending on building size, collection location, frequency of collection, vehicle access to storage area and level of waste segregation, different building collection systems are chosen. There are two residential waste collection services: waste pick-up by municipality (city collection), and private collection companies (contracted services) (Statistics Canada, 2012). Almost 95% of MURBs in Toronto receive garbage and recycling collection services from the city (GENIVAR Consultants LP, 2010). Also, waste can be transported to collection, recycling, and disposal facilities by households (no collection services) (Statistics Canada, 2012). In terms of waste pick-up frequency, around 80% of municipalities in Ontario have weekly pick up collection service and the other 20% have bi-weekly collection service (RCO, 2000). Some of the collected waste is sent to landfills or incineration and some others such as glass, aluminum, plastic, and paper are recycled. Incineration is a mass burn system of different kinds, from low-tech open burning to modern ones that have pollution control (Statistics Canada, 2012).

A total of 990 landfill sites exist in Ontario, 958 small and 32 large (Ontario Ministry of the Environment, 2011). There are seven municipal incineration plants across Canada, five of which generate energy. Between landfills and incineration, landfills are the main

waste disposal system in Canada (Statistics Canada, 2012). Different types of waste processing (landfill) exist. At some, generated methane resulting from burning waste is released to the atmosphere. And some others have the facility to use emitted methane for combustion and other purposes such as electricity production (energy recovery), etc. (ICF Consulting, 2005). Although incineration has the benefit of reducing the amount waste disposal and GHG emissions (Mohareba, Warith, & Diazb, 2008), on the other hand, installation of incineration facilities was found to be a challenge (cost included) (Mohareba, Warith, & Diazb, 2008). In addition, incineration creates a lot of ashes, and is suspected to danger the human health (Sawell, Hetherington, & Chandler, 1996). By and large, almost less than 5% of municipal solid waste is being sent to incinerators, of which, according to 2006 statistics, around 3% was converted to energy (Statistics Canada, 2012). Due to the mentioned drawbacks currently landfills have been chosen as a better solution as a disposal system.

2.4.2 Waste Benchmarking

The issue of Canadian landfills reaching their limits raises the concern of reducing the amount of solid waste generated (Babooram & Wang, 2008). According to Statistics Canada (2012), an average amount of municipal solid waste sent to landfills was 25,871,310 tonnes or 777 kg per person in 2008. In 2004, 418 kilograms of waste per person and 112 kilogram recycling waste per person were produced by the residential sector. The comparison of waste generated (per capita) by the residential sector in Canada and the U.S shows that Canada is generating 5% less than the U.S^{VII} (EnviroStats, 2007). Municipal solid waste contains residential and non-residential waste. The waste generated from the construction, renovation and demolition sector or those which are by-products of industrial, commercial, and institutional sectors are all covered under non-residential waste. Waste generation per capita in Alberta was 968 (kg/person) in 2004, which is the highest among the provinces in Canada (Alberta Environment, 2004-2007).

VII. Waste generation of the year 2001 has been taken into account for this comparison

In Toronto, annual waste generation of each suite in the MURBs was found to be 544 (kg/suite/year), including 462 kg/suite/yr of garbage and 82 kg/suite/yr of diversion waste). On the other hand, the results from the audit done on 15 MURBs in Toronto by Stewardship Ontario was found to be 601(kg/suite/yr) as total waste generation, in which 530 (kg/suite/yr) accounted for disposal waste and 72 (kg/suite/yr) for recycling waste (GENIVAR Consultants LP, 2010).

A lot of waste benchmarking has been done on different waste management systems in order to enhance the management and processing systems of municipal solid waste, for instance, the Waste and Resources Assessment Tool for the Environment (WRATE) software deployed by the UK Environment Agency, to evaluate and compare different municipal waste management systems (The Environment Agency, 2012). The Greenhealth Tracker is a tool allowed users to track and manage their waste disposal, both in terms of cost and volume. This has been designed for reducing and managing waste footprints within hospitals in the United States (Practice Greenhealth, 2012). A similar study has been undertaken to figuring out the way of improving the performance of municipal services. Benchmarking has been employed in the existing municipal solid waste recycling program, using data collected form a national survey, to find best fit benchmarking partners and practices (Folz, 2004). Also, the need of assessing the residential waste management system has been around for long time. Benchmarking on waste collection services was performed in 1998 with the aim of finding the most efficient waste collection services for the Bureau of Sanitation of the City of Los Angeles (City of Los Angeles, 2000). Following this study in 2001, the Solid Waste Association of America (SWANA) initiated benchmarking for residential solid waste services (O'Brien, 2010). Also the National Solid Waste Benchmarking Initiative (NSWBI) has been conducting benchmarking for the public sector throughout Canada (AECOM, 2011).

It is vital to understand what the baseline is for waste generation per household in order to apply effective waste management strategies and evaluate the existing waste management strategies. Therefore, benchmarking for waste generation within MURBS has been conducted in this study.

2.4.4 Waste Generation, Energy, Greenhouse Gas Emission: The Link

Canada is one of the world's most carbon-intensive countries per capita, discharging total of 720 megatonnes (Mt) of carbon dioxide equivalents (CO₂ eq) (Mohareba, Warith, & Diazb, 2008). Canada's landfill is responsible for almost 25% of methane emission in Canada (Babooram & Wang, 2008) and 20% of methane emission nation-wide (equivalent to almost 20 megatonnes (Mt) of carbon dioxide (CO₂)) (Environment Canada, 2010). The most important gases for analyzing GHG emissions resulting from processing residential waste are CO₂, CH₄, N₂O, HFCS, PFCS and SFE. As is shown in Figure 2.15 the largest portion of GHG emission is CO₂. Therefore, for calculating the GHG emissions the amounts of all gases are converted to equivalent CO₂^{VIII}.

Figure 2.15. GHG emissions composition breakdown expressed as carbon dioxide equivalents, 2009 (Environment Canada, 2011)

Depending on how waste generation is managed, different environmental impacts may result, for example, water and soil pollution (leachate^{IX}), resulting from waste disposal,

VIII. Global Warming Potentials (GWP) are as follows, CO₂ = 1; CH₄ = 21; N₂O = 310; HFCs = 140 to 11,700; PFCs = 6,500 to 9,200; SF₆ = 23,900.

IX. Toxic liquid produced from landfill, which it contaminates soil and ground water.

and GHG emissions or landfill gas^x (high methane concentration), which mainly results from burning waste in landfills. Methane is one of the most effective GHGs in global warming, it is 21 times more potent than CO₂ (Statistics Canada, 2012). As is shown in Figure 2.16, landfill disposals are responsible for the largest portion of GHG emissions, in which methane has the largest portion.

Figure 2.16. GHG emissions by different sources in waste sector (Statistics Canada, 2012)

Due to the potential air and water pollution resulting from landfills, a lot of smaller landfills have been closed by U.S EPA in 1991 (Themelis & Ulloa, 2007). But since it is not realistic and feasible to close all existing landfills, by reducing the amount of solid waste production and transforming landfill gases into useful energy (generate electricity), significant reduction in GHG emission can be achieved (Statistics Canada, 2012). According to Statistics Canada (2012), half of the methane produced from landfills (almost 175 kilotonnes) in 2009 was consumed in energy applications. However, it seems not a lot of studies have been done on the impact on GHG emissions of reducing the amount solid waste sent to landfills. Therefore, this has been chosen as one of the objectives of this study.

X. Landfill gas contains methane (high concentration), CO₂, and nitrogen and oxygen (very low concentration), which is resulting from anaerobic decomposition of organic matters at landfills (Sawell, Hetherington, & Chandler, 1996).

Chapter 3

Methodology

3.1 Background

This project is conducted as part of a major Ryerson project under the Toronto Tower Renewal Initiative, where detailed building characteristics and utility billing records on 120 MURBs from the Toronto Community Housing Corp. (TCHC), the City of Toronto and some private sectors are available.

The proposed methodology considers data collecting and screening of provided monthly utility data (2 to 5 years gas, electricity, water consumption plus solid waste generation) from TCHC. Performing energy (weather normalized using the Princeton Scorekeeping Method (PRISM) software), water, and solid waste benchmarking for the 120 data base size; developing meaningful performance indicators; determining performance ranking (identify the best, worst performer of the dataset plus the average and medians); and estimating different levels of savings (energy, water, solid waste, cost, and GHG emissions) according to best, 25th percentile, 50th percentile, and 75th percentile will be part of the analysis.

3.2 Data Collection: Survey Development

The first step of benchmarking is to gather the required information, called data collection. Originally a Microsoft Excel-based survey was developed for collecting MURBs' information, which is shown in Appendix C. The survey asked for information such as, 2 to 5 years of monthly utility bills (gas, electricity, and water consumption and waste generation), buildings' characteristics (size, age, number and type of the units, number of floors), occupancy type, and occupancy rate. Due to confidentiality concerns, the City of Toronto Tower Renewal office was assigned to collect data from building owners and send the collected information to Ryerson researchers. The provided information was received in MS Excel file format and buildings were shown by building ID numbers. Ryerson researchers

were not directly in contact with the buildings' owners. Any concerns such as missing information, and inconsistency in provided data were reported to the City of Toronto Tower Renewal office for follow-up and further investigations.

3.4 Energy Benchmarking

Figure 3.1 shows the overview of the proposed methodology for energy benchmarking developed to achieve the objective stated in Section 3.1, followed by the description of each process in the next sections of the chapter.

Figure 3.1. Overview of energy benchmarking methodology

3.4.1 Data Screening: Energy Consumption

On average, up to five years (2007 to 2011) of monthly utility bills (electricity and gas consumption) have been provided by TCHC, the City of Toronto, and some private companies in the Excel format. From available information on 120 MURBs, only the

information (both electricity and gas consumption) on 106 MURBs was reliable enough to be employed for the energy benchmarking analysis. Also, from five years of provided billing data only one year, 2010, has been taken into account for the benchmarking for consistency in the analysis. Some data were excluded from the dataset due to the following criteria:

1. The reason for not including the other four years (2007, 2008, 2009, and 2011) of data into the analysis:
 - Not having the full four years of data throughout the dataset (inconsistency)
2. The reasons for excluding those buildings having 2010 water information:
 - Too many missing months of data in a year
 - Drastically higher and lower water consumption than the remaining data (outliers)
 - The building being electric - heated
 - Having unrealistic fluctuation throughout the utility bills

3.4.2 Energy Consumption Calculation: PRISM Method

Energy used for the analysis has been weather normalized using PRISM software. PRISM uses regression models to provide the weather-adjusted Normalized Annual Consumption (NAC) index along with the best reference temperature for the studied buildings. In this regression model NAC is the dependant variable while HDD/CDD is the independent variable. The degree to which one variable appears to explain the behaviour of another variable has been studied by using the coefficient of correlation, R^2 . The range of R^2 varies from 0 to 1, in which 0 shows that two variables have no relationship and 1 indicates the strongest relationship between the two variables. It has been identified that the most reliable NAC can be achieved when the R^2 is higher than 0.7 and CV (measure the scatterings of probability distribution) is less than 7% (Fels, Kissock, Marean, & Reynolds, 1995)

The method requires a minimum of six bimonthly meter readings or nine monthly readings in one year without having more than two consecutive months of missing data (Fels, Kissock, Marean, & Reynolds, 1995). The effect of missing data (for each season individually) on the outcome of the PRISM for cold climate has been discussed by Goeltz &

Hirst (1987). The results showed that although missing spring/fall readings cannot cause unreliability issues for NAC estimation, missing winter readings result in underestimating of the NAC.

Daily weather temperature (mean temperature) of Toronto for thirty years, from January 1, 1981 to December 31, 2010, has been retrieved from the Environment Canada website (Climate Data and Information Archive). The average HDD and CDD of thirty years, long-term weather data, according to 18°C reference temperature has been calculated as typical Toronto weather for 30 years (average HDD and CDD based on 18°C are 3870 and 305 respectively). All the entered data had to be converted to Fahrenheit for the PRISM analysis; and the acceptable range of input temperature is from -50°F (-45.6°C) to 120°F (48.9°C).

The new version of the PRISM software, PRISM® (Advanced Version 1.0), which was released in 1995, has been used for calculating the NACs. The NACs are calculated according to three basic models, heating only (HO), cooling only (CO), and heating and cooling (HC). This version of the PRISM is equipped with the "robust" function, which makes the best use of data (Fels, Kissock, Marean, & Reynolds, 1995).

3.4.3 Energy Consumption Cost Calculation

Monthly gas and electricity charges and consumptions of the dataset were provided originally. But for consistency in the analysis, costs have been recalculated according to 2012 electricity and gas prices by the City of Toronto (\$0.097/kWh for electricity and \$0.012/ ekWh for gas) with the assumption that charges were paid before the due date (owing nothing from the previous month) (The City of Toronto, 2012; Enbridge gas, 2013).

3.4.4 Carbon Footprint Calculation of Energy Use

In 2005, Canada was responsible for two percent of global GHG emissions (Environment Canada, 2011). As a result, federal and provincial governments promised to reduce the GHG emission about 65Mt by 2020.

GHG emission that resulted from gas and electricity consumption has been calculated according to the emission factor provided for Ontario by the Environment Canada

website. The GHG intensity for electricity consumption of the year 2008 is 170 g CO₂ eq/kWh (Environment Canada, 2012), and the emission factor for gas consumption is 1,879 g CO₂ eq/m³ (180.3 g CO₂ eq /kWh^{XI}) (Environment Canada, 2012).

3.4.5 Developing Energy Performance Indicators

In order to improve the energy efficiency of the MURBs, it is necessary to understand the energy performance of similar buildings. To investigate the factors influence the energy consumption, quantitative variables, energy performance indicators (EPIs), are required to be developed to evaluate the effectiveness of existing energy managements with the MURBs. To derive the most meaningful EPIs for the energy benchmarking, the statistical correlation (R^2) between MURBs' overall energy, electricity, and gas consumption and their buildings' characteristics is investigated.

3.4.6 Ranking Distribution of Energy Performance Indicators

Attaching a numerical value to EPIs, turns them into benchmarks that demonstrate the past or current energy performance of buildings in terms of energy consumption. To describe the standard energy performance of the MURBs within the dataset, a percentile ranking method has been applied for the different selected metrics found in the previous section. The best case consumption benchmark for the dataset has been specified as a range of the 25th percentile and the lower quartile, while poor benchmarking is from the 75th and upper quartile of the dataset.

3.4.7 Potential Savings

The overall savings (cost and consumption) and environmental impacts of energy consumption of the dataset have been discussed in this section. For estimating the savings according to the EPI (ekWh/m²), the top performer has been defined as the building that shows the lowest consumption per square metre in each category (overall energy, base gas, heating gas, base electricity, heating/cooling electricity, etc. consumption). It means a building can be the top performer in terms of overall energy consumption while other

XI. Natural gas heating value is 10.42 ekWh/m³ (NRCan, 2009).

buildings are the top performers in each category. For example, building A is the top performer in annual energy consumption category; however, this building can still save energy by reducing annual electricity cooling-related consumption, annual gas base consumption, and annual gas heating-related consumption. The same method has been applied for the 25th percentile, 50th percentile, and 75th percentile.

The overall energy saving of a building and its associated cost and GHG emission reduction are achieved by adding the consumption, cost, and GHG emission reductions of the building's total gas consumption and total electricity consumption.

3.5 Water Benchmarking

Figure 3.2 is the flow chart of the breakdown step of water benchmarking methodology. More detail explanation of each step can be found in the following sections.

Figure 3.2. Overview of water benchmarking methodology

3.5.1 Data Screening: Water Consumption

On average, up to five years (2007 to 2011) of monthly water consumption data have been provided by TCHC and the City of Toronto in the Excel format. MURBs in the database are not equipped with sub-metering; and they are billed a flat rate for water. From available information on 107 MURBs, only the water information of 105 buildings was reliable enough to be employed for the benchmarking analysis. Also, from five years of provided billing data only one year, 2010, has been taken into account for the

benchmarking. Similar to Section 3.4.1 some data were excluded from the dataset due to the following criteria:

3. The reason for not including the other four years (2007, 2008, 2009, and 2011) of data into the analysis:
 - Not having the full four years of data throughout the dataset (inconsistency)
4. The reason for excluding those buildings having 2010 water information:
 - Too many missing months of data in a year
 - Drastically higher and lower water consumption than the remaining data (outliers)

3.5.2 Water Consumption Cost Calculation

Monthly water charges and consumptions (water and wastewater) of the dataset were provided originally. But for consistency in the analysis, costs have been recalculated according to 2012 water consumption price by the City of Toronto^{xii} (\$2.4897/m³) with the assumption that charges were paid before the due date (owing nothing from the previous month) (The City of Toronto, 2012).

3.5.3 Carbon Footprint Calculation of Water Use

There are direct and indirect links between water conservation, energy, and GHG savings. Direct energies, such as energy to heat the water, are those consumed by the end uses. Indirect energy is the energy consumed for treating and pumping the water and wastewater (Mass, 2009). Energy consumed by pumping, treating, heating the water, and steam generation (976 PJ/yr) can heat the entire Canadian residential sector. According to NRCan, the energy consumption for space heating was found to be 805 PJ/yr in 2006 (Mass, 2010).

In order to analyze the environmental impacts of the water use cycle in Ontario, the detailed calculations of GHG emissions of the water use cycle and achievable GHG emission savings from water conservations are discussed in this section.

xii. Wastewater disposal charges are excluded.

The following factors are beyond the scope of the project, and they are eliminated from the GHG emission calculations (Mass, 2009).

1. The energy and GHG savings from the wastewater treatment process, such as secondary wastewater treatment, have been excluded from the calculation.
2. The energy consumed for rainwater, grey-water and wastewater reuse treatment and pumping has not been considered.
3. The water distribution and wastewater collection pumping stations are not commonly equipped with individual flow meters. As a result the disaggregated energy consumption of individual stages in water treatment plants (WPTs), such as water pumping, treatment processes, etc. may not be easily achieved. Therefore, the energy intensity throughout the municipalities is based on averages.

Some assumptions that have been made for calculating the GHG emission reduction resulting from water conservations (that reduce water, wastewater, and hot water demand) in Ontario are as follows,

1. GHG emission savings are assumed to be a result of water conservation strategies that affect water, wastewater, and hot water demand.
2. All MURBs within the dataset use natural gas hot water systems.
3. The temperature rise has been assumed to be 55°C for Domestic Hot Water (DHW) systems in residential buildings (Cheng, 2002).
4. Half of the total saved water was assumed to be hot water.

The amount of energy being consumed within different components of the water use cycle (direct and indirect energy consumers) in Ontario is shown in Table 3.1.

