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BUILDING ENERGY MODELING AT NEIGHBORHOOD SCALE, CITY OF TORONTO

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I would like to dedicate this thesis to my small family, my loving husband Oday Hamad, and our son who we are waiting to come.

My parents, my sisters, and my husband’s family.

I dedicate it to everyone who believed in my abilities, trusted me, and helped me get here and succeed.

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Last but not least, I would like to thank Professor Guglielmina Mutani for helping and guiding me with this thesis throughout these months.

Abstract

Most of the world's population is concentrated in cities, and it is necessary to intervene in the management of energy consumption to ensure a high quality of people's lives with good air quality, thermal comfort, and general vitality in the urban environment.

This work begins by evaluating the different energy models that exist in the world at the urban scale and aims to define a model of energy consumption in the city of Toronto, which was the focus of this work, taking into account the region and its characteristics as well as the available technologies in order to exploit renewable energy sources that reduce of energy consumption.

For the city's population, the city of Toronto has a high overpopulation rate. In addition, Toronto is a major consumer of energy and produces an estimated 1.3 million tons of carbon dioxide each year, so human activities are the main cause of greenhouse gas emissions, and this indicates the need for a different management of energy consumption especially in housing. buildings.

The purpose of this research is to determine the average energy density of residential buildings in Toronto and to assess whether certain building characteristics affect energy density. This information is particularly important in the Toronto market, where the work is based on the evaluation of a simplified energy model that allows measuring the spatial distribution of energy consumption on an urban scale using a GIS tool. In this work, a model will be developed GIS environment in order to evaluate energy policies that can be applied in the City of Toronto.

The model estimates the space heating energy consumption of residential buildings, after classifying the buildings according to their characteristics. This simplified model was validated by comparison with real consumption data provided by the Canada statics platform.

Using this model, it is possible to develop energy strategies based on the building's true heritage and to identify critical areas that require priority intervention.

Keywords: Energy consumption, GIS model, Heated volume, Urban scale, Energy use, Toronto, Residential building, Top – down model, Linear regression.

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Introduction

Society is highly dependent on external energy sources more than before, but greenhouse gas emissions are increasing due to the great development of life and the increase in population. This is one of the factors that can affect energy, but it is possible to act according to the current situation, by working to reduce energy consumption, it has become necessary today to maintain a safe and clean environment, by improving energy efficiency in the city and focusing on the problems causing high Energy consumption.

The work of this thesis comes from the concept of energy sustainability at the urban scale and aims to analyze energy consumption at the building scale and to understand how the urban context affects energy consumption.

This work presents one way in which energy consumption and the opportunities in which energy can be saved in urban contexts are assessed.

The goal is to work on building a simplified urban energy model capable of optimizing energy use. This analysis was carried out using GIS (Geographical Information System) software, which was easy to link geo-referenced information and various information about buildings from available sources, which allowed this analysis to be carried out, relying heavily on different building parameters (form factor and different construction periods)

The thesis consists of three main parts:

Analysis of the case study and passed through different steps, the most important of which are:

- Application of a top-down model to apartment buildings in the context of the city of Toronto

- The use of geographic information systems in the geographical reference and analysis of the available data on the real consumption of energy in the city of Toronto.

- Analysis of the impact of the urban context and its characteristics on energy consumption

- In the last part of this work, the results of the study were announced, and a comparison was made between the results and the original available data on energy consumption.

In general, the energy consumption was estimated by using the Toronto 2030 platform for the residential sector, working on different types of homogeneous apartment buildings, in order to calculate the average energy consumption, and trying to apply this analysis to the urban context. ranging from the building scale to the urban scale, and the energy consumption was determined based on the total volume taken from the GIS for residential buildings (kWh/m^3/year).

The model of energy consumption Top-down model depends mainly on several factors, the most important of which are:

Analysis of the energy consumption (Natural gas) by relying on the analysis on the form factor and construction period, where the old building in particular affects energy consumption more than modern buildings and the reason for this is the use of many new technologies that save energy consumption in buildings and make buildings more efficient for its energy.

As for the form factor, this factor also affects energy consumption. Buildings that have lower energy consumption have a lower form factor due to the presence of a high percentage of heated volumes in the building, and on the contrary, the energy consumption is greater for buildings that have a larger form factor. Because there is a large percentage of unheated volumes in the building

Regarding energy consumption (Electricity), it has been relied heavily in this analysis on the number of people in each family, it is natural that the more people in the house, the higher the rate of energy consumption than the buildings where the population is less

The number of residents divided by the gross GIS volume of the building is considered.

Finally, a comparison has been made between these results obtained with the original available data on energy consumption with the development of some scenarios of how to reduce energy consumption in critical areas where energy consumption is greater

General considerations about energy consumption patterns

There are many different models that can be applied depending on the urban contexts of the energy consumption of the building stock (top-down model, bottom-up model, and hybrid model).

In general, estimating consumption using models provides clear results that are commensurate with the available real information about the case of study, especially the results at the neighborhood level. There are many differences, which are caused by the ability of each model to deal with the lack of information regarding the structure of the building and the behaviour of the inhabitants.

In fact, one of the main characteristics of the analysis is the presence of data available for the case of study.

The main required attributes are the buildings' thermophysical properties (construction time, and S/V ratio), information on the building's uses (residential sector, public sector, industrial sector, etc.), as well as climatic characteristics. As for the analysis used in this study, it is a top-down model, which is directly dependent on GIS environment data collection, modification and use in calculations and evaluation, which in turn works to make the correct analyses

ArcGIS

About the software (ArcGIS)

Geographical Information System (GIS) software is considered one of the most important programs used in the process of storing all kinds of geographical and spatial data of all kinds, and the ability to access them very easily, retrieve them, display, and analyse them.

GIS software allows the production of maps and other graphic representations for different presentations. In addition, there are many benefits of using this software, which is to collect and organize information to create building and energy models, especially in large urban areas and their database systems

This work was mainly based on this program, as the process of collecting, auditing, and using information for the purpose of this study was carried out on a regular basis. Some of the physical properties of residential buildings were calculated, which include, form factor, construction period, energy consumption, the total size of the buildings, and the total area, in addition to some urban characteristics, building coverage ratio, building height, and building density.

Also, many maps were produced that contain a complete summary of the physical characteristics of the residential buildings sector, and the urban characteristics at the urban scale.

It was the reason for facilitating this study and summarizing the results in an orderly manner in a data folder and arranged papers to make it easier to return to them when needed and modify them.

Chapter 1.

METHODOLOGY

The Energy modelling at neighbourhood scale

References

- Reading and understanding energy consumption trends, and the effect of the building types in the overall consumption

Collecting Data

- Collecting data from *Toronto Open Data* regarding the city in general, the buildings in detail
- Using GIS data base to collect different variables and calculate information regarding energy consumption
- Define the typical archetype which is representative of the urban building stock includes the uniform residential block of Toronto (2020) platform

Analyzing

- Apply the models of energy consumption to each single building (2020) platform
- Compare the energy performance with some data of urban scale in districts and apply the evaluation in urban scale
- Work on top-down model for the result of energy consumption on urban scale

Figure 1.1, The methodology workflow

A lot of research indicates that there are many factors that affect thermal energy sources, such as:

- **Climatic factors**: temperature, degree of days.

- **Period of construction**: which directly affects the type of building structure used, the level of thermal insulation of dispersed surfaces, and the efficiency of the heating system used in the buildings.

- **Building characteristics**: S/V form factor,

- **The intended use** of buildings greatly affects the energy needs, regarding both the methods of use and the characteristics of the building as well as the fact that the uses of the building increase or decrease energy consumption depending on the behavior of the inhabitants.

Therefore, the definition of the intended use is necessary in order to obtain reference values in energy consumption calculations (G.Mutani and G.Vicentini, 2013).

The current work will focus on several directions:

- The residential sector.

- Population.

- Urban variables: building density, building height, building coverage percentage

This chapter, which is a simplified explanation of the above factors, is divided into 4 main parts:

The first part (1.1) deals with the urban microclimate.

The second part (1.2) is about constructing variables and parameters.

The third part (1.3) presents the variables and indicators of urban morphology by dividing them into the variables of buildings on an urban scale.

The last part (1.4.) provides an overview of energy consumption models in buildings. Also, describe the main models used to estimate energy consumption.

In this work, powered by ArcGIS 10.7.1, the building inventory consumption in Toronto was estimated using a top-down model for the residential sector.

In summary, the main steps in doing the analysis are as follows:

• Estimation of energy consumption in Toronto by applying the top-down model. (by the information available in Toronto 2030 platform)

• Analysis of real energy consumption data. (by the information available on Canada statics platform).

• Assessing the impact of urban variables on energy consumption in buildings, starting from the district-scale ending by the urban scale.

1.1 Urban microclimate

Knowledge of the urban microclimate is an important guide to energy consumption and how urban morphology affects climate variables.

In the following paragraphs, climatic variables, and degree days (heating degree days and cooling degree days) coefficient are dealt with, both of which are important factors for a correct analysis of energy consumption.

1.2. Building variables and parameters

Heated loss surface and net heated volume are characteristic geometries of buildings that affect heat loss due to transportation and ventilation.

The heat requirements for winter conditioning of residential buildings in this study were determined from the time of construction and the shape factor of residential buildings, and these coefficients were calculated as features of each building in a GIS environment that have a significant impact on energy consumption in buildings.

It is noteworthy, that **the gross volume from the GIS environment** was used to calculate the form factor (S/V) ratio

1.2.1. Period of construction

The construction period is important to describe the structure of the building under analysis. In fact, it is possible to assess the level of thermal insulation and structural characteristics based on the construction time of each building.

The period of construction should take into account, the building characteristics. It is possible to refer to some of the important historical periods that characterize Toronto's building technologies:

- Before 1920: load-bearing buildings.
- 1910-1972: the presence of load-bearing walls and reinforced concrete structures
- 1980-1990: Reinforced concrete structures with insulating backfill
- 1991-2004: More insulated curtain walls to reduce energy consumption
- After 2005: more effective materials were used for insulators and more efficient systems were installed

In this study, buildings were classified according to three categories (according to information on the Toronto 2030 platform) considering the following construction periods:
- before - 1980
- From 1980 to 2004
- After 2004

Source: statics Canada, *www12.statcan.gc.ca*

1.2.2 Technical-geometric characteristics of the building

Subsequently, the technical-geometric characteristics of the buildings were identified the building stock:
The height of the buildings, the gross volume, the gross GIS volume, the heated Loss surfaces, the form factor S/V ratio (which gives information about the compactness of the building)

- **Gross Volume**: The gross volume of the building is defined as:

Gross Volume (m^3) = H (m) x Total floor area (m^2)
where: H = height of the building

- **Form Factor S/V Ratio**: The form factor is a geometric property of the building that goes to characterize its compactness.
- A building is defined as not very compact when it has a proportion between volume and dispersing surface which leads it to have a high S/V ratio, so it has a large dispersing surface compared to the heated volume; on the contrary, a very building compact has little dispersing surface compared to the heated volume and therefore has values of lower S/V.

The S/V ratio represents the ratio between the surface heated loss surface (S) and the net heated volume (V) of the building:

- **S** = dispersing surface (heated loss surface) (m^2)
- **V** = Gross GIS volume (m^3)

Dispersing surface [m 2] = (base area of the building x 2) (m^2) + (perimeter x height) (m^2)

To calculating the dispersing surface for the calculation of the S/V ratio is considered dispersing surfaces all the surfaces belonging to the heated room that faces towards the external environment, towards the ground, or towards unheated rooms.

Dispersing surface (m^2) = (base area of the building x 2) (m^2) + (perimeter x height) (m^2) - (common wall surfaces)

As for neighboring buildings, heat loss through the common surfaces is not considered, but, on the contrary, the common area must be subtracted from the dispersion surface.
The S/V form factor affects the energy performance of a building, and in relation to volume, the smaller the building, the more compact the building.

To reduce the scattering surface S, it is necessary to intervene with the compressibility of the building and the factor that characterizes it is the S/V ratio.

The form factor is an important variable for the purpose of reducing energy loss when transporting. Thus, scattering of the same shape will be inversely proportional to volume:
Larger buildings tend to transfer heat more easily compared to smaller buildings, which cool more easily.
This is the advantage of large buildings for the winter months and becomes a disadvantage in the summer months, when it will be difficult to get rid of heat from the building, and in small-sized buildings on the contrary.

Then the form factor is calculated with the following expression:

S/V ratio (m^{-l}) = heated loss surface (m^2) / Gross GIS Volume (m^3)

Since the calculated gross volume does not consider the unheated zones inside the building (stairwells, etc.) to normalize the result and make it more real, it is necessary to multiple the identified form factor by a coefficient that varies according to the S / V values calculated (see Chapter 3.1.) – Using Italian Coefficient.

1.3. Variables and indicators of the urban morphology

In the urban context, the energy consumption of a building is conditioned by the characteristics of the building itself (Chapter 4.1.)

- construction period, form factor (S/V) ratio, type, and the urban morphology of the area in which the building is located.

Several characteristics of the neighborhood must therefore be considered in the design phase.
It emerged that the parameters that most influence the variation in urban consumption are (G. Mutani, et al, 2016):

1. BD building density (m^3 / m^2)
2. BH building height (m)
3. BCR building coverage ratio (m^2 / m^2)

1.3.1. Variables of buildings on an urban scale

Building density (BD): is defined as the ratio between the total volumes of the buildings and the area of the district in which the buildings are located (analysis area).

Higher values will show a very dense urban context, on the contrary, the lower values will indicate a not very dense area.

In a GIS environment, it is possible to calculate this variable and as a first step, it is necessary to associate to each building the area of the district in which the building is located, in this way for each building you will have the information of the volume of the building and of the area of the district.
Through the “summarize” tool (in ArcGIS software) it is possible to add up all the volumes of the buildings divided by the total area of the district.

At this point with the following formula calculates the value of the variable BD:

Building density (BD) = Sum Volume (buildings) / Surface (The area of the district) (m^3 / m^2)

Which is Determines how much the site and the building is worth, not only how crowded, or built-up a neighborhood appears

Building height (BH): It is defined as the average height of the buildings within the district where the buildings are located.

To calculate this variable, in the GIS environment, multiply the height of each building by the corresponding volume (Height x Volume), at the district scale of both the (Height x Volume) value and all the volumes of the buildings falling into the district.

The formula for calculating the variable BH is the following:

Building height (BH) = Sum (Height x Volume) / Sum Volume (buildings) (m)

Building coverage ratio (BCR): is defined as the ratio between the sum of the area of the buildings and the total area of the district containing the buildings themselves.

The value can range from 0 without buildings, to 1 with one fully covered area of buildings

In a GIS environment, it is possible to calculate this variable, it is necessary to associate to each building the total area of the district in which the buildings are located, in this way for each building you will have the information of the building area and the area of the district. Through the "summarize" tool (in ArcGIS software) it is possible to add up all the areas of the buildings divided by the total area of the district.

At this point by using the following formula, the value of the BCR variable is calculated as:

Building coverage ratio (BCR) = Sum Area (buildings) / Surface (The area of the district) (m^2 / m^2)

1.4. Energy Consumption models of buildings in the residential sector

It is known from the state of the art, that there are different models that can be used to estimate the energy consumption of the building stock, there are three main models: the top-down models, models bottom-up, and hybrid models.

The top-down model was used in this work. In the following paragraphs, the model top-down model is presented for the residential building sector.

This happened after having identified in the GIS environment the different variables on building scale and on an urban scale, afterward, we applied the application of models for the estimation of energy consumption.

The top-down model: is defined as a model for the characterization of energy consumption and in this case, is especially for the residential sector.

The most simplified energy consumption models start from consumption data at the district scale and knowing the Gross GIS
volume of the buildings, they determine specific energy consumption.

According to the information mentioned on Toronto 2030 platform, the intended use of energy (Electrical and Natural Gas) in the district where the buildings are located, divided by the volumes of the buildings were estimated in the GIS environment.

In fact, by combining the information present in Toronto 2030 platform and applying different analyzes statistics, it was possible to calculate the average intensity of district consumption for residential buildings.

The main variables that influence energy consumption have been selected:
The gross GIS volume and heated loss surface, the form factor s/v, and the period of construction.

They were used the data of the GIS environment to calculate the average percentage of the heated volume

The Top-down model evaluates the specific energy [kWh/m3/year] for heat consumption as a function of form factor s/v for the different periods of construction.

Chapter 2.

Case Study (The city of Toronto)

This chapter provides an in-depth analysis of the city of Toronto of the work by analysis.

The First part: (2.1.) introduces the overview of Toronto, and the climatic conditions that have been analyzed, the meteorological stations, and the annual average temperatures.

The second part: (2.2.) gives an overview of the energy consumption of Toronto in the residential sector.

In the third part (2.3.) The districts of Toronto were identified, which the study is focused on.

2.1. The territorial and climatic context

2.1.1 The overview of the city of Toronto

Figure 2.1.1. 1, Location of the city of Toronto in relation to Ontario, Canada

Toronto is the capital of Canadian Ontario. With a population of 6,082,000, as per the latest statistics in 2017, which occurs every five years, it is the most populous city in Canada and the fourth most populous city in North America. The city is located on the golden horseshoe of the Ontario map, which surrounds the western end of Lake Ontario.

Toronto is the largest international center for business, arts, and culture, and one of the most multicultural cities in the world and was designated the capital of the Province of Ontario in 1867.

Throughout the city, there are hundreds of small neighborhoods scattered, some of which are large neighborhoods that cover a few square kilometers, and the most important characteristic of the city of Toronto is its high-rise apartment complexes and various commercial towers.

According to Statistics Canada, the number of residents residing in the city of Toronto has increased recently, "i.e., 1,122,000 in 1980, over the following years to reach in the year 2000 4,607,000 residents with a growth rate equal to 1.9%." *(Source: https://www.macrotrends.net/cities/20402/toronto/population)*

The population gradually increased. In 2015, Toronto registered 5,867,000 residents with a growth rate of 1.21%. In the following years, on December 31, 2020, the total population of Toronto was 6,197,000 with a growth rate of 0.94%" (*Statistics Canada platform*)

The following table shows the number of population and the annual change.

Year	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Population	3008000	3355000	3807000	4197000	4607000	5499000	5035000	5867000	6197000
Annual Change	1.76%	2.29%	2.61%	1.82%	1.90%	1.78%	1.76%	1.21%	0.94%

Table 2.1.1. 1, Yearly resident population and growth rate - United Nations - World Population Prospects

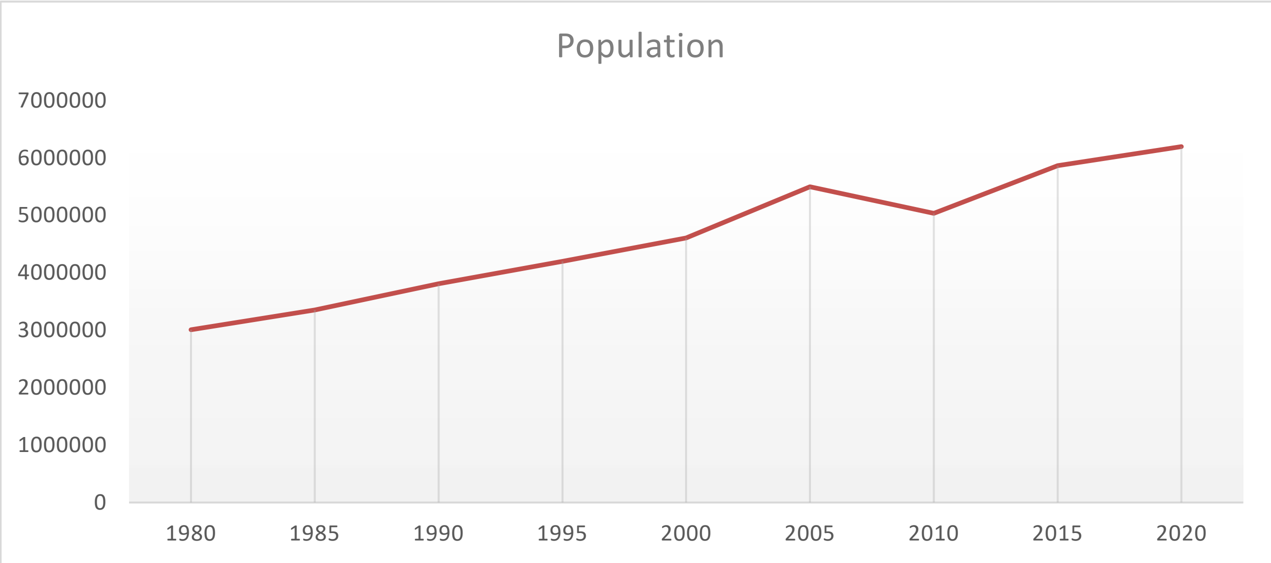


Figure 2.1.1. 2, Population 1980-2020 - United Nations - World Population Prospects

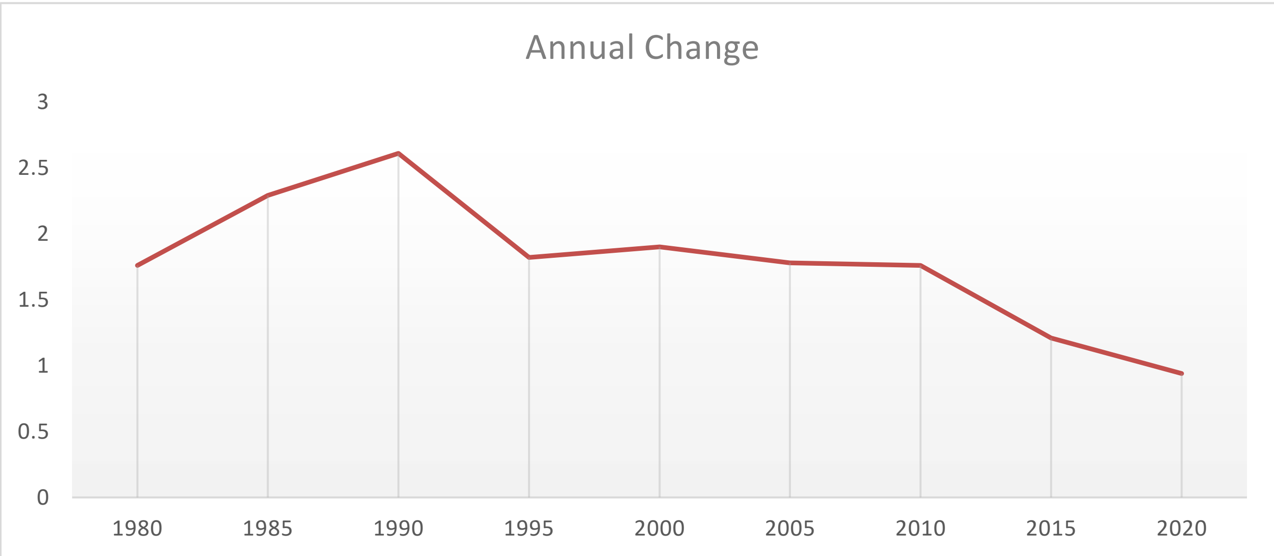


Figure 2.1.1. 3, Growth rata 1980-2020 - United Nations - World Population Prospects
(https://www.macrotrends.net/cities/20402/toronto/population)

2.1.2 The Climatic Context

Toronto's climate is the mildest in Canada due to Lake Ontario, due to Toronto's southern latitude within the country. Downtown Toronto lies in an enclave of humid climate (Köppen climate classification DFA) located at the southwestern tip of Lake Ontario, including downtown (but excluding the Toronto Islands), where the average annual temperature exceeds (48 °F).

Some areas of Turin and some suburbs are classified under the DFB climate, which lies outside the city limits, and the reason for the difference in climate classification is the urban heat island effect,
Regarding the seasons in the city of Toronto, spring and autumn are shorter seasons than summer and winter, as the city has varied weather, with dry, sunny, and rainy weather.
Many days in these seasons are sunny with pleasant temperatures, nights are generally cool, and snow can fall in early spring or late fall but usually melts quickly after contact with the ground. At these changing times of the year, temperatures vary up to (54°F) in extreme cases.
There is no dry season, as it rains for months and snowfalls especially in the winter.

The following table shows the annual temperature of Toronto from 1980 to 2020.

Year	1980	1985	1990	1995	2000	2005	2010	2015	2020
Maximum	31.9 °C	33.0 °C	35.4 °C	36.8 °C	31.3 °C	35.5 °C	34.5 °C	34.0 °C	35.5 °C
Hourly Mean	6.9 °C	7.5 °C	8.9 °C	8.0 °C	8.4 °C	9.2 °C	9.7 °C	8.8 °C	9.9 °C
Mean of Min/Max	6.7 °C	7.3 °C	8.8 °C	7.9 °C	8.3 °C	9.1 °C	9.6 °C	8.6 °C	9.7 °C
Minimum	-27.6 °C	-23.7 °C	-19.5 °C	-22.8 °C	-22.0 °C	-24.2 °C	-19.0 °C	-25.5 °C	-20.6 °C

Table 2.1.2 1, Temperature - Annual data (1980-2020)- Environmental and Natural resource – Government of Canada

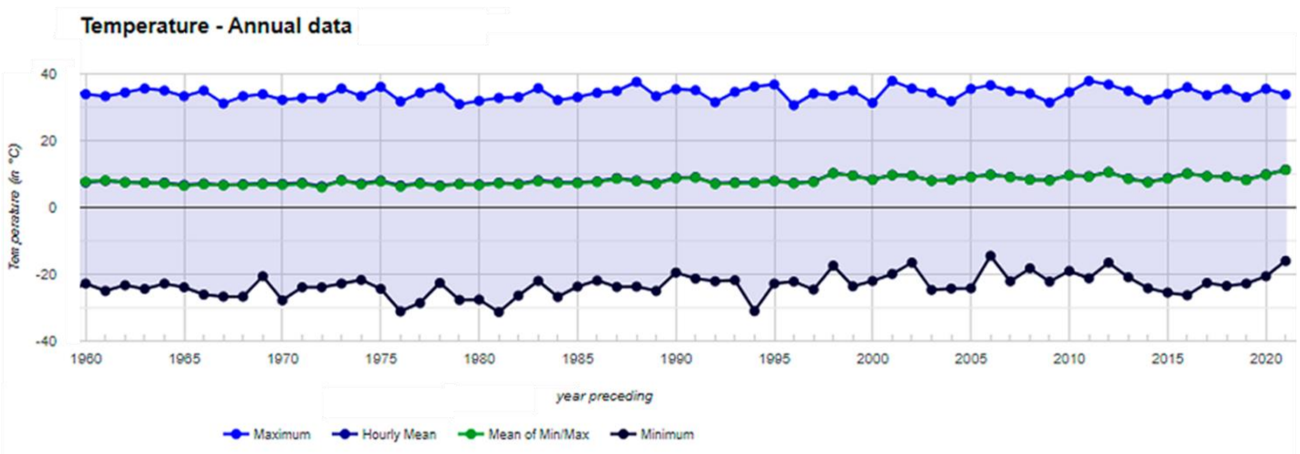


Figure 2.1.2. 1, Temperature - Annual data (1980-2020)- Environmental and Natural resource – Government of Canada

(https://toronto.weatherstats.ca/metrics/temperature.html,
https://weather.gc.ca/past_conditions/index_e.html?station=ykz)

Heating degree day (HDD): is a measurement designed to quantify the demand for energy needed to heat a building, In Environmental and Natural resource – Government of Canada platform, The heating degree day is 18 °C.

Year	1980	1985	1990	1995	2000	2005	2010	2015	2020
Total	4,384	4,112	3,640	4,044	3,829	3,797	3,504	3,769	3,516

Table 2.1.2. 1, Heating Degree Days - Annual data (1980-2020)- Environmental and Natural resource – Government of Canada

<u>Heating degree day (18 °C) – Annual Data</u>

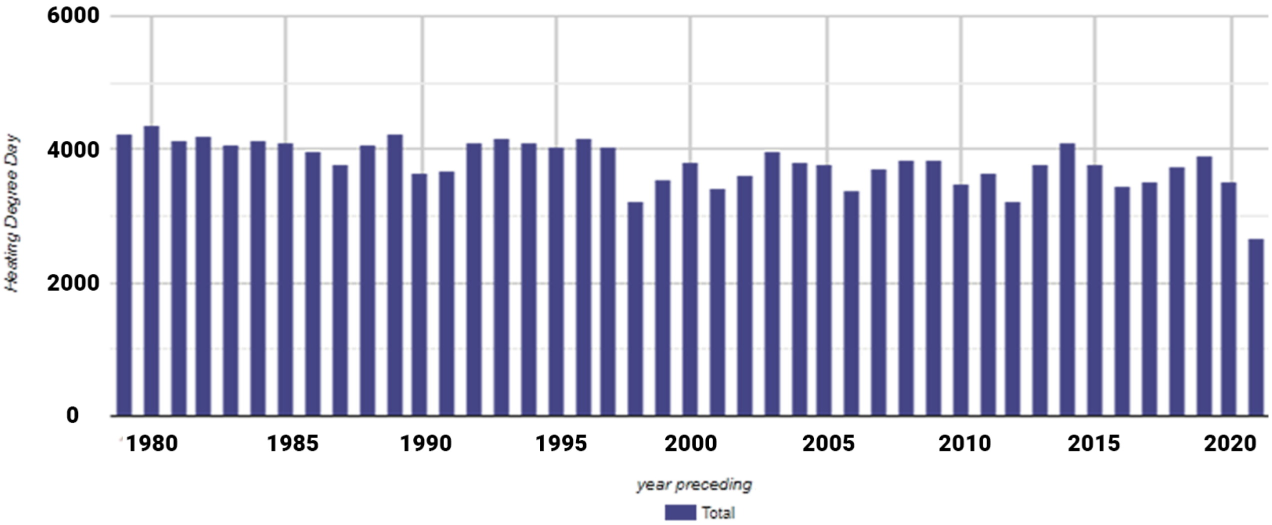


Figure 2.1.2. 2, Heating Degree Days - Annual data (1980-2020)- Environmental and Natural resource – Government of Canada, https://toronto.weatherstats.ca/charts/hdd-yearly.html

Cooling degree day (CDD): is a measure that helps to simplify the cost of projected energy consumption. It is based on the number of days where the temperature is above 65 degrees Fahrenheit, and the number of degrees above 65.