Table 3.1. Energy intensities of water use cycle components (Mass, 2009)

Source of energy consumption	Energy intensity (ekWh/m ³ water)
Indirect energy (municipal pumping)	0.68 -1.1
Direct energy (hot water – electric)	73
Direct energy (hot water – natural gas)	103
Embedded chemical energy	0.01

The amount of energy being consumed within the water use cycle of buildings located in Ontario is calculated by using Equation 1, and the sample calculation is available in Appendix D.

$$\text{Energy Intensity (ekWh/m}^3 \text{ /yr water)} = A \text{ (m}^3\text{)} \times (1.11^{\text{XIII}}) \text{ kWh/m}^3 + A/2(\text{m}^3) [(1 \times 103)] \text{ kWh/m}^3 \quad (1)$$

where,

A = Annual water consumption (m³)

As is shown in Equation 2, by taking the emission factor from Table 3.2 and multiplying it by the calculated energy intensity (from Equation 1), total GHG emissions resulting from water use cycle can be calculated.

Table 3.2. GHG emission factors for water use cycle component within Canada and Province of Ontario (Environment Canada, 2008)

	Emission Factor	Transmission Factor	Water	Wastewater	Hot Water (gas)	Hot Water (Electric)
	gCO ₂ e/kWh		gCO ₂ e/m ³			
Canada	205	1.06	124	21	21514	15,869
Ontario	270	1.06	166	28	21514	20,881

$$\text{Total GHG (kgCO}_2\text{eq /yr)} = \text{Energy Intensity (equiv. kWh/m}^3 \text{ /yr water)} \times 270\text{gCO}_2\text{eq/kWh} \times 1\text{kg}/1000 \text{ g} \quad (2)$$

For calculating the GHG emission savings, Equation 3 is used.

$$\text{GHG Savings Calculation (kgCO}_2\text{eq /yr)} = A \text{ (m}^3\text{)} \times (166 + 28) \text{ g CO}_2\text{eq / m}^3 + (A/2 \times 1 \times 21,514) \text{ g CO}_2\text{eq / m}^3 \times 1\text{kg}/1000 \text{ g} \quad (3)$$

where,

A = Annual water consumption reduction (m³)

3.5.4 Developing Water Performance Indicators

In order to investigate how efficiently the MURBs consume water, different water performance indicators have been developed. Combinations of variables (usually expressed

XIII. Indirect Energy + Embedded Chemical Energy = 1.1 (ekWh/m³ water) + 0.01 (ekWh/m³ water)

as a ratio) that result in meaningful interpretation of water consumption within buildings are called water performance indicators (WPIs). An example of a WPI is the annual water consumption per square metre (CWWA, 2009).

In order to recommend the most meaningful and appropriate WPIs and benchmarks for the existing MURBs dataset, the relationships of different buildings and occupancy characteristics plus the outside weather temperature with water consumption have been tested using R^2 method.

The volumes of MURBs' water consumptions are provided in different units, such as litres, gallons, and cubic metres. However, for consistency, all units have been converted to cubic metres for this study.

3.5.5 Ranking Distribution of Water Performance Indicators

By attaching a numerical value to WPIs, they either turn into targets that can predict the future consumption or benchmarks that demonstrate the past or current performance of buildings in terms of water consumption (CWWA, 2009). Similar to section 3.4.6, to describe the best practice range or standard performance of the MURBs within the dataset in terms of water consumption, the percentile ranking method has been applied for the different selected metrics found in the previous section as the most meaningful WPI. And the benchmark ranges are as follows: best performer is from the top performer to the 25th percentile of the dataset, while poor performer range is from the 75th percentile to the worst performer of the dataset.

3.5.6 Potential Savings

The overall impact of dataset MURBs and the potential achievable savings have been investigated. For estimating the potential savings, the water consumptions, costs, and GHG emissions of all the MURBs within the dataset have been enhanced to the top performer, the 25th percentile, the 50th percentile, and 75th percentile level of the dataset.

3.6 Waste Benchmarking

Figure 3.2 is the flow chart of the breakdown step of water benchmarking methodology. More detailed explanation of each step can be found in the following sections.

Figure 3.3. Overview of solid waste generation benchmarking methodology

3.6.1 Data Screening: Solid Waste Generation

Waste information has been provided by TCHC and the City of Toronto in the Excel format. On average, up to three years (2009 to 2011) of monthly bills, including the volume of the solid waste, recycling, and cost have been provided. And an assumption has been made that all the MURBs are serviced by the City of Toronto (waste collection- curbside).

From available information on 107 MURBs by TCHC and the City, only the waste information of 99 buildings was reliable enough to be used for the benchmarking analysis. On the other hand, from three years of provided billing data only one year, 2010, has been taken into account for the benchmarking.

Some data were excluded from the dataset due to the following criteria:

1. Not having the full year of solid waste data for 2009 and/or 2011 of the buildings being excluded from the dataset.
2. Too many missing months of data in a year.
3. Drastically higher and lower generation of waste than the remaining data (outliers).

3.6.2 Solid Waste Generation and Cost Calculations

Monthly volume of solid waste data has been provided in the form of compacted, un-compacted and in some instances both compacted and un-compacted waste. For all calculations and analyses, all compacted wastes have been converted to un-compacted. The conversion rate for un-compacted solid waste is 2x the compacted amount (The City of Toronto, 2012). In the case of having a mix of both compacted and un-compacted waste, the total un-compacted (yd³) is calculated as follows:

$$\text{Total Un-compacted Solid Waste (yd}^3\text{)} = \text{Compacted (Yd}^3\text{)} \times 2 + \text{Un-compacted (Yd}^3\text{)} \quad (1)$$

In terms of cost analysis, for consistency in the analysis, the costs have been calculated according to 2011 multi-residential bulk collection rates provided by the City of Toronto for un-compacted wastes (The City of Toronto, 2011). The step by step annual solid

waste cost calculations are shown in the following equations. Also, the simple calculation can be found in Appendix E.

$$\text{Allowable Base Volume of Waste (Yd}^3\text{)} = 1.917 * \text{Total Number of Units in a MURB} \quad (2)$$

$$\text{Excess Solid Waste (Yd}^3\text{)} = \text{Total Solid Waste Generated (Yd}^3\text{)} - \text{Allowable Base Volume of Waste (Yd}^3\text{)} \quad (3)$$

$$\text{Base Allowable Fee} = \$191.30 \text{ per Unit/yr} - \$180 \text{ per/Unit (rebate)}$$

$$= \$ 6.30 \text{ Unit/yr} \quad (4)$$

$$\text{Excess Cost \$} = \$13.27 * \text{Excess Solid Waste(Yd}^3\text{)} \quad (5)$$

$$\text{Total Annual Cost \$} = \text{Base Allowable Fee (\$)} + \text{Excess Cost (\$)} \quad (6)$$

3.6.3 Carbon Footprint Calculation of Solid Waste Disposal

Since the major portion of GHG emission from landfills is methane (CH₄), therefore, for calculating the GHG emission associated with solid waste disposal on land (land fillings), CH₄ emissions are evaluated. Methane is the production of organic material degradation of waste under anaerobic condition (IPCC, 2000). As is shown below, an equation has been developed by Scholl Canyon to estimate the amount of CH₄ generated (IPCC, 2006).

$$Q_{T,x} = k M_x L_o e^{-k(T-x)} \quad (7)$$

where,

$Q_{T,x}$ = amount of CH₄ generated in the current year T, (kilotons CH₄/year)

X = the year of waste input

M_x = the amount of waste disposed of in year x, megatons (Mt)

K = CH₄ generation rate constant, /year

L_0 = CH₄ generation potential, kg CH₄/tone waste

T = current year

CH₄ generation rate constant (k), which is the first order rate at which methane is emitted after waste has been landfilled, was estimated to be 0.045 for the Province of Ontario (Environment Canada, 2010). The generation potential (L_0) is defined by Equation (2) (IPCC, 2006), in which the L_0 value varies range from 4.4 to 194 kg CH₄/tone of waste (Pelt, et al., 1998).

$$L_0 = \text{MCF} \times \text{DOC} \times \text{DOC}_f \times F \times (16/12) \times (1000 \text{ kg CH}_4 / \text{tCH}_4) \quad (11)$$

where,

L_0 = CH₄ generation potential (kg CH₄/tone waste)

MCF = CH₄ methane correction factor (fraction)^{xiv}

DOC = degradable organic carbon (tone carbon/tone waste)^{xv}

DOC_f = fraction DOC dissimilated^{xvi}

F = fraction of CH₄ in landfill gas^{xvii}

16/12 = stoichiometric factor (molecular weight ratio CH₄/C (ratio))

XIV. According to the Revised 1996 IPCC Guidelines, the methane correction factor (MCF) for managed landfill sites has a value of 1.0 (IPCC, 2006).

XV. DOC has been assumed 0.21 for the Province of Ontario for the period of 1990 to present.

XVI. DOC_f value of 0.6 was selected from a default range of 0.5 to 0.6 (IPCC, 2000).

XVII. The fraction (F) of CH₄ emitted from a landfill ranges from 0.4 to 0.6 and was assumed to be 0.5 (Environment Canada, 2010).

As is shown, L_0 is a function of degradable organic carbon (DOC). DOC results from the composition of waste. Provincial waste composition data have been used for calculating DOC or the biodegradable portion of MSW (equation (3)) (IPCC, 2006).

$$\text{DOC} = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D) \quad (12)$$

where,

A = fraction of Municipal Solid Waste (MSW) that is paper and textiles

B = fraction of MSW that is garden or park waste

C = fraction of MSW that is food waste

D = fraction of MSW that is wood or straw

Information from different sources such as NRCan and Statistics Canada has been gathered and used for calculating DOC for different provinces in Canada. For the period of 1990 to present, the DOC value of Ontario was found to be 0.21 (Environment Canada, 2010).

The L_0 (kg CH_4 / tone waste) of 84^{XVIII} can be obtained for Ontario by substituting $\text{MCF}=1$, $\text{DOC}_f = 0.6$, $\text{DOC} = 0.21$, and $F=0.5$ into equation (2). Thus, the amount of methane produced in the year (T), $Q_{T,x}$, can be found by substituting $L_0= 84$ (kg CH_4 /tone waste), $K= 0.045/\text{year}$, and $T=\text{current year}$ into equation (1). The simple calculation can be found in Appendix F.

3.6.4 Developing Solid Waste Performance Indicators

Monthly residential solid waste generated by households living in the selected MURBs has been collected by the City of Toronto and private companies; and the information (2010 raw data) was used for calculating the annual solid waste generated by

XVIII. 1% of discrepancy between the calculated value for L_0 and given value in the reference (Environment Canada, 2010) is due to the rounds ups.

each building. The coefficient of correlation, R^2 , was implemented to verify the degree to which one variable appears to explain the behaviour of another variable.

3.6.5 Ranking Distribution of Solid Waste Generation Performance Indicators

In order to describe the best practice range or standard performance of the MURBs in terms of disposal solid waste generation (DSWG), same as the water and energy sections, the percentile ranking has been applied for the selected metrics across the dataset. Amount of annual un-compacted solid wastes generation (excluding recycled waste) of individual buildings were normalized by the factors that showed the strongest relationship with DSWG. The 2010 dataset analysis is the basis for the establishment of the benchmarking ranges (top, typical, and poor performer ranges) and the corresponding intensity distribution.

3.6.6 Potential Savings

Similar to other section savings calculations, different levels of savings in terms of DSWG, cost and GHG emission reduction for annual solid waste generation according to the appropriate metric have been evaluated.

Chapter 4

Results and Discussions

4.1 Data Collection: Survey Results

Information on energy, water consumption, and waste generation in addition to main building characteristics such as building size, numbers of floors, total number of units, etc. for 107 MURBs in the GTA have been provided. The main building characteristics have been summarized in Table 4.1.

Table 4.1. Database Characteristics

Building Characteristics	Range	Distribution in Database	
Building Age	1952-2008	1952-1960	4%
		1961-1970	36%
		1971-1980	44%
		1981-1990	9%
		1991-2000	6%
		2001-2008	1%
Buildings Size (m ²)	4,877-41,806	4,000-12,000	23%
		12,001-20,000	40%
		20,001-28,000	28%
		28,001-36,000	6%
		36,001-44,000	2%
Number of Occupant	208-1497	200-460	22%
		461-720	37%
		721-980	29%
		981-1240	7%
		1241-1500	4%
Number of Floors	5-30	5- 10	22%
		11-15	31%
		16-20	31%
		21-25	10%
		26-30	6%
Number of Suites	61-520	50 -150	21%
		151-250	45%
		251-350	24%
		351-450	7%
		451-550	2%
Location	GTA		

Table 4.1 demonstrates the proportion of buildings in the dataset which fall into different categories of building size, age, etc. Table 4.1 shows that a large percentage of buildings were built between 1971 to 1980 and 1961 to 1970, 44% and 36% respectively. And the majority of the buildings (40%) within the range of 12,001 to 20,000 square metres

in terms of size. The largest portion of the MURBs population (37%) fell into the range of 461 to 720. Lastly, from Table 4.1, it is apparent that most of the buildings are between 11 to 20 stories high with 151 to 250 units.

The dataset contains buildings from both TCHC and some private sectors. Buildings with TCHC building ID are those provided by TCHC and those with PRV building ID are from buildings having private owners. Figure 4.1 shows unit density of each floor within the selected MURBs. It demonstrates the unit distribution per floor within the MURBs in the dataset, for which the range is found to be from 8.68 to 43.44 (units/floor), and the median is 15 units/floor. The higher the ratio of unit per floor means there are more units per floor, in which the number of the smaller units are greater.

Figure 4.2 shows how many people on average live in each unit. The number of people per unit varies from 1.81 to 5.55, and the median was found to be 3.23 capita/unit. For calculating the actual occupancy, the occupancy rates have been provided for the majority of MURBs and when not available the minimum TCHC vacancy rate (1.5%) has been used (vacancy rate range is from 1.5% to 1.7% (TCHC, 2010)). Actual occupancy has been calculated based on the maximum occupancy standard (maximum two people in each bedroom) (The City of Toronto, 2002).

$$\text{Actual Occupancy} = \text{Maximum Occupancy} * \text{Occupancy Rate} \quad (1)$$

Due to having the large number of buildings within the dataset, not all the building IDs can be seen on the graphs. Building ID TCHC54, which is not shown on Figure 4.1 due to having a large number of the bars (buildings) on a graph, has the highest number of units per floor, 43.44. This indicates that the building contains a large number of smaller units per floor. On the other hand, Figure 4.2 shows the average number of people living in a unit is 1.91 for building TCHC54. According to the City standard on allowable number of occupants per unit (maximum two per bedroom), it can be concluded that the majority of the units in TCHC54 are bachelor and/or one bedroom. Figure 4.3 shows the allocated living in m² for each person in a building. The range is from 17.54 to 40.44 m²/capita within the developed dataset, and the median is found to be 26.84 m²/capita. Also, the average size of household within the dataset has been found to be 83 m², which compares to the study done by NRCan (90 m²/household) is 8% lower (Natural Resources Canada, 2011).

Figure 4.1. Unit distribution per floor for MURBs dataset

Figure 4.2. Population distribution within units in MURBs

Figure 4.3. Population distribution(per square metre) within the MURBs

4.2 Energy Benchmarking

4.2.1 Developing Energy Performance Indicators

The weather normalized energy consumption of the year 2010 used for the regression analysis has been achieved based on PRISM analysis. The influence of outside weather temperature on the energy consumption of the MURBs has also been studied. HDD for the year 2010 has been calculated according to the best reference temperature estimated by PRISM software for each building within the dataset. Different reference temperatures are determined for each building by the PRISM model. Table 4.2 summarizes the relationships between overall energy consumption and the following key variables by using the R^2 method for the dataset.

Table 4.2. Regression analysis of MURBs' overall energy consumption and buildings characteristics

Overall Energy Consumption	R^2				
Annual Energy Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.02	0.07	0.01	0.00	0.01
Building size (m ²)	0.81	0.00	0.04	0.05	0.06
Number of Floor	0.54	0.00	0.02	0.00	0.03
Number of Units	0.51	0.01	0.00	0.02	0.04
Capita	0.73	0.00	0.07	0.02	0.00
Capita/m ²	0.08	0.00	0.00	0.00	0.00
Capita/unit	0.01	0.00	0.00	0.00	0.00
CDD	0.18	0.00	0.01	0.00	0.01
HDD	0.01	0.01	0.02	0.00	0.00

Building size and total number of occupants appear to have the strongest statistical relationship with the overall energy consumption. And the total number of floors (above grade) and apartment units show a moderate relationship to the overall energy consumption. The poor correlation between the outside weather temperature and the overall energy consumption is due to the fact that the energy consumption has already been weather normalized using the PRISM method. On this basis it is established that building size, total number of occupants, total number of apartment units and total number of above grade floors are the best basis for the benchmark. The correlation between annual energy consumption and building size and total number of occupants within the dataset are shown in Figure 4.4 and Figure 4.5 respectively.

Figure 4.4. Scatter-plot of annual energy consumption vs. building size within 106 MURBs dataset

From Figure 4.4, typical total energy consumption of MURBs in Toronto is found to be almost 332 kWh per square metre. From other studies done on energy performance of the residential sector in Canada, the energy intensities were found to be 232^{XIX} kWh/m² (CMHC, 2007), 213^{XX} kWh/m² (Finch, Burnett, & Knowles, 2009), and 279^{XXI} kWh/m² (Enermodal Engineering Ltd, 2001). As a comparison, the above-mentioned cases perform better than the studied dataset by 30%, 36%, and 16% respectively. Lower energy intensity of the study done by CMHC (2007) compares to our dataset is due to the fact that the buildings were well- insulated (CMHC buildings). In the study done by Finch et al.(2009), the selected buildings were located in British Columbia (BC). And since the weather in BC is warmer than Ontario, the energy consumption is lower too (compare to our dataset). And about half of the buildings in the study done by Enermodal Engineering Ltd. (2001) were electric heated, which are more efficient than gas heated building (our dataset).

The median energy benchmark (weather normalized) resulted from another study for multi-unit family buildings in New York City was found to be 417 (kWh/m²/yr) (The City

XIX . Study on all types of buildings with different regions of Canada. The energy has not been weather normalized.

XX. Study on mix of mid and high-rise residential buildings in British Columbia. The energy has not been weather normalized.

XXI . Study on high-rise residential buildings across Canada. The energy has not been weather normalized.

of New York, 2012), which is 20% higher than the energy intensity within the developed dataset.

Figure 4.5. Scatter-plot of annual energy consumption vs. total number of occupants within 106 dataset

From Figure 4.5, total energy consumed per person within MURBs in Toronto is estimated to be around 9000 kWh.

The detailed correlation assessment of MURBs' energy consumption, such as gas and electricity consumption with their buildings' characteristics and outside weather temperature have been shown in Table 4.3 and Table 4.4. Total gas consumption is the summation of base gas consumption and heating gas consumption. The relationships of individual total gas components mentioned above with building characteristics and outside weather temperature have been studied. The statistical correlation results, R^2 , are shown in Table 4.3.

Table 4.3. Regression analysis of MURBs' gas consumption and buildings characteristics

Gas Consumption	R ²				
Total Annual Gas Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.07	0.26	0.09	0.08	0.13
Building size (m ²)	0.69	0.00	0.01	0.06	0.03
Number of Floor	0.51	0.01	0.02	0.00	0.04
Number of Units	0.43	0.02	0.00	0.01	0.02
Capita	0.65	0.00	0.04	0.04	0.00
Capita/m ²	0.05	0.00	0.00	0.00	0.00
Capita/unit	0.02	0.00	0.00	0.00	0.00
CDD	0.02	0.00	0.02	0.00	0.00
HDD	0.02	0.00	0.02	0.00	0.00
Annual Base Gas Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.00	0.00	0.00	0.01	0.00
Building size (m ²)	0.40	0.00	0.01	0.01	0.00
Number of Floor	0.22	0.01	0.00	0.00	0.00
Number of Units	0.15	0.05	0.00	0.00	0.01
Capita	0.37	0.00	0.02	0.00	0.00
Capita/m ²	0.03	0.00	0.00	0.00	0.00
Capita/unit	0.06	0.00	0.00	0.00	0.00
CDD	0.18	0.44	0.34	0.30	0.43
HDD	0.28	0.55	0.40	0.45	0.58
Annual Gas Heating Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.08	0.24	0.14	0.11	0.14
Building size (m ²)	0.48	0.00	0.01	0.02	0.00
Number of Floor	0.45	0.01	0.02	0.00	0.04
Number of Units	0.32	0.01	0.00	0.00	0.00
Capita	0.49	0.00	0.03	0.02	0.00
Capita/m ²	0.02	0.00	0.00	0.00	0.00
Capita/unit	0.03	0.00	0.00	0.00	0.00
CDD	0.06	0.05	0.01	0.04	0.05
HDD	0.06	0.07	0.02	0.03	0.04

According to Table 4.3 the base gas consumption has fairly high correlation with HDD and CDD. The base gas consumption is mainly for domestic hot water use in buildings. And this high correlation shows that seasonality affects the hot water use. The correlations between base gas consumption and outside weather temperature (heating degree days) from the dataset are shown in Figure 4.6 and Figure 4.7 respectively.

Figure 4.6. Scatter-plot of per capita annual base gas consumption vs. total 2010 heating degree days within 106 MURBs dataset

Figure 4.7. Scatter-plot of per square metre annual base gas consumption vs. total 2010 heating degree days within 106 MURBs dataset

Figure 4.6 demonstrates as HDD increases, the weather gets colder, and the base gas consumption per person decreases. Therefore, the conclusion can be made that, as weather tends to get colder or in winter, people use less hot water or take fewer showers. And as a result, the base gas consumption per square metre decreases also, as is shown in Figure 4.7

The correlations between base gas consumption (per capita and per square metre) and outside weather temperature (cooling degree days) from the dataset are shown in Figure 4.8 and Figure 4.9 respectively.

Figure 4.8. Scatter-plot of annual base gas consumption vs. total 2010 cooling degree days within 106 MURBs dataset

Figure 4.9. Scatter-plot of annual base gas consumption vs. total 2010 cooling degree days within 106 MURBs dataset

Figure 4.8 and Figure 4.9 complete and prove the above mentioned conclusion. As is shown in Figure 4.8, when CDD increases, the weather gets warmer and the base gas consumption per person increases also. The conclusion can be derived that the warmer the weather gets the higher the demand for hot water gets (more hot water will be used per person, which is indicated in more frequent showers per person).

The correlations between heating gas consumption and building size and number of occupants are demonstrated in Figure 4.10 and 4.11 respectively.

Figure 4.10. Scatter-plot of annual heating gas consumption vs. building size within 106 MURBs dataset

According to Figure 4.10, on average about 166 ekWh gas is consumed to heat one square metre (or 1.75 m³ natural gas/ft²) in the dataset, which compares to the findings by Enbridge gas (1 natural gas/ft² for space heating in Toronto) is 43% higher. This shows that the dataset is pretty energy intensive when in terms of heating gas consumption (space heating).

Figure 4.11. Scatter-plot of annual heating gas consumption vs. number of occupants within 106 MURBs dataset

Also, from Figure 4.11 can be found that average gas consumption (heating purpose) per person is 4,568 ekWh.

Total electricity consumption is the summation of base electricity, cooling and heating electricity consumption. The relationship between individual total electricity consumption components mentioned above with building characteristics and outside weather temperature has been studied. The statistical correlation results, R^2 , are shown in Table 4.4.

Table 4.4. Regression analysis of MURBs' electricity consumption and buildings characteristics

Electricity Consumption	R^2				
Total Electricity Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.00	0.09	0.04	0.12	0.04
Building size (m ²)	0.74	0.00	0.09	0.05	0.05
Number of Floor	0.50	0.00	0.04	0.00	0.02
Number of Units	0.57	0.00	0.00	0.04	0.07
Capita	0.61	0.00	0.09	0.02	0.00
Capita/m ²	0.14	0.00	0.00	0.00	0.00
Capita/unit	0.00	0.00	0.00	0.00	0.00
Annual Base Electricity Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.00	0.10	0.04	0.12	0.04
Building size (m ²)	0.81	0.00	0.08	0.06	0.06
Number of Floor	0.53	0.00	0.09	0.00	0.02
Number of Units	0.60	0.00	0.03	0.04	0.07
Capita	0.66	0.00	0.08	0.02	0.00
Capita/m ²	0.15	0.00	0.00	0.00	0.00
Capita/unit	0.00	0.00	0.00	0.00	0.00
Annual Electric Heating Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.00	0.01	0.00	0.02	0.01
Building size (m ²)	0.08	0.00	0.01	0.00	0.00
Number of Floor	0.07	0.00	0.01	0.00	0.00
Number of Units	0.07	0.00	0.00	0.01	0.01
Capita	0.06	0.00	0.01	0.00	0.00
Capita/m ²	0.02	0.00	0.00	0.00	0.00
Capita/unit	0.01	0.00	0.00	0.00	0.00
Annual Electric Cooling Consumption	kWh	(kWh/m ²)	(kWh/unit)	(kWh/floors)	(kWh/capita)
Age	0.01	0.04	0.04	0.05	0.05
Building size (m ²)	0.18	0.00	0.00	0.00	0.00
Number of Floor	0.05	0.05	0.02	0.00	0.04
Number of Units	0.13	0.00	0.00	0.00	0.00
Capita	0.20	0.00	0.01	0.00	0.00
Capita/m ²	0.02	0.00	0.00	0.00	0.00
Capita/unit	0.01	0.00	0.00	0.00	0.00

No correlation has been found between electricity consumption and outside weather temperature. Therefore, the HDD and CDD sections are not available in Table 4.4. Almost no correlation has been found between heating electric consumption and the key building characteristics, because the heating systems of the MURBs within the dataset are

mainly gas fired. Base electricity consumption refers to the electricity consumed for lighting, home appliances and plug loads when neither heating nor cooling are required. The highest correlations have been found between base electricity consumption and square metre, total number of capita, total number of units, and total of number of above grade floors. Figure 4.12 and Figure 4.13 show the relationship between base electricity consumption and building size and number of people.

Figure 4.12. Scatter-plot of annual electricity consumption vs. building size within 106 MURBs dataset

Typical annual base electricity consumption per square metre for the dataset has been found to be 87.43 as is shown in Figure 4.12. Furthermore, as Figure 4.13 demonstrates, when the building size increases the base electricity consumption increases also (larger number of lights, appliances, etc.). From Figure 4.11, typical base electricity consumption per capita is found to be 2,277.

Figure 4.13. Scatter-plot of annual base electricity consumption vs. total number of occupants within 106 MURBs dataset

The most appropriate EPIs for the energy benchmarking, which have been recognized, are as follows: annual energy consumption normalized by square metre (kWh/m^2), by number of occupants (kWh/capita), by number of units (kWh/units), and number of floors (kWh/floor). The benchmark ranges and potential savings for performance indicators (kWh/units , kWh/floor) have been shown in Appendixes, F and G accordingly.

4.2.2 Ranking Distribution: Based on per Square Metre Energy Performance Indicator (kWh/m^2)

Ranking is performed for the dataset according to the chosen EPIs from the previous section. The overall NACs for each building, which is the summation of overall gas NAC and overall electricity consumption, have been normalized by the chosen factors and ranked from lowest to highest. Annual energy consumptions of individual MURBs are normalized with respect to a unit of floor area, in order to state the typical range for the sample population. The benchmarking ranges have been identified as is outlined in Table 4.5 and demonstrated in Figure 4.14.

Table 4.5. Energy benchmarking range (EPI-kWh/m^2) for the 106 MURBs dataset

Consumption Benchmark	Normalized Annual Energy Consumption (kWh/m^2)
Poor Performer	378 -580
Typical	295 -377
Top Performer	141 -294

The achieved benchmark is comparable to other studies. The annual energy consumption for gas-heated MURBs located in the GTA were found to be from 281 to 581 ekWh/m^2 (CMHC, 2005), which is within the energy consumption range found for the developed dataset. Also, another study done by CMHC on high-rise buildings in Canada showed that the average annual energy consumption was found to be 279 ekWh/m^2 , which is within the top performer range of the developed dataset (Enermodal Engineering Ltd, 2001). Similar energy analysis has been done on high-rise residential buildings in New York City; and the median energy consumption was found to be 417 ($\text{kWh/m}^2/\text{yr}$) (The City of New York, 2012), which is within the poor performer range of our dataset.

The individual benchmarking ranges of energy consumption, cost and GHG emission components of MURBs (per square metre) within the dataset have been summarized in Table 4.6. The gas heating energy consumption represents the energy used for space heating. The worst performer of the electric heating range is 81.8 ekWh/m^2 . The high heating related electricity consumption of this building is due to having an inefficient central space heating system (or the central heating space cannot provide enough heat) that makes occupants use other devices to compensate for the lack of space heating (improve indoor comfort). There are three buildings within the dataset that have relatively high electric cooling energy consumption within the dataset. It is expected for those high electric cooling demand MURBs to be equipped with central cooling systems or individual window AC for suites. Base gas consumption is more related to the domestic hot water system, gas appliances, and indoor pool water heating (Finch, Burnett, & Knowles, 2010). The worst performer of the base gas consumption range, 186.5 ekWh/m^2 , may have an inefficient domestic hot water system, leakages (fixtures, piping, etc.) or be the result of occupants' behaviour (use hot water carelessly).

Table 4.6. Range of annual energy consumption, cost, and GHG emission components (per square metre) of the MURBs within the dataset

	EPI (ekWh/m ²)- Range	EPI (ekWh/m ²)-Median
Base Electricity	23.5 - 136	79
Electric Heating	0.2 - 81.8	7
Electric Cooling	0.3 - 19.2	4
Total Electricity	25.3 - 183.7	90
Base Gas	14.7 - 186.5	69
Heating Gas	52.7- 463.9	181
Total Gas	93.4 - 441.4	246
Total Energy	141 - 580	337
	Cost (\$/m ²)- Range	Cost (\$/m ²)-Median
Base Electricity	2.28 - 13.24	7.68
Electric Heating	0.02- 7.94	0.65
Electric Cooling	0.03 - 1.86	0.35
Total Electricity	2.46 - 17.82	8.79
Base Gas	0.18 -2.24	0.83
Heating Gas	0.38 - 5.57	2.17
Total Gas	1.12 -5.57	2.98
Total Energy	3.13 -21.60	11.86
	GHG (kg Co ₂ /m ²)- Range	GHG (kg Co ₂ /m ²)- Median
Base Electricity	3.99 -23.21	13.46
Electric Heating	0.04 -13.1	1.13
Electric Cooling	0.05 -3.27	0.62
Total Electricity	4.31 -31.22	15.41
Base Gas	2.67 -33.92	12.56
Heating Gas	5.77 -58.55	32.86
Total Gas	16.99 -68.96	44.92
Total Energy	23.61 -88.51	60.76

The findings from the study done by CMHC (2005) on energy consumption of 34 MURBs showed that for the MURBs equipped with central AC, the total annual electricity consumption was 116 kWh/m² and for MURBs not having central AC system the total annual electricity consumption is 101 kWh/m². Both values for the total electricity consumption are within the benchmark range. For the developed dataset the detailed information of mechanical system of the MURBs has not been provided. Therefore, identifying MURBs equipped with the central AC system cannot be accurately done.

As is shown in Figure 4.14, worst performer of the dataset consumes four times as much energy as the best performer of the dataset.

Figure 4.14. Annual energy consumption (per square metre) benchmarks of 106 MURBs within the GTA, 2010

Figures 4.15, 4.16, and 4.17 demonstrate the energy consumption, cost, and GHG emission breakdown of the dataset.

Figure 4.15 shows energy consumption breakdown within the dataset. As is shown gas consumption (base- and heating gas) contributes to the large portion of the energy consumption, which has been shown in yellow and grey color respectively. And heating gas (gas being used for space heating) is responsible for the larger portion of the total gas consumption.

Figure 4.16 demonstrates the cost related to energy consumption components. The electricity cost is higher than gas. As a result in terms of cost, electricity contributes to the larger portion of the total energy cost. MURBs within the dataset are gas heated and central AC is not operated also. Therefore, base electricity contributes to the largest portion of the total electricity cost.

Energy consumption GHG emission breakdown of the MURBs in the dataset has been shown in Figure 4.17. Since gas emission factor is higher than electricity and gas consumption is higher than electricity consumption within the dataset, GHG emission resulted from gas consumption is higher than electricity consumption as is shown in Figure 4.17.

Figure 4.15. Annual energy consumption (absolute value) breakdown benchmarks of 106 MURBs within the GTA, 2010

Figure 4.16. Annual energy cost (absolute value) breakdown benchmarks of 106 MURBs within the GTA, 2010

Figure 4.17. Annual energy related GHG emission (absolute value) breakdown benchmarks of 106 MURBs within the GTA, 2010

4.2.3 Potential Savings

4.2.3.1 Energy

Total energy consumption and associated cost (based on 2012 price rate) for the 106 MURBs dataset are estimated to be 642,178,729 kWh (334 kWh/m²) and \$22,605,581 (\$12/m²) respectively. The GHG emission range within the MURBs dataset is between 208,478 and 2,609,187 kg/yr (23.6 – 88.5 kg/m²/yr).

The overall savings (per square metre) in terms of consumption, cost, and GHG emission for each percentile has been calculated and summarized in Table 4.9. The results showed that gas consumption has higher contribution (73%) to the overall energy consumption than electricity consumption (27%). Compared to another study done on high-rise residential buildings in BC, on average electricity is responsible for 49% of overall energy consumption while gas is 51% (results are based on a dataset of both electric- and gas-heated buildings) (Finch et al., 2010).

Table 4.7. Achievable savings based on overall energy consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Overall Energy Consumption	Annual Energy Consumption (kWh/m ²)		Annual Energy Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	334		\$12		59	
	Annual Energy Consumption Reduction (kWh/m ²)	Percentage Energy Consumption Reduction (%)	Annual Energy Cost Reduction (\$/m ²)	Percentage Energy Cost Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emissions Reduction (%)
Top Performer	264	79%	\$9	76%	47	79%
25 th Percentile	79	24%	\$2	20%	14	24%
50 th Percentile	41	12%	\$1	12%	7	12%
75 th Percentile	15	4%	\$1	6%	3	4%

First, by elevating the MURBs within the dataset to the top performer level annual energy consumption and GHG emissions, 79%, 76%, and 79% energy consumption, cost and GHG emission reduction respectively can be achieved. Second, by improving the dataset to the 25th percentile level annual energy consumption and GHG emissions, 24%, 20%, and 24% energy consumption, cost and GHG emission reduction correspondingly can be achieved. Third, by bringing the dataset to the 50th percentile level energy consumption and GHG emissions, 12%, 12%, and 12% energy consumption, cost reduction, and GHG emission

reduction respectively can be achieved. Lastly, energy consumption and GHG emission level can reach the 75th percentile level of the dataset, and 4%, 6%, and 4% water consumption, cost, and GHG emissions reduction, respectively, can be achieved.

4.2.3.2 Gas

Analysis shows that a larger portion of savings (up to 74%) can be accomplished from the reduction in total gas consumption rather than total electricity consumption (up to 26% savings can be achieved). Compared to another study done on high-rise residential buildings in BC, on average electricity is responsible for 49% of overall energy consumption while gas is 51% (results are based on a dataset of both electric- and gas- heated buildings) (Finch, Burnett, & Knowles, 2010). Different levels of total gas consumption savings within the dataset have been illustrated in Table 4.10.

Table 4.8. Achievable savings based on total gas consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Total Gas Consumption	Annual Gas Consumption (kWh/m ²)		Annual Gas Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	243		6.65		44	
	Annual Gas Consumption Reduction (kWh/m ²)	Percentage Gas Consumption Reduction (%)	Annual Gas Consumption Cost Reduction (\$/m ²)	Percentage Gas Cost Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emission Reduction (%)
Top Performer	197	81%	5.36	81%	36	81%
25 th Percentile	63	26%	1.70	26%	11	26%
50 th Percentile	30	12%	0.81	12%	5	12%
75 th Percentile	9	4%	0.24	4%	2	4%

Savings from gas heating energy consumption plays a major role in total gas consumption savings (72% from heating gas consumption and 28% from base gas consumption). Different levels of savings for base and heating gas consumption are shown in Table 4.11 and Table 4.12 respectively.

Table 4.9. Achievable savings based on base gas consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Base Gas Consumption	Annual Gas Consumption (kWh/m ²)		Annual Gas Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	67		0.80		12	
	Annual Gas Consumption Reduction (kWh/m ²)	Percentage Gas Consumption Reduction (%)	Annual Gas Cost Reduction (\$/m ²)	Percentage Gas Cost Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emission Reduction (%)
Top Performer	53	79%	0.63	79%	10	79%
25 th Percentile	19	28%	0.22	28%	3	28%
50 th Percentile	9	14%	0.11	14%	2	14%
75 th Percentile	4	5%	0.04	5%	1	5%

Table 4.10. Achievable savings based on heating gas consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Heating Gas Consumption	Annual Gas Consumption (kWh/m ²)		Annual Gas Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	177		4.83		32	
	Annual Gas Consumption Reduction (kWh/m ²)	Percentage Gas Consumption Reduction (%)	Annual Gas Cost Reduction (\$/m ²)	Percentage Gas Cost Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emission Reduction (%)
Top Performer	144	81%	3.92	81%	26	82%
25 th Percentile	44	25%	1.19	25%	8	25%
50 th Percentile	20	11%	0.55	11%	4	12%
75 th Percentile	5	3%	0.14	3%	1	3%

In conclusion, more savings can be achieved by implementing energy efficiency strategies into space heating system rather than improving the domestic hot water system (base gas).