Year	1980	1985	1990	1995	2000	2005	2010	2015	2020
Total	236	187	262	349	263	533	437	349	495

Table 2.1.2. 2, Cooling Degree Days - Annual data (1980-2020)- Environmental and Natural resource – Government of Canada

<u>Cooling degree day (18 °C) – Annual Data</u>

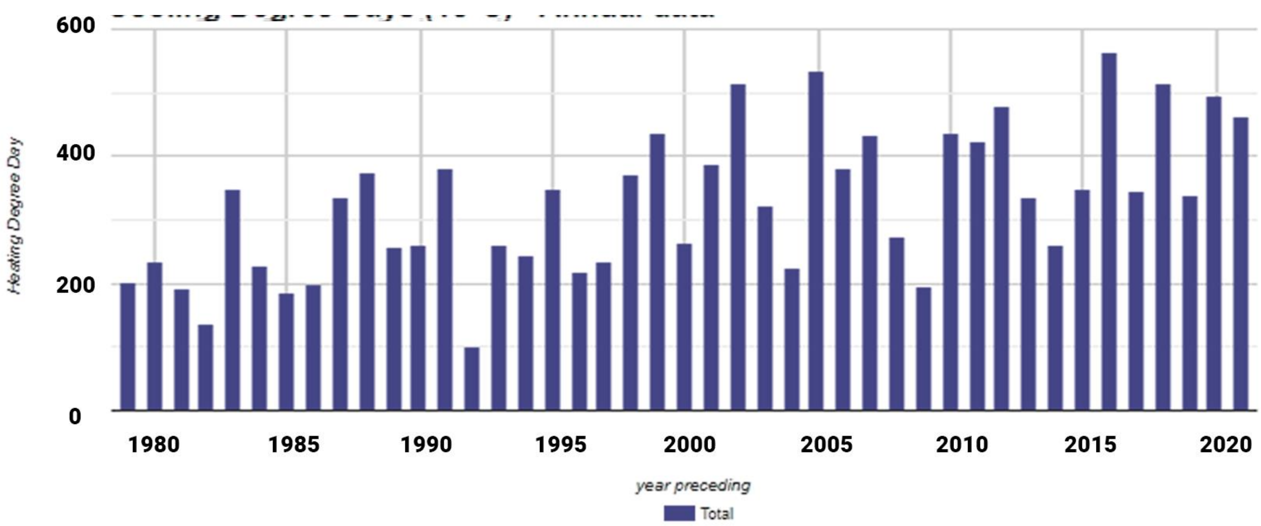


Figure 2.1.2. 3, Cooling Degree Days - Annual data (1980-2020)- Environmental and Natural resource – Government of Canada , *https://toronto.weatherstats.ca/metrics/cdd.html*

2.1.3 Weather Stations

Considering the weather stations within the city, there are differences in the monthly outdoor air temperature, this is mainly due to human activities (residential or industrial areas) and proximity to parks and rivers. Figure 9 are identified Four meteorological stations that worked in the Municipality of Toronto and near Toronto.

Figure 2.1.3. 1, Weather Station in and near Toronto – Environmental and Natural resource – Government of Canada

Stations Name

1- Toronto Buttonville Municipal Airport weather station

Location	Latitude	Longitude	Elevation
	43.86	-79.37	198 m
Station Identifiers	IATA	WMO	Climate ID
	YKZ	-	6158409
Starting Date (hourly data)	2016-01-13		

Table 2.1.3. 1, The weather station in Toronto (1) - Environmental and Natural resource – Government of Canada

2- Toronto City Centre Airport weather station

Location	Latitude	Longitude	Elevation
	43.63	-79.4	77 m
Station Identifiers	IATA	WMO	Climate ID
	YTZ	71265	6158359
Starting Date (hourly data)	2009-12-10		

Table 2.1.3. 2,The weather station in Toronto (1) - Environmental and Natural resource – Government of Canada

3- Toronto Island A weather station

Location	Latitude	Longitude	Elevation
	43.63	-79.4	77 m
Station Identifiers	IATA	WMO	Climate ID
	-	71265	6158665
Starting Date (hourly data)	1957-02-06		

Table 2.1.3. 3, The weather station in Toronto (1) - Environmental and Natural resource – Government of Canada

4- Toronto Intl A (Toronto Pearson Int'l Airport) weather station

Location	Latitude	Longitude	Elevation
	43.68	-79.63	173 m
Station Identifiers	IATA	WMO	Climate ID
	YYZ	71624	6158731
Starting Date (hourly data)	2014-08-27		

Table 2.1.3. 4, The weather station in Toronto (1) -

Condition of the weather from the weather Stations

Station Name	Lowest Temperature (°F)	Highest Temperature (°F)
Toronto Buttonville Municipal Airport	30 (29.8)	43 (43.0)
Toronto City Centre Airport	32 (32.4)	44 (44.2)
TORONTO ISLAND A	30	43
TORONTO INTL A (Toronto Pearson Int'l Airport)	30 (29.5)	44 (43.5)

Table 2.1.3. 5, Air temperatures registered by the weather stations in Toronto in the reference year 2016, *https://toronto.weatherstats.ca/about.html*

2.2. Energy overview

Achieving energy sustainability is fundamental to achieving the City of Toronto's goals regarding climate change and improving air quality and thermal comfort. In addition, energy sustainability means having a reliable guarantee of energy supply and reducing energy costs in the long term, which leads to the preservation of the local economy.

Toronto is currently dependent on natural gas for energy, accounting for 63% of the total energy used (excluding transportation) in Toronto while local renewables provide only 0.6%. There are major attempts to reduce emissions of greenhouse gases and other pollutants due to various factors.
According to the information in Toronto 2030 platform for the annual energy use (2017), (greenhouse gas emissions factor), it is divided into different types of energy, where the electricity consumption is 32 grams CO2eq/kWh "*Source - Toronto Hydro* While the natural gas is 1874.6 gCO2/cubic meter" Source - Enbridge Inc ", as well as steam (District Heat) is 73.8 gCO2/lb,"*Source - Enwave Energy Corporation*", for deep lake water cooling 41.3 gCO2/ton per hour, water 114.4 gCO2/m3 " *Source - Toronto Open City data*", even the water's GHG emission factor is based on an average City of Toronto emissions for water and wastewater pumping and treatment. *(Toronto 2030 Platform, https://www.toronto2030platform.ca/data-and-definitions)*

2.2.1 The Residential sector

The residential sector alone is responsible for 40% of all CO2 emissions. Toronto has a huge amount for residential use, 27% built before 1945 to more than 50% between 1980-2000, which has high levels of energy consumption primarily for winter heating. Based on this information and due to the high energy consumption in the residential sector, we worked in this sector to try to make buildings more energy-efficient, and to find some alternatives to reduce energy consumption.

The following figure show the annual energy consumption (PJ) in the city of Toronto for the residential sector from 2000 to 2018:

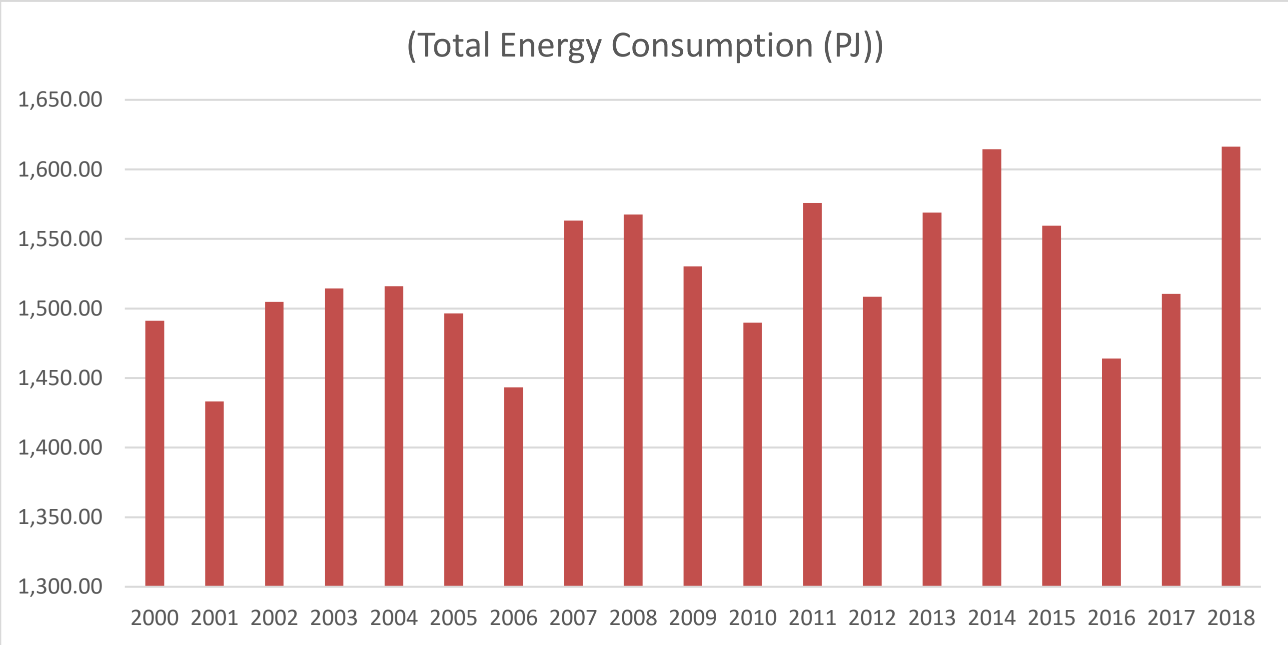


Figure 2.2.1. 1, Total Energy Consumption during the years for the residential sector, Source: Survey of Household Energy Use – Detailed Statistical Report, (Source: pdf of the energy consumption (PJ) attached with the total work)

The following figures show the total energy consumption in Ontario, the city of Toronto, according to several considerations:

- **The types of energy consumption (Electricity, Natural Gas) – Period of consumption:**

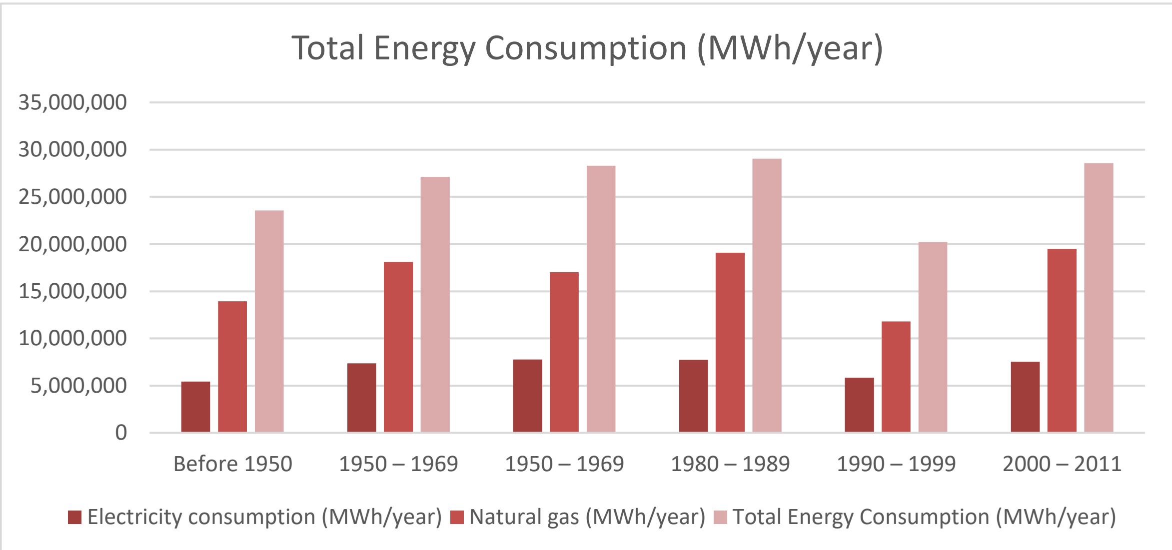


Figure 2.2.1. 2, Total Energy Consumption according to the type of energy consumption and the period of construction, Source: Survey of Household Energy Use – Detailed Statistical Report (Source: pdf of the energy consumption (PJ) attached with the total work)

- **The archetypes of buildings – Period of consumption:**

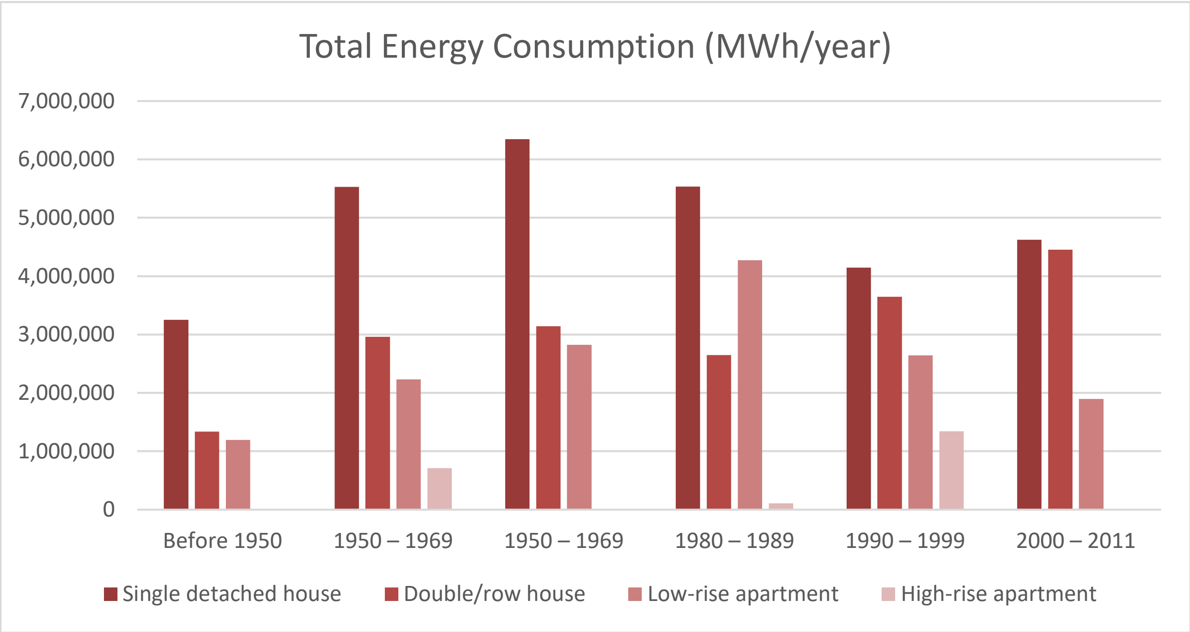


Figure 2.2.1. 3, Total Energy Consumption during the years for the residential sector according to the archetype of buildings and the period of construction, Source: Survey of Household Energy Use – Detailed Statistical Report - (Source: pdf of the energy consumption (PJ) attached with the total work)

- **The area of the buildings – Types of energy consumption:**

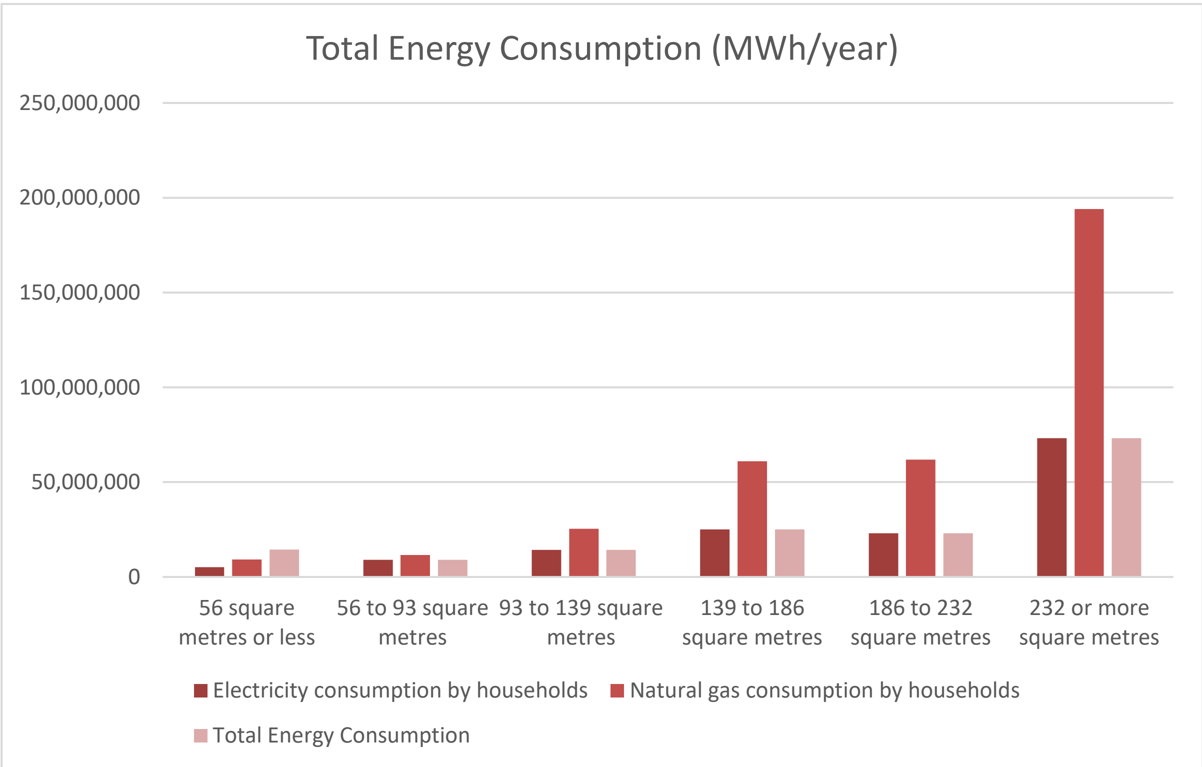


Figure 2.2.1. 4, Total Energy Consumption for the residential sector according to the area of buildings and the types of using energy, Source: Survey of Household Energy Use – Detailed Statistical Report - (Source: pdf of the energy consumption (PJ) attached with the total work)

2.3. The neighbourhoods

The city of Toronto's layout contains many neighborhoods, with 140 neighborhoods in existence since the late 1990s. However, the significant population growth in recent years in the city has led to a lack of balance and led to significant overpopulation in many neighborhoods. In order to balance population growth, the Social Research and Information Management Unit (SRIM), along with partners, has developed in other city departments and public agencies, city planning, and work examined many divisions in neighborhoods that led to 34 new neighborhoods, in which the population was distributed more evenly.

The map below shows 140 social planning neighborhoods in the City of Toronto shown by neighborhood number

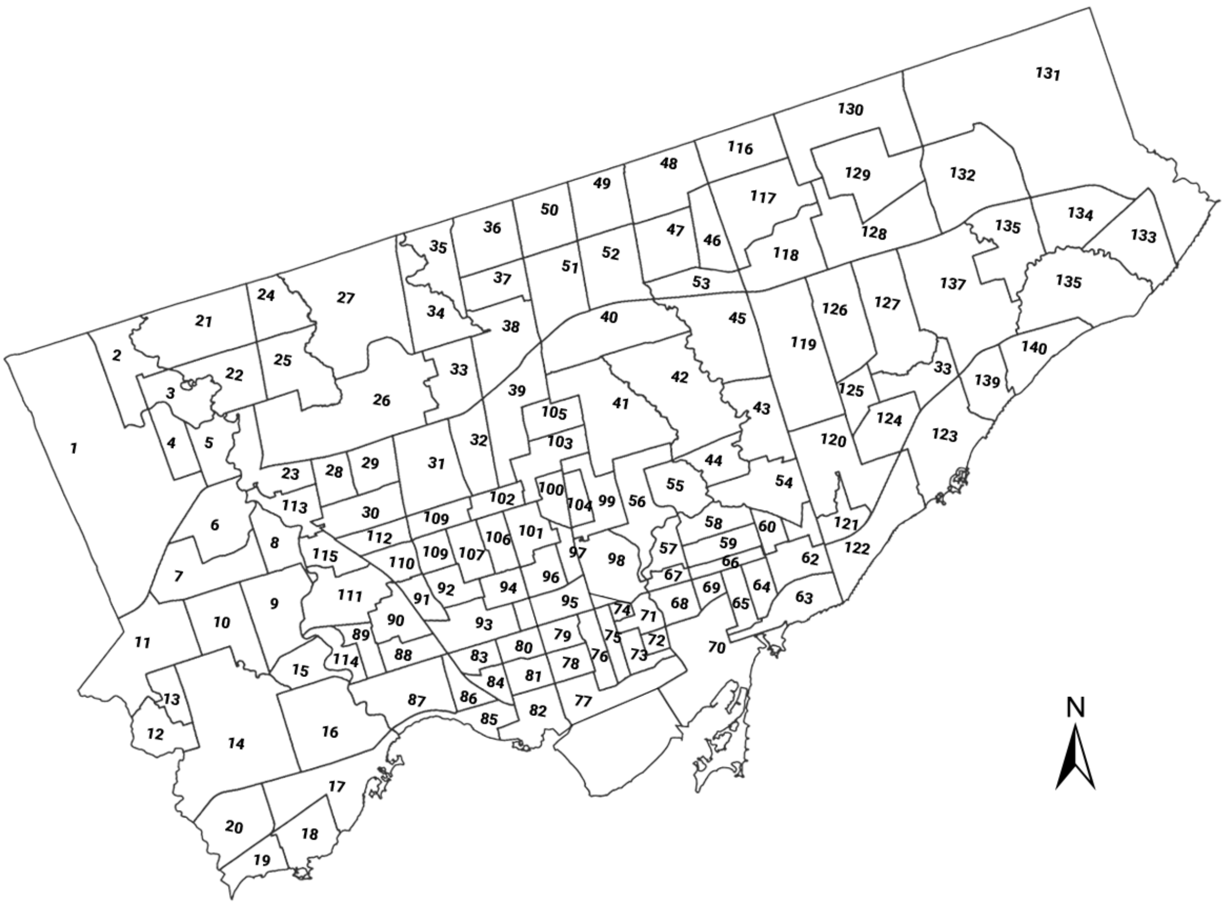


Figure 2.4. 1, Toronto neighborhood - Statistics Canada, Census of Population, 2016-

Source: https://www.toronto.ca/city-government/data-research-maps/neighbourhoods-communities/neighbourhood-profiles/

2.3.1. Study Area

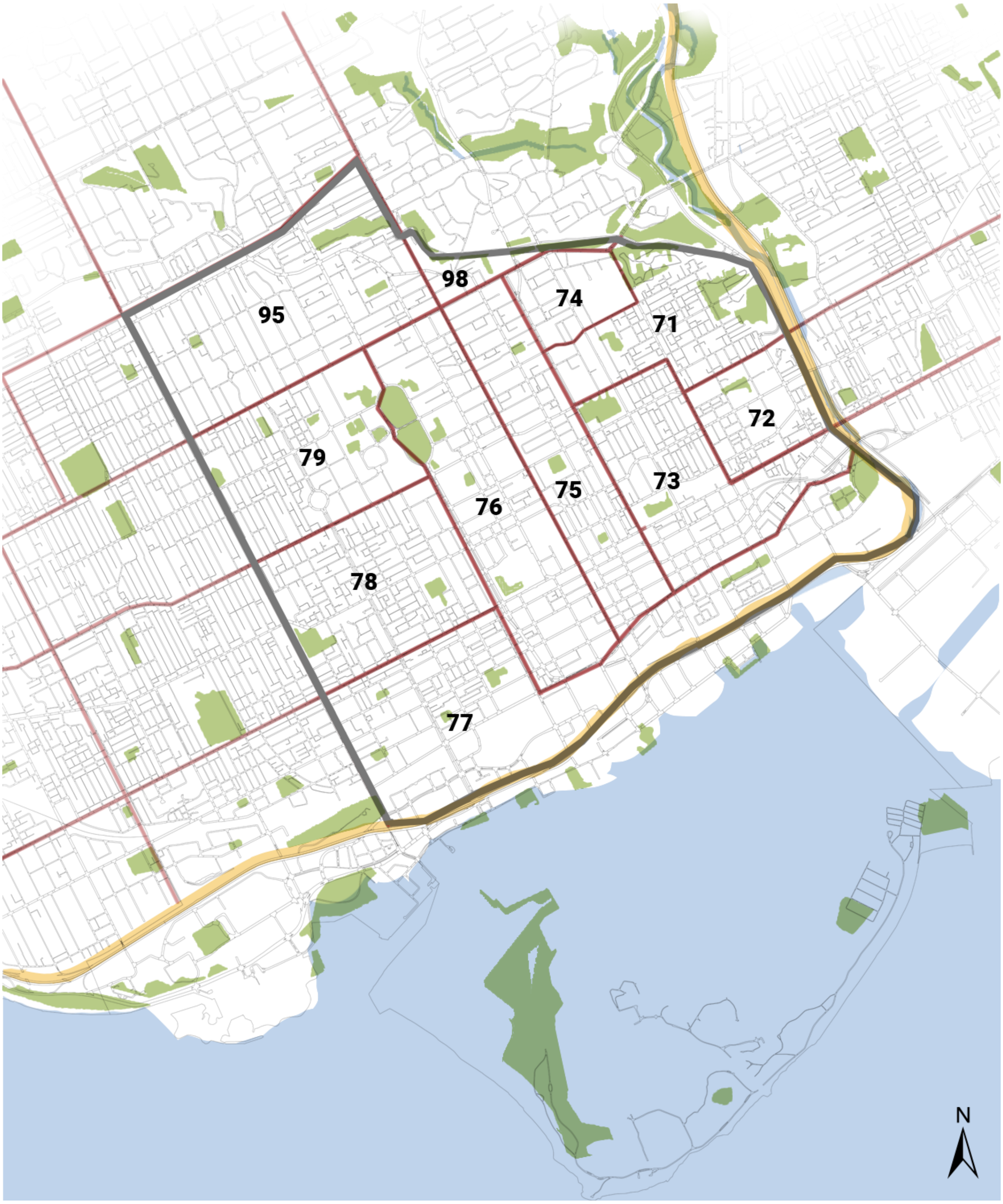
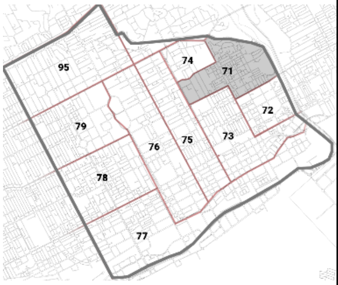
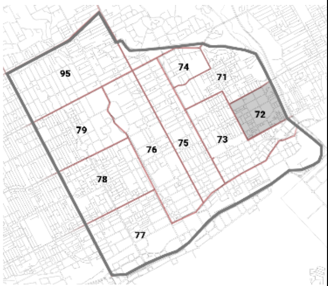
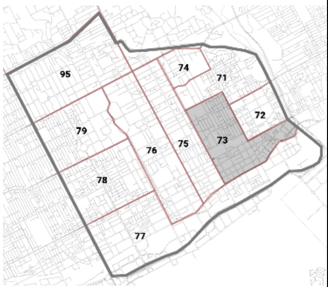
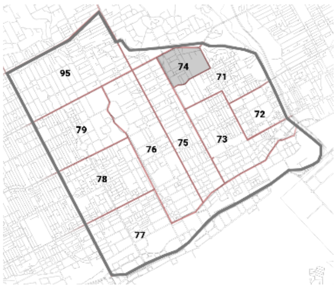
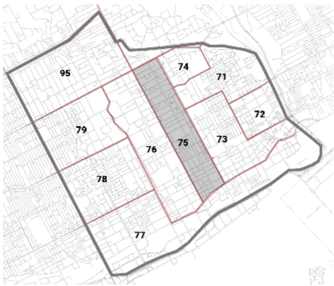
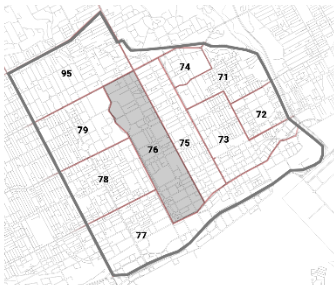
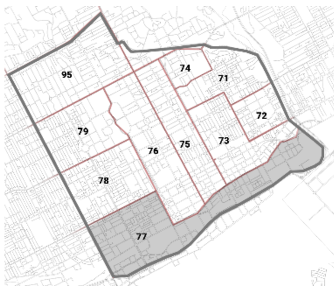


Figure 2.3.1. 1, Map of the city of Toronto, Study area - https://www.toronto.ca/city-government/data-research-maps/neighbourhoods-communities/neighbourhood-profiles/

The study area in Toronto is divided into 10 Neighborhoods, were divided into the following:
1. Cabbagetown-South St. James Town (71)
2. Regent Park (72)
3. Moss Park (73)
4. North St. James Town (74)
5. Church-Yonge Corridor (75)
6. Bay Street Corridor (76)
7. Waterfront Communities-The Island (77)
8. Chinatown circumscriptions (78)
9. University (79)
10. Annex (95)

The following are the neighborhoods with the main characteristics:
Some definitions:
- **Population**: the sum of the population residing in the neighborhood defined in the time if 2016 census
- **Household size**: The average (mean) number of persons in private households in the neighborhood -

Neighborhoods	Location	Population	Total Private Dwellings	Household size Componen ts / family	Period of construction	Area of the neighborhood (km²)
Cabbagetown-South St. James Town (71)		11669	6761	1.71	Pre-1960: 42% 1961-1980: 27% 1981-1990: 19% 1991-2000: 4% 2001-2005: 4% 2006-2010: 4% 2011-2016: 0%	1.17
Regent Park (72)		10803	5183	2.15	Pre-1960: 23% 1961-1980: 18% 1981-1990: 6% 1991-2000: 3% 2001-2005: 2% 2006-2010: 12% 2011-2016: 35%	0.65
Moss Park (73)		20506	12513	1.60	Pre-1960: 22% 1961-1980: 18% 1981-1990: 7% 1991-2000: 9% 2001-2005: 9% 2006-2010: 11% 2011-2016: 23%	1.43