4.2.3.3 Electricity

Total electricity consumption is the summation of base, heating and cooling electricity consumption. Different levels of total electricity consumption savings within the dataset are shown in Table 4.13.

Table 4.11. Achievable savings based on total electricity consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Total Electricity Consumption	Annual Electricity Consumption (kWh/m ²)		Annual Electricity Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	90.98		8.83		15.47	
	Annual Electricity Consumption Reduction (kWh/m ²)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Cost Reduction (\$/m ²)	Percentage Electricity Cost Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emission Reduction (%)
Top Performer	67.61	74%	6.56	74%	11.49	74%
25 th Percentile	16.84	19%	1.63	19%	2.86	19%
50 th Percentile	11.08	12%	1.07	12%	1.88	12%
75 th Percentile	6.03	7%	0.59	7%	1.03	7%

Among base-, heating-, and cooling- related electricity consumption, total electricity consumption components, the highest level of savings can be achieved through reducing base electricity consumption (savings up to 82% can be achieved). Different levels of savings for base, heating, and cooling electricity consumption within the dataset have been summarized in Table 4.14, Table 4.15, and Table 4.16.

Table 4.12. Achievable savings based on base electricity consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Base Electricity Consumption	Annual Electricity Consumption (kWh/m ²)		Annual Electricity Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	78		8		13	
	Annual Electricity Consumption Reduction (kWh/m ²)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Consumption Cost Reduction (\$/m ²)	Percentage Electricity Consumption Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage Electricity Consumption Reduction (%)
Top Performer	55	71%	5	71%	9	71%
25 th Percentile	10	12%	1	12%	2	12%
50 th Percentile	6	8%	1	8%	1	8%
75 th Percentile	2	3%	0	3%	0	3%

Table 4.13. Achievable savings based on heating electricity consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Heating Electricity Consumption	Annual Electricity Consumption (kWh/m ²)		Annual Electricity Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	9.64		0.93		1.64	
	Annual Electricity Consumption Reduction (kWh/m ²)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Consumption Cost Reduction (\$/m ²)	Percentage Electricity Consumption Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emission Reduction (%)
Top Performer	9.42	98%	0.91	98%	1.60	98%
25 th Percentile	5.82	60%	0.56	60%	0.99	60%
50 th Percentile	4.40	46%	0.43	46%	0.75	46%
75 th Percentile	3.36	35%	0.33	35%	0.57	35%

Table 4.14. Achievable savings based on cooling electricity consumption for each percentile (per square metre) within the 106 MURBs dataset, 2010

Cooling Electricity Consumption	Annual Electricity Consumption (kWh/m ²)		Annual Electricity Consumption Cost (\$/m ²)		Total GHG Emissions (kg/m ²)	
Existing Database	3.32		0.32		0.57	
	Annual Electricity Consumption Reduction (kWh/m ²)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Consumption Cost Reduction (\$/m ²)	Percentage Electricity Consumption Reduction (%)	GHG Emissions Reduction (kg/m ²)	Percentage GHG Emission Reduction (%)
Top Performer	3.04	91%	0.30	91%	0.52	91%
25 th Percentile	1.38	41%	0.13	41%	0.23	41%
50 th Percentile	0.78	24%	0.08	24%	0.13	24%
75 th Percentile	0.46	14%	0.05	14%	0.08	14%

The contributions of cooling and heating electricity consumption to total electricity consumption are 4% and 14% respectively.

4.2.4 Ranking Distribution: Based on per Person Energy Performance Indicator (kWh/capita)

In order to analyze the energy performance of a building fairly, the energy consumption has to be normalized to the different factors. For example, in a low-income building a larger number of people live in each suite than in luxury condominium. Comparing these two buildings according to the per square metre performance indicator masks the influence of occupants' behaviour, and does not demonstrate the true performance of the building. The low-income building may show higher energy consumption per square metre than the luxury building (due to having more people in smaller space). However, by analyzing their per capita energy consumption, it may appear that the luxury building is consuming more (people wasting energy more) than the low income building. Therefore, annual energy consumptions of individual MURBs are normalized by number of occupants, in order to state the typical range for the sample population. The benchmarking ranges have been shown in Figure 4.19 and listed in Table 4.17.

Table 4.15. Energy benchmarking range (EPI-kWh/capita) for the 106 MURBs dataset

Consumption Benchmark	Normalized Annual Energy Consumption (kWh/Capita)
Poor Performer	10,031 -15,282
Typical	7,559 -10,030
Top Performer	3333 -7,558

The median and benchmark ranges (per capita) for normalized annual energy consumption, cost and GHG emission components are outlined in Table 4.18.

Table 4.16. Range of annual energy consumption, cost, and GHG emission components (per capita) of the MURBs within the dataset

	EPI (ekWh/capita) - Range	EPI (ekWh/capita) - Median
Base Electricity	474.4 - 3,854.7	2153
Electric Heating	5.4 - 2,368.6	169
Electric Cooling	8.8 - 511.2	89
Total Electricity	506.6 - 5,096.1	2426
Base Gas	416.1- 4,346.3	1766
Heating Gas	918.1 - 8,581.0	4883
Total Gas	2321.5 - 11,613.0	6599
Total Energy	3333.01 -15,281.72	9118
	Cost (\$/Capita)- Range	Cost (\$/Capita)-Median
Base Electricity	46.02 -373.90	209
Electric Heating	0.52 -229.75	16
Electric Cooling	0.85 - 49.59	9
Total Electricity	49.14 - 494.32	235
Base Gas	4.99 -52.16	21
Heating Gas	11.02 -102.97	58
Total Gas	27.86 -139.36	80
Total Energy	68.05 -549.49	316
	GHG (kg Co₂ /Capita)- Range	GHG (kg Co₂ /Capita)- Median
Base Electricity	80.65 -655.29	366
Electric Heating	0.91 -402.66	29
Electric Cooling	1.50 -86.90	15
Total Electricity	435.59 -2,736.09	412
Base Gas	75.69 -790.60	321
Heating Gas	167.01 -1,560.88	888
Total Gas	422.28 -2,112.40	1204
Total Energy	435.59 -2,736.09	1625

Figure 4.19 shows that the worst performer building uses five times as much energy (per capita) as the best performer building in the dataset.

Figure 4.18. Annual energy consumption benchmarks of 106 MURBs within the GTA, 2010

4.2.5 Potential Savings

4.2.5.1 Energy

The overall savings (cost and consumption) and environmental impacts of energy consumption per capita for each percentile within the dataset has been demonstrated in Table 4.19.

Table 4.17. Achievable savings based on overall energy consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Overall Energy Consumption	Annual Energy Consumption (ekWh/capita)		Annual Energy Consumption Cost (\$/capita)		Total GHG Emissions (kg/capita)	
Existing Database	8,809		310		1,569	
	Annual Energy Consumption Reduction (ekWh/capita)	Percentage Energy Consumption Reduction (%)	Annual Energy Cost Reduction (\$/capita)	Percentage Energy Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG Emission Reduction (%)
Top Performer	7,016	80%	248	80%	1,253	80%
25 th Percentile	2,275	26%	78	25%	407	26%
50 th Percentile	1,124	13%	41	13%	201	13%
75 th Percentile	484	5%	23	7%	86	5%

First, by elevating the MURBs within the dataset to the top performer level, annual energy consumption and GHG emissions, 80%, 80%, and 80% energy consumption, cost and GHG emission reduction respectively can be achieved. Second, by improving the dataset to the 25th percentile level, annual energy consumption and GHG emissions, 26%, 25%, and 26% energy consumption, cost and GHG emission reduction correspondingly can be achieved. Third, by bringing the dataset to the 50th percentile level, energy consumption and GHG emissions, 13%, 13%, and 13% energy consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if the 106 MURBs' energy consumption and GHG emission level can reach the 75th percentile level of the dataset, 5%, 7%, and 5% water consumption, cost, and GHG emissions reduction respectively can be achieved.

4.2.5.2 Gas

Different levels of savings according to the per capita performance indicator have been calculated for total gas consumption within the dataset of 106 MURBs. The summary of the results is shown in Table 4.20.

Table 4.18 Achievable savings based on total gas consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Total Gas Consumption	Annual Gas Consumption (kWh/capita)		Annual Gas Consumption Cost (\$/capita)		Total GHG Emissions (kg/capita)	
Existing Database	6,409		\$175		1,161	
	Annual Gas Consumption Reduction (kWh/capita)	Percentage Gas Consumption Reduction (%)	Annual Gas Cost Reduction (\$/capita)	Percentage Gas Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	5,089	79%	\$139	79%	926	80%
25th Percentile	1,684	26%	\$46	26%	306	26%
50th Percentile	805	13%	\$22	13%	146	13%
75th Percentile	284	4%	\$8	4%	52	4%

Different levels of savings for total gas consumption components, base and heating gas consumption have been shown in Table 4.21 and Table 4.22 respectively.

Table 4.19. Achievable savings based on base gas consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Base Gas Consumption	Annual Gas Consumption (ekWh/capita)		Annual Gas Consumption Cost (\$/capita)		Total GHG Emissions (kg/capita)	
Existing Database	1,761		\$48		320	
	Annual Gas Consumption Reduction (ekWh/capita)	Percentage Gas Consumption Reduction (%)	Annual Gas Cost Reduction (\$/capita)	Percentage Gas Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	1,367	78%	\$37	78%	249	78%
25th Percentile	450	26%	\$12	26%	82	26%
50th Percentile	267	15%	\$7	15%	49	15%
75th Percentile	111	6%	\$3	6%	20	6%

Table 4.20. Achievable savings based on heating gas consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Heating Gas Consumption	Annual Gas Consumption (kWh/capita)		Annual Gas Consumption Cost (\$/capita)		Total GHG Emissions (kg/capita)	
Existing Database	67		\$127		12	
	Annual Gas Consumption Reduction (kWh/capita)	Percentage Gas Consumption Reduction (%)	Annual Gas Cost Reduction (\$/capita)	Percentage Gas Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	53	79%	\$101	80%	10	79%
25th Percentile	19	28%	\$34	26%	3	28%
50th Percentile	9	14%	\$15	12%	2	14%
75th Percentile	4	5%	\$5	4%	1	5%

4.2.5.3 Electricity

As mentioned in section 4.3.2.3, the total electricity saving per capita is the summation of the savings that can be achieved from base-, heating-, and cooling- electricity consumption per capita. Savings per percentiles for total, base, heating, cooling electricity

consumption have been listed respectively in Table 4.23, Table 4.24, Table 4.25, and Table 4.26.

Table 4.21. Achievable savings based on total electricity consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Total Electricity Consumption	Annual Electricity Consumption (kWh/capita)		Annual Electricity Consumption Cost		Total GHG Emissions (kg/capita)	
Existing Database	2,400		233		408	
	Annual Electricity Consumption Reduction (kWh/capita)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Cost Reduction (\$/capita)	Percentage Electricity Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	1,927	80%	187	80%	328	80%
25th Percentile	591	25%	57	25%	100	25%
50th Percentile	319	13%	31	13%	54	13%
75th Percentile	200	8%	19	8%	34	8%

Table 4.22. Achievable savings based on base electricity consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Base Electricity Consumption	Annual Electricity Consumption (kWh/capita)		Annual Electricity Consumption Cost		Total GHG Emissions (kg/capita)	
Existing Database	2,058		200		350	
	Annual Electricity Consumption Reduction (kWh/capita)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Cost Reduction (\$/capita)	Percentage Electricity Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	1,598	78%	155	78%	272	78%
25th Percentile	393	19%	38	19%	67	19%
50th Percentile	173	8%	17	8%	29	8%
75th Percentile	92	4%	9	4%	16	4%

Savings up to 1,598 kWh, \$155, and 272 kg per capita for base electricity consumption can be achieved by improving the whole dataset energy consumption, cost, and GHG emission level to the energy consumption, cost, and GHG emission level of the top performer dataset.

Table 4.23. Achievable savings heating electricity consumption for each percentile (per capita) within the 106 MURBs dataset, 2010

Heating Electricity Consumption	Annual Electricity Consumption (kWh/capita)		Annual Electricity Consumption Cost		Total GHG Emissions (kg/capita)	
Existing Database	254		25		43	
	Annual Electricity Consumption Reduction (kWh/capita)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Cost Reduction (\$/capita)	Percentage Electricity Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	249	98%	24	98%	42	98%
25 th Percentile	160	63%	15	63%	27	63%
50 th Percentile	123	48%	12	48%	21	48%
75 th Percentile	94	37%	9	37%	16	37%

As explained in Section 4.3.2.3 also, savings from heating and cooling related electricity consumptions do not have a significant influence on overall electricity savings as is shown in Table 4.25 and Table 4.26 respectively.

Table 4.24. Achievable savings cooling electricity consumption for each percentile per (per capita) within the 106 MURBs dataset, 2010

Cooling Electricity Consumption	Annual Electricity Consumption (kWh/capita)		Annual Electricity Consumption Cost		Total GHG Emissions (kg/capita)	
Existing Database	88		9		15	
	Annual Electricity Consumption Reduction (kWh/capita)	Percentage Electricity Consumption Reduction (%)	Annual Electricity Cost Reduction (\$/capita)	Percentage Electricity Cost Reduction (%)	GHG Emissions Reduction (kg/capita)	Percentage GHG emission Reduction (%)
Top Performer	80	92%	8	92%	14	92%
25 th Percentile	38	44%	4	44%	6	44%
50 th Percentile	23	26%	2	26%	4	26%
75 th Percentile	13	15%	1	15%	2	15%

4.3 Water Benchmarking

4.3.1 Developing Water Performance Indicators

Table 4.28 is the summary of the relationship between annual water consumption and the following key variables by using the R^2 method.

Table 4.25. Regression analysis of MURBs annual water consumption and buildings characteristics

	R ²				
Annual Water Consumption	m ³	(m ³ /m ²)	(m ³ /unit)	(m ³ /floors)	(m ³ /capita)
Age	0.02	0.00	0.00	0.00	0.00
Building size (m ²)	0.66	0.00	0.04	0.05	0.05
Number of Floor	0.33	0.00	0.00	0.06	0.03
Number of Units	0.37	0.01	0.03	0.00	0.01
Capita	0.66	0.02	0.09	0.06	0.01
Capita/m ²	0.01	0.13	0.02	0.00	0.11
Capita/unit	0.06	0.10	0.47	0.06	0.00
CDD	0.02	0.00	0.00	0.01	0.02
HDD	0.02	0.00	0.00	0.01	0.01

Buildings size and total number of occupants appear to have the strongest statistical relationship with annual water consumption. And the total number of apartment units and total number of floors (above grade) show a moderate relationship to annual water consumption. The correlation between outside weather temperature and water consumption has been studied but it is found to be very unreliable. On this basis it was established that building size, total number of occupants, total number of apartment units and total number of above grade floors are the best basis for the benchmark. The correlation between annual water consumption and building size and total number of occupants within the dataset are shown in Figure 4.20 and Figure 4.21 respectively.

Figure 4.19. Scatter-plot of annual water consumption vs. building size within 105 MURBs dataset

Figure 4.20. Scatter-plot of annual water consumption vs. total number of occupants within 105 MURBs dataset

From Figure 4.20 and Figure 4.21, the typical living area (in metre) per person in MURBs has been estimated to be 27.42. The most appropriate performance indicators for the benchmarking, which have been recognized, are as follows, annual water consumption normalized by square metre (m^3/m^2), by number of occupants (m^3/capita), by number of units (m^3/units), and number of floors (m^3/floor).

4.3.2 Ranking Distribution: Based on per Square Metre Water Performance Indicator (m^3/m^2)

Annual water consumption of individual MURBs has been normalized with respect to a unit of floor area, in order to state the typical range for the sample population. The benchmark ranges (per square metre) are outlined in Table 4.29 and demonstrated in Figure 4.22 for the sample dataset. The worst performer of the dataset consumes 4 times as much water (per square metre) as the best performer.

Table 4.26. Water benchmarking range (m^3/m^2) for the 105 MURBs dataset

Consumption Benchmark	Normalized Annual Water Consumption (m^3/m^2)
Poor Performer	3.07 -4.19
Typical	2.16 -3.07
Top Performer	1.06 -2.16

Figure 4.21. Annual water consumption benchmarks (per square metre) of 105 MURBs within the GTA, 2010

The accomplished benchmark range is comparable to some of the studies done in Canada. From the water audit done on 88 buildings owned by the Ontario Housing Corporation (OHC), the average annual water consumption was found to be $1.91 \text{ m}^3/\text{m}^2$ (Enermodal Engineering Limited, 2007). Also, from another study done by CMHC on apartment buildings (HiSTAR database), the average annual water consumption of $1.85 \text{ m}^3/\text{m}^2$ was found. Both above mentioned benchmarks are within the top performer range of the developed benchmark (Enermodal Engineering Ltd, 2000).

4.3.3 Potential Savings

Total water consumption and associated cost (based on 2012 price rate) for the 105 MURBs dataset are estimated to be $5,102,089 \text{ m}^3$ ($2.62 \text{ m}^3/\text{m}^2$) and $\$12,721,671$ ($\$6.54/\text{m}^2$) respectively. The GHG emission range within the MURBs dataset is between 139,470 and 1,497,306 kg/yr ($15.03 - 59 \text{ kg}/\text{m}^2/\text{yr}$). The total GHG emission resulting from water use cycle of the 105 MURBs dataset in 2010 is estimated to be 71,582,047 kg ($37.29 \text{ kg}/\text{m}^2$). The overall savings (cost and consumption) and environmental impacts of water consumption per square metre have been discussed in this section. Table 4.30 shows different levels of savings per square metre when the dataset' consumption level is enhanced to each percentile level.

Table 4.27. Achievable savings based on total water consumption for each percentile (per square metre) within the 105 MURBs dataset, 2010

	Total Water Consumption (m^3/m^2)		Total Water Consumption Cost ($\$/\text{m}^2$)		Total GHG emissions (kg/m^2)	
Existing Database	2.62		6.54		37.29	
	Total Water Consumption Reduction (m^3/m^2)	Percentage Water Consumption Reduction (%)	Cost reduction ($\$/\text{m}^2$)	Percentage Water Consumption Cost Reduction (%)	GHG Emission Reduction (kg/m^2)	Percentage of GHG Emission Reduction (%)
Top Performer	1.57	60%	3.90	60%	17.16	46%
25 th Percentile	0.55	21%	1.36	21%	5.97	16%
50 th Percentile	0.30	12%	0.75	12%	3.31	9%
75 th Percentile	0.12	5%	0.30	5%	1.33	4%

First, by elevating the MURBs within the dataset to the top performer level, annual water consumption and GHG emissions, 60%, 60%, and 46% water consumption, cost and GHG emission reduction respectively can be achieved. Second, by improving the dataset to the 25th percentile level, annual water consumption and GHG emissions, 21%, 21%, and 16%

water consumption, cost and GHG emission reduction correspondingly can be achieved. Third, by bringing the dataset to the 50th percentile level, water consumption and GHG emissions, 12%, 12%, and 9% water consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if 105 dataset MURBs' water consumption and GHG emission level can reach the 75th percentile level, of the dataset, 5%, 5%, and 4% water consumption, cost, and GHG emissions reduction respectively can be achieved.

4.3.4 Ranking Distribution: Benchmarking Based on per Number of Occupants Water Performance Indicator (m³/capita)

The same as per square metre WPI, the annual water consumption per capita performance indicator has been identified as the most meaningful metric to be used for the benchmarking. As is shown in Figure 4.23, percentile ranking distribution has been performed within the dataset for the water consumptions. And corresponding benchmark ranges are summarized in Table 4.31. Figure 4.23 shows that the worst performer building uses five times as much water (per capita) as the best performer building in the dataset.

Table 4.28. Water benchmarking range (m³/capita) for the 105 MURBs dataset

Consumption Benchmark	Normalized Annual Water Consumption (m³/Capita)
Poor Performer	79 -124
Typical	58 -79
Top Performer	28 -58

Figure 4.22. Annual water consumption benchmarks (per capita) of 105 MURBs within the GTA, 2010

The 2006 Municipal Water and Waste Water Survey results showed that water consumption per person varies depending on the communities' sizes. People living in smaller communities tend to consume more water than those living in larger and more populated communities (Environment Canada, 2010). The benchmarking results are compared with the existing benchmarks in Canada In order to validate the outcome of the study. Environment Canada (2011) declares that the average residential water consumption was 225 liter per capita per day (82 m³/capita/yr) in 2009, which is 18% more than the total annual water consumption per capita of the developed dataset. The benchmarks from Environment Canada are within the poor performance range of the established dataset.

4.3.5 Potential Savings

The GHG emission range within the MURBs dataset is between 404 and 1,763.54 kg/capita/yr. The summary of estimated different level of savings per capita (by percentiles) can be found in Table 4.32.

Table 4.29. Achievable savings based on total water consumption for each percentile (per capita) for each percentile within the 105 MURBs dataset, 2010

	Total Water Consumption (m ³ /capita)		Total Water Consumption Cost (\$/capita)		Total GHG Emissions (kg/capita)	
Existing Database	70		174		994	
	Total Water Consumption Reduction (m ³ /capita)	Percentage Water Consumption Reduction (%)	Cost reduction (\$/capita)	Percentage Water Consumption Cost Reduction (%)	GHG Emission Reduction (kg/m ²)	Percentage of GHG Emission Reduction (%)
Top Performer	42	59%	103	59%	455	46%
25 th Percentile	15	21%	37	21%	162	16%
50 th Percentile	7	11%	19	11%	82	8%
75 th Percentile	3	5%	8	5%	37	4%

The estimated percentage of consumption, cost, and GHG emission savings are 59%, 59%, and 46% respectively when the water consumption and GHG emission level of the whole dataset improves to the top performer level of the dataset. And the percentage of savings (consumption, cost, and GHG emission) once the dataset consumption and GHG generation level elevate to the 25th percentile level of the dataset will be as follows; 21%, 21%, and 20% correspondingly. By bringing all the water consumption and GHG emission level of the whole dataset to the 50th percentile level for water consumption and GHG emissions, 10%, 10%, and 10% water consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if all water consumption and GHG emission

of the whole dataset reaches the 75th percentile level, 5%, 5%, and 5% water consumption, cost, and GHG emissions reduction can be achieved respectively.

4.3.6 Ranking Distribution: Benchmarking Based on per Number of Units Water Performance Indicator (m^3/unit)

Benchmarking the MURBs' water use according to the per apartment units performance indicator has been discussed in this section. As is shown in Figure 4.24, annual water consumptions of the dataset have been normalized by number of apartment units and a ranking distribution has been performed. Database water performances are categorized into three groups that have been shown in Table 4.33. Figure 4.24 shows that the worst performer building uses ten times as much water (per suite) as the best performer building in the dataset.

Table 4.30. Water benchmarking range (m^3/unit) for the 105 MURBs dataset

Consumption Benchmark	Normalized Annual Water Consumption (m^3/unit)
Poor Performer	255 -550
Typical	162 -255
Top Performer	56 -162

Figure 4.23. Annual water consumption benchmarks (per unit) of 105 MURBs within the GTA, 2010

According to a study done by CMHC on a sample of twenty one Canadian MURBs, the average annual water consumption was found to be 209 m³/unit/yr (CMHC, 2005), which is within the typical range of the developed dataset.

4.3.7 Potential Savings

In this section, water consumption, cost, and GHG emissions saving based on WPI- (m³/unit) are summarized in Table 4.34. The GHG emission range within the MURBs dataset is from 802 to 7,816 kg/unit/yr.

Table 4.31. Achievable Savings based on total water consumption for each percentile (per unit) for each percentile within the 105 MURBs dataset, 2010

	Total Water Consumption (m ³ /unit)		Annual Water Consumption Cost (\$/unit)		Total GHG emissions (kg/unit)	
Existing Database	217		540		3,080	
	Total Water Consumption Reduction (m ³ /unit)	Percentage Water Consumption Reduction (%)	Cost reduction (\$/unit)	Percentage Water Consumption Cost Reduction (%)	GHG Emission Reduction (kg/unit)	Percentage of GHG Emission Reduction (%)
Top Performer	160	74%	399	74%	1,756	57%
25 th Percentile	62	29%	155	29%	680	22%
50 th Percentile	36	16%	89	16%	391	13%
75 th Percentile	18	8%	45	8%	196	6%

When the dataset level (in terms of water consumption, cost, GHG emissions) is brought down to the top performance level of the dataset, 74%, 74%, and 57% water consumption, cost and GHG emissions reduction respectively can be achieved. Moreover, by improving the dataset MURBs' annual water consumption and GHG emission level to the 25th percentile level annual water consumption and GHG emissions, 29%, 29%, and 22% water consumption, cost and GHG emission reduction can be achieved respectively. Also, by bringing the entire water consumption and GHG emission level of the dataset to the 50th percentile level water consumption and GHG emissions, 16%, 16%, and 13% water consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if all water consumption and GHG emission of the whole dataset reached the 75th percentile level, 8%, 8%, and 6% water consumption, cost, and GHG emissions reduction could be achieved respectively.

4.3.8 Ranking Distribution: Benchmarking Based on per Number of Floors Water Performance Indicator (m^3/floor)

Annual water consumptions of individual MURBs are normalized with respect to number of floors, in order to state the typical benchmark range for the sample population. The following benchmarks are obtained and outlined in Table 4.35 and demonstrated in Figure 4.25. Figure 4.25 shows that the worst performer building uses almost seven times as much water (per floor) as the best performer building in the dataset.

Table 4.32. Water benchmarking range (m^3/floor) for the 105 MURBs dataset

Consumption Benchmark	Normalized Annual Water Consumption (m^3/floor)
Poor Performer	4,239 -6,655
Typical	2,392 -4,339
Top Performer	981-2,392

Figure 4.24. Annual water consumption benchmarks (per floor) of 105 MURBs within the GTA, 2010

4.3.9 Potential Savings

The GHG emission range within the MURBs dataset is from 13,940 to 94,532 kg/floor/yr. Savings have been calculated according to each percentile for water consumption per floor indicator. Different levels of savings, including consumption, cost, and GHG emission are summarized in Table 4.36.

Table 4.33. Achievable savings based on total water consumption for each percentile (per floor) for each percentile within the 105 MURBs dataset, 2010

	Total Water Consumption (m ³ /floor)		Total Water Consumption Cost (\$/floor)		Total GHG emissions (kg/floor)	
Existing Database	3,197		7,971		45,477	
	Total Water Consumption Reduction (m ³ /floor)	Percentage Water Consumption Reduction (%)	Cost reduction (\$/floor)	Percentage Water Consumption Cost Reduction (%)	GHG Emission Reduction (kg/floor)	Percentage of GHG Emission Reduction (%)
Top Performer	2,220	69%	5,528	69%	24,313	53%
25 th Percentile	938	29%	2,336	29%	10,273	23%
50 th Percentile	556	17%	1,385	17%	6,091	13%
75 th Percentile	179	6%	445	6%	1,957	4%

First, by bringing all the MURBs within the dataset (105 MURBs) to the top performer level, annual water consumption and GHG emissions, 69%, 69%, and 53% water consumption, cost and GHG emission reduction can be achieved respectively in a year. Second, by improving water consumption and GHG emission of all MURBs within dataset to the 25th percentile level, annual water consumption and GHG emissions, 29%, 29%, and 23% water consumption, cost and GHG emission reduction respectively can be achieved. Third, by bringing the water use and GHG emission of the MURBs to the 50th percentile level, water consumption and GHG emissions of the dataset, 17%, 17%, and 13% water consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if all water consumption and GHG emission of the whole dataset reached to the 75th percentile level, 6%, 6%, and 4% water consumption, cost, and GHG emissions reduction can be achieved respectively.

4.3.10 Gas and Water Consumption: The link

As is shown in Figure 4.26, Ontario is heavily reliant on natural gas (for steam production, gas fired boilers, etc.). In terms of hot water production, the largest portion of

the DHW systems uses natural gas as fuel. On the other hand, Figure 4.27 shows that the residential sector is the major hot water consumer compared to other sectors.

Figure 4.25. Water related energy used for different sectors in Ontario (Mass, 2010)

Figure 4.26. Fuel sources distribution for different water services in Ontario (Mass, 2010)

Implementing water conservation is more cost-effective than HVAC and/or envelope retrofit. If the correlation between gas and water consumption is found to be strong

enough, the conclusion can be derived that by applying water conservation measures, both water and gas (energy) savings can be achievable.

In this section the correlation between gas consumption (both total gas and base-gas) and water consumption has been studied. Total gas consumption refers to the summation of base gas consumption and heating gas consumption. Base gas consumption is the minimum amount of gas that is required for a building to operate. During the winter seasons, gas consumption refers to the summation of gas consumed both for space and water heating. But during the summer, the only usage of gas would be for DHW (no energy is required to heat the space). Therefore, base gas consumption can be interpreted as the amount of gas consumed for DHW system.

From a dataset of 105 MURBs, only 78 buildings were selected for this analysis. For consistency with the rest of the analysis, year 2010 has been taken into account for the analysis. Due to the reasons listed below, some of the data have been eliminated from the dataset for this analysis.

1. Electric-heated buildings are excluded
2. The reason for excluding those buildings having 2010 water information:
 - Too many missing months of data in a year.
 - Drastically higher and lower consumptions (gas and/or water) than the remaining data (outliers)

As is shown in Figure 4.28 and Figure 4.29, regression was applied to investigate the gas (both total gas and base-gas) and water consumption relationship with the dataset. Both total and base-gas consumptions were weather normalized using PRISM software.

Figure 4.27. Correlation between annual water and total gas consumption for 78 MURBs dataset

Figure 4.28. Correlation between annual water and base-gas consumption for 78 MURBs dataset

From Figure 4.23, the conclusion can be made that 71.68 kWh gas has to be consumed typically for one cubic metre of water. From the regression analysis, a stronger correlation was found between total annual gas consumption and annual water consumption ($R^2 = 0.67$) than annual base gas consumption.

The value achieved from the regression analysis ($Q = 71.68 \text{ ekWh}$) has been used for investigating the DHW efficiency of the MURBs. With knowing that the typical hot water to total water use ratio range is 40% -50% (Aguilar, Aguilar, & Ryan, 2005) and typical temperature raise varies (ΔT) is within the range of 50 to 55 °C (Cheng, 2002), boiler efficiency has been roughly estimated by using below formula.

$$Q = (\dot{m} C_p \Delta T) / \eta$$

Q = Energy (kJ)

$\dot{m}$ = Mass density of water (1kg/L)

C_p = Specific Heat (4.186 kJ/kg- °C)

ΔT = Rise temperature (55 °C)

η = Boiler efficiency

The summary of the results have been shown in Table 4.37. The boiler efficiency within the dataset has been estimated to be within 35% to 45% (poor).

Table 4.34. Domestic hot water system efficiency analysis for the dataset

Boiler efficiency	Estimated Hot water (L)- $\Delta T=45^\circ\text{C}$	Hot water(L) /Total water (1000L)	Estimated Hot water (L)- $\Delta T=50^\circ\text{C}$	Hot water(L) /Total water (1000L)	Estimated Hot water (L)- $\Delta T=55^\circ\text{C}$	Hot water(L) /Total water (1000L)
35%	480.15	0.48	432.14	0.43	392.85	0.39
40%	548.75	0.55	493.87	0.49	448.97	0.45
45%	617.34	0.62	555.61	0.56	505.10	0.51
50%	685.93	0.69	617.34	0.62	561.22	0.56
55%	754.53	0.75	679.07	0.68	617.34	0.62
60%	823.12	0.82	740.81	0.74	673.46	0.67
65%	891.71	0.89	802.54	0.80	729.58	0.73
70%	960.31	0.96	864.28	0.86	785.71	0.79
78%	1070.06	1.07	963.05	0.96	875.50	0.88

1.4 Solid Waste Benchmarking

4.4.1 Developing Solid Waste Performance Indicators

Table 4.38 is the summary of the relationship between annual solid waste generation and the following key variables, evaluated in terms of R^2 values.

Table 4.35. Relationship evaluation of annual solid waste and buildings characteristics

Annual Solid Waste Generation	R ²			
	yd ³	yd ³ /m ²	yd ³ /capita	yd ³ / unit
Age	0.02	0.05	0.04	0.05
Size (m ²)	0.15	0.14	0.03	0.06
No. Floor	0.12	0.05	0.04	0.05
No. Unit	0.22	0.04	0.00	0.12
No. Occupant	0.13	0.06	0.05	0.03
Capita per m ²	0.01	0.09	0.00	0.03
Capita per Unit	0.04	0.00	0.04	0.08

On this basis it was established that a total number of units form the best basis for the benchmark. The correlation between annual solid waste generation and total number of units within the dataset is graphed in Figure 4.30.

Figure 4.29. Annual solid waste generation vs. total number of units

The most appropriate benchmark was found to be solid waste generation per total number of units.

4.4.2 Ranking Distribution: Benchmarking Based on per Number of Unit Solid Waste Performance Indicator (yd³/unit)

Amount of annual un-compacted solid wastes generation per apartment unit performance indicator has been identified as the most meaningful metric to be used for the

benchmarking. Table 4.39 and Figure 4.31 demonstrate benchmark ranges and ranking distribution of the dataset. Figure 4.31 shows that the worst performer building generates eleven times as much solid waste (per floor) as the best performer building in the dataset.

Table 4.36. Solid waste benchmarking range (yd³/unit) for the 99 MURBs dataset

Consumption Benchmark	Normalized Solid Waste Generation (yd³/unit)
Poor Performer	9.29 - 17.4
Typical	4.62 - 9.29
Top Performer	1.58 - 4.62

Figure 4.30. Annual disposal solid waste generation benchmarks (per unit) of 99 MURBs within the GTA, 2010

Analysis of MURBs waste generation data resulted in a recommended Best Practice Range based on the percentile ranking. Based on the data and analysis, a Best Practice Range of 1.58 to 17.40 yd³/unit/yr was established. As is shown in Table 4.36, this range is comparable to the existing metrics audit done in Canada. From the solid waste generation audit done by Stewardship Ontario on ten MURBs in Toronto, the total amount of solid waste, including recycling waste, was found to be 776 kilograms per apartment unit (8.43 yd³/unit^{XXII}) (Bacopo Environmental Solutions Inc, 2007). This value is within the benchmark range but in the lowest median part of the range. That can be explained by the fact that the best practiced range has been developed for the total DSWG, for which recycling waste is not included the value 8.43 yd³/unit was found by Bacopo Environmental Solutions Inc (2007) represent the total solid waste (including recycling waste). Also, from the study done by the City of Toronto, the annual disposal solid waste generated by MURBs in Toronto was found to be 462 kilogram per unit (5.02 yd³/unit) (GENIVAR Consultants LP, 2010) and it was compared with the value found from the audit done by Stewardship Ontario in DSWG per unit of MURBs in Toronto within the period of 2005 to 2007, 602 kg /unit/yr (6.45 yd³/unit/yr). Both above mentioned benchmarks are within the highest median part of the developed benchmark range.

4.4.3 Potential Savings

Total solid waste generation and associated cost (based on 2011 price rate) for the 99 MURBs dataset are estimated to be 151,383 yd³ (6.68 yd³/unit) and \$1,622,040 (\$7.58/unit) respectively. The GHG emission range associated with solid waste disposal, landfill, within the MURBs dataset is between 80 and 1,091 kg/yr (1.3 - 6.1kg/unit/yr). The total GHG emission resulted from landfilling of the 105 MURBs' solid waste within the dataset is estimated to be 54,017 kg (2.38 kg/unit). Table 4.40, demonstrate the achievable different levels of savings for each percentile.

XXII. Conversion between cubic yards and kilogram of waste is as follows (Bacopo Environmental Solutions Inc, 2007): 1 yd³ = 92 kg of un-compacted waste. 1 yd³ = 210 kg of compacted waste.