Neighborhoods	Location	Population	Total Private Dwellings	Household size	Period of construction	Area of the neighborhood (km²)
North St. James Town (74)		18615	10109	1.92	Pre-1960: 22% 1961-1980: 51% 1981-1990: 8% 1991-2000: 4% 2001-2005: 2% 2006-2010: 10% 2011-2016: 4%	0.44
Church-Yonge Corridor (75)		31340	21983	1.54	Pre-1960: 17% 1961-1980: 24% 1981-1990: 14% 1991-2000: 13% 2001-2005: 8% 2006-2010: 14% 2011-2016: 11%	1.41
Bay Street Corridor (76)		25797	18436	1.70	Pre-1960: 4% 1961-1980: 16% 1981-1990: 17% 1991-2000: 14% 2001-2005: 6% 2006-2010: 16% 2011-2016: 26%	1.60
Waterfront Communities-The Island (77)		65913	47209	1.61	Pre-1960: 2% 1961-1980: 7% 1981-1990: 9% 1991-2000: 10% 2001-2005: 15% 2006-2010: 24% 2011-2016: 45%	5.09

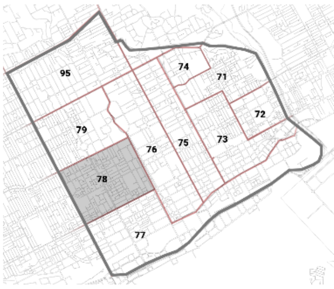
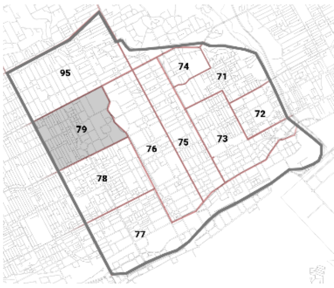
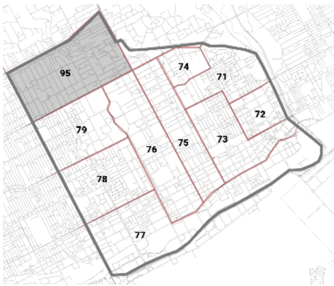
Neighborhoods	Location	Population	Total Private Dwellings	Household size	Period of construction	Area of the neighborhood (km²)
Chinatown circumscriptions (78)		17945	9745	2.00	Pre-1960: 22% 1961-1980: 18% 1981-1990: 7% 1991-2000: 9% 2001-2005: 9% 2006-2010: 11% 2011-2016: 23%	1.48
University (79)		7697	3826	1.97	Pre-1960: 57% 1961-1980: 24% 1981-1990: 4% 1991-2000: 3% 2001-2005: 1% 2006-2010: 5% 2011-2016: 6%	1.56
Annex (95)		30526	18109	1.80	Pre-1960: 43% 1961-1980: 26% 1981-1990: 9% 1991-2000: 6% 2001-2005: 5% 2006-2010: 5% 2011-2016: 6%	2.18

Table 2.3.1. 1, Some details of the defined districts, https://www.toronto.ca/city-government/data-research-maps/neighbourhoods-communities/neighbourhood-profiles/

2.3.2. Methodology for choosing the districts that worked on

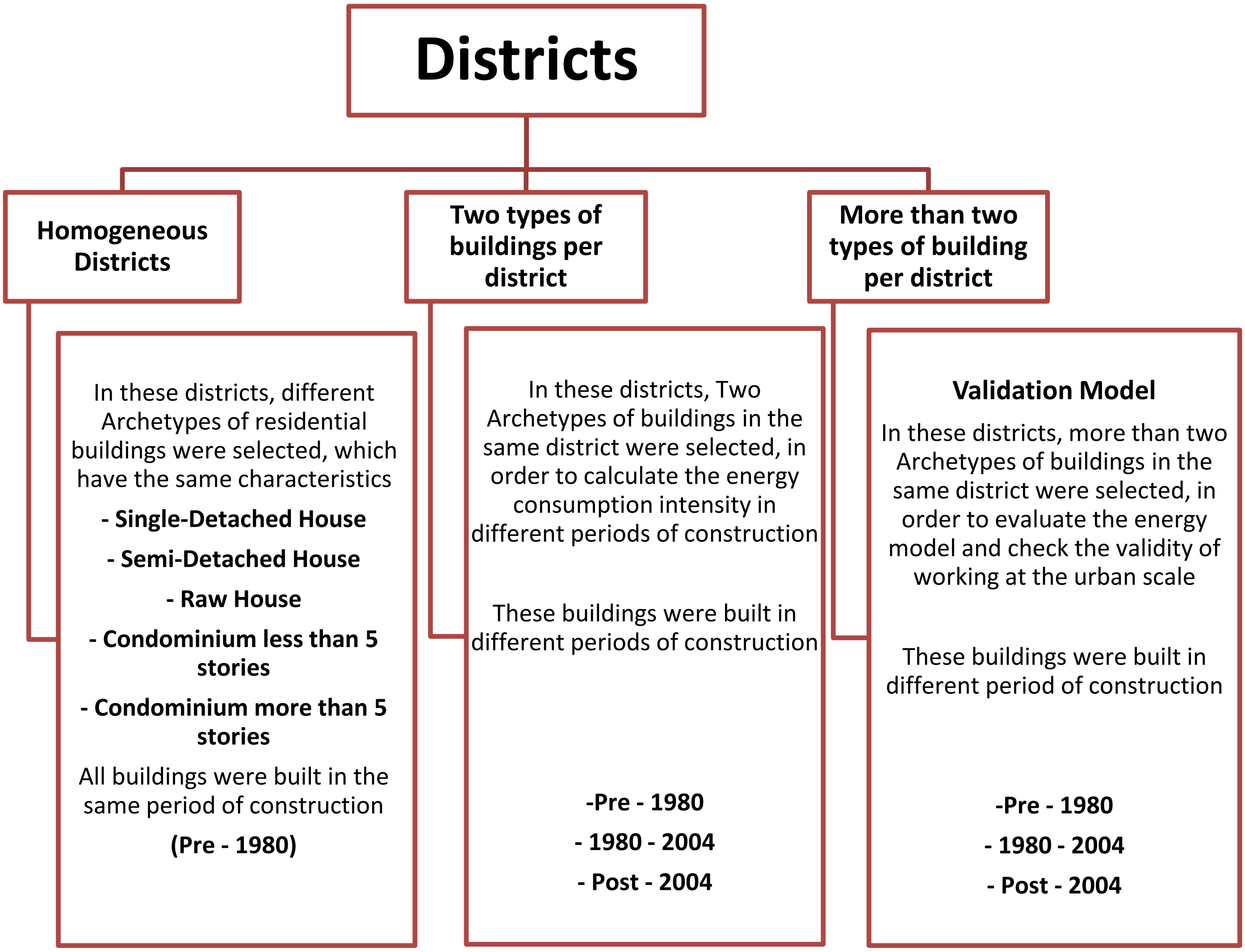
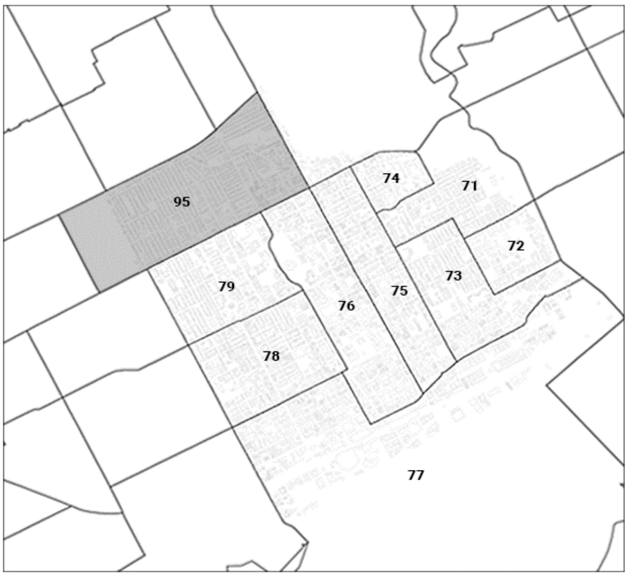


Figure 2.3.2. 1, the methodology of choosing the districts.

2.3.3. Defined Neighborhoods Description

2.3.3.1 Annex Neighborhood (95)

Location	Description



The Annex is an old downtown neighborhood in Toronto, Ontario, Canada.
The neighborhood boundary extends north to Dupont Street and east to Bloor Street, west to Bathurst Street and east to Annino Street.
The neighborhood is a place for students, as well as a place for university faculty. Its residents are mostly English-speaking, and they are well educated, and it is a lively area because of the University of Toronto, and the many restaurants, nightclubs and alleys that meet along Bloor Street.
Many of the townhouses and multi-unit homes in the annex were later converted into single family homes marking the return of this historic Toronto neighborhood to prominence

Figure 2.3.3.1 1, The Annex Neighborhood position

2.3.3.2 Cabbagetown-South St. James Town Neighborhood (71)

Location	Description

Cabbagetown is a neighborhood in central Toronto, Ontario, Canada.
This neighborhood features many semi-detached Victorian homes and is known to be the largest continuous area of Victorian dwellings in all North America.
The neighborhood is bounded by Don Valley to the east, Parliament and Jarvis Streets to the west, Gerrard and Carlton Streets to the south and Bloor and Wellesley Streets to the north.
The neighborhood is home to many artists, musicians, and journalists. Many professors, doctors, social workers, students, and many of the University of Toronto's affiliates reside.

Figure 2.3.3.1 2, The Cabbagetown-South St. James Town Neighborhood position

2.3.3.3 North St. James Town Neighborhood (74)

Location	Description

St. Jamestown is Toronto's most populous neighborhood and is a high-rise community in Canada.
It is bounded by Sherborne Street to the west, Bloor Street to the north, Parliament Street to the east and Wellesley Street to the south.
It is a community that receives a large number of residents coming to Canada, which is a multicultural and multilingual region. In the 19th century it was considered home to the city's middle class.
In the last century, this neighborhood was redistricted from Victorian housing in the 1950s.

Figure 2.3.3.1 3, The North St. James Town Neighborhood position

2.3.3.4 Kensigton - Chinatown Neighborhood (78)

Location	Description

Kensigton Market is a premium neighborhood in downtown Toronto. In November 2006, it was designated a National Historic Site.
Most of the neighborhood's shops, amusement parks, and other attractions are located along Augesta Ave. In addition to the Great Market, the neighborhood is home to many Victorian homes. It has a high proportion of the ethnic Chinese population whose grip emerged in Toronto during the nineteenth century, as well as businesses along Dundas Street west and Sabadian Street west of downtown.

Figure 2.3.3.1 4, The North St. James Town Neighborhood position

Chapter 3.

Analysis of the model of specific consumption in the city of Toronto

The objective of this part of the analysis is to identify models for estimating specific energy consumption

In the first part of the work, the database available in the GIS environment, which contains many characteristics of each individual building, is analyzed

In the second part of the work, the consumption data for the Toronto 2030 platform is analyzed and, by applying a descending model for the residential sector, the specific energy consumption [kWh/m3/year].

In the final part of the analysis, depreciation models are applied to the Toronto context considering the climatic conditions of the site.

3.1. Database analysis and selection of the building stock

The main information that was obtained in the first part of the work is the variables and parameters of the building (Chapter. 3.2.), which we have from the Toronto open data platform for the database, and the basic GIS data preparation from Professor G. Mutani.

3.1.1. Reworking of the database in a GIS environment

In a GIS environment, we started from the generated database with the information in the following shp files:
- **Buildings_Toronto.shp** - (area, parameters, length, location)
- **3DMassing_2020_WGS84.shp** - (Building heights)
- **Ontario-latest-free.shp** - (buildings type)

This first process was necessary to correlate important information about Toronto with the height of the buildings to calculate the parameters of the various variables.

In the "Buildings_Toronto" shp file, the necessary fields have been added to the attribute table for calculating building parameters, which are useful for subsequent analyzes of the necessary study of energy consumption estimation in apartment buildings, which are made by performing some calculations in GIS:

- Total area (m^2).
- Total Gross GIS volume (m^3).
- surface dispersion (heated loss surface) (m^2).
- Form factor S/V (m^{-l}).

- Form Factor S / V - **4 classes (0.90, 0.63, 0.51, 0.32).**

Correction factor to be able to go from S/V ratio to a S/V real, in the following table, the Italian coefficients used to calculate the real S/V for each range of s/v are shown

Average S/V	S/V Range	Italian Coefficient
0.90	s / v > 0.71	1.31
0.63	0.56 <s / v ≤ 0.71	1.25
0.51	0.45 <s / v ≤ 0.56	1.24
0.32	s / v ≤ 0.45	1.145

Table 3.1.1. 1, Italian Coefficients for the calculation of the real S / V form factor (data calculated on a database updated to 2015 – CTC Turin).

Then for the period of construction, we use the database mentioned on the Toronto 2030 Platform and inserted it on GIS environment to use it.
- Period of constrcution – **3 calsses (Pre – 1980, 1980 – 2004, Post – 2004).**

In this way, we have a database relating to the building stock of the city of Toronto of where we have the information for each building relating to the period of construction, the basic parameters, Type of the buildings, and technical-geometric characteristics of the building.

Gross GIS Volume for building stock

Figure 3.1.1. 1,. Gross GIS volume for the building stocks in Toronto neighborhoods (data calculated on ArcGIS)

Form Factor (S/V) Ratio

Figure 3.1.1. 2, Form factor for Toronto neighborhoods (data calculated on ArcGIS)

Building stock by intended use

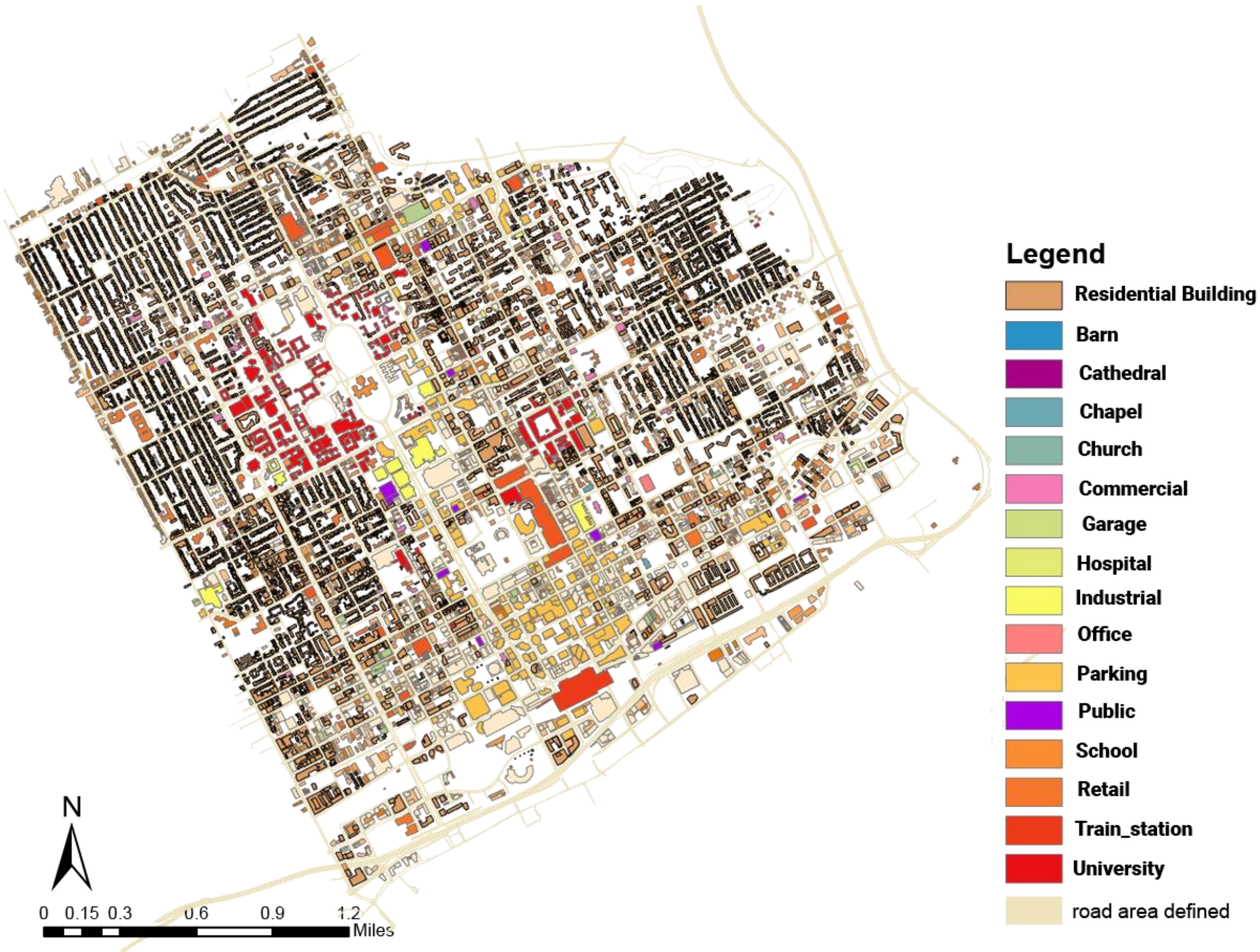


Figure 3.1.1. 3, Building stock by intended use (data calculated on ArcGIS)

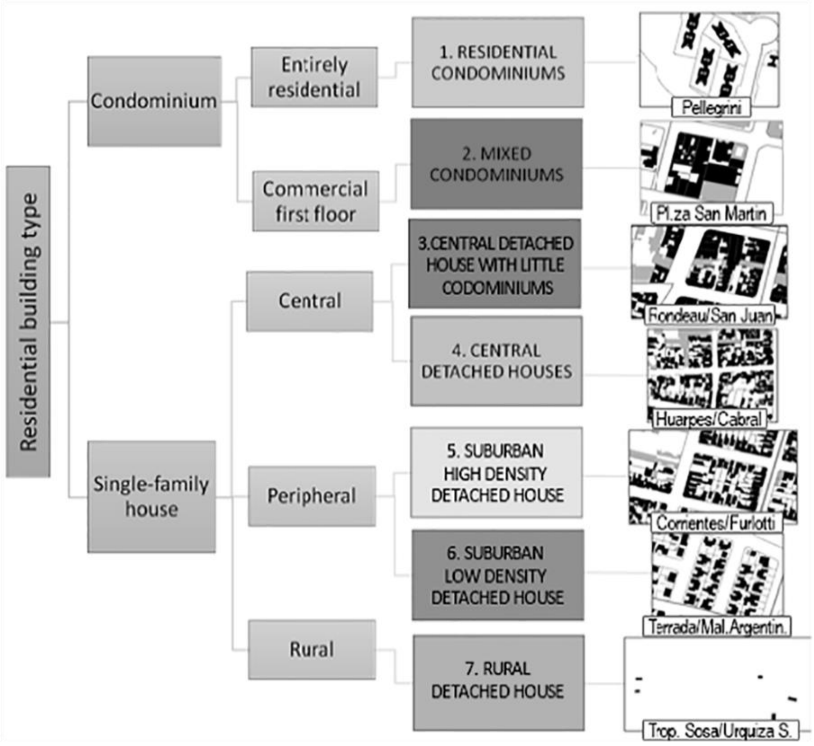
3.2. Analysis of the residential sector

This paragraph shows the data on the Toronto building stock, for each sector you have all information necessary for the Top-down model setting.

For the residential sector it is indicated:
- **Period of construction**
- **Dimensional data**: Area of the building (m^2), Gross GIS volume (m^3)
- **Energy consumption intensity**: Electricity (kWh/m^3/year), Natural gas (kWh/m^3/year)

For the city of Toronto, the analysis shows that there are different types of buildings according to their intended use, which also shows the built heritage that characterizes the different areas of Toronto. this analysis has allowed us to understand the different areas of Toronto that include some types of recurring apartment buildings.

The identification of different types of apartment buildings in Toronto can be based on the following analysis conducted in Gran Mendoza, Argentina.



From this point, we started to define the typical model of the apartment building in different neighborhoods of the city, then the different areas were listed and analyzed along with the main characteristics that could affect the energy consumption so that each archetype has different energy consumption if the construction period different.
The city of Toronto and its four identified neighborhoods were represented by a GIS tool through a technical map, with hot and non-hot volumes defined. In the study area, five repeated building models were identified, and each had a percentage of hot volume.

Figure 3.2. 1, Recurrent groups of residential buildings – Energy use modeling for residential building in the metropolitan area of Gran Mendoza, G. Mutani 2018.

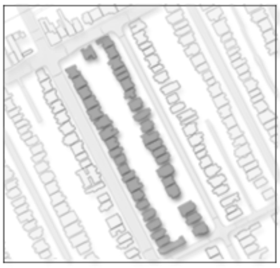
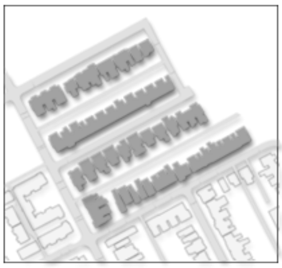
The types of residential buildings analyzed are as follows:
- **Detached house**
- **Semi-detached houses.**
- **Raw house.**
- **Condominiums of less than 5 floors.**
- **Condominiums of more than 5 floors.**

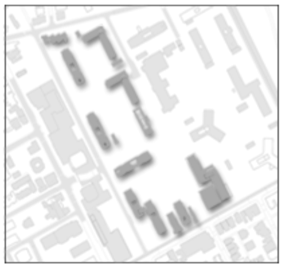
Starting from the information of building blocks (census divisions), a sample of building block types by frequent characteristics was selected to obtain as homogeneous positions as possible within the city.

3.2.1. Selection of the building stock
3.2.1.1. Homogeneous Archetypes

ANNEX	CABBAGETOWN-SOUTH ST. JAMES TOWN		NORTH ST. JAMES TOWN	KENSIGTON - CHINATOWN

BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5

Block of building		Block 1	Block 2	Block 3	Block 4	Block 5
Neighborhood name		Annex	Cabaragetown - South St. James Town		North St. James Town	ChinaTown
Number of neighborhood		95	71	71	74	78
Archetype of building		Single-detached house	Raw house	Semi-detached house	Condominium > 5 stories	Condominium < 5 stories
Characteristics	Unit					
Number of Buildings	-	41	27	14	29	12
Components per family	Inh/fam	3	1.8	2.5	1.9	1.2
Period of construction	-	Pre - 1980	Pre - 1980	Pre - 1980	Pre - 1980	Pre - 1980
Footprint area	m^2	8537.0	7872.1	3079.3	13422.8	3872.8
Gross GIS volume	m^3	135137.5	59919.0	26663.6	27951.5	776583.7
S/V Ratio	m^{-1}	0.86	0.66	0.83	0.40	0.62
Building Density	m^3/m^2	2.40	2.29	3.03	2.08	7.6
Building coverage ratio	m^2/m^2	0.26	0.30	2.40	0.28	0.22

Table 3.2.1.1. 1,Characteristics of the Homogenous archetypes of residential building

3.2.1.2. Mixed Archetypes (Two types of buildings per district)

REGENT PARK		MOSS PARK	WATERFRONT COMMUNITIES - ISLAND	ANNEX

BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5

Block of building		Block 1	Block 2	Block 3	Block 4	Block 5
Neighborhood name		Regent Park		Moss Park	Regent Park	Annex
Number of neighborhoods		72	72	73	72	95
Archetype of building	1	Raw house	Semi-Detached House	Condominium > 5 stories	Condominium > 5 stories	Condominium > 5 stories
	2	Condominium > 5 stories	Condominium > 5 stories	Condominium < 5 stories	Raw house	Semi-Detached House
Characteristics	Unit					
Number of Buildings	-	7	9	12	5	13
		9	13	5	14	16
Components per family	Inh/fam	1.8	2.5	1.2	1.2	1.2
		1.2	1.2	1.9	1.8	2.5
Period of construction	-	Pre - 1980	Pre - 1980	Post - 2004	Pre - 1980	Pre - 1980
		Post - 2004	1980 - 2004	Post - 2004	1980 - 2004	Post - 2004
Footprint area	m^2	15227.4	15828.9	11994.2	21809.2	7690.7
Gross GIS volume	m^3	243709.9	477058.1	133343.3	268422.4	61832.7
S/V Ratio	m^{-1}	0.69	0.85	0.33	0.37	0.47
		0.42	0.38	0.50	0.69	0.81
Building Density	m^3/m^2	8.53	11.1	6.88	3.71	12.8
Building coverage ratio	m^2/m^2	0.40	0.27	0.46	0.22	0.37

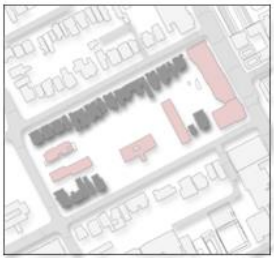
UNIVERSITY	ANNEX	CABBAGETOWN-SOUTH ST. JAMES TOWN





BLOCK 6	BLOCK 7	BLOCK 8	BLOCK 9	BLOCK 10

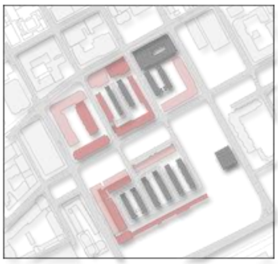
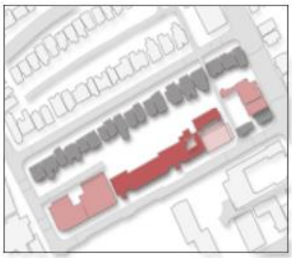



Block of building		Block 6	Block 7	Block 8	Block 9	Block 10
Neighborhood name		University			Annex	Cabaragetown - South St. James Town
Number of neighborhoods		79	79	79	95	71
Archetype of building	1	Institutional	Institutional	Institutional	Condominium > 5 stories	Single-Detached House
	2	-	Semi-Detached House	Single-Detached House	Single-Detached House	Raw house
Characteristics	Unit					
Number of Buildings		31	23	56	6	12
		-	30	21	21	11
Components per family	Inh/fam	-	-	-	1.2	3
		-	2.5	3	3	1.8
Period of construction	-	Pre - 1980	Pre - 1980	Pre - 1980	Pre - 1980	Pre - 1980
		-	1980 - 2004	1980 - 2004	Post - 2004	Post- 2004
Footprint area	m^2	15227.4	20369.1	35530.2	10223.8	7555.0
Gross GIS volume	m^3	243709.9	699001.4	486086.3	179087.8	46374.5
S/V Ratio	m^{-1}	0.69	0.5	0.70	0.31	1.02
		-	0.95	1.03	0.81	0.68
Building Density	m^3/m^2	--	16.4	6.51	6.72	2.43
Building coverage ratio	m^2/m^2	--	0.35	0.35	0.28	0.29

Table 3.2.1.2. 1, Characteristics of the Mixed archetypes of residential building (two buildings per district)

3.2.1.3. Mixed Archetypes (More than two types of building per district)

WATERFRONT COMMUNITIES - ISLAND	Annex	North St. James Town	WATERFRONT COMMUNITIES - ISLAND
			
BLOCK 1	**BLOCK 2**	**BLOCK 3**	**BLOCK 4**
			

Block of building		Block 1	Block 2	Block 3	Block 4
Neighborhood name		Waterfront communities – Island	Annex	North St. James Town	Waterfront communities – Island
Number of neighborhoods		77	95	74	77
Archetype of building	**1**	Condominium > 5 stories	Semi-Detached house	Semi-Detached house	Raw House
	2	Single-Detached House	Condominium < 5	Condominium < 5	Condominium < 5
	3	Condominium < 5	Offices	Hospitality	Hospitality
Characteristics	**Unit**				
Number of Buildings	-	24	21	8	7
		6	7	6	4
		6	7	1	4
Components per family	Inh/fam	1.2	2.5	2.5	1.8
		3	1.9	1.9	1.9
		1.9	-	-	-
Period of construction	-	Pre - 1980	Pre - 1980	Pre - 1980	Pre - 1980
		1980 - 2004	Pre - 1980	Pre - 1980	Pre - 1980
		1980 - 2004	Pre - 1980	Pre - 1980	Post - 2004
Footprint area	m²	33402.1	9236.5	6538.6	10121.3
Gross GIS volume	m³	608808.4	133054.4	54867.6	69489.7
S/V Ratio	m^{-1}	0.68	0.69	0.68	0.62
		0.35	0.55	0.69	0.52
		0.47	0.43	0.41	0.62
Building Density	m^3/m^2	4.63	5.81	3.13	2.97
Building coverage ratio	m^2/m^2	0.25	0.397	0.37	0.43

Table 3.2.1.3 1,Characteristics of the Mixed archetypes of residential building (two buildings per district)

3.3. Analysis of energy consumption

For calculating the needs of energy consumption of the residential sector, it was consulted the " Toronto 2030 platform " which includes all the information about the energy consumption for the GHG gas, Electricity, and Natural gas, even in this study we considered the Electricity and natural gas consumption, focusing on the volume of the building stock. In this study, we relied on the unit for energy consumption kWh/m3/year, therefore consumption refers to the period of construction also.

As mentioned earlier, that in this work we work on the Homogeneous archetype of residential buildings, also we touched on the districts that contain mixed buildings which includes two types of buildings per district, and more than two types of buildings per district, in order to obtain the energy consumption in different construction periods, because we need to see how the difference in the period of construction effect on the energy consumption.
In the database two fields relate to form factor S/V ratio, period of construction. The main characteristics are therefore known for each building in Toronto.
Furthermore, the outdoor air temperature and its relative value of Heating degree days (HDD) is a variable influencing energy consumption, even if the temperature is low so there is high energy consumption. Then for each weather station, the HDD is calculated at 18°C, and the altitudes differences of the various areas in Toronto.
The simplified energy model of residential buildings was then normalized, to depend only on the characteristics of the buildings, population, and the urban context.