Table 4.37. Achievable Savings based on total solid waste generation for each percentile (per floor) for each percentile within the 99 MURBs dataset, 2010

	Total Disposal Solid Waste Generation (yd ³ /unit)		Annual Total Disposal Solid Waste Generation Cost (\$/unit)		Total GHG emissions (kg/unit)	
Existing Database	6.68		71.58		2.38	
	Total Disposal Solid Waste Generation Reduction (yd ³ /unit)	Total Disposal Solid Waste Generation Reduction Percentage	Cost savings (\$/unit)	Total Disposal Solid Waste Cost Reduction Percentage	GHG savings (kg/unit)	Percentage of GHG emission reduction
Top Performer	5.22	78%	56.02	78%	1.83	77%
25 th Percentile	2.53	38%	28.45	40%	1.06	45%
50 th Percentile	1.13	17%	13.14	18%	0.40	17%
75 th Percentile	0.46	7%	5.50	8%	0.16	7%

First, by enhancing all the MURBs within the dataset (99 MURBs) to the top performer level DSWG and GHG emissions, 78%, 78%, and 77% disposal solid waste generation, cost and GHG emission reduction can be achieved respectively. Second, by improving all the dataset to the 25th percentile level, DSWG and GHG emissions, 38%, 40%, and 45% disposal solid waste generation, cost and GHG emission reduction can be achieved respectively. Third, by bringing all the dataset to the 50th percentile level DSWG, cost, and GHG emissions, 17%, 18%, 17% savings in disposal solid waste generation, cost reduction, and GHG emission can be achieved respectively. Lastly, if all DSWG, cost, and GHG emission of the whole dataset reached to the 75th percentile level of the dataset, 7%, 8%, 7% disposal solid waste generation, cost reduction, and GHG emission reduction can be achieved accordingly.

Chapter 5

5.1 Conclusion and Recommendation

5.1.1 Energy

The most appropriate energy performance indicators have been defined as follows; energy consumption per square metre (kWh/m²), energy consumption per number of occupants (kWh/capita), energy consumption per number of units (kWh/units), and energy consumption per number of floors (kWh/floor). Table 5.1 shows the breakdown energy consumption, cost and GHG emission (absolute values) of the dataset.

Table 5.1. Summary of overall energy consumption, cost, and GHG emission resulted by the 106 MURBs dataset

	Energy Consumption (ekWh/yr)- Range	Energy Consumption (ekWh/yr)-Median
Base Electricity	153,989 - 4,718,066	1,478,739
Electric Heating	3,370 -2,191,166	124,135
Electric Cooling	3,678 -311,149	66,107
Total Electricity	153,989 - 4,989,275	1,699,182
Base Gas	114,794 -3,685,997	1,179,385
Heating Gas	601,582 -8,281,214	3,225,420
Total Gas	930,730 - 10,204,898	4,253,120
Total Energy	1,250,715 -14,670,476	5,913,911
	Energy Cost (\$/yr)- Range	Energy Cost (\$/yr)-Median
Base Electricity	14,937 - 457,652	143,438
Electric Heating	327-212,543	12,041
Electric Cooling	357 - 30,181	6,412
Total Electricity	14,937 -483,960	164,821
Base Gas	1,377.53 - 44,231.96	14,152
Heating Gas	7,219 - 99,375	38,705
Total Gas	12,250 -122,458	51,037
Total Energy	34,543.58 - 600,134.08	214,709
	GHG (kg CO ₂)- Range	GHG (kg CO ₂)- Median
Base Electricity	26,178 - 802,071	251,386
Electric Heating	537-372,498	21,103
Electric Cooling	625 -52,895	11,238
Total Electricity	26,178 -848,177	288,861
Base Gas	20,881 -670,483	214,530
Heating Gas	109,428 -1,506,353	586,291
Total Gas	185,701 -1,856,271	773,643
Total Energy	208,478 -2,609,187	1,054,592

From the analysis, the conclusion was derived that between two fuel sources of energy, gas and electricity, in the MURBs dataset, gas consumption has the higher contribution (74%) to the overall energy consumption as is also shown in Figure 5.1, of which gas heating energy

consumption is responsible for 53% and base gas consumption is responsible 21% of total gas consumption. In terms of electricity related energy consumption, the largest portion of total electricity consumption comes from base electricity consumption.

Figure 5.1. Energy consumption breakdown of the dataset

In terms of cost, as is shown in Figure 5.2, electricity (base electricity) is responsible for the largest portion of the cost. Even though that gas consumption is responsible for the largest portion of the energy consumption, but in terms of cost, it is not the largest.

Figure 5.2. Energy cost breakdown of the dataset

GHG emission resulted from gas consumption (heating gas- and base gas- consumption) is higher than electricity as is demonstrated in Figure 5.3.

Figure 5.3. Energy related GHG emission breakdown of the dataset

Although reducing the overall gas consumption (improving heating system and/or domestic hot water system) may not lead into much of cost savings, it can have significant positive environmental impacts (reducing GHG emissions).

5.1.2 Water

The most appropriate water consumption performance indicators have been found to be as follows; water consumption per square metre (m^3/m^2), water consumption per number of occupants (m^3/capita), water consumption per number of units (m^3/units), and water consumption per number of floors (m^3/floor).

A relatively strong correlation is found between annual gas consumption and annual water consumption. The correlation between base gas and water consumption shows that on average 72 kWh gas has to be used for 1 m^3 water use in MURBs. Also, another outcome of the correlation is that MURBs DHW system efficiencies are low (35% -45%).

Fairly strong correlation has been found between base gas consumption and CDD, which shows hot water consumption correlates with outside weather temperature. The conclusion can be derived that the warmer the weather gets, the higher the demand for hot

water gets (more hot water will be used per person, which is indicated in more frequent showers per person).

5.1.3 Solid Waste

Solid waste generation per number of units (yd³/unit) has been found to be the most meaningful performance indicator, in which the total solid waste generation and associated cost (based on 2011 price rate) for the 99 MURBs dataset are estimated to be 151,383 yd³ and \$1,622,040 respectively. The total GHG emission resulting from landfilling of the 105 MURBs' solid waste generation within the dataset is estimated to be 54,017 kg.

5.2 Recommendations and Future Work

5.2.1 Energy

Artificial Neural Networks (ANN) is an application that has been widely used for different purposes such as modeling, prediction and optimization (Yalcintas, 2006). The ANN model is capable of predicting buildings 'energy consumption precisely and estimating energy savings after retrofits within 10% accuracy (Cohen A & Krarti, 1995). As a future extension of the energy part of the project, using the ANN model for predicting the energy consumption and cost savings of the selected buildings after retrofit is recommended.

Also it is recommended to investigate the most cost effective upgrade options in terms of energy efficiency and GHG emission for those energy intensive buildings using building energy simulation software. Information such as detailed information on the building mechanical system and building envelope is required.

5.2.2 Water

As a future extension of the water part of the project, a more detailed analysis of the relationship between gas and water consumption. The potential savings that can be achieved by implementing water conservations in MURBs is suggested.

5.2.3 Waste

It is recommended for future work that further investigations be undertaken on developing the most effective educational program for both occupants and staff in MURBs in order to make them fully engaged with the importance of waste diversion programs. The education can significantly help the system to reduce residential solid waste generation.

An Investigation on the most cost effective technologies and strategies that can contribute to GHG emissions reduction associated with land filling and making the best of GHG emissions (turn them into energy) is also recommended.

Appendices

The appendices have been drafted with the intention of providing a clear statement of the methodological approach, including equations used and assumptions made, for the benefit of readers looking for specific technical details or to replicate this study elsewhere for other contexts.

Appendix A

This benchmarking calculation prepared at the time when the information on only 19 buildings were provided for the analysis.

Benchmarking Calculation Description

The Current database for the Tower Renewal project consists of 19 eligible buildings. The energy consumption, water consumption and waste generation have been benchmarked for all buildings. This report explains the analysis used to achieve the following energy, water and waste benchmarking. Building Bldg1 is used as an example. A few numbers are slightly different from the formal report. This is due to the round-ups used in this calculation description.

The building characteristics of building Bldg1 is given below:

- Building ID: Bldg1
- Year Built: 1978
- Occupancy Type: N/A
- Gross Floor Area (m²): 28,986
- Number of Units: 228
- Number of Stories: 23

Top Performers

Energy

In this analysis, the top performer has been defined as the building that shows the lowest consumption per square metre in each category as listed in Table 1. A building can be the top performer in terms of overall energy consumption while other buildings are the top performers in each category. For example, building Bldg1 is the top performer in annual energy consumption category, however, this building can still save energy by reducing annual electricity cooling-related consumption, annual gas base consumption, and annual gas heating-related consumption.

Table 1: Top performing buildings and their consumptions based on 19 GTA apartment buildings

Consumption Indicators	Building ID	Annual Consumption
Annual Electricity Base Consumption	Bldg1	53.2 kWh/m ²
Annual Electricity Heating-related Consumption	5528	2.4 kWh/m ²
Annual Electricity Cooling-related Consumption ^{XXIII}	Bldg3	2.4 kWh/m ²
Annual Electricity Consumption	Bldg1	63.7 kWh/m ²
Annual Gas Base Consumption	5549	21.9 kWh/m ²
Annual Gas Heating-related Consumption	Bldg1	116 kWh/m ²
Annual Gas Consumption	Bldg1	188 kWh/m ²
Annual Gross Energy Consumption	Bldg1	252 kWh/m ²

Water

In this analysis, the top performer has been defined as the building that shows the lowest water consumption per square metre in the category as listed in Table 2.

Table 2: Top performing building and its consumption within 19 GTA apartment buildings

Water Consumption Indicator	Building ID	Annual Consumption
Annual Water Consumption	5549	1.90 m ³ /m ²

Waste

In this analysis, the top performer has been defined as the building that shows the lowest waste generation per number of units in the category as listed in Table 3.

Table 3: Top performing building and its generation within 19 GTA apartment buildings

XXIII Among the 19 buildings in the database, 13 of them show peak consumption in summer months. The extra energy use in the summer is considered as cooling-related consumption. The top performer of annual electricity cooling-related consumption is selected within the 13 buildings. The other six buildings don't show the demand for cooling-related electricity consumption; thus their consumption is zero.

Waste Generation Indicator	Building ID	Annual Generation
Annual Waste Generation	5549	1.89 yd ³ /unit

Energy Benchmarking

The following results are calculated using the PRInceton Scorekeeping Method (PRISM). PRISM normalizes the energy consumption by long-term weather. In Toronto, there are two types of energy consumption: 1) demand for cooling in the summer and heating in the winter (HC), and 2) demand for heating in the winter only (HO). PRISM can identify if the building is HC or HO based on the best fit between energy consumption and the weather (30 years Toronto weather data).

PRISM can automatically decide how much weight to assign to each data point, with the lowest weights going to the unusual and/or stray values. This is to make the best use of all data while minimizing the influence by a single bad data point. At the end of the calculation, all results have to pass the reliability test: $R^2 \geq 0.7$ and $CV\% \leq 0.07$. The reliability test ensures the estimate is sufficiently reliable.

Gas consumptions are converted from m³ to equivalent kWh. ^{1 m³ gas is equivalent to 10.3 kWh^{XXIV}}

Annual Electricity Base Consumption (kWh): 1,542,730 kWh

Annual Electricity Heating- related Consumption (kWh): 199,782 kWh

Annual Electricity Cooling- related Consumption (kWh): 105,292 kWh

Annual Electricity Consumption (kWh): 1,847,804 kWh

Annual Gas Base Consumption (m³): 202,391 m³ converted to kWh: $202,391 \text{ m}^3 \times 10.33 \text{ kWh/m}^3 = 2,090,699 \text{ kWh}$

Annual Gas Heating- related Consumption (m³): 325,733 m³, converted to kWh: $325,733 \text{ m}^3 \times 10.33 \text{ kWh/m}^3 = 3,364,822 \text{ kWh}$

Annual Gas Consumption (m³): 528,124 m³, converted to kWh: $528,124 \text{ m}^3 \times 10.33 \text{ kWh/m}^3 = 5,455,521 \text{ kWh}$

An energy consumption decrease was identified in building Bldg1 starting in May 2010. There have been 16 readings provided since then. PRISM requires at least 9 monthly readings for one year, and the missing readings cannot be two consecutive months. However, there are two different readings on one reading date, and three readings are not reliable possibly with inaccurate reading dates. Among the unchanged readings there is a two-month gap, which made it ineligible for PRISM analysis. Adjustment has been made for the four readings to meet the methodology requirement. Although the result based on adjusted readings passed the

^{XXIV} Source: Natural Resources Canada, retrieved on March 20, 2012 <http://oee.nrcan.gc.ca/publications/commercial/6299>

reliability tests, it is necessary to request more monthly readings to assess if the adjustments were made properly. The building owner should also provide information on building retrofit so that the researchers can identify if the energy decrease was due to retrofit, management change, or other hidden reasons.

Electricity

Electricity - Energy Performance Indicators (EPIs)

Annual Electricity Base Consumption by Square Metres (kWh/m²)

Annual Electricity Base Consumption (kWh)/Building Gross Area (m²) = 1,542,730 kWh/28,986 m² = 53.2 kWh/m²

Annual Electricity Heating-related Consumption by Square Metres (kWh/m²)

Annual Electricity Heating-related Consumption (kWh)/Building Gross Area (m²) = 199,782 kWh/28,986 m² = 6.9 kWh/m²

Annual Electricity Cooling-related Consumption by Square Metres (kWh/m²)

Annual Electricity Cooling-related Consumption (kWh)/Building Gross Area (m²) = 105,292 kWh/28,986 m² = 3.6 kWh/m²

Annual Electricity Consumption by Square Metres (kWh/m²)

Annual Electricity Consumption (kWh)/Building Gross Area (m²) = 1,847,804 kWh/28,986 m² = 63.7 kWh/m²

Saving Potential (SP %)

Annual Electricity Base Consumption Saving Potential (SP %)

(SP %) = (Annual Electricity Base Consumption of the Studied Building – Annual Electricity Base Consumption of the Top Performer)/Annual Electricity Base Consumption of the Studied Building × 100% = (53.2 kWh/m² – 53.2 kWh/m²)/53.2 kWh/m² × 100% = 0.0%

Building Bldg1 is the top performer in annual electricity base consumption category.

Annual Electricity Heating-related Consumption Saving Potential (SP %)

(SP %) = (Annual Electricity Heating-related Consumption of the Studied Building – Annual Electricity Heating-related Consumption of the Top Performer) /Annual Electricity Heating-related Consumption of the Studied Building × 100% = (6.9 kWh/m² – 1.6 kWh/m²)/6.9 kWh/m² × 100% = 76.8%

Annual Electricity Cooling-related Consumption Saving Potential (SP %)

(SP %) = (Annual Electricity Cooling-related Consumption of the Studied Building – Annual Electricity Cooling-related Consumption of the Top Performer) / Annual Electricity Cooling-related Consumption of the Studied Building × 100% = (3.6 kWh/m² – 2.4 kWh/m²) / 3.6 kWh/m² × 100% = 33.3%

Annual Electricity Consumption Saving Potential (SP %)

(SP %) = (Annual Electricity Consumption of the Studied Building – Annual Electricity Consumption of the Top Performer) / Annual Electricity Consumption of the Studied Building × 100% = (63.7 kWh/m² – 63.7 kWh/m²) / 63.7 kWh/m² × 100% = 0.0%

Building Bldg1 is the top performer in annual electricity consumption category.

Electricity - Saving Potential (\$ SP)

Estimated Electricity^{Rate (\$/kWh)}

Estimated electricity rate is derived from cost information of the most recent full year bills that are provided.

Building Bldg1 provided electricity bills from January 31, 2008 to October 3, 2011. The most recent full year bill is 2010 as listed in Table 2.

For reading on February 1, 2010, Electricity Rate = Total Invoice Cost/ Electricity Consumption (kWh) = \$16,338/165,812 kWh = 0.099 \$/kWh

Estimated Electricity Rate is the average of the monthly rates of the year = (0.099 + 0.100 + 0.086 + 0.106 + 0.108 + 0.094 + 0.090 + 0.084 + 0.081 + 0.094 + 0.106 + 0.104) / 12 = 0.096 \$/kWh

Table 4: Electricity rates calculation for building Bldg1

Meter Reading Date DD/MM/YYYY	Electricity Consumption (kWh)	Total Invoice Charge (\$)	Electricity Rates (\$/kWh)
01/02/2010	165,812	\$16,338	0.099
02/03/2010	168,402	\$16,846	0.100
30/03/2010	151,282	\$12,950	0.086
30/04/2010	184,278	\$19,528	0.106
31/05/2010	153,150	\$16,552	0.108
29/06/2010	133,850	\$12,618	0.094
29/07/2010	197,400	\$17,766	0.090

30/08/2010	184,278	\$15,466	0.084
28/09/2010	147,235	\$11,998	0.081
27/10/2010	139,500	\$13,166	0.094
29/11/2010	162,000	\$17,224	0.106
29/12/2010	154,500	\$16,096	0.104
Estimated Electricity Rate (\$/kWh)		0.096	

Annual Electricity Base Consumption Saving Potential (\$ SP)

(\$ SP) = (Annual Electricity Base Consumption of the Studied Building × Annual Electricity Base Consumption Saving Potential %) × Building Gross Area (m²) × Estimated Electricity Rate (\$/kWh) = 53.2 kWh/m² × 0.0% × 28,986 m² × 0.096 (\$/kWh) = \$0

Annual Electricity Heating-related Consumption Saving Potential (\$ SP)

(\$ SP) = (Annual Electricity Base Consumption of the Studied Building × Annual Electricity Base Consumption Saving Potential %) × Building Gross Area (m²) × Estimated Electricity Rate (\$/kWh) = 6.9 kWh/m² × 76.8% × 28,986 m² × 0.096 (\$/kWh) = \$14,746

Annual Electricity Cooling-related Consumption Saving Potential (\$ SP)

(\$ SP) = (Annual Electricity Cooling-related Consumption of the Studied Building × Annual Electricity Annual Cooling-related Saving Potential %) × Building Gross Area (m²) × Estimated Electricity Rate (\$/kWh) = 3.6 kWh/m² × 33.3% × 28,986 m² × 0.096 \$/kWh = \$3,336

Annual Electricity Consumption Saving Potential (\$ SP)

Annual Electricity Consumption Saving Potential is the sum of all saving potentials.

(\$ SP) = Electricity- Annual Base Consumption Saving Potential (\$) + Annual Heating-related Saving Potential (\$) + Annual Cooling-related Saving Potential (\$) = \$0 + \$14,746 + \$3,336 = \$18,082

Gas

Gas EPIs

Annual Gas Base Consumption by Square Metres (kWh/m²)

Annual Gas Base Consumption (kWh)/Building Gross Area (m²) = 2,084,627 kWh/28,986 m² = 72.1 kWh/ m²

Annual Gas Heating-related Consumption by Square Metres (kWh/m²)

Annual Gas Heating-related Consumption (kWh)/ Building Gross Area (m²) = 3,364,822 kWh /28,986 m² = 116 kWh/m²

Annual Gas Consumption by Square Metres (kWh/m²)

Annual Gas Consumption (kWh)/Building Gross Area (m²) = 5,455,521 kWh/28,986 m² = 188 kWh/m²

Gas Saving Potential (%)

Annual Gas Base Consumption Saving Potential (SP %)

(SP %) = (Annual Gas Base Consumption of the Studied Building – Annual Gas Base Consumption of the Top Performer)/Annual Gas Base Consumption of the Studied Building = (72.1 kWh/m² - 21.9 kWh/m²)/72.1 kWh/m² × 100% = 69.6%

Annual Gas Heating-related Consumption Saving Potential (SP %)

(SP %) = (Annual Gas Heating-related Consumption of the Studied Building – Annual Gas Heating-related Consumption of the Top Performer) /Annual Gas Heating- related Consumption of the Studied Building = (116 kWh/m² – 116 kWh/m²)/116 kWh/m² × 100% = 0%

Annual Gas Consumption Saving Potential (SP %)

(SP %) = (Annual Gas Consumption of the Studied Building – Annual Gas Consumption of the Top Performer)/Annual Gas Consumption of the Studied Building = (188 kWh/m² – 188 kWh/m²)/188 kWh/m² × 100% = 0%

Building Bldg1 is the top performer in annual gas base consumption.

Gas Saving Potential (\$)

Estimated Gas Rates (\$/m³)

Estimated gas rate is derived from cost information of the most recent full year bills that are provided.

Building Bldg1 provided gas bills from January 24, 2008 to October 18, 2011. The most recent year with full bills is 2010 as listed in Table 3.

For reading on March 23, 2010, Gas Rate = Total Invoice Cost (\$)/ Gas Consumption (m³)= \$40,337/71,172 = 0.57 \$/m³

However, the rates on 23/03/2010 and 16/04/2010 are significantly different from other months. Those two rates are excluded from calculating the average of the gas rate.

Estimated Gas Rate is the average of the monthly rates of the year = (0.28 + 0.25 + 0.27 + 0.29 + 0.28 + 0.28)/6 = 0.28 \$/m³

Table 5: Gas rates calculation for building Bldg1

Meter Reading Date DD/MM/YYYY	Gas Consumption (m³)	Total Invoice Charge (\$)	Gas Rates (\$/m³)
22/02/2010	97,686	N/A	N/A
23/03/2010	71,172	\$40,337	\$0.57
16/04/2010	104,987	\$39,095	\$0.37
12/05/2010	18,244	\$5,099	\$0.28
15/06/2010	N/A	N/A	N/A
12/07/2010	17,311	\$4,388	\$0.25
15/08/2010	18,467	\$5,049	\$0.27
12/09/2010	15,039	\$4,339	\$0.29
14/10/2010	18,895	N/A	N/A
11/16/2010	48,948	\$13,711	\$0.28
12/22/2010	64,885	\$18,101	\$0.28
Estimated Gas Rate* (\$/m³)	0.28		

*The gas unit used in Table 3 is m³ while gas consumption EPIs use kWh. There is unit conversion in the following saving potential (\$) calculations.

Annual Gas Base Consumption Saving Potential (\$ SP)

(\$ SP) = (Annual Gas Base Consumption of the Studied Building × Annual Gas Base Consumption Saving Potential %) × 1/(10.33 kWh/m³) × Building Gross Area (m²) × Estimated Gas Rate (\$/m³) = 72.1 kWh/m² × 69.6% × 1/(10.33 kWh/m³) × 28,986 m² × 0.28 \$/m³ = \$39,427

Annual Gas Heating-related Consumption Saving Potential (\$ SP)

(\$ SP) = (Annual Gas Heating-related Consumption of the Studied Building × Annual Gas Heating-related Consumption Saving Potential %) × Building Gross Area (m²) × 1/(10.33 kWh/m³) × Estimated Gas Rate (\$/m³) = 116 kWh/m² × 0% × 1/(10.33 kWh/m³) × 28,986 m² × 0.28 \$/m³ = \$0

Annual Gas Consumption Saving Potential (\$ SP)

(\$ SP) = Annual Gas Base Consumption Saving Potential (\$) + Annual Gas Heating-related Consumption Saving Potential (\$) = \$39,427 + \$0 = \$39,427

Annual Energy Consumption

Annual Energy Consumption (kWh/m²)

Annual Energy Consumption = Annual Electricity Consumption + Annual Gas Consumption = 63.7 kWh/m² + 188 kWh/m² = 252 kWh/m²

Saving Potential (SP %)

(SP %) = (Annual Energy Consumption of the Studied Building – Annual Energy Consumption of the Top Performer) / Annual Energy Consumption of the Studied Building = (252 kWh/m² – 252 kWh/m²) / 252 kWh/m² × 100% = 0.0%

Building Bldg1 is the top performer in annual energy base consumption category.

Saving Potential (\$ SP)

(\$ SP) = Annual Electricity Consumption Saving Potential (\$) + Annual Gas Consumption Saving Potential (\$) = \$18,082 + \$39,427 = \$57,509

Results Comparison

Vs. Median (Annual Energy Consumption (kWh/m²))

The Median of the database is 340 kWh/m².

Vs. Median = (Annual Energy Consumption of the Studied Building – Annual Energy Consumption of the Median) / Annual Energy Consumption of the Studied Building = (252 kWh/m² – 340 kWh/m²) / 252 kWh/m² = -35.0%

Building Bldg1 consumes 35.0% less energy than the median of the database.

Vs. Average (Annual Energy Consumption (kWh/m²))

The average of the database is 337 kWh/m².

Vs. Average = (Annual Energy Consumption of the Studied Building – Annual Energy Consumption of the Average) / Annual Energy Consumption of the Studied Building = (252 kWh/m² – 337 kWh/m²) / 252 kWh/m² = -33.7%

Building Bldg1 consumes 33.7% less energy than the average of the database.

Vs. Top Performer (Annual Energy Consumption (kWh/m²))

The top performer of the database is 252 kWh/m².

Vs. Top Performer = (Annual Energy Consumption of the Studied Building – Annual Energy Consumption of the Top Performer) / Annual Energy Consumption of the Studied Building = (252 kWh/m² – 252 kWh/m²) / 252 kWh/m² = 0%

Building Bldg1 is the top performer in annual (overall) energy consumption category.

Water Benchmarking

Three to four years of water bills have been provided for this benchmarking analysis.

Normalized Annual Water Consumption by Square Metres (NWC)

$$\text{NWC} = \text{WC}_{\text{SB}} / \text{GFA} \quad (1)$$

Where WC_{SB} = Average Annual Water Consumption of the Studied Building (m³)

GFA = Gross Floor Area of the Building (m²)

Table 6: Calculation for annual water consumption normalized by square meter

	Annual Water Consumption (m ³)	WC _{SB} (m ³)	NWC _{SB} (m ³ /m ²)
2008	62,871	64,053	64,053 m ³ /28,986 m ² = 2.21 m ³ /m ²
2009	68,553		
2010	60,734		

Saving Potential (SP %)

$$\text{SP \%} = (\text{NWC}_{\text{SB}} - \text{NWC}_{\text{TP}}) / \text{NWC}_{\text{SB}} \quad (2)$$

Where NWC_{SB} = Annual Water Consumption of the Studied Building (m³/m²)

NWC_{TP} = Annual Water Consumption of the Top Performer (m³/m²)

Table 7. Calculation for potential saving percentage for water consumption

$NWC_{SB} (m^3/m^2)$	$NWC_{TP} (m^3/m^2)$	(SP %)
2.21	1.90	$[(2.21-1.90)/2.21] \times 100 = 14.0\%$

Annual Water Consumption Saving Potential (\$ SP)

Potential cost saving calculation has been done according to the most recent year of the water consumption bill that has been provided. In this case, saving potentials has been estimated based on 2010 invoice payments. The potential savings for this part has been compared with the corresponding top performer of the category.

$$\text{\$ SP} = WCC_{SB} \times (\text{SP \%}) \quad (3)$$

Where WCC_{SB} = Annual Water Consumption Cost of the Studied Building

Table 8. Calculation for potential saving cost for water consumption

	$WCC_{SB} (\text{\$})$	(\\$ SP)
2010	131,796	$131,796 \times 14.0\% = \$18,452$

Results Comparison

Vs. Median (Annual Water Consumption (m^3/m^2))

The Median of the database is $2.86 m^3/m^2$.

Vs. Median = (Annual Water Consumption of the Studied Building – Annual Water Consumption of the Median) / Annual Water Consumption of the Studied Building = $(2.21 m^3/m^2 - 2.86 m^3/m^2) / 2.21 m^3/m^2 = -29.4\%$

Building Bldg1 consumes 29.4% less water than the median of the database.

Vs. Average (Annual Water Consumption (m^3/m^2))

The average of the database is $2.79 m^3/m^2$.

Vs. Average = (Annual Water Consumption of the of the Studied Building – Annual Water Consumption of the Average) / Annual Water Consumption of the Studied Building = $(2.21 m^3/m^2 - 2.79 m^3/m^2) / 2.21 m^3/m^2 = -26.2\%$

Building Bldg1 consumes 26.2% less water than the average of the database.

Vs. Top Performer (Annual Water Consumption (m^3/m^2))

The top performer of the database is $1.90 \text{ m}^3/\text{m}^2$.

Vs. Top Performer = (Annual Water Consumption of the Studied Building – Annual Water Consumption of the Top Performer)/Annual Water Consumption of the Studied Building = $(2.21 \text{ m}^3/\text{m}^2 - 1.90 \text{ m}^3/\text{m}^2)/2.21 \text{ m}^3/\text{m}^2 = 14.0 \%$

Building Bldg1 consumed 14.0 % more water than the top performer of the database.

Waste Benchmarking

One to two years of bills for solid waste generation have been provided for this benchmarking analysis. Since bills for 2010 have the best quality of data throughout the data-base, they have been used for waste benchmarking analysis.

Normalized Annual Waste Generated by Number of Units (NWG)

$$\text{NWG} = \text{WG}_{\text{SB}} / \text{number of units} \quad (4)$$

Where WG_{SB} = Annual Waste Generated (un-compacted) (yd^3)

Table 9: Calculation for waste generated normalized by number of units

	$\text{WG}_{\text{SB}} (\text{yd}^3)$	$\text{NWG} (\text{yd}^3/\text{unit})$
2010	2,240	$(2,240/228) = 9.82$

Saving potential (SP %)

$$\text{SP \%} = (\text{NWG}_{\text{SB}} - \text{NWG}_{\text{TP}}) / \text{NWG}_{\text{SB}} \quad (5)$$

Where NWG_{SB} = Normalized Waste Generated of the Studied Building (yd^3/unit)

NWG_{TP} = Normalized Waste Generated of the Top Performer (yd^3/unit)

Table 10: Calculation for potential saving percentage for waste generated

NWG _{SB} (yd ³ /unit)	NWG _{TP} (yd ³ /unit)	(SP %)
9.82	1.89	$[(9.82-1.89)/9.82]*100 = 80.8\%$

Saving Potential (\$ SP)

The potential cost saving calculation has been done according to the most recent year of the solid waste generation bill that has been provided. In this case, saving potentials have been estimated based on 2010 invoice payments. The potential savings for this part have been compared with the corresponding top performer of the category.

$$\text{\$ SP} = \text{WGC}_{\text{SB}} \times (\text{SP \%}) \quad (6)$$

Where WGC_{SB} = Annual Waste Generated Cost of the Studied Building

Table 11: Calculation for potential saving cost for waste generated

	WGC _{SB} (yd ³)	(\$ SP)
2010	A**	A** × 80.8%

**The waste generation cost for building Bldg 1 has been not provided.

Results Comparison

Vs. Median (Annual waste Generated (yd³/number of units))

The Median of the database is 3.09 yd³/unit.

Vs. Median = (Annual Waste Generated of the Studied Building – Annual Waste Generated of the Median) / Annual Waste Generated of the Studied Building = $(9.82 \text{ yd}^3/\text{unit} - 3.09 \text{ yd}^3/\text{unit}) / 9.82 \text{ yd}^3/\text{unit} = 68.5\%$

Building Bldg1 generates 68.5% more waste than the median of the database.

Vs. Average (Annual waste Generated (yd³/number of units))

The average of the database is 5.23 yd³/unit.

Vs. Average = (Annual Waste Generated of the Studied Building – Annual Waste Generated of the Average)/Annual Waste Generated of the Studied Building = $(9.82 \text{ yd}^3/\text{unit} - 5.23 \text{ yd}^3/\text{unit})/9.82 \text{ yd}^3/\text{unit} = 46.7\%$

Building Bldg1 generates 46.7% more waste than the average of the database.

Vs. Top Performer (Annual Waste Generated ($\text{yd}^3/\text{number of units}$))

The top performer of the database is $1.89 \text{ yd}^3/\text{unit}$.

Vs. Top Performer = (Annual Waste Generated of the Studied Building – Annual Waste Generated of the Top Performer)/Annual Waste Generated of the Studied Building = $(9.82 \text{ yd}^3/\text{unit} - 1.89 \text{ yd}^3/\text{unit})/9.82 \text{ yd}^3/\text{unit} = 80.8\%$

Building Bldg1 generates 80.8 % more waste than the top performer of the database.

As is shown in below, in order to inform the participant buildings' owners on their building's performance (in terms of energy, water, solid waste) compare to other similar buildings, Individual building performance assessment reports have been conducted.

The Building Performance Assessment provides analysis using benchmarked utility consumption of 52 buildings located in City of Toronto. All buildings meet the characteristics of the City's Tower Renewal program: the buildings are 8 stories or more and were built from 1945 to 1984.

Building ID:	3146	Year Built:	1971		
Gross Floor Area (m ²):	22633	# of Units:	278	# of Stories:	24

BUILDING PERFORMANCE ASSESSMENT

PERFORMANCE ANALYSIS^a

ENERGY ^b		Building ID	Saving Potential	
		3146 ^c	(%)	(\$) ^d
ELECTRICITY (kWh/m ²)	Annual Base Consumption	77.0 (53.2)	31%	\$51713
	Annual Heating-related Consumption	5.3 (0.2)	96%	\$11081
	Annual Cooling-related Consumption	1.1 (0.9)	18%	\$435
	Annual Electricity Consumption	83.4 (63.7)	26%	\$63229
GAS (kWh/m ²)	Annual Base Consumption	69 (21.9)	68%	\$38480
	Annual Heating-related Consumption	226 (85.0)	62%	\$116597
	Annual Gas Consumption	295 (141)	52%	\$155077
Annual Energy Consumption (kWh/m ²)		378	36%	\$218305

WATER	Building ID	Saving Potential	
	3146	(%)	(\$)
Annual Water Consumption (m ³ /m ²)	3.02	52%	\$69097

WASTE ^e	Building ID	Saving Potential	
	3146	(%)	(\$)
Annual Waste Generated (yd ³ /unit)	8.09	80%	\$27936

^aThis building is not eligible for Tower Renewal Project; thus it is not included in the benchmark database. The saving potential is estimated by comparing its performance with the top performer of Tower Renewal eligible buildings. The saving potential estimation is for reference use only and may not be available.

^b Energy benchmarks provided in this report are weather normalized.

^c In this analysis, the Top Performer has been defined as the building that shows the lowest consumption in each sub-category or category. A building can be the Top Performer overall while other buildings are the Top Performer in each sub-category. The number in parentheses is the Top Performer consumption amount for that sub-category.

^d Saving potential estimates are based on 2011 invoice payments.

^e This waste benchmark is based on the most recent year 2011 bill.

Appendix C

Data collection: sample survey

The below Microsoft Excel-based survey was developed originally by Ryerson group for the collection purpose.

This survey collects historical utility data as part of the Toronto Tower Renewal initiative on behalf of our partners, The City of Toronto, Canadian Mortgage and Housing Corporation, Ontario Ministry of Municipal Affairs and Housing, and Enbridge Inc. The result will provide in-depth understanding of the full cost of energy consumption and opportunities to improve energy efficiency. Suggestions of potential retrofits and investments will be made based on individual buildings, to reduce energy costs and Greenhouse Gas (GHG) emissions.

The data is being collected for research purposes only. Your information will be kept confidential.

Instructions:

1. This survey uses Microsoft Excel Macro. In order to enable the macro security, please click on "Option" security warning message bar on the top of the page and choose the "enable content" option and then click OK.
2. Please fill in the blanks according to your energy use. Items written and sheets specified in **red** are mandatory. Missing mandatory information may lead to inaccuracy in evaluation of building energy consumption.

This survey covers building information, building specification, waste, water, gas, gas commodity, electricity, steam, fuel, green power, and occupancy. Please ensure to go through the whole workbook.

3. Optional questions in **black** are designed to help us to better assess your building, which will be valuable as to provide you with potential retrofit and investment options.
4. **You are encouraged to provide with 1) blue print of the building and 2) original energy bills/file of three-five complete years. If you do so, you'll be exempted from the sections that are in green. This will save you significant amount of time while ensuring the data is accurate.** If you'd like to provide blue print and energy bills/files, please refer to the contacts.
6. If you have more than 2 accounts for any energy type, add a new worksheet for the appropriate energy type by copying the previous worksheet and renaming it.
7. Will you allow us to retrieve your energy bills from your utility provider? Please check below. (This is not a formal consent. If further information is required, we will contact you for your formal consent.)

☐ Yes, you may access to my billing information from my utility provider

☒ Not sure at the moment

☐ No. You can't retrieve billing information from my utility provider.

Please feel free to ask any questions about the research and your involvement with it, we will gladly respond.

Mahssa Ghajar	mghajark@ryerson.ca
Emily Y. Huang	yirong.huang@ryerson.ca
Work Phone:	416-979-5000 ext. 7833

Building Information			
Date of Completion (mm/dd/yyyy) <input type="text"/>			
Building Name			
Street No.		Postal Code	
Street Name			
Building Owner Company			
Property Management Company Name (if different than Building Owner Company Name)			
Person Completing Workbook		Property Manager Contact	
First Name		First Name	
Last Name		Last Name	
Title		Title	
Phone		Phone	
Email		Email	

Building Specifications																																																																					
Building Type (Please check all that applies)																																																																					
☐ Rental Apartment (Market rate) ☐ Condominium ☐ Social Housing (Non-profit or co-operative housing communities where some or all the rents are subsidized)																																																																					
*Do tenants pay their own hydro?																																																																					
☒ No, hydro is included in the rent. ☐ Yes, tenants pay their own hydro. ☐ Other (Please specify) <input type="text"/>																																																																					
<table border="1"> <thead> <tr> <th>Year Built</th> <th></th> </tr> </thead> <tbody> <tr> <td>Number of Stories</td> <td></td> </tr> <tr> <td>Total Floor Area</td> <td>Select Unit</td> </tr> <tr> <td>Total floor area that is common space only</td> <td>Select Unit</td> </tr> <tr> <td>Percent of the gross floor area that is heated</td> <td>Select</td> </tr> <tr> <td>Percent of the gross floor area that is cooled</td> <td>Select</td> </tr> <tr> <td>Building Orientation</td> <td>Select</td> </tr> <tr> <td>Underground Garage Floor Area</td> <td>Select Unit</td> </tr> <tr> <td>Number of Parking Levels</td> <td></td> </tr> </tbody> </table>										Year Built		Number of Stories		Total Floor Area	Select Unit	Total floor area that is common space only	Select Unit	Percent of the gross floor area that is heated	Select	Percent of the gross floor area that is cooled	Select	Building Orientation	Select	Underground Garage Floor Area	Select Unit	Number of Parking Levels																																											
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Mechanical System/Equipment and Operation

Operation

This information is very important. Please provide as much details as possible, define the oldest year as a Year 1 and the most recent Year as year 5.