3.3.1 Identification of the energy consumption of Homogeneous Archetypes

The following information calculated in the GIS environment is known for the consumption of georeferenced buildings:-

- Characteristics of the building (at this stage of the work they are indispensable for the sector residential information on the S / V form factor and the time of construction).

- Consumption data normalized according to Toronto 2030 platform, which is identified the energy consumption specific for the electricity and the natural gas that worked on.

- The homogeneous groups of buildings were identified considering the residential sector (Single-Detached house, Semi-Detached house, Raw houses, Condominium less than 5 stories, condominium more than 5 stories)

For identifying the energy consumption for the Natural gas: (Using the multiple linear regression)
- The form factor S/V ratio **(4 average data classes: 0.90, 0.63, 0.51, 0.32).**

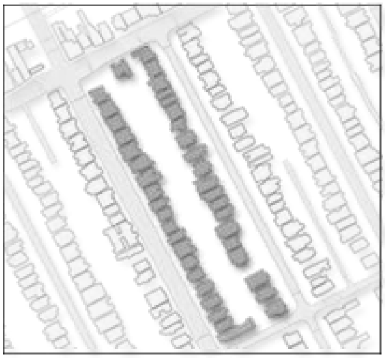
- The period of construction **(3 classes: Pre - 1980, 1980 - 2004, Post - 2004)**

For identifying the energy consumption for the Electricity: (Using the Single linear regression)
-Inhabitants/m³ were defined **(5 classes: 0.00072, 0.00125, 0.00134, 0.0016, 0.00103)**

- The consumption data (kWh/m³/year): through the Toronto 2030 platform, and by considering the gross volume of the building, Calaulated energy consumption for Electricity and Natural gas by the following fermula:

Energy consumption Intensity (kWh/m³/year)
= Energy consumption (electricity/Natural gas)(MWh/year) x 1000 / gross volume

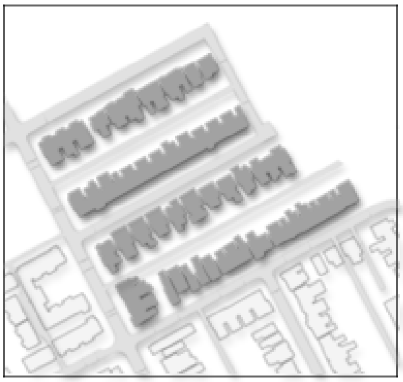
Archetype 1: Single – Detached House



Period of Construction	Pre - 1980
Gross GIS Volume (m³)	57371.3
Form Factor S/V ratio (m^{-l})	0.86
Energy consumption per 41 buildings (MWh/ year)	
- Electricity consumption	2500 – 2800
- Natural Gas consumption	2000 - 2200
Energy consumption (kWh/m³/ year)	Using Gross Volume from GIS
- Electricity consumption	43.5 - 48.8
- Natural Gas consumption	34.8 – 38.3

Table 3.3.1. 1, The Single-Detached house archetype

Archetype 2: Raw House



Period of Construction	Pre - 1980
Gross GIS Volume (m³)	59919.0
Form Factor S/V ratio (m^{-l})	0.66
Energy consumption per 27 buildings (MWh/ year)	
- Electricity consumption	1900 – 2100
- Natural Gas consumption	1400 - 1750
Energy consumption (kWh/m³/ year)	Using Gross GIS Volume
- Electricity consumption	31.7 – 35.0
- Natural Gas consumption	23.3 – 29.2

Table 3.3.1. 2, The Raw house archetype

Archetype 3: Semi – Detached House

Period of Construction	Pre - 1980
Gross GIS Volume (m³)	26663.6
Form Factor S/V ratio (m^{-l})	0.83
Energy consumption per 14 buildings (MWh/ year)	
- Electricity consumption	700 - 800
- Natural Gas consumption	300 - 400
Energy consumption (kWh/m³/ year)	Using Gross GIS Volume
- Electricity consumption	35.0 - 40.0
- Natural Gas consumption	15.0 – 20.0

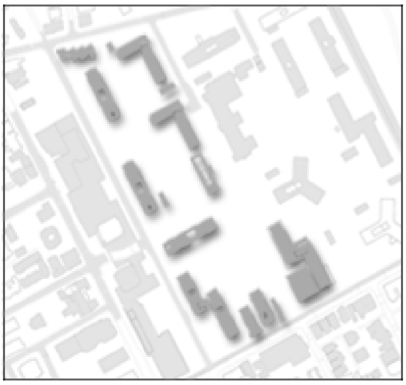
Table 3.3.1. 3, The Semi-Detached house archetype

Archetype 4: Condominium less than 5 stories

Period of Construction	Pre - 1980
Gross GIS Volume (m^3)	20963.6
Form Factor S/V ratio (m^{-1})	0.62
Energy consumption per 12 buildings (MWh/ year)	
- Electricity consumption	400 - 500
- Natural Gas consumption	200 - 200
Energy consumption (kWh/m^3/ year)	Using Gross GIS Volume
- Electricity consumption	26.2 – 30
- Natural Gas consumption	9.5 – 9.5

Table 3.3.1. 4, The Condominium less than 5 stories archetype

Archetype 5: Condominium more than 5 stories



Period of Construction	Pre - 1980
Gross GIS Volume (m^3)	906341.7
Form Factor S/V ratio (m^{-1})	0.40
Energy consumption per 29 buildings (MWh/ year)	
- Electricity consumption	17700 – 19500
- Natural Gas consumption	25000-27500
Energy consumption (kWh/m^3/ year)	Using Gross GIS Volume
- Electricity consumption	19.5 - 21.5
- Natural Gas consumption	31.9 – 35.3

Table 3.3.1. 5, The Condominium more than 5 stories archetype

Institutional (Used to find the energy consumption for the other archetypes in different period of construction)

Period of Construction	Pre - 1980
Gross GIS Volume (m^3)	908719.7
Form Factor S/V ratio (m^{-1})	0.69
Energy consumption per 29 buildings (MWh/ year)	
- Electricity consumption	11,300 – 12,500
- Natural Gas consumption	16,900 – 18,700
Energy consumption (kWh/m^3/ year)	Using Gross GIS Volume
- Electricity consumption	12.4 - 13.7
- Natural Gas consumption	18.5 - 20.5

Table 3.3.1. 6, The Condominium less than 5 stories archetype

3.3.2 Identification of the energy consumption of Mixed Archetypes – (Two types of buildings per district)

Mixed Archetype 1: Raw house / Condominium more than 5 stories

<table>
<tr><td rowspan="9"></td><td>Period of Construction</td><td>Pre – 1980</td><td>Post - 2004</td></tr>
<tr><td>Gross GIS Volume (m^3)</td><td>62159.1</td><td>262787.4</td></tr>
<tr><td>Form Factor S/V ratio (m^{-l})</td><td>0.69</td><td>0.42</td></tr>
<tr><td colspan="3">Energy consumption per 16 buildings (MWh/ year)</td></tr>
<tr><td>- Electricity consumption</td><td colspan="2">8,100 – 9,000</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="2">5000 - 6200</td></tr>
<tr><td>Energy consumption per <u>Raw house</u> (kWh/m^3/ year)</td><td colspan="2">Using Gross GIS Volume</td></tr>
<tr><td>- Electricity consumption</td><td colspan="2">31.7 – 35.0</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="2">23.3 – 29.2</td></tr>
<tr><td>Electricity consumption: (using Gross Volume)
- 31.7*62159.1 = 1,970,443.4 kWh/year
- 8100000-1,970,443.4= 6,129,556.5 kWh/year
- 6,129,556.5/262787.4= 15.1 kWh/m^3/year</td><td rowspan="2">Energy consumption per <u>Condominium more than 5 stories</u> (kWh/m^3/ year)</td><td colspan="2" rowspan="2">Using Gross GIS Volume</td></tr>
<tr><td>- 35*62159.1= 2,175,568.5 kWh/year
- 9000000-2,175,568.5= 6,824,431.5 kWh/year
- 6,824,431.5/262787.4= 19.2 kWh/m^3/year</td></tr>
<tr><td>Natural Gas consumption: (using Gross Volume)
- 23.3*62159.1= 1,448,307.03 kWh/year
- 5000000- 1,448,307.03= 3,551,692.97 kWh/year
- 3,551,692.97/262787.4= 13.5 kWh/m^3/year</td><td>- Electricity consumption</td><td colspan="2">15.1 – 19.2</td></tr>
<tr><td>- 29.2*62159.1=1,815,045.72 kWh/year
- 6200000-1,815,045.72= 4,384,954.28 kWh/year
- 4,384,954.28/262787.4 = 16.6 kWh/m^3/year</td><td>- Natural Gas consumption</td><td colspan="2">13.5 - 16.6</td></tr>
</table>

Table 3.3.2. 1,The Mixed archetype (1)

Mixed Archetype 2: Semi-Detached House / Condominium more than 5 stories

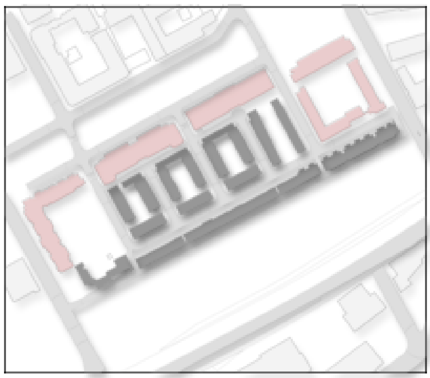
<table>
<tr><td rowspan="9"></td><td>Period of Construction</td><td>Pre – 1980</td><td>1980 - 2004</td></tr>
<tr><td>Gross GIS Volume (m^3)</td><td>100021.6</td><td>257874.8</td></tr>
<tr><td>Form Factor S/V ratio (m^{-l})</td><td>0.85</td><td>0.38</td></tr>
<tr><td colspan="3">Energy consumption per 19 buildings (MWh/ year)</td></tr>
<tr><td>- Electricity consumption</td><td colspan="2">10,800 – 12,000</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="2">13,300 – 14,700</td></tr>
<tr><td>Energy consumption per <u>Semi-Detached house</u> (kWh/m^3/ year)</td><td colspan="2">Using Gross GIS Volume</td></tr>
<tr><td>- Electricity consumption</td><td colspan="2">35 - 40</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="2">15 - 20</td></tr>
<tr><td>Electricity consumption: (using Gross Volume)
- 35*100021.6= 3,500,756 kWh/year
- 10800000-3,500,756= 7,299,244 kWh/year
- 7,299,244 /257874.8= 27.5 kWh/m^3/year</td><td rowspan="2">Energy consumption per <u>Condominium more than 5 stories</u> (kWh/m^3/ year)</td><td colspan="2" rowspan="2">Using Gross GIS Volume</td></tr>
<tr><td>- 40*100021.6= 4,000,864 kWh/year
- 12000000-4,000,864= 7,999,136 kWh/year
- 7,999,136/257874.8= 30.3 kWh/m^3/year</td></tr>
<tr><td>Natural Gas consumption: (using Gross Volume)
- 15*100021.6= 1,500,324 kWh/year
- 13300000- 1,500,324=11,799,676 kWh/year
- 11,799,676 /257874.8=29.5 kWh/m^3/year</td><td>- Electricity consumption</td><td colspan="2">27.5 – 30.3</td></tr>
<tr><td>- 20*100021.6=2,000,432 kWh/year
- 14700000-2,000,432= 12,699,568 kWh/year
- 12,699,568/257874.8= 31.2 kWh/m^3/year</td><td>- Natural Gas consumption</td><td colspan="2">29.5 – 31.2</td></tr>
</table>

Table 3.3.2. 2, The Mixed archetype (2)

Mixed Archetype 3: Condominium more than 5 stories / Condominium less than 5 stories

	**Period of Construction**	Post - 2004	Post - 2004
	Gross GIS Volume (m³)	84262.3	93528.7
	Form Factor S/V ratio (m⁻ˡ)	0.33	0.50
	Energy consumption per 17 buildings (MWh/ year)		
	- Electricity consumption	1,600 – 1,800	
	- Natural Gas consumption	1,500 – 1,600	
	Energy consumption per Condominium more than 5 stories (kWh/m³/ year)	Using Gross GIS Volume	
	- Electricity consumption	15.1 – 19.2	
	- Natural Gas consumption	13.5 - 16.6	
Electricity consumption: (using Gross Volume) - 15.1*84262.3= 1,272,360.73 kWh/year - 1600000-1,272,360.73= 363,311.59 kWh/year - 211,004.15/100065.5= **9.3** kWh/m³/year - 19.2*77725.5= 2,013,090.45kWh/year - 1800000-2,013,090.45= 213,090.45 kWh/year - 213,090.45/100065.5= **11.7** kWh/m³/year	**Energy consumption per Condominium less than 5 stories (kWh/m³/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 13.5*77725.5= 2,114,133.6 kWh/year - 1500000- 2,114,133.6 =614,133.6 kWh/year - 614,133.6/100065.5=**6.1** kWh/m³/year	**- Electricity consumption**	9.3 – 11.7	
- 16.6*77725.5=2,355,082.65kWh/year - 1600000-2,355,082.65= 187,675kWh/year - 187,675/100065.5= **7.5** kWh/m³/year	**- Natural Gas consumption**	6.10 – 7.50	

Table 3.3.2. 3, The Mixed archetype (4)

Mixed Archetype 4: Condominium more than 5 stories / Raw House

	**Period of Construction**	Pre – 1980	1980 - 2004
	Gross GIS Volume (m³)	599650.3	36427.2
	Form Factor S/V ratio (m⁻ˡ)	0.37	0.69
	Energy consumption per 22 buildings (MWh/ year)		
	- Electricity consumption	7,500 – 8,300	
	- Natural Gas consumption	15,800 – 17,500	
	Energy consumption per Condominium more than 5 stories (kWh/m³/ year)	Using Gross GIS Volume	
	- Electricity consumption	19.5 – 21.5	
	- Natural Gas consumption	31.9 – 35.3	
Electricity consumption: (using Gross Volume) - 19.5 * 599650.3= 11,693,180.85 kWh/year - 7500000-11,693,180.85= 4,193,180.85 kWh/year - 4,193,180.85/36427.2= **24.4** kWh/m³/year - 21.5*599650.3= 9,654,369.83 kWh/year - 8300000-9,654,369.83= 4,193,180.85 kWh/year - 4,193,180.85/36427.2= **27.1** kWh/m³/year	**Energy consumption per Raw house (kWh/m³/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 31.9 *599650.3= 21,647,375.83 kWh/year - 15800000- 21,647,375.83=5,847,375.83 kWh/year - 5,847,375.83/36427.2=**16.0** kWh/m³/year	**- Electricity consumption**	24.1 – 27.1	
- 35.3*599650.3=23,926,046.97 kWh/year - 17500000-23,926,046.97= 6,426,046.97 kWh/year - 6,426,046.97/36427.2= **19.6** kWh/m³/year	**- Natural Gas consumption**	16.0 – 19.6	

Table 3.3.2. 4, The Mixed archetype (4)

Mixed Archetype 5: Institutional / Semi-Detached House

	**Period of Construction**	Pre – 1980	1980 - 2004
	Gross GIS Volume (m³)	872869.7	59132.2
	Form Factor S/V ratio (m^{-1})	0.50	0.95
	Energy consumption per 53 buildings (MWh/ year)		
	- Electricity consumption	18,400 – 20,300	
	- Natural Gas consumption	20,800 – 23,000	
	Energy consumption per Institutional (kWh/m³/ year)	**Using Gross GIS Volume**	
	- Electricity consumption	12.9 – 13.7	
	- Natural Gas consumption	18.5 – 20.5	
Electricity consumption: (using Gross Volume) - 12.9 * 872869.7=11,260,019.13 kWh/year - 18400000-8,117,688.21= 7,139,980.87 kWh/year - 7,139,980.87/59132.2= **30.8** kWh/m³/year - 13.7*872869.7= 8,990,557.91kWh/year - 20300000-8,990,557.91= 11,309,442.09 kWh/year - 11,309,442.09 /59132.2= **32.7** kWh/m³/year	**Energy consumption per <u>Semi-Detached House</u> (kWh/m³/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 18.5 *872869.7= 12,132,888.83 kWh/year - 20800000- 12,132,888.83=8,667,111.17 kWh/year - 8,667,111.17/59132.2=**35.9** kWh/m³/year	**- Electricity consumption**	30.8 – 32.7	
- 20.5*872869.7=17,893,814.5 kWh/year - 23000000-17,893,814.5=5,106,185.5 kWh/year - 5,106,185.5/59132.2= **38.6** kWh/m³/year	**- Natural Gas consumption**	35.9 – 38.6	

Table 3.3.2. 5, The Mixed archetype (5)

Mixed Archetype 6: Institutional / Single-Detached House

	**Period of Construction**	Pre – 1980	1980 - 2004
	Gross GIS Volume (m³)	625698.3	22416.7
	Form Factor S/V ratio (m^{-1})	0.70	1.03
	Energy consumption per 77 buildings (MWh/ year)		
	- Electricity consumption	13,700 – 15,100	
	- Natural Gas consumption	10,700 – 11,500	
	Energy consumption per Institutional (kWh/m³/ year)	**Using Gross GIS Volume**	
	- Electricity consumption	12.9 – 13.7	
	- Natural Gas consumption	18.5 – 20.5	
Electricity consumption: (using Gross Volume) - 12.9*625698.3=8,071,508.07 kWh/year - 13700000-8,071,508.07= 5,628,491.93kWh/year - 7,881,005.81/22416.7= **35.1** kWh/m³/year - 13.7*625698.3= 6,444,692.49 kWh/year - 15100000-6,444,692.49= 8,655,307.51kWh/year - 8,655,307.51/22416.7= **38.6** kWh/m³/year	**Energy consumption per <u>Single-Detached House</u> (kWh/m³/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 18.5 *625698.3= 197,950,000 kWh/year - 10700000- 197,950,000 =187,250,000 kWh/year - 187,250,000/22416.7=**27.7** kWh/m³/year	**- Electricity consumption**	35.1 – 38.6	
- 20.5*625698.3=8,697,206.37 kWh/year - 11500000-8,697,206.37= 2,002,793.63 kWh/year - 2,002,793.63/22416.7= **30.4** kWh/m³/year	**- Natural Gas consumption**	27.7 – 30.4	

Table 3.3.2. 6, The Mixed archetype (6)

Mixed Archetype 7: Condominium more than 5 stories / Single-Detached House

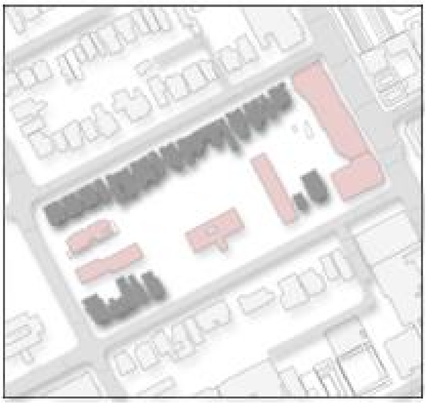
	**Period of Construction**	Pre – 1980	Post - 2004
	Gross GIS Volume (m³)	194390.9	44392.8
	Form Factor S/V ratio (m⁻ˡ)	0.31	0.89
	Energy consumption per 27 buildings (MWh/ year)		
	- Electricity consumption	7,100 – 7,900	
	- Natural Gas consumption	12,100 – 13,400	
	Energy consumption per <u>Condominium more than 5 stories</u> (kWh/m³/ year)	**Using Gross GIS Volume**	
	- Electricity consumption	19.5 – 21.5	
	- Natural Gas consumption	31.9 – 35.3	
Electricity consumption: (using Gross Volume) - 19.5*194390.9=3,790,622.55 kWh/year - 7100000-3,790,622.55= 3,309,377.45 kWh/year - 3,309,377.45/44392.8= **16.4 kWh**/m³/year - 21.5*194390.9= 3,129,693.49 kWh/year - 7900000-3,129,693.49= 4,770,306.51kWh/year - 4,770,306.51/44392.8= **18.7** kWh/m³/year	**Energy consumption per <u>Single-Detached House</u> (kWh/m³/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 31.9 *194390.9= 7,036,950.58 kWh/year - 12100000 -7,036,950.58=5,063,049.42 kWh/year - 5,063,049.42/44392.8=**20.4** kWh/m³/year	**- Electricity consumption**	16.4 – 18.7	
- 35.3*194390.9=7,756,196.91 kWh/year - 13400000-7,756,196.91= 5,643,803.09kWh/year - 5,643,803.09/44392.8= **22.7** kWh/m³/year	**- Natural Gas consumption**	20.4 – 22.7	

Table 3.3.2. 7, The Mixed archetype (7)

Mixed Archetype 8: Single-Detached House / Raw House

	**Period of Construction**	Pre – 1980	Post - 2004
	Gross GIS Volume (m³)	14624.8	47207.9
	Form Factor S/V ratio (m⁻ˡ)	1.02	0.68
	Energy consumption per 23 buildings (MWh/ year)		
	- Electricity consumption	2,100 – 2,300	
	- Natural Gas consumption	1,000 – 1,100	
	Energy consumption per <u>Single-Detached House</u> (kWh/m³/ year)	**Using Gross GIS Volume**	
	- Electricity consumption	43.5 – 48.8	
	- Natural Gas consumption	34.8 – 38.3	
Electricity consumption: (using Gross Volume) - 43.5*14624.8=636,178.8 kWh/year - 2100000-636,178.8= 1,463,821.2 kWh/year - 1,463,821.2/47207.9= **31.0** kWh/m³/year - 48.8*14624.8= 713,690.24 kWh/year - 2300000-713,690.24= 1,586,309.76 kWh/year - 1,994,341.68/47207.9= **33.6** kWh/m³/year	**Energy consumption per <u>Semi-Detached House</u> (kWh/m³/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 20.9 *14624.8= 305,658.32kWh/year - 1000000- 305,658.32=694,341.68 kWh/year - 694,341.68/47207.9=**14.7** kWh/m³/year	**- Electricity consumption**	31.0 – 33.6	
- 24.4*14624.8=356,845.12 kWh/year - 1100000-356,845.12= 743,154.88 kWh/year - 743,154.88/47207.9= **15.7** kWh/m³/year	**- Natural Gas consumption**	14.7 – 15.7	

Table 3.3.2. 8, The Mixed archetype (8)

Mixed Archetype 9: Condominium more than 5 stories / Semi-Detached House

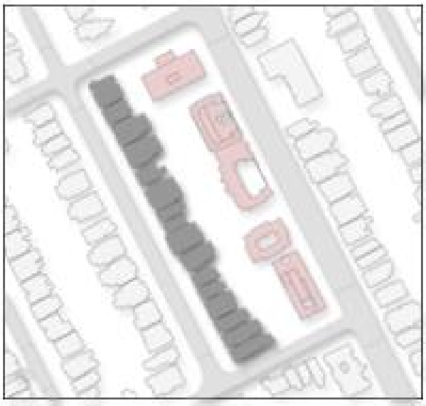
	**Period of Construction**	Pre – 1980	Post - 2004
	Gross GIS Volume (m^3)	228949.2	32443.2
	Form Factor S/V ratio (m^{-l})	0.47	0.81
	Energy consumption per 29 buildings (MWh/ year)		
	- Electricity consumption	3,600 – 4,000	
	- Natural Gas consumption	7,400 – 8,100	
	Energy consumption per <u>Condominium more than 5 stories</u> (kWh/m^3/ year)	**Using Gross GIS Volume**	
	- Electricity consumption	19.5 – 21.5	
	- Natural Gas consumption	31.9 – 35.3	
Electricity consumption: (using Gross Volume) - 19.5*228949.2=4,464,509.4 kWh/year - 3600000-4,464,509.4= 864,509.4 kWh/year - 864,509.4/32443.2= **26.6** kWh/m^3/year - 21.5*228949.2= 4,922,407.8 kWh/year - 4000000-4,922,407.8= 922,407.8 kWh/year - 922,407.8/32443.2= **28.4**kWh/m^3/year	**Energy consumption per <u>Semi-Detached House</u> (kWh/m^3/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 31.9 *228949.2= 11,035,351.44 kWh/year - 7400000- 11,035,351.44=3,635,351.44 kWh/year - 3,635,351.44/32443.2=**15.4** kWh/m^3/year	**- Electricity consumption**	26.6 – 28.4	
- 35.3 *228949.2=9,135,073.08 kWh/year - 8100000-9,135,073.08= 1,035,073.08 kWh/year - 1,035,073.08/32443.2= **17.8** kWh/m^3/year	**- Natural Gas consumption**	15.4 – 17.8	

Table 3.3.2. 9, The Mixed archetype (9)

Mixed Archetype 10: Semi-Detached House / Condominium less than 5 stories

	**Period of Construction**	Pre – 1980	1980 - 2004
	Gross GIS Volume (m^3)	30673.6	109390.7
	Form Factor S/V ratio (m^{-l})	0.47	0.81
	Energy consumption per 29 buildings (MWh/ year)		
	- Electricity consumption	1,000 – 1,200	
	- Natural Gas consumption	2,200 – 2,400	
	Energy consumption per <u>Semi-Detached House</u> (kWh/m^3/ year)	**Using Gross GIS Volume**	
	- Electricity consumption	35 - 40	
	- Natural Gas consumption	15 - 20	
Electricity consumption: (using Gross Volume) - 35*30673.6=1,073,576 kWh/year - 1000000-1,073,576= 73,576 kWh/year - 73576/109390.7= **22.3** kWh/m^3/year - 40*30673.6= 3,686,078.9 kWh/year - 1200000-3,686,078.9= 313,921.1 kWh/year - 313,921.1/109390.7= **24.8** kWh/m^3/year	**Energy consumption per <u>Condominium less than 5 stories</u> (kWh/m^3/ year)**	**Using Gross GIS Volume**	
Natural Gas consumption: (using Gross Volume) - 15 *30673.6= 460,104 kWh/year - 2200000- 460,104=1,739,896kWh/year - 1,739,896/109390.7=**20.1** kWh/m^3/year	**- Electricity consumption**	22.3 – 24.8	
- 20*30673.6=613,472 kWh/year - 2400000-613,472= 1,786,528 kWh/year - 1,786,528/109390.7= **23.6** kWh/m^3/year	**- Natural Gas consumption**	20.1 – 23.6	

Table 3.3.2. 10,The Mixed archetype (10)

3.3.3 Identification of the energy consumption of Mixed Archetypes – (More than two types of buildings per district)

Mixed Archetype 1: Raw House/Condominium >5 stories / Condominium <5 stories

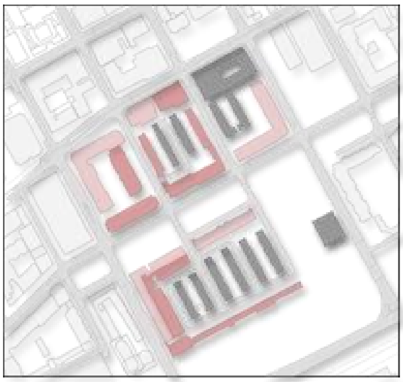
	**Period of Construction**	Pre – 1980	1980 - 2004	1980 - 2004
	Gross Volume (m^3)	105241.2	329206.5	174360.6
	Form Factor S/V ratio (m^{-1})	0.68	0.35	0.47
	Energy consumption per 24 buildings (MWh/ year)			
	- Electricity consumption	11,000 – 12,100		
	- Natural Gas consumption	17,400 – 19,200		
	Energy consumption per Raw House (kWh/m^3/ year)	**Using Gross Volume**		
	- Electricity consumption	31.7 – 35.0		
	- Natural Gas consumption	15.0 – 16.6		
Electricity consumption: (using Gross Volume) - 31.7*105241.2= 3,336,146.04 kWh/year - 31.7*329206.5= 10,435,830.2 kWh/year - 11000000 - 7,099,684.16 = 3,900,315.84 kWh/year - 3,900,315.84/174360.6= **22.3** kWh/m³/year	**Energy consumption per Condominium more than 5 stories (kWh/m^3/ year)**	**Using Gross Volume**		
	- Electricity consumption	31.7 – 34.8		
- 35*105241.2= 3,683,442kWh/year - 34.8*329206.5= 11,456,386.2 kWh/year - 12100000 - 7,772,944.2= 4,327,055.8 kWh/year - 4,327,055.8/174360.6= **24.8** kWh/m³/year	**- Natural Gas consumption**	47.0 – 51.1		
Natural Gas consumption: (using Gross Volume) - 15*105241.2= 1,578,618 kWh/year - 47*329206.5= 15,472,705.5 kWh/year - 17400000 - 13,894,087.5= 3,505,912.5 kWh/year - 3,505,912.5/174360.6= **20.1** kWh/m³/year	**Energy consumption Condominium less than 5 stories (kWh/m^3/ year)**	**Using Gross Volume**		
- 16.6*105241.2= 1,747,003.92 kWh/year - 51.1*329206.5= 16,822,452.15 kWh/year - 19200000 - 15,075,448.23= 4,124,551.77kWh/year - 4,124,551.77/174360.6= **23.6** kWh/m³/year	**- Electricity consumption**	22.3 – 24.8		
	- Natural Gas consumption	20.1 – 23.6		

Table 3.3.4. 1, The Mixed archetype (1)

Mixed Archetype 2: Semi-Detached house/ Condominium <5 stories/ Offices

<table>
<tr><td rowspan="9"></td><td>Period of Construction</td><td>Pre – 1980</td><td>Pre – 1980</td><td>Pre – 1980</td></tr>
<tr><td>Gross GIS Volume (m^3)</td><td>31263.4</td><td>58874.9</td><td>60632.5</td></tr>
<tr><td>Form Factor S/V ratio (m^{-l})</td><td>0.69</td><td>0.55</td><td>0.43</td></tr>
<tr><td colspan="3">Energy consumption per 24 buildings (MWh/ year)</td><td></td></tr>
<tr><td>- Electricity consumption</td><td colspan="3">3,300 – 3,700</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="3">3,400 – 3,700</td></tr>
<tr><td>Energy consumption per <u>Semi-Detached house</u> (kWh/m^3/ year)</td><td colspan="3">Using Gross Volume</td></tr>
<tr><td>- Electricity consumption</td><td colspan="3">35.0 - 40.0</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="3">15.0 – 20.0</td></tr>
<tr><td rowspan="2">Electricity consumption: (using Gross GIS Volume)
- 35.0*31263.4= 1,094,219.0 kWh/year
- 26.2*58874.9= 1,542,522.38 kWh/year
- 3300000 - 448,303.38= 2,851,696.62 kWh/year
- 2,851,696.62/60632.5= 10.5 kWh/m^3/year</td><td>Energy consumption per <u>Condominium less than 5 stories</u> (kWh/m^3/ year)</td><td colspan="3">Using Gross Volume</td></tr>
<tr><td>- Electricity consumption</td><td colspan="3">26.2 – 30</td></tr>
<tr><td>- 40.0*31263.4= 1,250,536 kWh/year
- 30*58874.9= 1,766,247 kWh/year
- 3700000 - 1,641,194= 2,058,806 kWh/year
- 2,058,806/60632.5= 13.7 kWh/m^3/year</td><td>- Natural Gas consumption</td><td colspan="3">9.5 – 9.5</td></tr>
<tr><td>Natural Gas consumption: (using Gross GIS Volume)
- 15 *31263.4= 468,951 kWh/year
- 9.5*58874.9= 559,311.55 kWh/year
- 3400000 - 90,360.55= 2,058,806 kWh/year
- 2,058,806/60632.5= 17.3 kWh/m^3/year</td><td>Energy consumption <u>Offices</u> (kWh/m^3/ year)</td><td colspan="3">Using Gross GIS Volume</td></tr>
<tr><td rowspan="2">- 20 *31263.4= 1,250,536 kWh/year
- 9.5*58874.9= 1,766,247 kWh/year
- 3700000 - 1,641,194= 3,309,639.45 kWh/year
- 3,309,639.45/60632.5= 19.4 kWh/m^3/year</td><td>- Electricity consumption</td><td colspan="3">10.5 – 13.7</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="3">17.3 – 19.4</td></tr>
</table>

Table 3.3.4. 2, The Mixed archetype (2)

Mixed Archetype 3: Semi – Detached House /Condominium < 5 stories / Hospitality

<table>
<tr><td rowspan="9"></td><td>Period of Construction</td><td>Pre – 1980</td><td>Pre – 1980</td><td>Pre – 1980</td></tr>
<tr><td>Gross GIS Volume (m^3)</td><td>36054.8</td><td>7832.6</td><td>10980.0</td></tr>
<tr><td>Form Factor S/V ratio (m^{-1})</td><td>0.68</td><td>0.69</td><td>0.41</td></tr>
<tr><td colspan="3">Energy consumption per 24 buildings (MWh/ year)</td><td></td></tr>
<tr><td>- Electricity consumption</td><td colspan="3">2,000 – 2,200</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="3">1,500 – 1,600</td></tr>
<tr><td>Energy consumption per <u>Semi - Detached house</u> (kWh/m^3/ year)</td><td colspan="3">Using Gross GIS Volume</td></tr>
<tr><td>- Electricity consumption</td><td colspan="3">35.0 - 40.0</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="3">15.0 – 20.0</td></tr>
<tr><td rowspan="2">Electricity consumption: (using Gross GIS Volume)
- 35.0*36054.8= 1,094,219.0 kWh/year
- 26.2*7832.6= 1,542,522.38 kWh/year
- 2000000 - 448,303.38= 2,851,696.62 kWh/year
- 2,851,696.62/10980.0= 6.3 kWh/m^3/year</td><td>Energy consumption per <u>Condominium less than 5 stories</u> (kWh/m^3/ year)</td><td colspan="3">Using Gross GIS Volume</td></tr>
<tr><td>- Electricity consumption</td><td colspan="3">26.2 – 30</td></tr>
<tr><td>- 40.0*36054.8= 1,250,536 kWh/year
- 30*7832.6= 1,766,247 kWh/year
- 2200000 - 1,641,194= 2,058,806 kWh/year
- 2,058,806/10980.0= 8.2 kWh/m^3/year</td><td>- Natural Gas consumption</td><td colspan="3">9.5 – 9.5</td></tr>
<tr><td>Natural Gas consumption: (using Gross GIS Volume)
- 15 *36054.8= 468,951 kWh/year
- 9.5*7832.6= 559,311.55 kWh/year
- 1500000 - 90,360.55= 2,058,806 kWh/year
- 2,058,806/10980.0= 15.05 kWh/m^3/year</td><td>Energy consumption <u>Hospitality</u> (kWh/m^3/ year)</td><td colspan="3">Using Gross GIS Volume</td></tr>
<tr><td rowspan="2">- 20 *36054.8= 1,250,536 kWh/year
- 9.5*7832.6= 1,766,247 kWh/year
- 1600000 - 1,641,194= 3,309,639.45 kWh/year
- 3,309,639.45/10980.0= 17.3 kWh/m^3/year</td><td>- Electricity consumption</td><td colspan="3">6.3 – 8.2</td></tr>
<tr><td>- Natural Gas consumption</td><td colspan="3">15.05 – 17.3</td></tr>
</table>

Table 3.3.4. 3,The Mixed archetype (3)

Mixed Archetype 3: Raw House/Condominium < 5 stories / Hospitality

Period of Construction	Pre – 1980	Pre – 1980	Post - 2004
Gross GIS Volume (m^3)	17017.6	28023.7	24448.3
Form Factor S/V ratio (m^{-1})	0.62	0.52	0.62
Energy consumption per 24 buildings (MWh/ year)			
- Electricity consumption	1,900 – 2,200		
- Natural Gas consumption	1,400 – 1,600		
Energy consumption per <u>Raw House</u> (kWh/m^3/ year)	**Using Gross GIS Volume**		
- Electricity consumption	31.7 – 35.0		
- Natural Gas consumption	23.3 – 29.2		
Energy consumption per <u>Condominium less than 5 stories</u> (kWh/m^3/ year)	**Using Gross GIS Volume**		
- Electricity consumption	26.2 – 30		
- Natural Gas consumption	9.5 – 9.5		
Energy consumption <u>Hospitality</u> (kWh/m^3/ year)	**Using Gross GIS Volume**		
- Electricity consumption	12.6 – 15.1		
- Natural Gas consumption	9.5 – 11.2		

Electricity consumption: (using Gross GIS Volume)
- 31.7*17017.6= 3,336,146.04 kWh/year
- 26.2*329206.5= 10,435,830.2 kWh/year
- 11000000 - 7,099,684.16 = 3,900,315.84 kWh/year
- 3,900,315.84/24448.3= **12.6** kWh/m³/year

- 35*17017.6= 3,683,442kWh/year
- 30*329206.5= 11,456,386.2 kWh/year
- 12100000 - 7,772,944.2= 4,327,055.8 kWh/year
- 4,327,055.8/24448.3= **15.1** kWh/m³/year

Natural Gas consumption: (using Gross GIS Volume)
- 23.3*17017.6= 1,578,618 kWh/year
- 9.5*329206.5= 15,472,705.5 kWh/year
- 17400000 - 13,894,087.5= 3,505,912.5 kWh/year
- 3,505,912.5/24448.3 = **9.5** kWh/m³/year

- 29.2*17017.6= 1,747,003.92 kWh/year
- 9.5*329206.5= 16,822,452.15 kWh/year
- 19200000 - 15,075,448.23= 4,124,551.77kWh/year
- 4,124,551.77/24448.3= **11.2** kWh/m³/year

Table 3.3.4. 4, The Mixed archetype (4)

The analysis of several typical buildings in the city of Toronto allowed the assessment of energy consumption patterns, and how energy savings could be achieved in residential buildings after energy redevelopment interventions.
The procedures can be applied to different areas of the city of Toronto after this assessment, allowing for a variety of assessments that could potentially work for energy rehabilitation, considering the many characteristics of each apartment building,

3.4. Top–Down Model

The energy needs of the existing building stock is a **Top-down model** that was used in this analysis.

Top-down model: This model starts from consumption data at the local or regional level, by comparing many characteristics, and determining the average consumption of buildings
Specific annual consumption (kWh/m^3/y) was calculated for the area's consumption, by electricity and natural gas consumption, and gross volume.

For the analysis of the built environment, the recurring blocks of building patterns were divided into 5 homogeneous groups, in order to define the energy consumption categories in each area. For repetitive building patterns, a number of characteristics that can affect energy consumption are taken into account:

- The building's archetype
- Compactness which limits the heat loss of the building which can be assessed by the form factor S/V ratio
- The period of construction, which affects the degree of insulation.

In order to analyze the main energy variables and their relative correlations, the following linear regressions were performed, for each of:

- **Natural Gas**: <u>Multiple linear regression,</u> surface-to-volume ratio S/V and period of construction.

- **Electricity**: <u>Single linear regression,</u> Inhabitants/m^3 because of the high use of this type of energy.

3.4.1. Natural Gas energy consumption model

Determined the surface-to-volume ratio S/V and period of construction by using **multiple linear regression**.

Form factor, S/V ratio:

Energy classes were divided into the different classes of **S/V** for each census section:

- **Class 1**: 0.10- 0.42 m^{-1}
- **Class 2**: 0.43-0.63 m^{-1}
- **Class 3**: 0.64-0.80 m^{-1}
- **Class 4**: 0.81-1.30 m^{-1}

In order to determine the energy needs as a function of the aspect ratio (S/V) for different construction periods, the surface to volume ratios have been related to the building construction period, in order to assess the energy consumption of natural gas (kWh/m^3/year)

The Multiple straight-line equations for different period of construction

Accuracy was measured in a linear regression model for consumption data as a function of the S/V form factor by coefficients of determination by using GIS tools.

For determine energy performance values (kWh/m^2/year) depending on the surface-to-volume ratio and on the construction period of each building on this reaserch.

- **Pre – 1980**: 21.36 (s/v) + 7.5913
- **1980 – 2004**: 6.5409 (s/v) + 21.428
- **Post – 2004**: 17.278 (s/v) + 3.5347

3.4.2. Electricity energy consumption model

Determine the inhabitants/m^3 because of the high use of this type of energy by using **single linear regression.**

Single linear regression has an equation as the next formula:

$Y = a + bx + \in$ ……… (1)
where:

- Y – is the dependent variable
- X – is the independent (explanatory) variable
- a – is the intercept
- b – is the slope
- $\in$ – and is the residual (error)

Chapter 4.

Analysis on variability of data of consumption compared to urban context in the city of Toronto

After analyzing and reprocessing the energy consumption data (Chapter 3.), the urban morphology variables and parameters for the city of Toronto were calculated.
Values were calculated on the district scale and after linking urban variables information to buildings as much as possible, by identifying homogeneous groups of buildings (taking into account s/v form factor, construction period, and district-by-province energy consumption (kWh/m³/year). This model was applied to districts containing heterogeneous buildings in order to determine energy consumption and to evaluate the ability of this model to determine energy consumption in different areas of the city of Toronto.

4.1. Calculation of variables and indicators of urban morphology

The urban morphology variables that have been calculated in the environment are listed below on GIS for each district based on the information that we have from the Toronto Platform

BD	**Building density**	**(m3 / m2)**
BH	**Building height**	**(m)**
BCR	**Building coverage ratio**	**(m2 / m2)**

Building Density (BD) = Sum (Gross volume) / Sum Volume (Buildings)

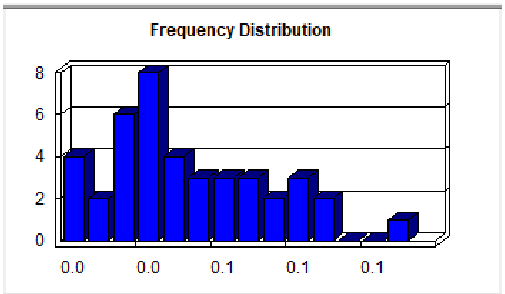
Building height (BH) = Sum (Height of the building X Gross volume of the building) / Sum Volume (Buildings)

Building coverage ratio (BCR) = Sum (Gross area) / Sum (Area of the district)

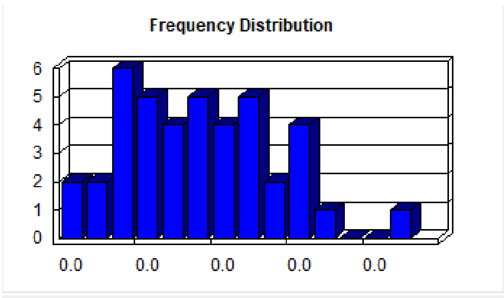
4.1.1. Calculation of urban variables by Districts For residential building.

Archetype 1: Single – Detached House

Building density (m^3/m^2) / 41 buildings	
Number of districts	95
Min.	0.034
Max.	0.10
Sum	2.40
Avg.	0.05



Building Coverage Ratio (m^2/m^2) / 41 buildings	
Number of districts	95
Min.	0.003
Max.	0.01
Sum	0.26
Avg.	0.006



Building Height (m) / 41 buildings	
Number of districts	95
Min.	0.16
Max.	0.95
Sum	16.2
Avg.	0.39

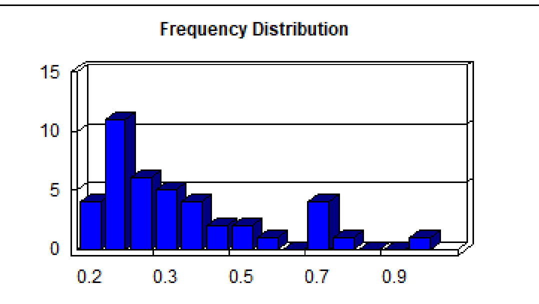
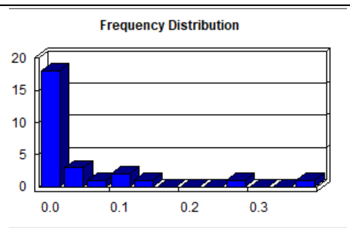


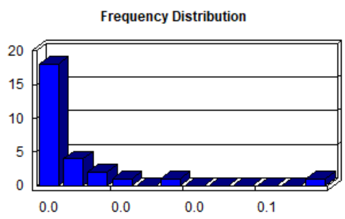
Table 4.1.1. 1, The Urban variables for the Single – Detached House

Archetype 2: Raw House

Building density (m³/m²) / 27 buildings	
Number of districts	71
Min.	0.02
Max.	0.43
Sum	2.29
Avg.	0.08



Building Coverage Ratio (m²/m²) / 27 buildings	
Number of districts	71
Min.	0.003
Max.	0.06
Sum	0.30
Avg.	0.01



Building Height (m) / 27 buildings	
Number of districts	71
Min.	0.12
Max.	3.43
Sum	15.9
Avg.	0.59

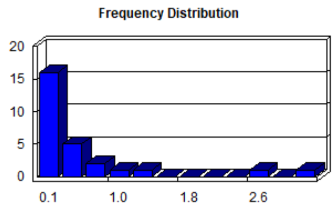
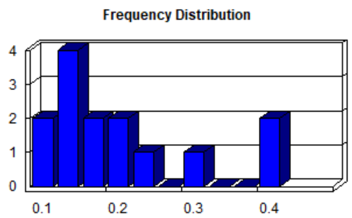


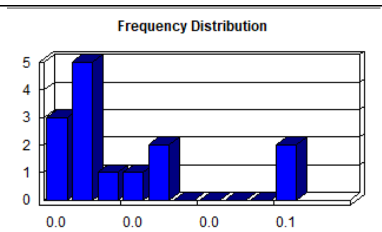
Table 4.1.1. 2, The Urban variables for the Raw House

Archetype 3: Semi – Detached House

Building density (m³/m²) / 14 buildings	
Number of districts	71
Min.	0.09
Max.	0.43
Sum	3.03
Avg.	0.21



Building Coverage Ratio (m²/m²) / 14 buildings	
Number of district	71
Min.	0.01
Max.	0.05
Sum	0.35
Avg.	0.025



Building Height (m) / 14 buildings	
Number of district	71
Min.	0.034
Max.	0.10
Sum	2.40
Avg.	0.05

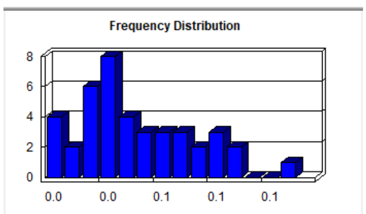
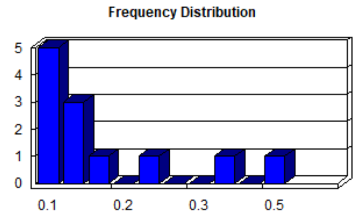


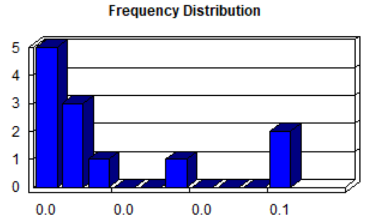
Table 4.1.1. 3, The Urban variables for the Semi – Detached House

Archetype 4: Condominium less than 5 stories

Building density (m^3/m^2) / 12 buildings	
Number of districts	78
Min.	0.055
Max.	0.48
Sum	2.08
Avg.	0.17



Building Coverage Ratio (m^2/m^2) / 12 buildings	
Number of districts	78
Min.	0.008
Max.	0.05
Sum	0.28
Avg.	0.024



Building Height (m) / 12 buildings	
Number of districts	78
Min.	0.23
Max.	3.83
Sum	12.6
Avg.	1.05

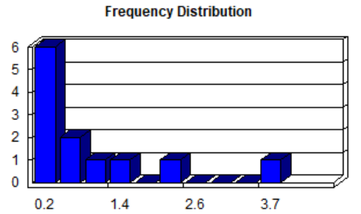
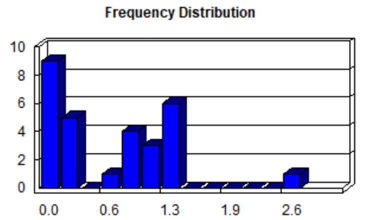


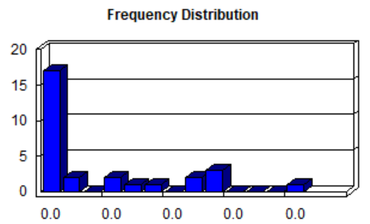
Table 4.1.1. 4, The Urban variables for the Condominium less than 5 stories

Archetype 5: Condominium more than 5 stories

Building density (m^3/m^2) / 29 buildings	
Number of districts	74
Min.	0.002
Max.	2.60
Sum	20.6
Avg.	0.71



Building Coverage Ratio (m^2/m^2) / 29 buildings	
Number of districts	74
Min.	0.00
Max.	0.034
Sum	0.22
Avg.	0.007



Building Height (m) / 29 buildings	
Number of districts	74
Min.	0.00
Max.	11.6
Sum	67.9
Avg.	2.34

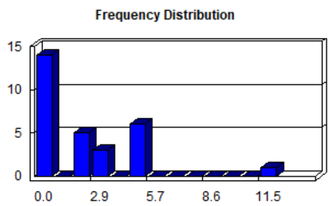
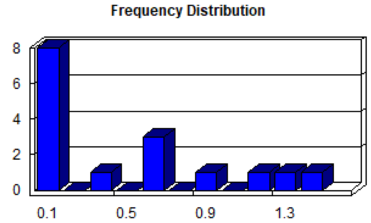


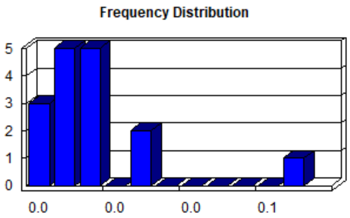
Table 4.1.1. 5, The Urban variables for the Condominium more than 5 stories

Mixed Archetype 1: Raw house / Condominium more than 5 stories

Building density (m³/m²) / 16 buildings	
Number of districts	72
Min.	0.07
Max.	1.40
Sum	8.53
Avg.	0.53



Building Coverage Ratio (m²/m²) / 16 buildings	
Number of districts	72
Min.	0.01
Max.	0.071
Sum	0.40
Avg.	0.025



Building Height (m) / 16 buildings	
Number of districts	72
Min.	0
Max.	7.29
Sum	12.7
Avg.	0.79

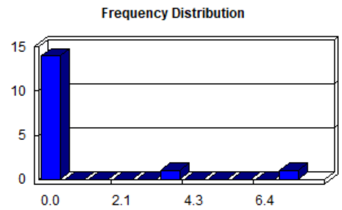
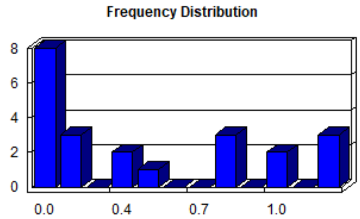


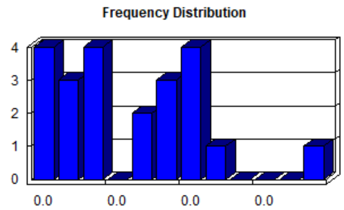
Table 4.1.1. 6, The Urban variables for the Mixed archetypes (1)

Mixed Archetype 2: Semi-Detached House / Condominium more than 5 stories

Building density (m³/m²) / 22 buildings	
Number of districts	72
Min.	0.019
Max.	1.30
Sum	11.1
Avg.	0.5



Building Coverage Ratio (m²/m²) / 22 buildings	
Number of districts	72
Min.	0.0002
Max.	0.035
Sum	0.27
Avg.	0.012



Building Height (m) / 22 buildings	
Number of districts	72
Min.	0
Max.	50
Sum	29.5
Avg.	0.05

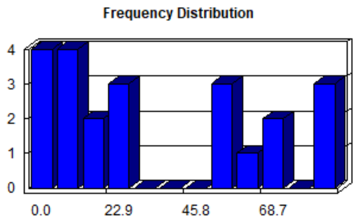
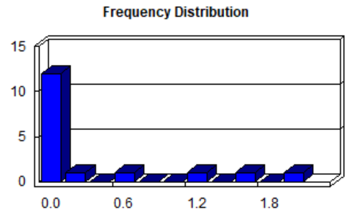


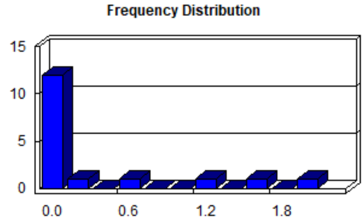
Table 4.1.1. 7, The Urban variables for the Mixed archetypes (2)

Mixed Archetype 3: Condominium more than 5 stories / Condominium less than 5 stories

Building density (m³/m²) / 13 buildings	
Number of districts	73
Min.	0.01
Max.	2.08
Sum	6.88
Avg.	0.40



Building Coverage Ratio (m²/m²) / 13 buildings	
Number of districts	73
Min.	0.0006
Max.	0.17
Sum	0.46
Avg.	0.02



Building Height (m) / 13 buildings	
Number of districts	73
Min.	0
Max.	0.10
Sum	2.40
Avg.	0.05

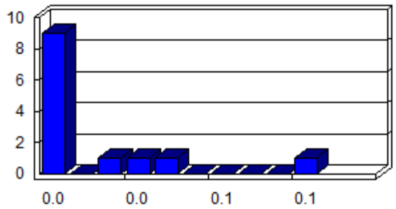
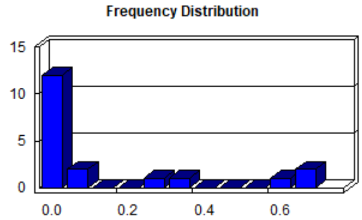


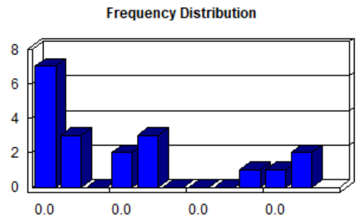
Table 4.1.1. 8, The Urban variables for the Mixed archetypes (3)

Mixed Archetype 4: Condominium more than 5 stories / Raw House

Building density (m³/m²) / 19 buildings	
Number of districts	72
Min.	0.035
Max.	0.69
Sum	3.71
Avg.	0.19



Building Coverage Ratio (m²/m²) / 19 buildings	
Number of districts	72
Min.	0.004
Max.	0.026
Sum	0.22
Avg.	0.011



Building Height (m) / 19 buildings	
Number of districts	72
Min.	0.10
Max.	6.76
Sum	30.4
Avg.	1.60

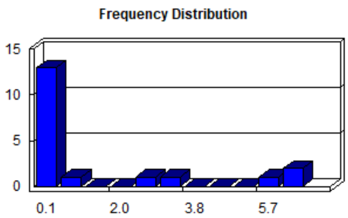
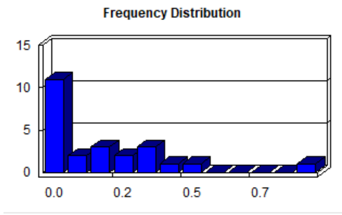


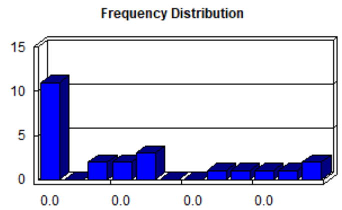
Table 4.1.1. 9, The Urban variables for the Mixed archetypes (4)

Mixed Archetype 5: Raw House/Condominium >5 stories / Condominium <5 stories

Building density (m³/m²) / 24 buildings	
Number of districts	77
Min.	0.029
Max.	0.84
Sum	4.63
Avg.	0.19



Building Coverage Ratio (m²/m²) / 24 buildings	
Number of districts	77
Min.	0.004
Max.	0.024
Sum	0.25
Avg.	0.010



Building Height (m) / 24 buildings	
Number of districts	77
Min.	0.00
Max.	3.07
Sum	13.4
Avg.	0.55

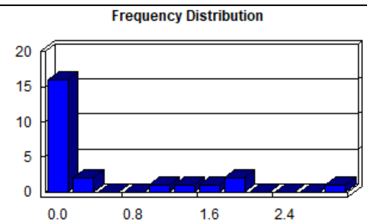
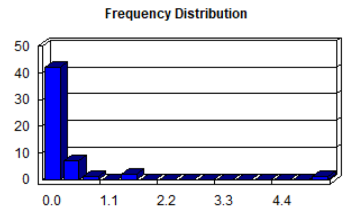


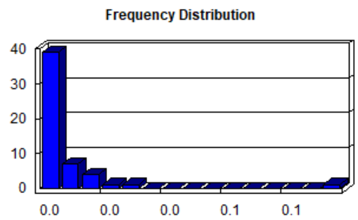
Table 4.1.1. 10, The Urban variables for the Mixed archetypes (5)

Mixed Archetype 6: Institutional / Semi-Detached House

Building density (m³/m²) / 53 buildings	
Number of districts	79
Min.	0.005
Max.	5.22
Sum	16.4
Avg.	0.30



Building Coverage Ratio (m²/m²) / 53 buildings	
Number of districts	79
Min.	0.0002
Max.	0.084
Sum	0.358
Avg.	0.0067



Building Height (m) / 53 buildings	
Number of districts	79
Min.	0.00
Max.	22.4
Sum	52.95
Avg.	0.99

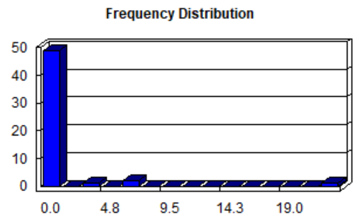
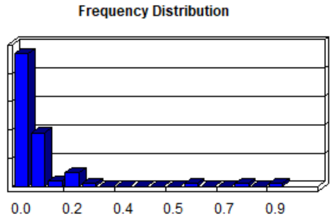


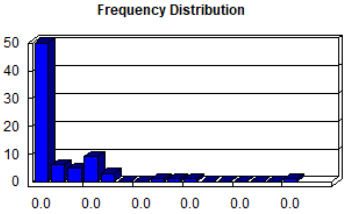
Table 4.1.1. 11, The Urban variables for the Mixed archetypes (6)

Mixed Archetype 7: Institutional / Single-Detached House

Building density (m³/m²) / 14 buildings	
Number of districts	79
Min.	0.004
Max.	0.89
Sum	6.51
Avg.	0.084



Building Coverage Ratio (m²/m²) / 14 buildings	
Number of districts	79
Min.	0.0001
Max.	0.043
Sum	0.357
Avg.	0.004



Building Height (m) / 32 buildings	
Number of districts	79
Min.	0.006
Max.	0.047
Sum	0.54
Avg.	0.016

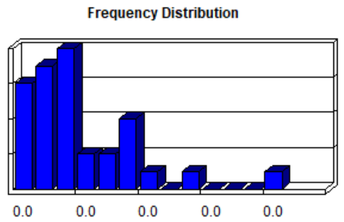
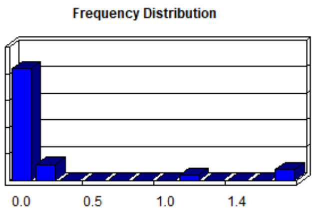


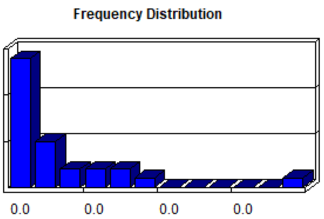
Table 4.1.1. 12, The Urban variables for the Mixed archetypes (7)

Mixed Archetype 8: Condominium more than 5 stories / Single-Detached House

Building density (m³/m²) / 27 buildings	
Number of districts	95
Min.	0.027
Max.	1.88
Sum	6.72
Avg.	0.24



Building Coverage Ratio (m²/m²) / 27 buildings	
Number of districts	95
Min.	0.002
Max.	0.052
Sum	0.28
Avg.	0.01



Building Height (m) / 27 buildings	
Number of districts	95
Min.	0.00
Max.	12.77
Sum	17.47
Avg.	0.64

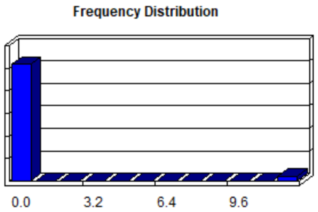
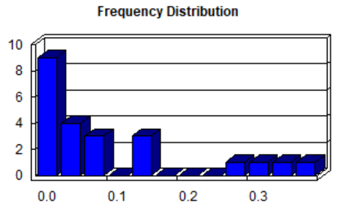


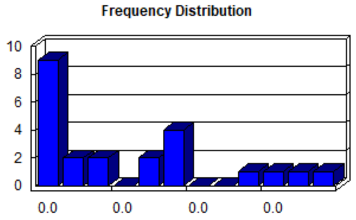
Table 4.1.1. 13, The Urban variables for the Mixed archetypes (8)

Mixed Archetype 9: Single-Detached House / Raw House

Building density (m^3/m^2) / 23 buildings	
Number of districts	71
Min.	0.026
Max.	0.026
Sum	2.43
Avg.	0.10



Building Coverage Ratio (m^2/m^2) / 23 buildings	
Number of districts	71
Min.	0.003
Max.	0.032
Sum	0.29
Avg.	0.012



Building Height (m) / 23 buildings	
Number of districts	71
Min.	0.078
Max.	2.63
Sum	16.6
Avg.	0.72

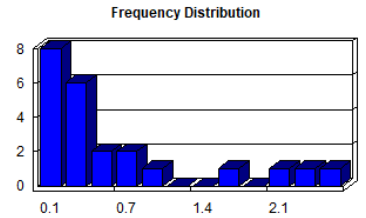
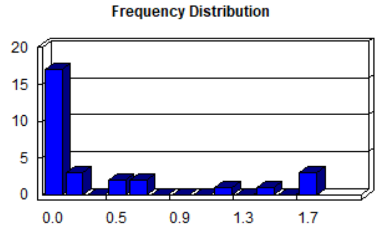


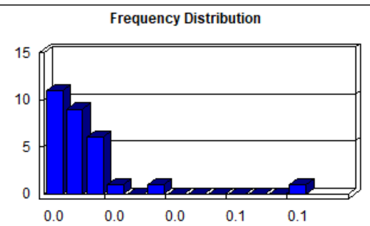
Table 4.1.1. 14, The Urban variables for the Mixed archetypes (9)

Mixed Archetype 10: Condominium more than 5 stories / Semi-Detached House

Building density (m^3/m^2) / 29 buildings	
Number of districts	95
Min.	0.043
Max.	1.76
Sum	12.8
Avg.	0.44



Building Coverage Ratio (m^2/m^2) / 29 buildings	
Number of districts	95
Min.	0.0005
Max.	0.084
Sum	0.378
Avg.	0.013



Building Height (m) / 29 buildings	
Number of districts	95
Min.	0.046
Max.	9.595
Sum	44.31
Avg.	1.52

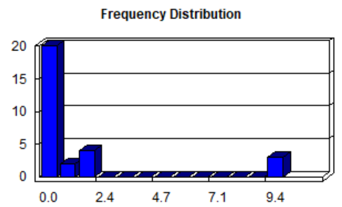


Table 4.1.1. 15,The Urban variables for the Mixed archetypes (10)

Urban variables for whole districts

The Values presented were developed in a GIS environment (ArcGIS 10.7.1) following the calculation of urban variables and indicators for all studied districts.