No. of Year	Heating Season			Cooling Season (If Central AC is available)		
	Indoor Minimum Temperature Set	Heating Start Date MM/DD/YYYY	Heating End Date MM/DD/YYYY	Indoor Minimum Temperature Set	Cooling On Date MM/DD/YYYY	Cooling End Date MM/DD/YYYY
Year 1	Select unit			Select unit		
Year 2	Select unit			Select unit		
Year 3	Select unit			Select unit		
Year 4	Select unit			Select unit		
Year 5	Select unit			Select unit		

When was the last energy audit conducted on the building?

☐ Less than a year
 ☐ 1-3 years ago
 ☐ 3-5 years ago
 ☐ More than 5 years ago
 ☐ Do not know
 ☐ Never

System Type	Year Installed (yyyy)	Fuel Type	System Type	Other (Please specify)	Efficiency %	Capacity	Condition
Space Heating System		Select	Select		Select	Select Unit	Select
Domestic Hot Water System		Select	Select		Select	Select Unit	Select

	Type	Other (Please specify)	AC Unit if applicable	Year Installed (yyyy)	Efficiency %	Capacity	Condition	Operating Hours
Air conditioning system	Select				Select	Select Unit	Select	
Ventilation System	Select					Select Unit	Select	Select

Appliances

In-Units Appliances	Year Installed (yyyy)	Total Number of Appliances	Manufacture	Model Number	Have appliances been changed within past five years?	If yes, please specify whether it is Energy Star or
Refrigerator					Select	Select
Stove and Oven					Select	Select
Dishwasher					Select	Select
Washer (In-Unit)					Select	Select
Dryer (In-Unit)					Select	Select

Shared Appliances	Year Installed (yyyy)	Total Number of Appliances	Manufacture	Model Number	Operation Hours/day	Is laundry facility coin operated	What's the cost per load?	Did you switch appliances within past five years?	Previous Manufacture if applicable	Previous Model Number if applicable
Washer (In Common Area)					Select	Select		Select		
Dryer (In Common Area)					Select	Select		Select		

Windows

	layer of glazing	Frame Material	Other (Please specify)	Window/Wall ratio	Were windows replaced during the past three year? Y/N
Windows	Select	Select			

Lightings

Location	Incandescent	Compact Fluorescent	T5	T8	T12	Other (Please specify)	No. of lights	Incandescent to compact fluorescent lamp conversion? Y/N	did you convert from incandescent to
Hallways	☐	☐	☐	☐	☐	☐			
Stairwells	☐	☐	☐	☐	☐	☐			
Garages	☐	☐	☐	☐	☐	☐			
Suites	☐	☐	☐	☐	☐	☐			

Amenities

Please provide required information if it's applicable.

Room Type	Monthly Ave. Hours of	In Use (Y/N)
Party Room		
Fitness Centre		
Cooling Room		
Meeting Space		
Playgrounds		
Sitting Areas		
Swimming Pools		
Tennis Courts		
Basketball Courts		
Community Gardens		
Other (specify)		
Other (specify)		

Has your building implemented any of the following building envelope measures? If yes, Please specify the date (MM/YYYY).

☐ Re-Caulk Around Windows to Reduce Infiltration	
☐ Cladding Exterior Walls (R-18), Non-Enclosed Balconies	
☐ Install Double Pane Windows and Balcony Doors	
☐ Re-Clad Exterior Walls (R-18), Enclosed Balconies	
☐ Solarwall Ventilation Preheat System	
☐ Photovoltaic Panels on Roof	
☐ Facade-Integrated Photovoltaic Panels (BIPV)	

Solid Waste Generation

Waste Collection

1. What type of garbage pickup does your building for waste removal to landfill?

- ☒ City of Toronto
- ☐ Private Commercial Service

2. Check off all that apply to your building

- ☐ Tenants drop off garbage and recycling at one designated location
- ☐ Tenants drop off garbage and recycling at different locations
- ☐ Floor-to-floor recycling collection
- ☐ Chute rooms on each floor - garbage only
- ☐ Chute rooms on each floor - garbage and recycling
- ☐ Door-to-door recycling collection
- ☐ The building collects organics

Description of the form:

The following can be entered directly from your bill:

No. of days - Number of days in the billing period

Compacted (Y/N) - Specify if the building has the waste compactor *** Unusually buildings with more than 30 units should have waste compactor

Container type - The type of the container used for collecting solid waste. If your waste collection service is provided by City of Toronto, please choose the City of Toronto containers.

Collection frequency - Specify how often your waste is collected

No. set out/ week - Total number of each type of garbage bag container set out each week

Start Date - The starting date shown on the bill (not the Billing Date)

End Date - The ending date shown on the bill (not the Billing Date)

Landfill (m³) - The gather waste volume to landfill - (note that consumption MUST be converted to m³)

Recycling (m³) - The gather waste volume for recycling - (note that consumption MUST be converted to m³)

Organics (m³) - The gather waste volume for organics - (note that consumption MUST be converted to m³)

No. of days	
Compacted (Y/N)	
Container type	Select type
Collection frequency	select
No. set out/ week	
Total cubic yard (yd ³)	

Three to five years' current garbage billing data is required

Year	Start Date	End Date	Landfill	Recycling					Total Recycle	Organics
				Paper	Plastic	Glass	Metal	Other (Please specify)		
	MM/DD/YYYY	MM/DD/YYYY	m ³	m ³	m ³	m ³	m ³	m ³	m ³	m ³

Water Consumption

Building Name:	0
Utility provider:	

Water Consumption

1. Have you ever implemented any of the following water conservation measures and/or storm water managements techniques? If yes, please specify the date that has been applied.

Water Conservation Strategy	Applied Date mm/yyyy
☐ Toilets (dual flush)	
☐ Toilets (low flush, less than 6 liters per flush)	
☐ Toilets (ultra low flush, less than 4 liters per flush)	
☐ Faucet Aerators	
☐ LowFlowShower Heads	
☐ Washing machine replacement to front loaders	
☐ Increased vegetation coverage through landscaping	
☐ Permeable pavement for infiltration	
☐ Rainwater harvesting techniques	
☐ Green roofs	
☐ Grey water recycling	
☐ Share your water efficiency improvements with other property	
☐ Develop corporate standards for water efficiency for other property under shared ownership	

3. Check off all the water uses from this meter for the building:

☐ Car Washing	☐ Janitorial Services	☐ Swimming Pool
☐ Fire Suppression	☐ Landscape Irrigation	☐ Toilets
☐ Faucets	☐ Outdoor Cleaning Pressure Washing	☐ Washers
☐ HVAC System	☐ Other Uses of Water (Please Explain)	

Water Bills Data Input:

Instructions:

We encourage you to provide original records of monthly water readings for the previous three years. If you do so, you can skip the following section.

Description of the form:

Start Date: The starting date that meter was read, as shown on the bill (not the Billing Date)

End Date: The ending date that meter was read, as shown on the bill (not the Billing Date)

Consumption : The actual amount of water consumed

Actual/Estimated Reading (A or E): The reading type (Actual/Estimated) is indicated on the bill. If this indicated, enter A for Actual or E for Estimated. If this is not indicated, enter A (Actual)

Source (Bills/Files) : Enter Bill if the data is obtained directly from the utility bill; enter File if the data is obtained from a utility data spreadsheet

Three to five years' current data is required. This section is mandatory.

Year	Start Date MM/DD/YYYY	End Date MM/DD/YYYY	Monthly Consumption Select Unit	Actual/Estimated Reading A or E	Source Bills/File

Gas Consumption

Building Name:	0
Utility provider:	

Gas Consumption

Instructions:

We encourage you to provide original records of monthly water readings for the previous three years. If you do so, you can skip the following section.

Description of the form:

The following can be entered directly from your utility bill:

Start date : The starting date that meter was read as shown on the bill (not the Billing Date)

End Date : The ending date that the meter was read, as shown on the bill (not the Billing Date)

Consumption : the actual amount of gas consumed, in the appropriate energy units

Actual/Estimated Reading (A or E) - the reading type (Actual/Estimated) is indicated on the bill. If this is indicated, enter **A** for Actual or **E** for Estimated. If this is not indicated, enter **A** (Actual)

Source (Bills/Files) - enter Bill if the data is obtained directly from the utility bill; enter File if the data is obtained from a utility data spreadsheet

Three to five years' current data is required

Year	Start Date	End Date	Monthly Consumption	Actual/Estimated Reading	Source
	MM/DD/YYYY	MM/DD/YYYY	select unit	A or E	Bills or File

Electricity Consumption

Utility provider:	
-------------------	--

Electricity Consumption

We encourage you to provide original records of monthly water readings for the previous three years. If you do so, you can skip the following section.

Description of the form:

The following can be entered directly from your utility bill: (please note that all of these factors may not appear on every bill - if factors do not appear, leave blank)

Start date: The starting date that meter was read as shown on the bill (not the Billing Date)

End Date - The ending date that the meter was read, as shown on the bill (not the Billing Date)

Demand - the actual value of Demand (not adjusted Demand)

kVA - The actual value of kVA (not adjusted kVA)

Power Factor - the ratio between true power (kW) and apparent power (kVA) (Value between 0 and 1)

Actual/Estimated Reading (A or E) - the reading type is indicated on the bill. If this is indicated, enter **A** for Actual or **E** for Estimated. If this is not indicated, enter **A** (Actual)

Source (Bills/Files) - Enter Bill if the data is obtained directly from the utility bill; enter File if the data is obtained from a utility data spreadsheet

Three to five years' current data is required

Year	Start Date	End Date	Monthly Consumption	Actual/Estimated Reading	Demand	kVA	Power Factor
	MM/DD/YYYY	MM/DD/YYYY	kWh	A or E	kW		

Occupancy

Historical Occupancy				
	Month	Total Number of Occupants	Number of Vacant Unit	Vacancy Rate
Year 1	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			

Green Power

Building Name	0				
Please check all green power that you have purchased					
Green Power Purchase	Provider Name	Period of Generation		Quantity	
		Starting Date MM/YYYY	Ending Date MM/YYYY		
☐ Biogas				Select Unit ▾	
☐ Biomass				Select unit ▾	
☐ Geothermal				Select Unit ▾	
☐ Small Hydropower				Select unit ▾	
☐ Solar				Select unit ▾	
☐ Wind				Select unit ▾	

Appendix D

➤ Sample GHG Emission Calculation from Water Use Cycle of Building TCHC 24

Assumptions:

Annual water consumption (A): 32,107 m³

Calculation

Energy Intensity (ekWh/m³ /yr water) = A (m³) x (1.11) ekWh/m³ + A/2(m³) [(1 x 103)]
kWh/m³

$$= 32,107 \text{ (m}^3\text{)} \times 1.11 \text{ (ekWh/m}^3\text{)} + [(32,107/2) \text{ (m}^3\text{)} \times (1 \times 103) \text{ (ekWh/m}^3\text{)}]$$

$$= 1,689,149 \text{ ekWh/m}^3 \text{ /yr water}$$

Total GHG (kgCO₂eq /yr) = Energy Intensity (equiv. kWh/m³ /yr water) x 270gCO₂eq/kWh x
1kg/1000 g

$$= 1,689,149 \text{ (ekWh/m}^3 \text{ /yr water)} \times 270 \text{gCO}_2\text{eq/kWh} \times 1 \text{kg/1000 g}$$

$$= 456,070 \text{ kgCO}_2\text{eq /yr}$$

➤ Sample GHG Emission Savings Calculation from Water Use Cycle of Building TCHC 24

Assumptions:

Annual water consumption savings (A): 3,750 m³

Savings type: cold and hot water consumption (50% each)

DHW system: gas fired

Calculation

**Note: A = Annual water consumption savings (m³)*

GHG Savings Calculation (kgCO₂eq /yr) = A (m³) x (166 + 28) g CO₂eq / m³ + (A/2 x 1 x 21,514)
g CO₂eq / m³ x 1kg/1000 g

$$\begin{aligned}
&= 3,750 \text{ (m}^3\text{)} \times (166 + 28) \text{ g CO}_2\text{eq / m}^3 + (3,750/2 \times 1 \times \\
&\quad 21,514) \text{ g CO}_2\text{eq / m}^3 \times 1\text{kg}/1000 \text{ g} \\
&= 41,066 \text{ kgCO}_2\text{eq /yr}
\end{aligned}$$

Appendix E

Sample Solid Waste Generation Cost Calculation (based on 2011 price rates) of Building TCHC 24

Assumptions:

Number of suites: 327

Annual Solid Waste Generation (un-compacted) = 2,304 yd³

Calculation

Allowable Base Volume of Waste (Yd³) = 1.917 * Total Number of Units in a MURB

$$= 1.917 \times 327 = 627 \text{ Yd}^3$$

Excess Solid Waste (Yd³) = Total Solid Waste Generated (Yd³) - Allowable Base Volume of Waste (Yd³)

$$= 2,304 \text{ (Yd}^3\text{)} - 627 \text{ (Yd}^3\text{)}$$

$$= 1,677 \text{ (Yd}^3\text{)}$$

Base Allowable Fee = \$191.30 per Unit/yr- \$180 per/Unit (rebate)

$$= \$ 6.30 \text{ per unit/yr}$$

$$= \$ 6.30 \text{ per unit/yr} \times 327 \text{ units}$$

$$= \$ 2,060 \text{ per year}$$

Excess Cost \$ = \$13.27* Excess Solid Waste (Yd³)

$$= \$13.27 \times 1,677 \text{ (Yd}^3\text{)}$$

$$= \$22,254 \text{ per year}$$

Total Annual Cost \$ = Base Allowable Fee (\$) + Excess Cost (\$)

$$= \$22,254 + \$2,060$$

$$= \$24,314 \text{ per year}$$

Appendix F

Annual energy consumptions of individual MURBs are normalized by number of suites, in order to state the typical range for the dataset. The benchmark ranges and the potential savings for each percentile have been outlined in Table A.1 and Table A.2.

Table A.1. Energy benchmarking range (EPI-kWh/unit) for the 106 MURBs dataset

Consumption Benchmark	Normalized Annual Energy Consumption (kWh/unit)
Poor Performer	32,279 -67,791
Typical	22,491- 32,278
Top Performer	10,327 - 22,491

The annual energy consumption for gas-heated MURBs located in the British Columbia were found to be from 11,566 to 34,812 ekWh/suite (Finch, Burnett, & Knowles, 2010), which is within the energy consumption range found for the developed dataset.

Table A.2. Achievable savings based on overall energy consumption for each percentile (per suite) within the 106 MURBs dataset, 2010

Overall Energy Consumption	Annual Energy Consumption (kWh/unit)		Annual Energy Consumption Cost (\$/unit)		Total GHG Emissions (kg/unit)
Existing Database	27,159		5,482		4,838
	Annual Energy Consumption Reduction (kWh/unit)	Percentage Energy Consumption Reduction (%)	Annual Energy Consumption Cost Reduction (\$/unit)	Percentage Energy Consumption Reduction (%)	GHG Emissions Reduction (kg/unit)
Top Performer	22,144	82%	4,453	81%	3,956
25th Percentile	7,596	28%	1,547	28%	1,359
50th Percentile	3,784	14%	767	14%	677
75th Percentile	1,725	6%	342	6%	308

First, by elevating the MURBs within the dataset to the top performer level for annual energy consumption and GHG emissions, 82%, 81%, and 82% energy consumption, cost and GHG emission reduction respectively can be achieved. Second, by improving the dataset to the 25th percentile level for annual energy consumption and GHG emissions, 28%, 28%, and 28% energy consumption, cost and GHG emission reduction correspondingly can be achieved. Third, by bringing the dataset to the 50th percentile level for energy consumption and GHG emissions, 14%, 14%, and 14% energy consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if energy consumption and GHG emission level can reach the 75th percentile level of the dataset, 6%, 6%, and 6% water consumption, cost, and GHG emissions reduction respectively can be achieved.

Appendix G

The benchmark range for annual energy consumptions normalized by number of floors above ground for the dataset has been is Table A.3.

Table A.3. Energy benchmarking range (EPI-kWh/unit) for the 106 MURBs dataset

Consumption Benchmark	Normalized Annual Energy Consumption (kWh/floor)
Poor Performer	485,947 -949,954
Typical	343,155 - 485,946
Top Performer	133,382-343,154

Overall savings according to per floor performance indicator for each percentile have been outlined in Table A.3.

Table A.4. Achievable savings based on overall energy consumption for each percentile (per suite) within the 106 MURBs dataset, 2010

Overall Energy Consumption	Annaul Energy Consumption (kWh/floor)		Annual Energy Consumption Cost (\$/floor)		Total GHG Emissions (kg/floor)
Existing Database	407,215		82,198		72,532
	Annaul Energy Consumption Reduction (kWh/floor)	Percentage Energy Consumption Reduction (%)	Annual Energy Consumption Cost Reduction (\$/floor)	Percentage Energy Consumption Reduction (%)	GHG Emissions Reduction (kg/floor)
Top Performer	330,276	81%	66,167	80%	58,987
25th Percentile	112,077	28%	22,221	27%	19,998
50th Percentile	65,660	16%	13,111	16%	11,723
75th Percentile	29,533	7%	5,622	7%	5,250

First, by elevating the MURBs within the dataset to the top performer level for annual energy consumption and GHG emissions, 81%, 80%, and 81% energy consumption, cost and GHG emission reduction respectively can be achieved. Second, by improving the dataset to the 25th percentile level for annual energy consumption and GHG emissions, 28%, 27%, and 28% energy consumption, cost and GHG emission reduction correspondingly can be achieved. Third, by bringing the dataset to the 50th percentile level for energy consumption and GHG emissions, 16%, 16%, and 16%energy consumption, cost reduction, and GHG emission reduction respectively can be achieved. Lastly, if energy consumption and GHG emission level can reach the 75th percentile level of the dataset, 7%, 7%, and 7% water consumption, cost, and GHG emissions reduction respectively can be achieved.

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