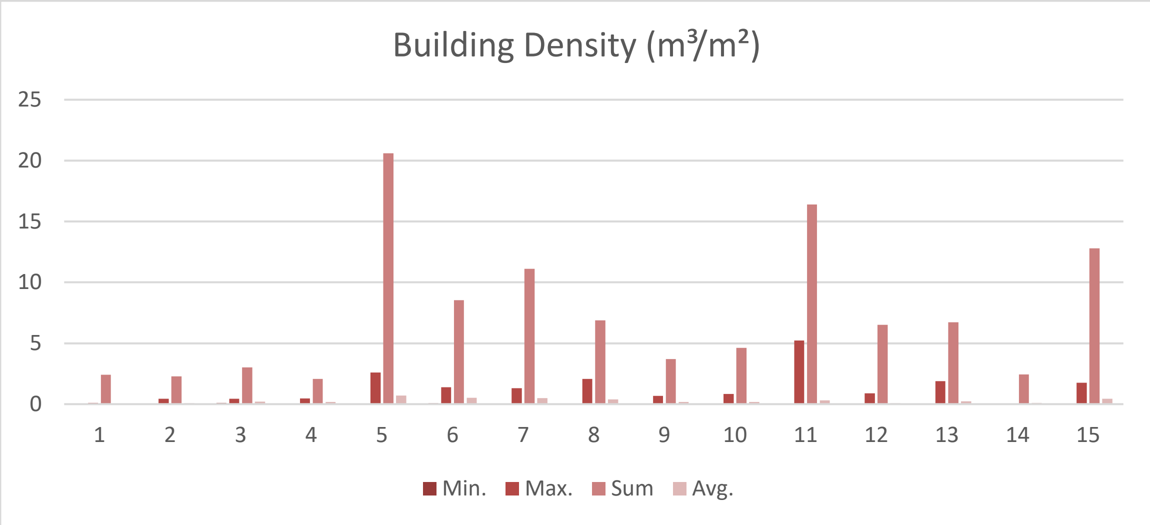


Figure 4.1.1. 1, The building density for the residential buildings

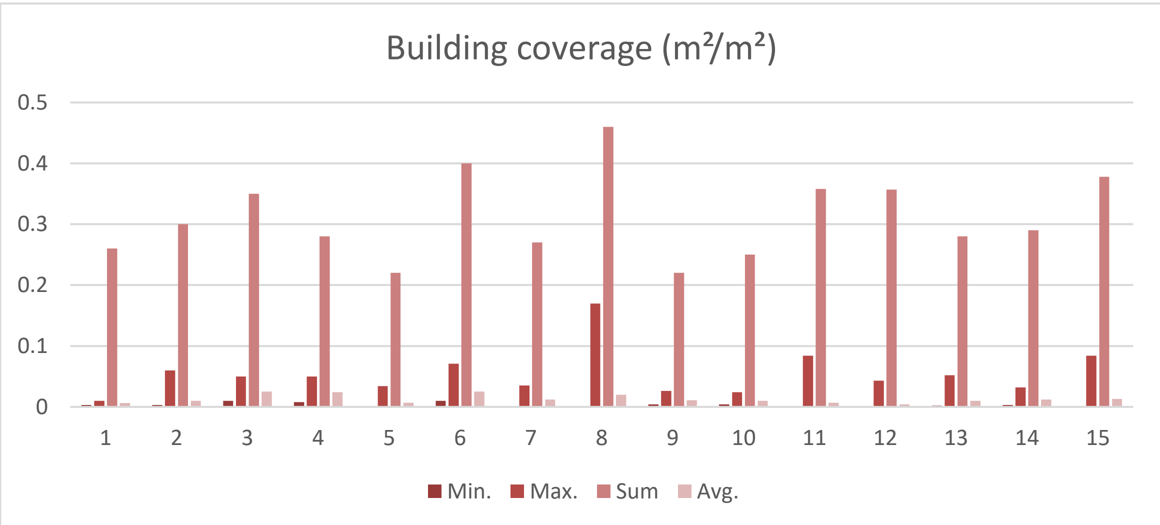


Figure 4.1.1. 2, The building coverage for the residential buildings

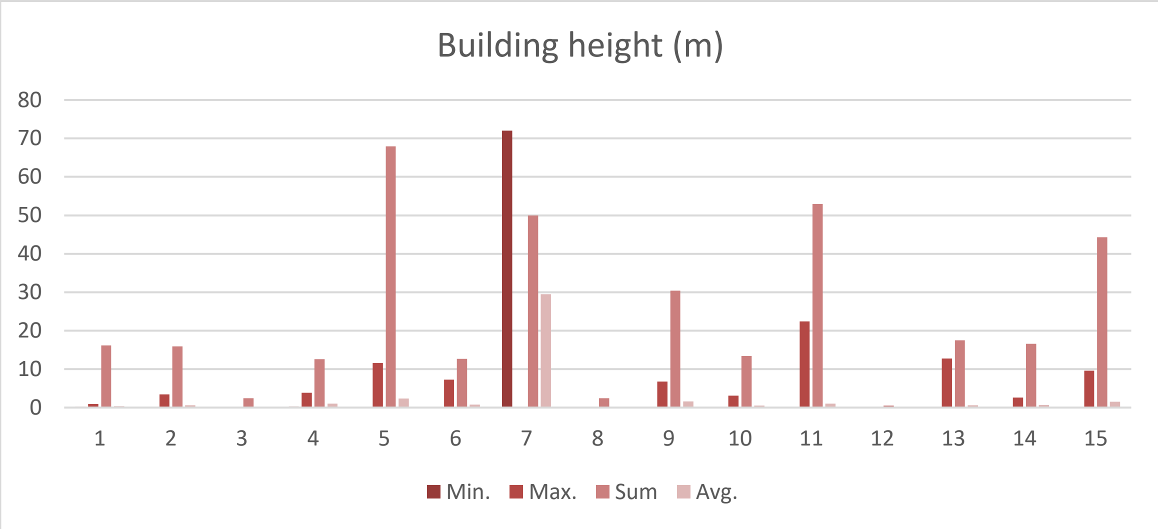


Figure 4.1.1. 3, The building coverage for the residential buildings

Average Values for Urban variables for whole districts

Values	BD	BCR	BH
Min.	0.031267	0.00324	0.0516
Max.	1.341733	0.055	24.63147
Sum	7.340667	0.311533	22.878
Avg.	0.2796	0.013047	0.7564

Table 4.1.1. 16, Average values of the urban variables and indicators calculated by districts

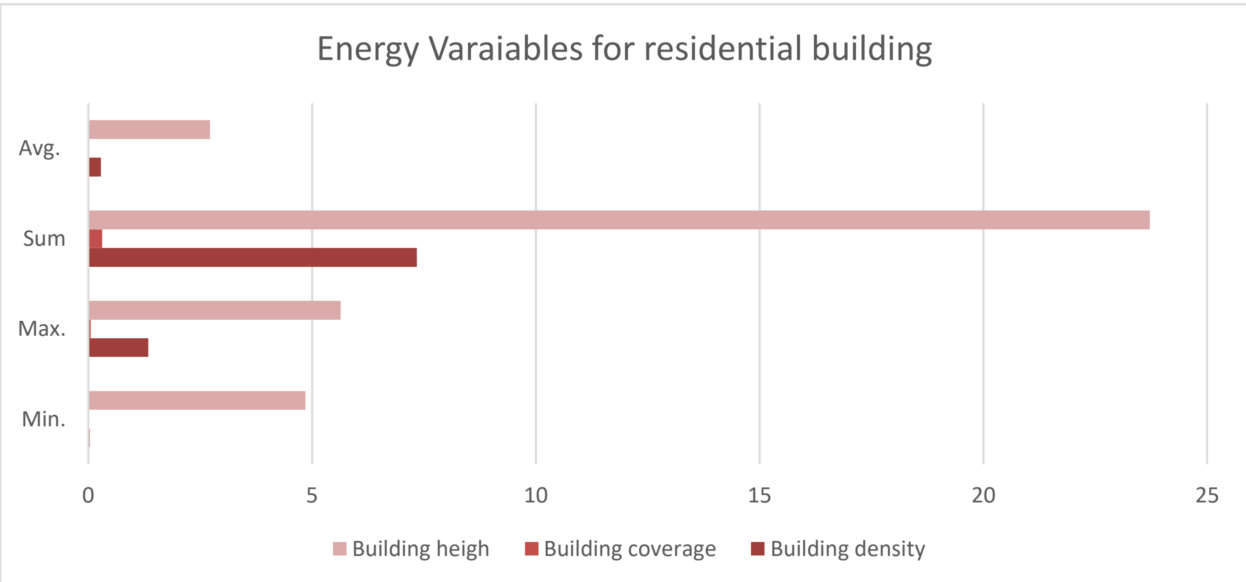


Figure 4.1.1. 4, Average values of the urban variables and indicators calculated by districts

Chapter 4.

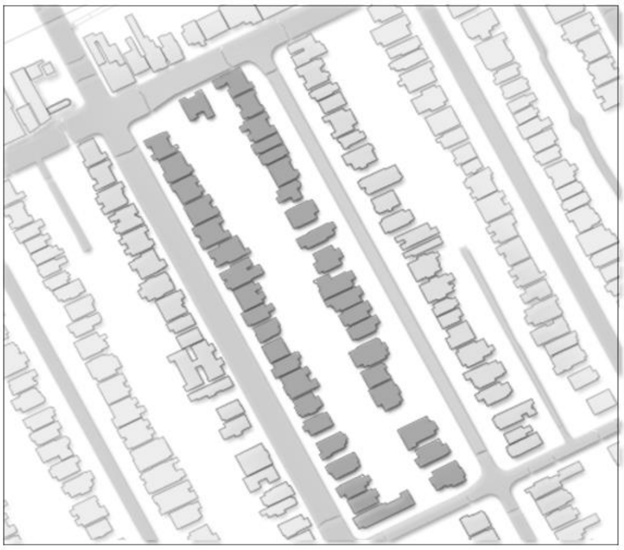
Results and Discussion

From this analysis, the following 5 archetypes of recurrent residential buildings have been identified:

1- Single- Detached House, 2- Semi-Detached House , 3- Rawy House , 4- Condominium less than 5 stories, 5- Condominium more than 5 stories.

5.1. Residential Sector: analysis the districts with variables

Archetype 1: Single – Detached House



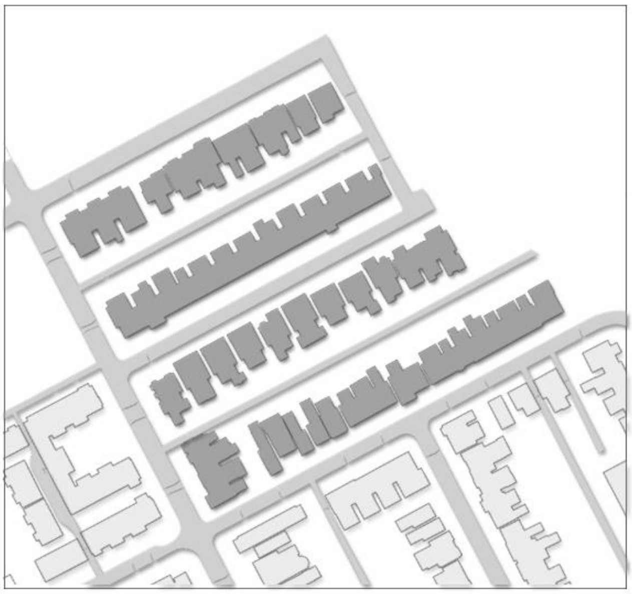
Zone and district scale features	Archetype building scale features
- **Zone**: ANNEX (95) - **Population**: 30526 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 43% **1961-1980**: 26% **1981-1990**: 9% **1991-2000**: 6% **2001-2005**: 5% **2006-2010**: 5% **2011-2016**: 6% - **Total Private dwellings**: 18109 buildings - **Number of Building in selected district:** 41 Buildings	- **Private dwellings by structure type**: Residential – Detached House - **Period of Construction**: Pre - 1980 - **Average of S/V Ratio:** 0.86 m^{-1} - **Average of S/V Ratio (Real)**: 0.97 m^{-1}
- **Area of the district:** 31704.9 m^2 - **Footprint of the buildings:** 8537.0 m^2	- **Heated Loss Surface**: 48826.1 m^2 - **Gross GIS Volume**: 76495.0 m^3

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 32.6 – 36.6 - **Natural Gas:** 15.6 – 18.3

Urban Variables
Building Density (m³/m²) = 2.4 **Building Coverage ratio (m²/m²) =** 0.26 **Building Height (m) =** 16.2

Figure 5.1. 1, The results of the characteristics of the Single – Detached House

Archetype 2: Raw House



Zone and district scale features	Archetype building scale features
- **Zone**: CABBAGETOWN-SOUTH ST. JAMES TOWN (71) - **Population**: 11669 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 42% **1961-1980**: 27% **1981-1990**: 19% **1991-2000**: 4% **2001-2005**: 4% **2006-2010**: 4% **2011-2016**: 0%	- **Private dwellings by structure type**: Residential – Raw House - **Period of Construction**: Pre - 1980
- **Total Private dwellings**: 6761 buildings - **Number of Building in selected district:** 27 Buildings	- **Average of S/V Ratio:** 0.66 m^{-1} - **Average of S/V Ratio (Real)**: 0.83 m^{-1}
- **Area of the district:** 26159 m^2 - **Footprint of the buildings:** 7872.1 m^2	- **Heated Loss Surface**: 48826.1 m^2 - **Gross GIS Volume**: 76495.0 m^3

Specific consumption model

Energy consumption (kWh/m³/year) Using gross volume
- **Electricity**: 31.7 – 35.0
- **Natural Gas:** 15.0 – 16.6

Urban Variables

Building Density (m^3/m^2) = 2.29
Building Coverage ratio (m^2/m^2) = 0.30
Building Height (m) = 15.9

Figure 5.1. 2, The results of the characteristics of the Raw House

Archetype 3: Semi – Detached House

Zone and district scale features	Archetype building scale features
- **Zone**: CABBAGETOWN-SOUTH ST. JAMES TOWN (71) - **Population**: 11669 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 42% **1961-1980**: 27% **1981-1990**: 19% **1991-2000**: 4% **2001-2005**: 4% **2006-2010**: 4% **2011-2016**: 0% - **Total Private dwellings**: 6761 buildings - **Number of Building in selected district:** 14 Buildings	- **Private dwellings by structure type**: Residential – Semi – Detached House - **Period of Construction**: Pre - 1980 - **Average of S/V Ratio:** 0.83 m^{-1} - **Average of S/V Ratio (Real)**: 1.0 m^{-1}
- **Area of the district:** 8793.6 m^2 - **Footprint of the buildings:** 3079.3 m^2	- **Heated Loss Surface**: 16279.2 m^2 - **Gross GIS Volume**: 26663.6 m^3
Specific consumption model	
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 30.8 – 32.7 - **Natural Gas:** 35.9 – 38.6	
Urban Variables	
Building Density (m³/m²) = 3.03 **Building Coverage ratio (m²/m²) =** 0.35 **Building Height (m) =** 15.01	

Figure 5.1. 3, The results of the characteristics of the Semi – Detached House

Archetype 4: Condominium less than 5 stories

Zone and district scale features	Archetype building scale features
- **Zone**: CHINATOWN (78) - **Population**: 17945 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 31% **1961-1980**: 29% **1981-1990**: 15% **1991-2000**: 9% **2001-2005**: 5% **2006-2010**: 4% **2011-2016**: 7% - **Total Private dwellings**: 9745 buildings - **Number of Building in selected district:** 12 Buildings	- **Private dwellings by structure type**: Residential – Condominium less than 5 stories - **Period of Construction**: Pre - 1980 - **Average of S/V Ratio:** 0.62 m^{-1} - **Average of S/V Ratio (Real)**: 0.77 m^{-1}
- **Area of the district:** 13420.3 m² - **Footprint of the buildings:** 3872.8 m²	- **Heated Loss Surface**: 17743.4 m² - **Gross GIS Volume**: 27951.5 m³

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 26.2 – 30 - **Natural Gas:** 11.2 – 15

Urban Variables
Building Density (m³/m²) = 2.08 **Building Coverage ratio (m²/m²) =** 0.28 **Building Height (m) =** 12.6

Figure 5.1. 4, The results of the characteristics of the Condominium less than 5 stories

Archetype 5: Condominium more than 5 stories

Zone and district scale features	Archetype building scale features
- **Zone**: NORTH ST. JAMES TOWN (74) - **Population**: 18615 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 22% **1961-1980**: 51% **1981-1990**: 8% **1991-2000**: 4% **2001-2005**: 2% **2006-2010**: 10% **2011-2016**: 4% - **Total Private dwellings**: 10109 buildings - **Number of Building in selected district:** 29 Buildings	- **Private dwellings by structure type**: Residential – Condominium more than 5 stories - **Period of Construction**: Pre - 1980 - **Average of S/V Ratio:** 0.40 m^{-1} - **Average of S/V Ratio (Real)**: 0.68 m^{-1}
- **Area of the district:** 62691.4 m^2 - **Footprint of the buildings:** 13422 .8 m^2	- **Heated Loss Surface**: 310737.8 m^2 - **Gross GIS Volume**: 1208455.7 m^3

Specific consumption model

Energy consumption (kWh/m³/year) Using gross volume
- **Electricity**: 14.6 – 16.1
- **Natural Gas:** 36.1 – 39.9

Urban Variables

Building Density (m³/m²) = 3.68
Building Coverage ratio (m²/m²) = 0.22
Building Height (m) = 27.9

Figure 5.1. 5, The results of the characteristics of the Condominium more than 5 stories

Mixed Archetype 1: Raw house / Condominium more than 5 stories

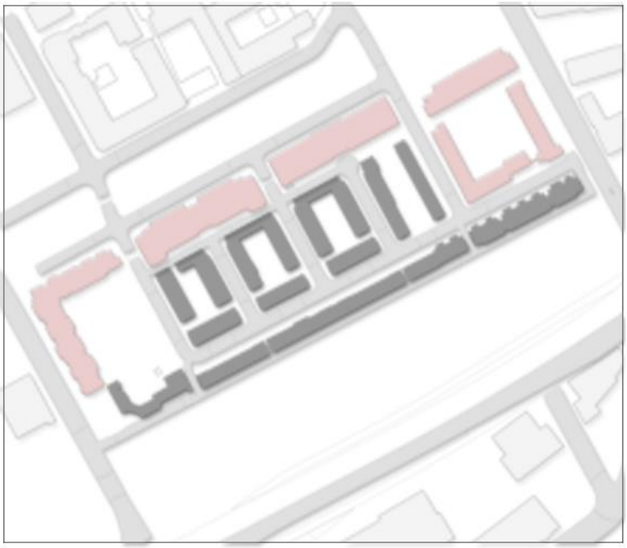
Zone and district scale features	Archetype building scale features
- **Zone**: REGENT PARK (72) - **Population**: 10803 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 23% **1961-1980**: 18% **1981-1990**: 6% **1991-2000**: 3% **2001-2005**: 2% **2006-2010**: 12% **2011-2016**: 35% - **Total Private dwellings**: 5183 buildings - **Number of Building in selected district:** 16 Buildings	- **Private dwellings by structure type**: Residential – Raw house Residential – Condominium more than 5 stories - **Period of Construction**: Pre – 1980 Post - 2004 - **Average of S/V Ratio:** 0.69 m^{-l} / 0.42 m^{-l} - **Average of S/V Ratio (Real)**: 0.83 m^{-l} / 0.45
- **Area of the district:** 38066.7m^2 - **Footprint of the buildings:** 15227.**4** m^2	- **Heated Loss Surface**: 93830.3 m^2 - **Gross GIS Volume**: 324946.5 m^3

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 31.7 – 35.0 / 23.3 – 25.9 - **Natural Gas:** 15.0 – 16.6 / 27.2 – 30.3

Urban Variables
Building Density (m³/m²) = 4.53 **Building Coverage ratio (m²/m²) =** 0.40 **Building Height (m) =** 12.7

Figure 5.1. 6, The results of the characteristics of the Mixed archetype (1)

Mixed Archetype 2: Semi-Detached House / Condominium more than 5 stories



<table>
<tr><th>Zone and district scale features</th><th>Archetype building scale features</th></tr>
<tr><td rowspan="3">- Zone: REGENT PARK (72)
- Population: 10803 inhabitants
- Period of Construction in whole zone:
Pre-1960: 23%
1961-1980: 18%
1981-1990: 6%
1991-2000: 3%
2001-2005: 2%
2006-2010: 12%
2011-2016: 35%
- Total Private dwellings: 5183 buildings
- Number of Building in selected district:
22 Buildings</td><td>- Private dwellings by structure type:
Residential – Semi-Detached House
Residential – Condominium more than 5 stories</td></tr>
<tr><td>- Period of Construction:
Pre – 1980
1980 - 2004</td></tr>
<tr><td>- Average of S/V Ratio: 0.85 m^{-1} / 0.38 m^{-1}
- Average of S/V Ratio (Real): 1.02 m^{-1} / 0.41</td></tr>
<tr><td>- Area of the district: 57131.0 m^2
- Footprint of the buildings: 15828.9 m^2</td><td>- Heated Loss Surface: 173745.7 m^2
- Gross GIS Volume: 636077.5 m^3</td></tr>
<tr><th colspan="2">Specific consumption model</th></tr>
<tr><td colspan="2">Energy consumption (kWh/m³/year) Using gross volume
- Electricity: 26.2 – 30 / 31.7 – 34.8
- Natural Gas: 11.2 – 15 / 47.0 – 51.1</td></tr>
<tr><th colspan="2">Urban Variables</th></tr>
<tr><td colspan="2">Building Density (m³/m²) = 11.1
Building Coverage ratio (m²/m²) = 0.27
Building Height (m) = 17.4</td></tr>
</table>

Figure 5.1. 7, The results of the characteristics of the Mixed archetype (2)

Mixed Archetype 3: Condominium more than 5 stories / Condominium less than 5 stories

Zone and district scale features	Archetype building scale features
- **Zone**: MOSS PARK (73) - **Population**: 20506 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 22% **1961-1980**: 18% **1981-1990**: 7% **1991-2000**: 9% **2001-2005**: 9% **2006-2010**: 11% **2011-2016**: 32 - **Total Private dwellings**: 12513 buildings - **Number of Building in selected district:** 17 Buildings	- **Private dwellings by structure type**: Residential – Condominium more than 5 stories Residential – Condominium less than 5 stories - **Period of Construction**: Post - 2004 Post - 2004 - **Average of S/V Ratio:** 0.33 m^{-1} / 0.50 m^{-1} - **Average of S/V Ratio (Real)**: 0.35 m^{-1} / 0.60
- **Area of the district:** 25812.1 m^2 - **Footprint of the buildings:** 11994.2 m^2	- **Heated Loss Surface**: 74485.8 m^2 - **Gross GIS Volume**: 177791.1 m^3

Specific consumption model

Energy consumption (kWh/m³/year) Using gross volume
- **Electricity**: 23.3 – 25.9/ 2.10 – 2.12
- **Natural Gas:** 27.2 – 30.3 / 6.10 – 7.50

Urban Variables

Building Density (m³/m²) = 6.88
Building Coverage ratio (m²/m²) = 0.46
Building Height (m) = 11.8

Figure 5.1. 8, The results of the characteristics of the Mixed archetype (3)

Mixed Archetype 4: Condominium more than 5 stories / Raw House

Zone and district scale features	Archetype building scale features
- **Zone**: REGENT PARK (72) - **Population**: 10803 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 23% **1961-1980**: 18% **1981-1990**: 6% **1991-2000**: 3% **2001-2005**: 2% **2006-2010**: 12% **2011-2016**: 35% - **Total Private dwellings**: 5183 buildings - **Number of Building in selected district:** 19 Buildings	- **Private dwellings by structure type**: Residential – Condominium more than 5 stories Residential – Raw House - **Period of Construction**: Pre – 1980 1980 - 2004 - **Average of S/V Ratio:** 0.37 m^{-1} / 0.69 m^{-1} - **Average of S/V Ratio (Real)**: 0.39 m^{-1} / 0.83
- **Area of the district:** 96302.7m^2 - **Footprint of the buildings:** 21809**.2** m^2	- **Heated Loss Surface**: 120735.6 m^2 - **Gross GIS Volume**: 357896.5 m^3

Specific consumption model

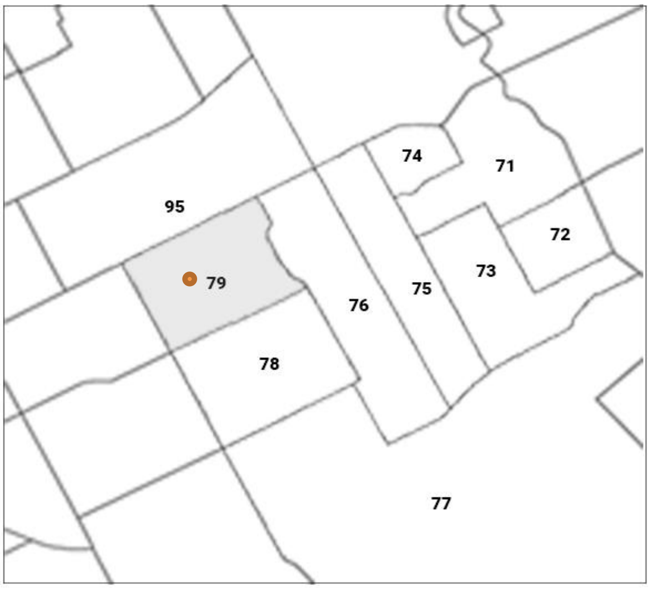
Energy consumption (kWh/m³/year) Using gross volume
- **Electricity**: 14.6 – 16.1/ 24.1 – 27.1
- **Natural Gas:** 36.1 – 39.9 / 16.0 – 19.6

Urban Variables

Building Density (m^3/m^2) = 3.71
Building Coverage ratio (m^2/m^2) = 0.22
Building Height (m) = 30.4

Figure 5.1. 9, The results of the characteristics of the Mixed archetype (4)

Mixed Archetype 5: Institutional / Semi-Detached House



Zone and district scale features	Archetype building scale features
- **Zone**: University (79) - **Population**: 7607 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 57% **1961-1980**: 24% **1981-1990**: 4% **1991-2000**: 3% **2001-2005**: 1% **2006-2010**: 5% **2011-2016**: 6% - **Total Private dwellings**: 3826 buildings - **Number of Building in selected district:** 53 Buildings	- **Private dwellings by structure type**: Public – Institutional Residential – Semi – Detached House - **Period of Construction**: Pre – 1980 1980 – 2004 - **Average of S/V Ratio:** 0.50 m^{-1} / 0.95 m^{-1} - **Average of S/V Ratio (Real)**: 0.60 m^{-1} / 1.24
- **Area of the district:** 56786.2 m^2 - **Footprint of the buildings:** 20369.**1** m^2	- **Heated Loss Surface**: 212234.7 m^2 - **Gross GIS Volume**: 932001.9 m^3

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 9.3 - 10.3/ 30.8 – 32.7 - **Natural Gas:** 13.9 - 15.4 / 35.9 – 38.6

Urban Variables
Building Density (m³/m²) = 9.4 **Building Coverage ratio (m²/m²) =** 0.35 **Building Height (m) =** 22.9

Figure 5.1. 10, The results of the characteristics of the Mixed archetype (5)

Mixed Archetype 6: Institutional / Single-Detached House

Zone and district scale features	Archetype building scale features
- **Zone**: University (79) - **Population**: 7607 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 57% **1961-1980**: 24% **1981-1990**: 4% **1991-2000**: 3% **2001-2005**: 1% **2006-2010**: 5% **2011-2016**: 6% - **Total Private dwellings**: 3826 buildings - **Number of Building in selected district:** 77 Buildings	- **Private dwellings by structure type**: Public – Institutional Residential – Single – Detached House - **Period of Construction**: Pre – 1980 1980 – 2004 - **Average of S/V Ratio:** 0.70 m^{-1} / 1.03 m^{-1} - **Average of S/V Ratio (Real)**: 0.87 m^{-1} / 1.39
- **Area of the district:** 99475.7 m^2 - **Footprint of the buildings:** 35530.**2** m^2	- **Heated Loss Surface**: 237893.2 m^2 - **Gross Volume**: 648115.0 m^3

Specific consumption model

Energy consumption (kWh/m³/year) Using gross volume
- **Electricity**: 9.3 - 10.3/ 35.1 – 38.6
- **Natural Gas:** 13.9 - 15.4 / 22.2 – 25.6

Urban Variables

Building Density (m^3/m^2) = 6.51
Building Coverage ratio (m^2/m^2) = 0.35
Building Height (m) = 22.5

Figure 5.1. 11, The results of the characteristics of the Mixed archetype (6)

Mixed Archetype 7: Condominium more than 5 stories / Single-Detached House

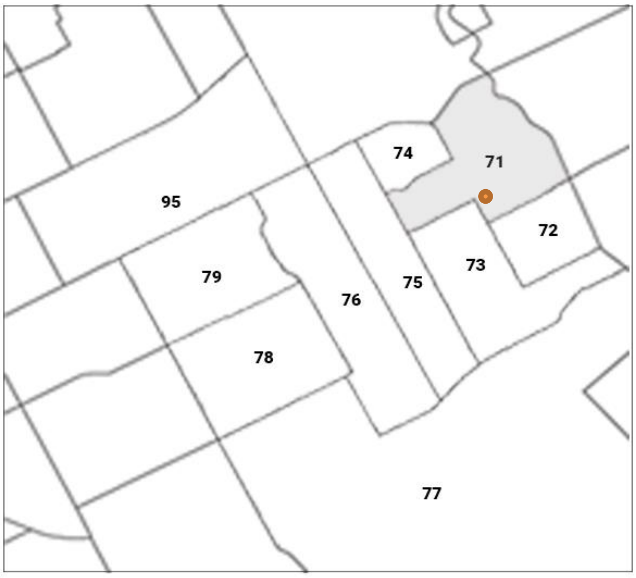
Zone and district scale features	Archetype building scale features
- **Zone**: ANNEX (95) - **Population**: 30526 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 43% **1961-1980**: 26% **1981-1990**: 9% **1991-2000**: 6% **2001-2005**: 5% **2006-2010**: 5% **2011-2016**: 6% - **Total Private dwellings**: 18109 buildings - **Number of Building in selected district:** 27 Buildings	- **Private dwellings by structure type**: Residential – Condominium more than 5 stories Residential – Single - Detached House - **Period of Construction**: Pre – 1980 Post - 2004 - **Average of S/V Ratio:** 0.31 m^{-1} / 0.81 m^{-1} - **Average of S/V Ratio (Real)**: 0.33 m^{-1} / 1.09
- **Area of the district:** 35494.7 m^2 - **Footprint of the buildings:** 8537.0 m^2	- **Heated Loss Surface**: 78477.0 m^2 - **Gross GIS Volume**: 238783.7 m^3

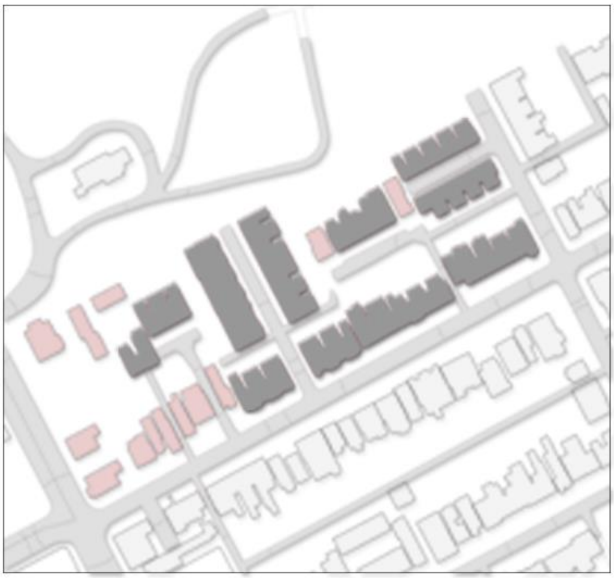
Specific consumption model
Energy consumption (kWh/m^3/year) Using gross volume - **Electricity**: 14.6 – 16.1 / 16.4 – 18.7 - **Natural Gas:** 36.1 – 39.9 / 20.4 – 22.7

Urban Variables
Building Density (m^3/m^2) = 6.72 **Building Coverage ratio (m^2/m^2) =** 0.28 **Building Height (m) =** 17.4

Figure 5.1. 12, The results of the characteristics of the Mixed archetype (7)

Mixed Archetype 8: Single-Detached House / Raw House





Zone and district scale features	Archetype building scale features
- **Zone**: CABBAGETOWN-SOUTH ST. JAMES TOWN (71) - **Population**: 11669 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 42% **1961-1980**: 27% **1981-1990**: 19% **1991-2000**: 4% **2001-2005**: 4% **2006-2010**: 4% **2011-2016**: 0% - **Total Private dwellings**: 6761 buildings - **Number of Building in selected district:** 23 Buildings	- **Private dwellings by structure type**: Residential – Single- Detached House Residential – Raw House - **Period of Construction**: Pre – 1980 Post - 2004 - **Average of S/V Ratio:** 1.02 m^{-1} / 0.68 m^{-1} - **Average of S/V Ratio (Real)**: 0.83 m^{-1} /1.02
- **Area of the district:** 25404.4 m^2 - **Footprint of the buildings:** 7555.0 m^2	- **Heated Loss Surface**: 38566.6 m^2 - **Gross GIS Volume**: 61832.7 m^3

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 32.6 – 36.6 / 34.3 – 37.3 - **Natural Gas:** 15.6 – 18.3 / 16.3 – 17.6

Urban Variables
Building Density (m³/m²) = 2.43 **Building Coverage ratio (m²/m²) =** 0.29 **Building Height (m) =** 16.6

Figure 5.1. 13, The results of the characteristics of the Mixed archetype (8)

Mixed Archetype 9: Condominium more than 5 stories / Semi-Detached House

Zone and district scale features	Archetype building scale features
- **Zone**: ANNEX (95) - **Population**: 30526 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 43% **1961-1980**: 26% **1981-1990**: 9% **1991-2000**: 6% **2001-2005**: 5% **2006-2010**: 5% **2011-2016**: 6% - **Total Private dwellings**: 18109 buildings - **Number of Building in selected district:** 29 Buildings	- **Private dwellings by structure type**: Residential – Condominium more than 5 stories Residential – Semi - Detached House - **Period of Construction**: Pre – 1980 Post - 2004 - **Average of S/V Ratio:** 0.47 m^{-1} / 0.81 m^{-1} - **Average of S/V Ratio (Real)**: 0.58 m^{-1} / 1.09
- **Area of the district:** 589149.5m^2 - **Footprint of the buildings:** 7690.7 m^2	- **Heated Loss Surface**: 87802.7 m^2 - **Gross Volume**: 261392.5 m^3

Specific consumption model

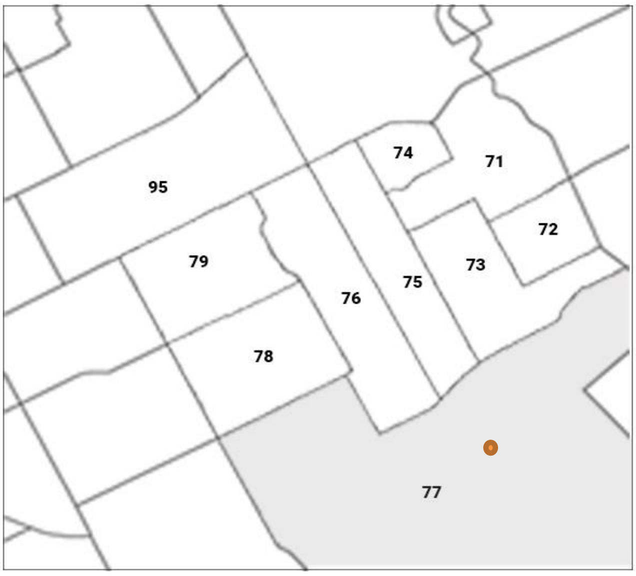
Energy consumption (kWh/m³/year) Using gross volume
- **Electricity**: 14.6 – 16.1 / 7.9 – 9.6
- **Natural Gas:** 36.1 – 39.9 / 26.6 – 31.9

Urban Variables

Building Density (m^3/m^2) = 9.8
Building Coverage ratio (m^2/m^2) = 0.37
Building Height (m) = 24.3

Figure 5.1. 14, The results of the characteristics of the Mixed archetype (9)

Mixed Archetype 1: Raw House/Condominium >5 stories / Condominium <5 stories



Zone and district scale features	Archetype building scale features
- **Zone**: Waterfront Communities-The Island (77) - **Population**: 65913 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 2% **1961-1980**: 7% **1981-1990**: 9% **1991-2000**: 10% **2001-2005**: 15% **2006-2010**: 24% **2011-2016**: 35% - **Total Private dwellings**: 47209 buildings - **Number of Building in selected district:** 24 Buildings	- **Private dwellings by structure type**: Residential – Raw House Residential – Condominium more than 5 stories Residential – Condominium less than 5 stories - **Period of Construction**: Pre – 1980 1980 – 2004 1980 - 2004 - **Average of S/V Ratio:** 0.68 m^{-1} / 0.35 m^{-1}/ 0.47 m^{-1}
- **Area of the district:** 131280.1 m^2 - **Footprint of the buildings:** 33402.**1** m^2	- **Heated Loss Surface**: 193405.0 m^2 - **Gross GIS Volume**: 608808.4 m^3

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 31.7 – 35.0/ 31.7 – 34.8 / 22.3 – 24.8 - **Natural Gas:** 15.0 – 16.6/ 47.0 – 51.1 / 20.1 – 23.6

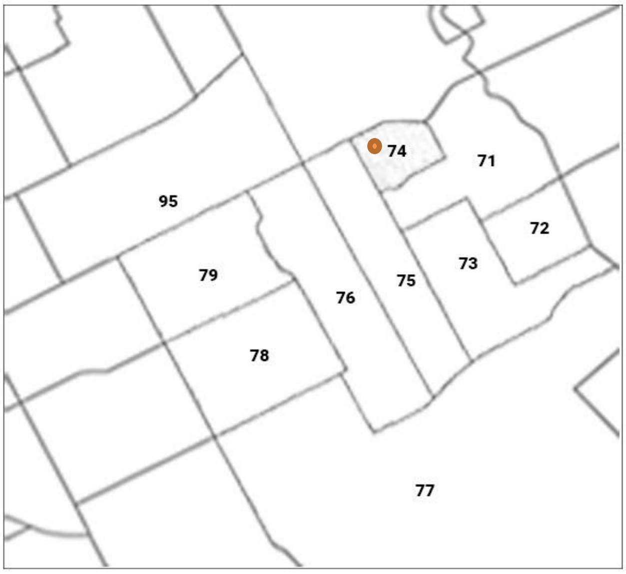
Urban Variables
Building Density (m^3/m^2) = 4.63 **Building Coverage ratio (m^2/m^2) =** 0.25 **Building Height (m) =** 13.4

Mixed Archetype 2: Semi-Detached House/Condominium < 5 stories / Offices

Zone and district scale features	Archetype building scale features
- **Zone**: ANNEX (95) - **Population**: 30526 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 43% **1961-1980**: 26% **1981-1990**: 9% **1991-2000**: 6% **2001-2005**: 5% **2006-2010**: 5% **2011-2016**: 6% - **Total Private dwellings**: 18109 buildings - **Number of Building in selected district:** 35 Buildings	- **Private dwellings by structure type**: Residential – Semi – Detached house Residential – Condominium less than 5 stories Public – Offices - **Period of Construction**: Pre – 1980 Pre – 1980 Pre – 1980 - **Average of S/V Ratio:** 0.69 m^{-l} / 0.55 m^{-l}/ 0.43 m^{-l}
- **Area of the district:** 22880.5 m^2 - **Footprint of the buildings:** 9236.**54** m^2	- **Heated Loss Surface**: 61221.7 m^2 - **Gross GIS Volume**: 133054.4m^3
Specific consumption model	
Energy consumption (kWh/m³/year) Using gross GIS volume - **Electricity**: 35.0 - 40.0 / 26.2 – 30 / 10.5 – 13.7 - **Natural Gas:** 15.0 – 20.0/ 9.5 – 9.5 / 17.3 – 19.4	
Urban Variables	
Building Density (m^3/m^2) = 5.81 **Building Coverage ratio (m^2/m^2) =** 0.397 **Building Height (m) =** 10.53	

Figure 5.1. 15,The results of the characteristics of the Mixed archetype (more than two buildings per district) (2)

Mixed Archetype 3: Raw House/Condominium< 5 stories / Hospitality



Zone and district scale features	Archetype building scale features
- **Zone**: **Zone**: NORTH ST. JAMES TOWN (74) - **Population**: 18615 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 22% **1961-1980**: 51% **1981-1990**: 8% **1991-2000**: 4% **2001-2005**: 2% **2006-2010**: 10% **2011-2016**: 4% - **Total Private dwellings**: 10109 buildings - **Number of Building in selected district:** 13 Buildings	- **Private dwellings by structure type**: Residential – Semi – Detached house Residential – Condominium less than 5 stories Public – Hospitality - **Period of Construction**: Pre – 1980 Pre – 1980 Post - 2004 - **Average of S/V Ratio:** 0.68 m^{-1} / 0.69 m^{-1}/ 0.41 m^{-1}
- **Area of the district:** 17509.6 m^2 - **Footprint of the buildings:** 6538.**6** m^2	- **Heated Loss Surface**: 31339.1 m^2 - **Gross GIS Volume**: 54867.6 m^3

Specific consumption model
Energy consumption (kWh/m³/year) Using gross volume - **Electricity**: 35.0 - 40.0 / 26.2 – 30 / 6.3 – 8.2 - **Natural Gas:** 15.0 – 20.0/ 9.5 – 9.5 / 15.05 – 17.3

Urban Variables
Building Density (m³/m²) = 3.13 **Building Coverage ratio (m²/m²) =** 0.37 **Building Height (m) =** 13.7

Figure 5.1. 16, The results of the characteristics of the Mixed archetype (more than two buildings per district) (3)

Mixed Archetype 4: Raw House/Condominium > 5 stories / Hospitality

Zone and district scale features	Archetype building scale features
- **Zone**: Waterfront Communities-The Island (77) - **Population**: 65913 inhabitants - **Period of Construction in whole zone**: **Pre-1960**: 2% **1961-1980**: 7% **1981-1990**: 9% **1991-2000**: 10% **2001-2005**: 15% **2006-2010**: 24% **2011-2016**: 35% - **Total Private dwellings**: 47209 buildings - **Number of Building in selected district:** 15 Buildings	- **Private dwellings by structure type**: Residential – Raw House Residential – Condominium less than 5 stories Residential – Hospitality - **Period of Construction**: Pre – 1980 Pre – 1980 Post - 2004 - **Average of S/V Ratio:** 0.62 m^{-1} / 0.52 m^{-1}/ 0.62 m^{-1}
- **Area of the district:** 23346.2 m^2 - **Footprint of the buildings:** 10121.**3** m^2	- **Heated Loss Surface**: 37760.9 m^2 - **Gross GIS Volume**: 69489.7 m^3

Specific consumption model

Energy consumption (kWh/m³/year) Using gross GIS volume
- **Electricity**: 31.7 – 35.0/ 23.3 – 29.2/ 12.6 – 15.1
- **Natural Gas:** 15.0 – 16.6/ 9.5 – 9.5 / 9.5 – 11.2

Urban Variables

Building Density (m³/m²) = 2.97
Building Coverage ratio (m²/m²) = 0.43
Building Height (m) = 13.2

Figure 5.1. 17, The results of the characteristics of the Mixed archetype (more than two buildings per district) (4)

5.2. Energy performance classes and energy consumptions

From the analysis of the different types of buildings in this work, the rate of energy consumption was determined for each type of building on which the study was conducted, through the consumption of electricity and natural gas in each of the study areas.
As residential buildings have a different rate of energy consumption if the period of construction varies, and this is what was clarified in this work, as we note that most of the residential buildings on which the study was applied, in the near construction period have less energy consumption than the energy consumption in the old construction period.

In order to analyze the main variables that are directly related to energy, the work was done as follows:

- To determine the **Natural Gas** energy consumption: Multiple linear regressions were selected for surface-to-volume ratio S/V and period of construction.

- To determine the **Electricity** energy consumption: inhabitants/m³

In both determinations, the gross volume variable of residential buildings from GIS was used to evaluate most of the data on the distribution of buildings, consumption, and inhabitants.

5.2.1. Energy model for Natural gas

A multiple linear regression analysis was performed considering the surface-to-volume ratio S/V and the period of construction of residential buildings.

In the following Table, it is represented the model of the specific consumption of Natural Gas (kWh/m³/year) for the residential building of the City of Toronto according to the period of construction and the form factor S/V ratio.

Energy consumption (1): Condominuim more than 5 stories, **Energy consumption (2):** Condominuim less than 5 stories, **Energy consumption (3):** Raw houses, **Energy consumption (4):** Average of Single-Detached house and Semi-Detached house

Period of construction	Surface to Volume ratio S/V (m^{-l})				Energy Use for the Natural Gas (kWh/m³/year)			
	Class 1	Class 2	Class 3	Class 4	Energy consumption (1)	Energy consumption (2)	Energy consumption (3)	Energy consumption (4)
Pre - 1980	< 0.40	0.40 – 0.63	0.63 – 0.80	> 0.80	20.5	9.5	26.25	25.7
1980 - 2004	< 0.38	0.38 – 0.56	0.56 – 0.80	> 0.80	30.35	21.85	17.5	33.15
Post - 2004	< 0.42	0.42 – 0.50	0.50 – 0.80	> 0.80	15.05	6.8	15.2	19.075

Table 5.2.1 1, Subdivision of buildings in classes for period of construction and surface-to-volume ratio, showing the energy consumption (kWh/m³/year) for the Natural gas.

In the following Figures, it is represented the model of the specific consumption of Natural Gas (kWh/m³/year):

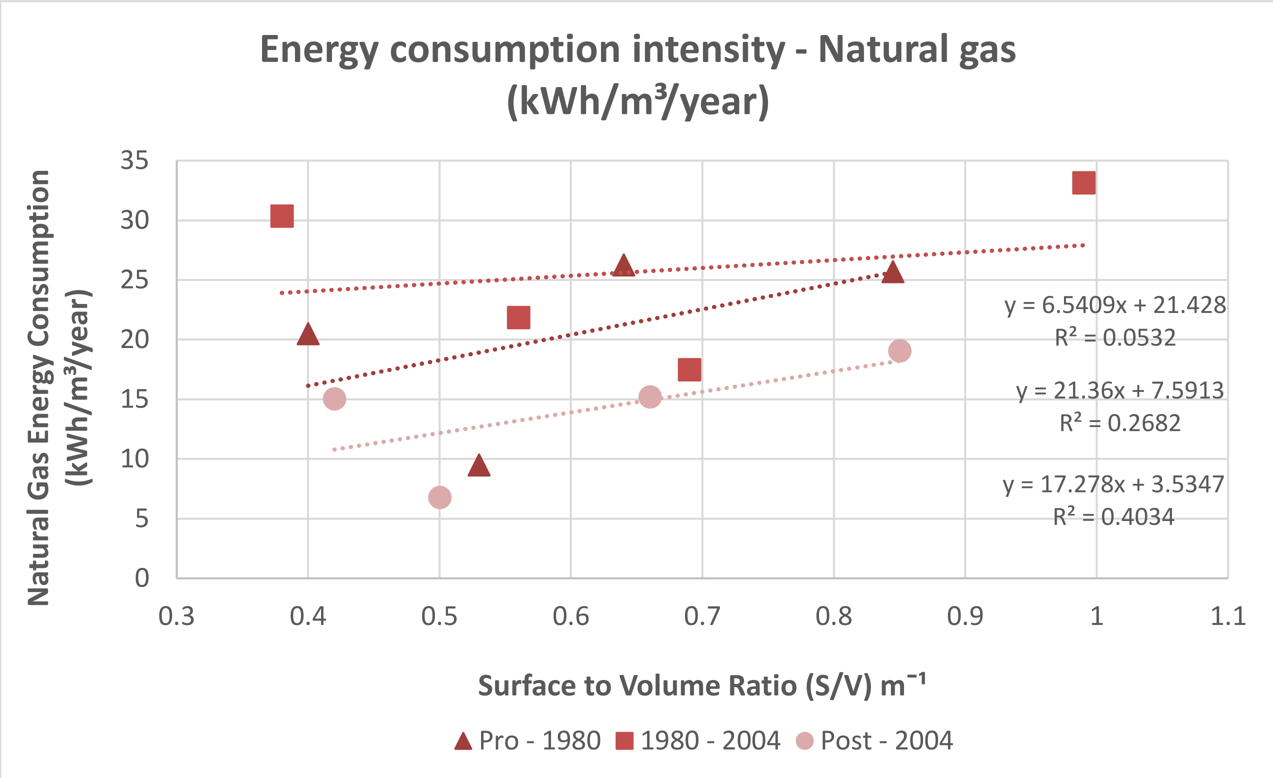


Figure 5.2.1 1, Linear regressions for energy consumption index on Natural gas per unit of gross volume and period of construction, (kWh/m³/year)

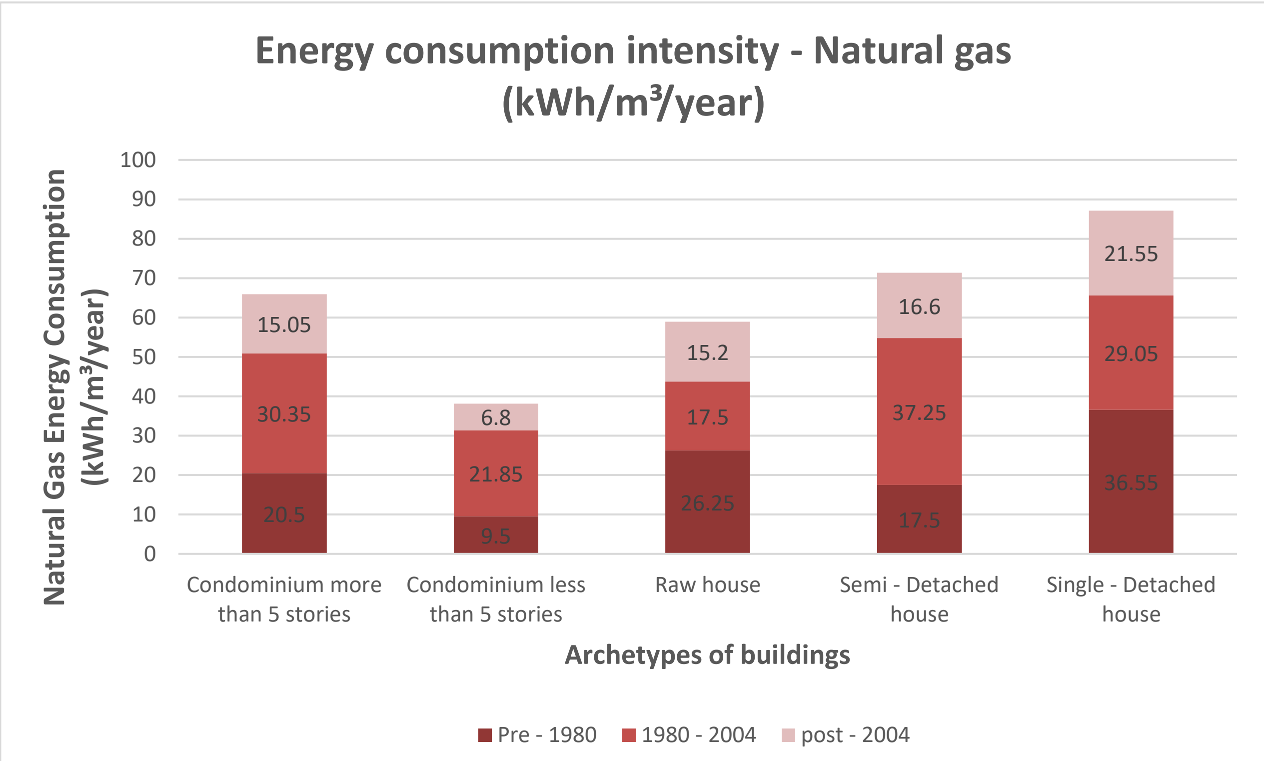


Figure 5.2.1 2, Total energy consumption for the Natural gas (kWh/m³/year) considering the consumption of different archetypes of the residential buildings during different periods of construction.

Through this model, we can note that energy consumption in previous construction periods was large compared to modern construction periods, due to the use of many new technologies and different energy policies, attempt to reach the highest percentage of energy efficiency, in order to work on Reducing energy consumption as much as possible, which has a significant impact on the city at the economic level.

As for the form factor S/V ratio, the results show that the buildings that have a larger form factor - for example single and semi-detached houses buildings - which have a form factor S/V ratio larger than 0.80, their energy consumption are large compared to those that have a form factor Less, and the reason for this is that there is a big percentage of heated volume on the buildings that have a lower form factor value such as the large condominium units that are more compact.

5.2.2. Energy model for Electricity

A Single linear regression analysis was performed considering the inhabitatnt per gross volume (m^3)

In the following Table, it is represented the model of the specific consumption of Electricity ($kWh/m^3/year$) for the residential building of the City of Toronto according to the Inhabitants/ m^3:

	Condominium more than 5 stories	Condominium less than 5 stories	Raw house	Semi- Detached house	Single- Detached house
Inhabitants/Family	1.2	1.9	1.8	2.5	3
Inhabitants/m³	0.00072	0.00125	0.00134	0.0016	0.00103
	0.00054	0.000205	0.0014	0.0019	0.0016
	0.0009	0.00084	0.00056	0.0014	0.0032
Pre - 1980	20.5	28	33.35	37.5	46.15
1980 - 2004	28.9	23.55	25.6	31.75	36.85
post - 2004	17.15	10.5	32.3	27.5	17.55

Table 5.2.2 1, Subdivision of buildings in classes for inhabitants, showing the energy consumption (kWh/m³/year) for the Electricity.

In the following Figures, it is represented the model of the specific consumption of Natural Gas (kWh/m³/year):

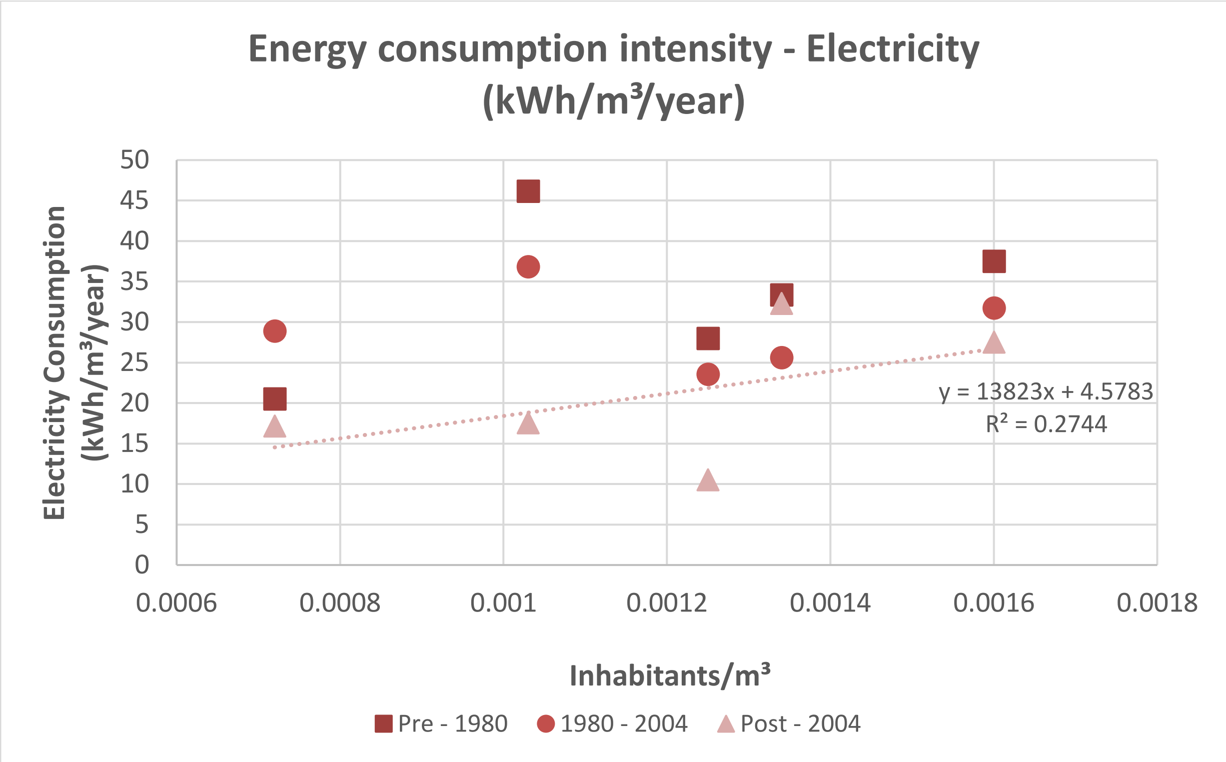


Figure 5.2.2 1, Linear regressions for energy consumption index on Electricity (kWh/m³/year) per unit of gross volume and Inhabits

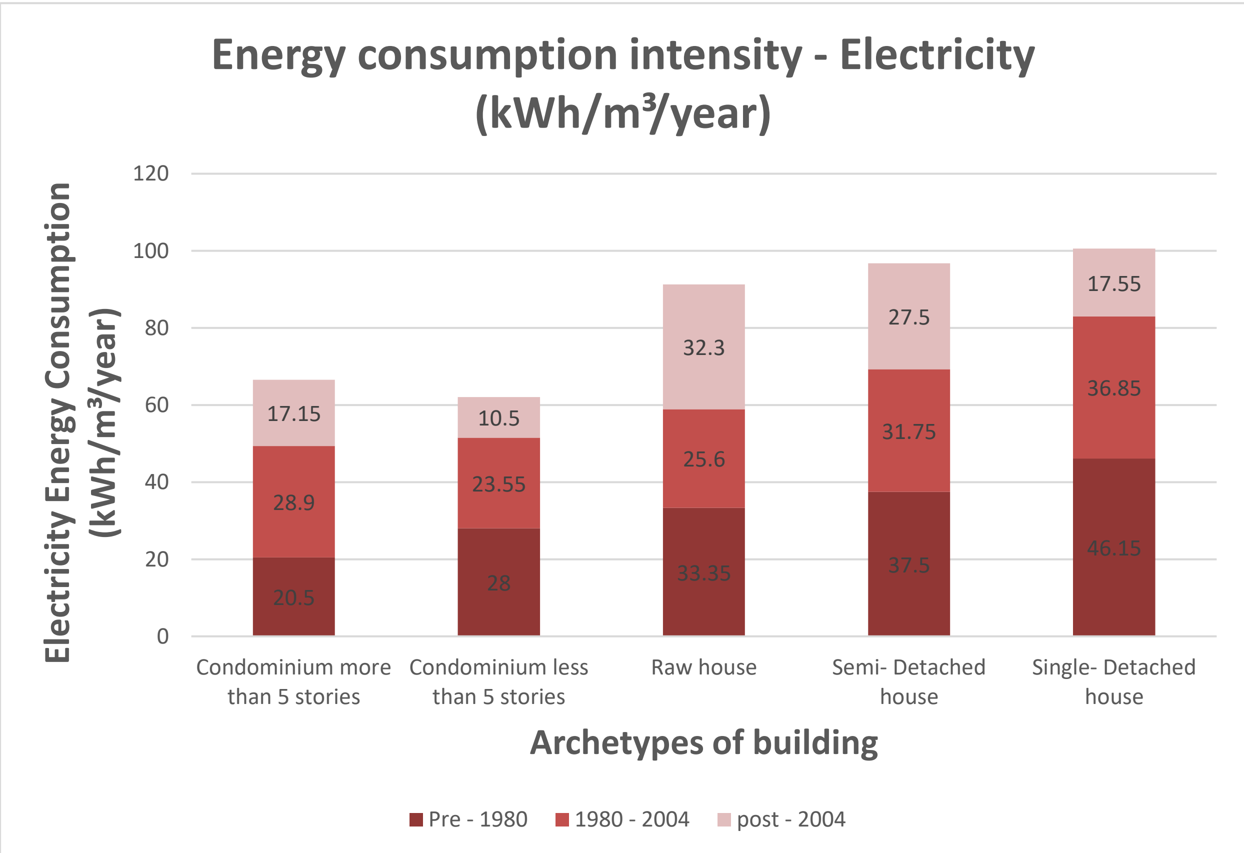


Figure 5.2.2 2, Total energy consumption for the Electricity (kWh/m³/year) considering the consumption of different archetypes of the residential buildings according to the inhabitants/m³.

Through this model, we note that the energy consumption of buildings consisting of a larger number of people has greater energy consumption than residential buildings that consist of fewer people.

5.2.3. Total energy consumption within the studied districts

The following table shows the average energy consumption in the residential building sector in the study area divided by gross volume.

Period of construction	Energy consumption type ($kWh/m^3/year$)	Single – Detached House	Semi-Detached House	Raw House	Condominium less than 5 stories	Condominium more than 5 stories
Pre - 1980	Electricity	46.15	37.5	33.35	28.1	20.5
	Natural Gas	36.55	17.5	26.25	9.5	33.6
1980 - 2004	Electricity	36.85	31.75	25.6	23.55	28.9
	Natural Gas	29.05	37.25	17.5	21.85	30.35
post - 2004	Electricity	17.55	27.5	32.3	10.5	17.15
	Natural Gas	21.55	16.6	15.2	6.8	15.05

Table 5.2.3 1, Total energy consumption ($kWh/m^3/year$) considering the period of construction per each archetype of residential building, Using Gross volume (m^3)

The following table shows the average energy consumption in the residential building sector in the study area divided by gross volume.

Period of construction	Total Gross Volume by GIS (m^3)	Total Energy consumption (Electricity) (kWh/m^3/ year)	Total Energy consumption (Natural gas) (kWh/m^3/ year)	Total Energy consumption intensity (kWh/m^3/ year)
Pre - 1980	139944.8	165.6	123.4	289
1980 - 2004	211504.8	146.65	136	282.65
Post - 2004	480360.0	105	75.2	180.2

Table 5.2.3 2, average energy consumption in the residential building sector in the study area divided by gross volume

5.2.4. Validation of energy consumption models

At the end of this work, the results of the energy model used for both electricity and natural gas were compared with the energy consumption data in Canada statics platform, The results were to some extent similar, with a difference between the calculated data and the existing data, and the reason for this is due to the use of the total size of the buildings In a GIS environment that also includes unheated volumes

It is considered that there is a small error rate in the results compared to the available data on energy consumption for the city of Toronto

	Pre - 1980	1980 - 2004	Post - 2004
Database	157.58	139.64	99.96
Calculated	131.30	134.56	85.76

Table 5.2.4. 1, Total energy consumption for Natural gas and Electricity (kWh/m²/year)

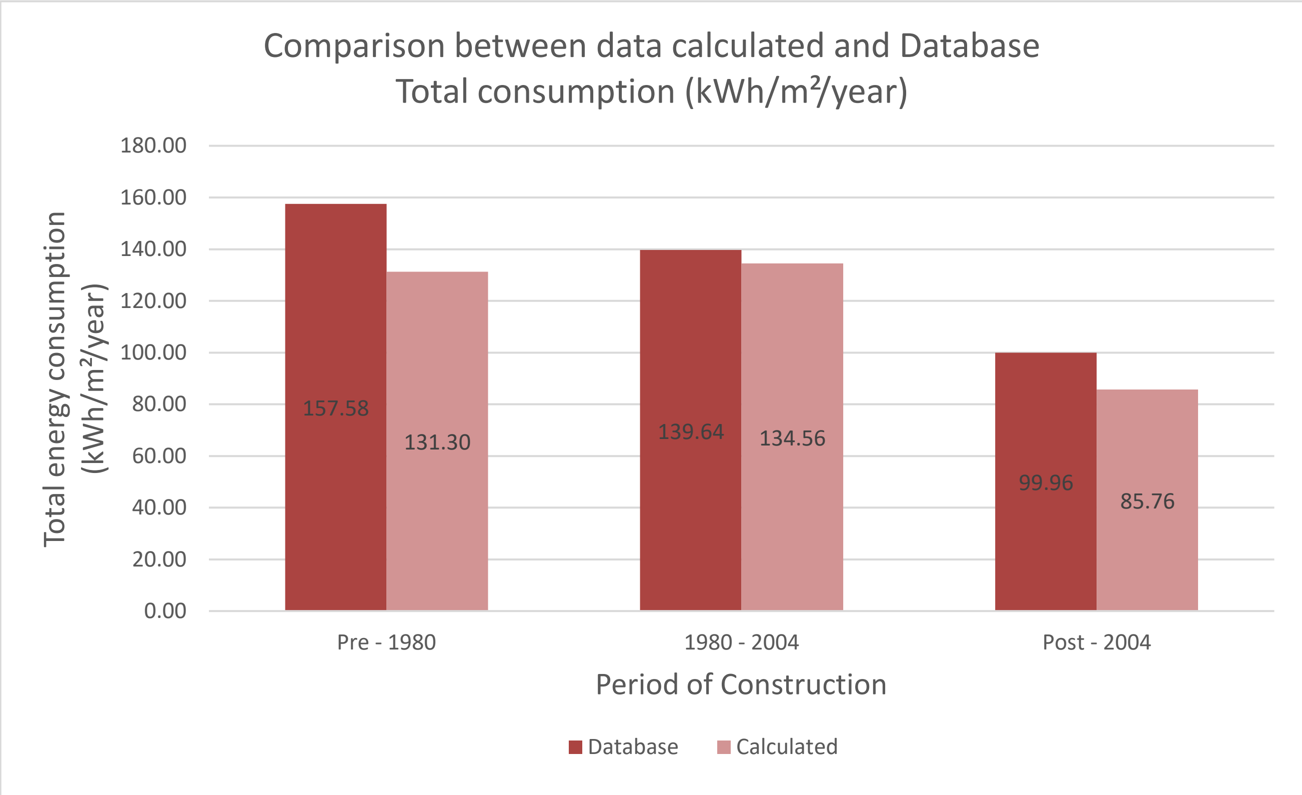


Figure 5.2.4 1, Total data for energy consumption

6.2.5. The energy-related characteristics of buildings calculated in GIS environment

- Archetypes of buildings per district

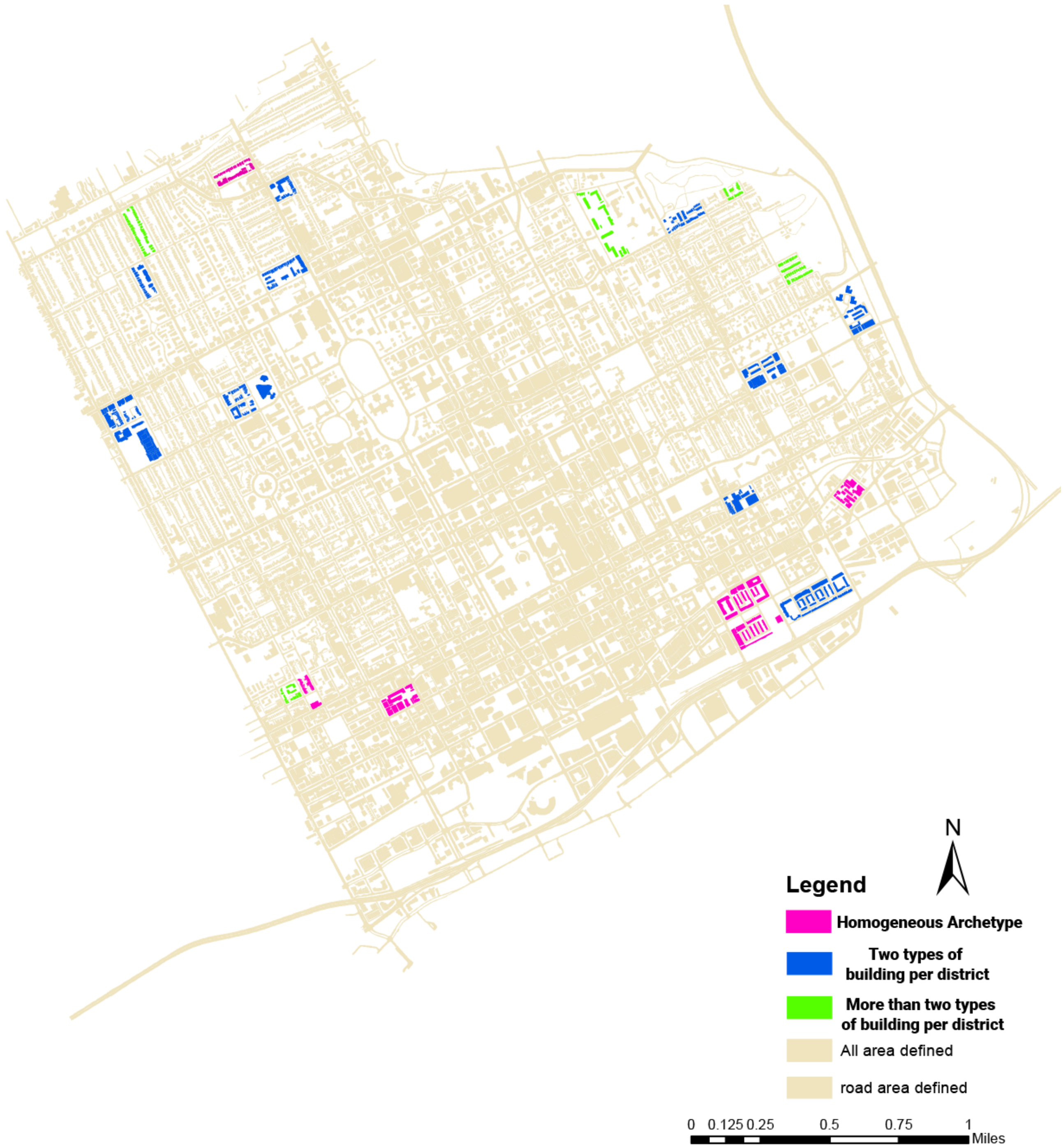


Figure results 1. 1, Different type of buildings per district (Data calculated on ArcGIS)

-Total Energy Consumption for the studied districts using the gross GIS volume

Figure results 1. 2, total energy consumption for in district scales (data calculated on ArcGIS)

Period of construction for the studied districts

Figure results 1. 3, period of construction for the building in the district scales (data calculated on ArcGIS)

Form factor S/V ratio for the studied districts

Figure results 1. 4, Form factor for the buildings on the district scale (data calculated on ArcGIS)

Inhabitants / m³

Figure results 1. 5, Inhabitants/m³ on the district scale (data calculated on ArcGIS)

Conclusion

The city of Toronto works to develop its cities in order to reach a country that promotes clean energy generation and access to a large level of renewable energy generation, also reduce the energy consumption of buildings by working to make cities more energy efficient and improve them through the use of many alternatives and solutions that work on Rationalizing energy consumption, whether in the residential sector or other public sectors.

In this work, the tool used for analysis is ArcGIS 10.7.1, which helped greatly to manage the various databases available and to create an updated and complete database as possible.
All forms presented in the letter and worked on them are geo-documented and computerized so that they can be easily updated and used when needed.
The analyzes started from the urban indicators that have the greatest impact in the urban context, and which must be intervened in order to effectively reduce the energy consumption of buildings.
In fact, the models presented in this work can be supportive of the regional planning process and help to understand the nature of the analyzed area, and the amount of energy consumption.

This work is based on determining the rate of energy consumption in residential buildings, understanding the urban environment,
and knowing the amount of specific energy at the local and regional levels. The results achieved in this work are a simple contribution in order to help develop solutions and alternatives for many residential buildings where the energy consumption level is high to some extent.

For better sustainability, and to work on the development of the city, future work is possible on many key points, The most important of which are:
- Rehabilitation of existing buildings in order to improve housing conditions, to generate renewable energy.
- Working on using natural resources for energy production, water heating, and heating in winter also using solar photovoltaics that generates renewable energy to be used.

The use of the simplified model of energy top-bottom model, and based on GIS in mapping, has had a great role in understanding the rate of energy consumption in different types of residential buildings on the urban scale, in addition to collecting all the information resulting from this model in GIS data sheets contain all the characteristics of the archetype of buildings in a systematic manner with all the results obtained in this work, making this information comparable and easy to update.

In the context of the city of Toronto, it appears that the different building characteristics that have been analyzed and considered in this work, have different effects on actual consumption,

- Considering the **Form factor S/V ratio** and the different **periods of construction** of residential buildings in calculating the consumption of **Natural gas** of residential buildings in the city of Toronto

S/V ratio: It was found that buildings that have a higher form factor, have a greater energy consumption, due to the presence of a large proportion of the building is not heated.

The period of construction: each type of residential building has a different energy consumption according to the different construction periods. Due to the availability of many technologies to reduce energy consumption used in modern buildings.

- Considering the **Inhabitants** of residential buildings in calculating the consumption of **Electricity** of residential buildings in the city of Toronto

Inhabitants: which is considering according to the gross volume of the buildings (Inhabitants/m^3)
It was found that the buildings which are includes more inhabitants, that means the energy consumption will be higher.

As for the urban variables that were taken into consideration, it was found that the urban variable **BCR** has a significant impact on energy consumption, as the trend of consumption with the difference in BCR is an equal trend, that is, when its value is high, it means that there is high consumption, and the average value means that consumption is low.

In the following Tables show the Database for the Natural Gas and Electricity energy consumption from the Canada statics platform (GJ/m^2)/(kWh/m^2):

- Natural Gas energy consumption

Period of construction	Energy consumption (GJ/m^2)	Energy consumption (kWh/m^2)
Before 1946	0.51	141.6667
1946 – 1960	0.44	122.2222
1961 – 1977	0.44	122.2222
1978 – 1983	0.39	108.3333
1984 – 1995	0.38	105.5556
1996 – 2000	0.37	102.7778
2001 - 2010	0.32	88.88889
2011 or later	0.34	94.44444

Table conclusion 1. 1, Total Natural gas energy consumption – Canada statics platform

- Electricity energy consumption

Period of construction	Energy consumption (GJ/m^2)	Energy consumption (kWh/m^2)
Before 1946	0.23	63.88889
1946 – 1960	0.24	66.66667
1961 – 1977	0.24	66.66667
1978 – 1983	0.32	88.88889
1984 – 1995	0.31	86.11111
1996 – 2000	0.26	72.22222
2001 - 2010	0.28	77.77778
2011 or later	0.36	100

Table conclusion 1. 2,Total Natural gas energy consumption – Canada statics platform.

In the following Tables show the comparison between the database for the Natural Gas and Electricity energy consumption from the Canada statics platform (GJ/m²) converted to (kWh/m²/year) and the Energy consumption calculated in this work (kWh/m²/year):

- Natural Gas energy consumption (kWh/m²/year)

	Pre - 1980	1980 - 2004	Post - 2004
Database	123.61	104.17	91.67
Calculated	105.02	129.48	71.57

Table conclusion 1. 3, Total Natural gas energy consumption

- Electricity energy consumption (kWh/m²/year)

	Pre - 1980	1980 - 2004	Post - 2004
Database	71.5	79.1	88.8
Calculated	157.58	139.64	99.96

Table conclusion 1. 4, Natural gas energy consumption

- Total energy consumption for electricity and natural gas (kWh/m²/year)

	Pre - 1980	1980 - 2004	Post - 2004
Database	157.58	139.64	99.96
Calculated	131.30	134.56	85.76

Table conclusion 1. 5, Total energy consumption for Natural gas and Electricity

- Total data about the energy consumption (kWh/m²/year)

	Natural Gas (Calculated)	Natural Gas (Database)	Electricity (Calculated)	Electricity (Database)	Total (Calculated)	Total (Database)
Pre - 1980	105.02	123.61	157.58	71.5	131.30	157.58
1980 - 2004	129.48	104.17	139.64	79.1	134.56	139.64
Post - 2004	71.57	91.67	99.96	88.8	85.76	99.96

Table conclusion 1. 6, Total data for energy consumption

- The comparison between the Natural gas and electricity energy consumption calculated throw this work with the database of energy consumption inserted on the Canada statics platform (kWh/m²/year)

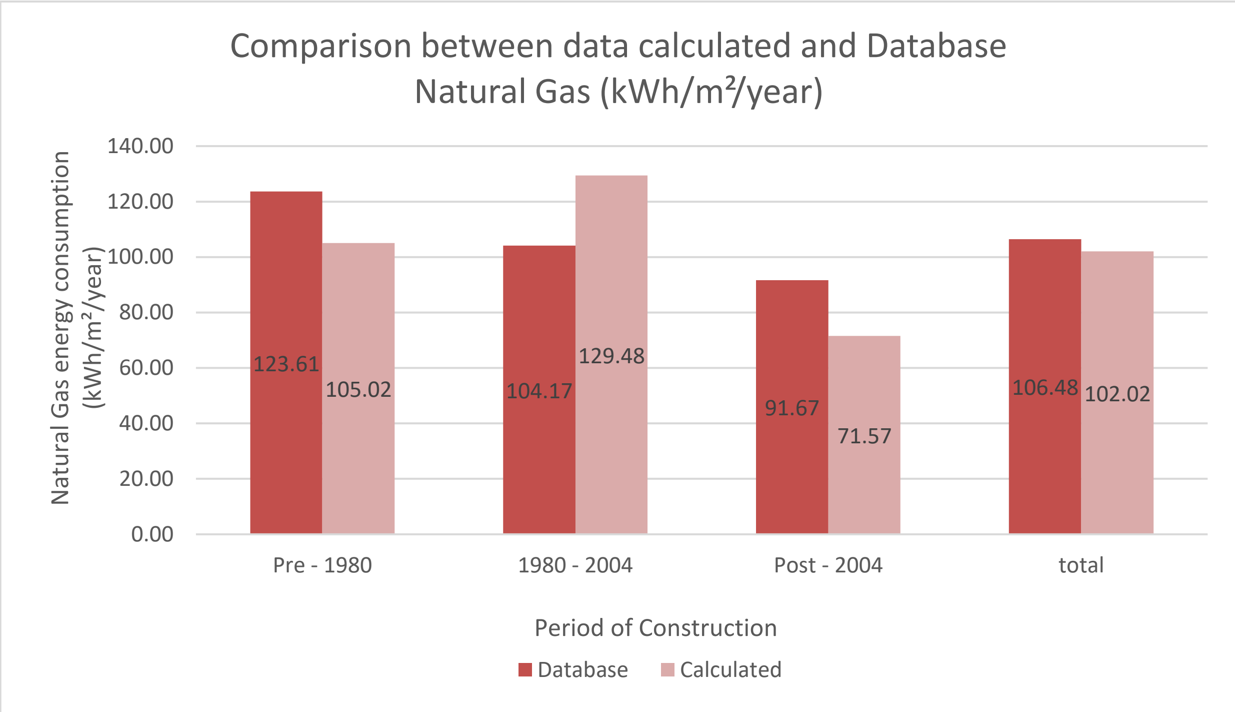


Figure Conclusion 1. 1, Total data for energy consumption

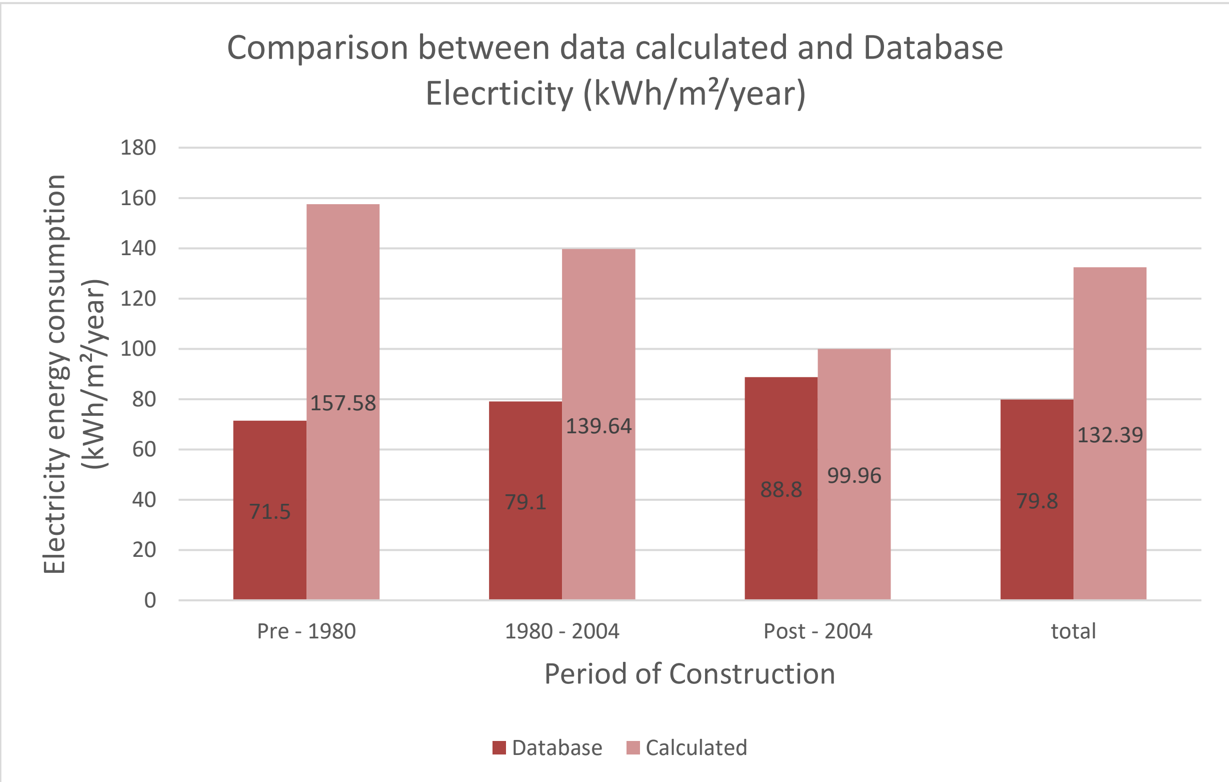


Figure Conclusion 1. 2, Total data for energy consumption

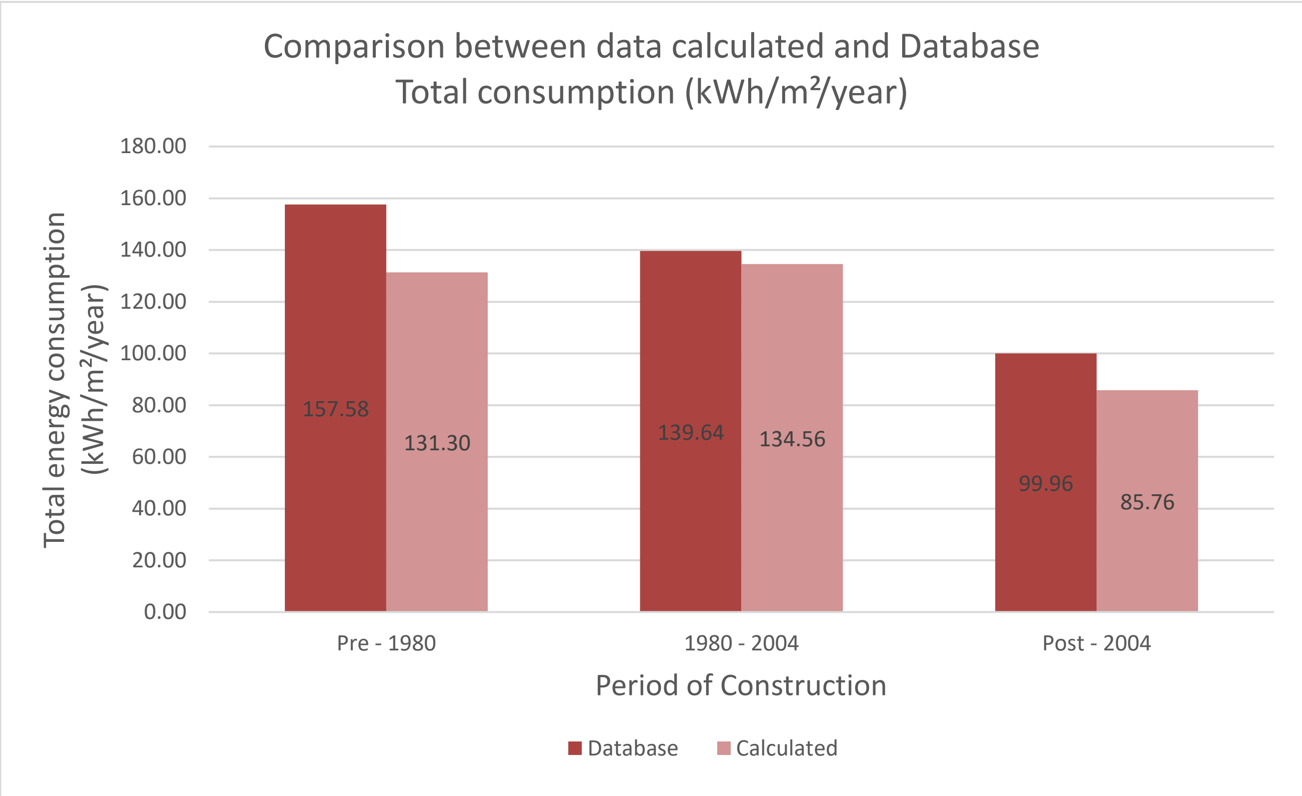


Figure Conclusion 1. 3, Total data for energy consumption

As for the results of the work, the results showed that they are fairly close to the basic data reported in the Canada statics platform for energy consumption, with some minor differences that are due to the intensity of energy consumption was based on the gross volume from the GIS environment, which includes unheated volumes, on the contrary, the available data takes into account that the total energy intensity of the city of Toronto depends mainly on the heated area of the building. Therefore, we find that the results were somewhat larger than the available data.

At all levels, the goal of this work, as we mentioned earlier, is to analyze energy consumption in the city of Toronto in urban scale in order to work on finding solutions and alternatives that reduce energy consumption in residential buildings where energy consumption is high,

In order to increase economic and population growth, this has led to the need to provide many energy efficiency improvements in residential buildings, which have significant benefits for the climate and energy consumers.
For example, the availability of efficiency in buildings reduces energy use and expenditure, which improves affordability, especially for households.

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