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Making Toronto Solar Ready: Proposing Bbuilding Formations For The Integration Of Solar Strategies

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MAKING TORONTO SOLAR READY: PROPOSING BUILDING FORMATIONS FOR THE INTEGRATION OF SOLAR STRATEGIES

by

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ABSTRACT

As highly dense urban areas are also the top energy consumers per capita, the question as to how we can design our cities to be "solar ready", i.e. suitable for successful integration of active and passive solar strategies in buildings, arises. Through a series of insolation simulations of typical urban morphologies found in the city of Toronto, this study will (i) identify if Toronto is "solar ready", (ii) suggest strategies to overcome obstacles, and (iii) propose new building formations that maximize insolation levels to promote the integration of solar strategies in our built environments.

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LIST OF ABBREVIATIONS

3-D - three dimension

CAAD- Computer-aided architectural design

CMHC- Canada Mortgage and Housing Corporation

EDP- early design phase

FIT- feed-in tariff

GFA- gross floor area

GHG - greenhouse gas

GJ/m^2- gigajoule per meter square

GWh/m^2 -gigawatt hours per meter square

IEA- International Energy Agency

kWh- kilowatt hour per

kWh/m^{2-} kilowatt hour per meter square

PV- photovoltaic

ST- solar thermal

CHAPTER 1

Introduction

Cities are increasingly growing in population: in 1900 only 15% of the global population lived in cities (fig. 1) (United Nations, 1999). This has increased to more than 3.3 billion people (just above 50% of the world's population) in 2008 and is expected that by 2030 this number will increase to five billion people (United Nations Population Fund, 2005). It is these very urban landscapes that are consuming much of the world's energy. They are located on only 2 per cent of the earth's surface yet consume approximately 75 per cent of the world's resources (Girardet, 1999). These statistics, combined with an estimated global population of approximately 9 billion people by the year 2050 (U.S. Census Bureau, 2011), stresses the need of alternative sources of energy if society is to continue functioning with the needs and comforts which are experienced today.

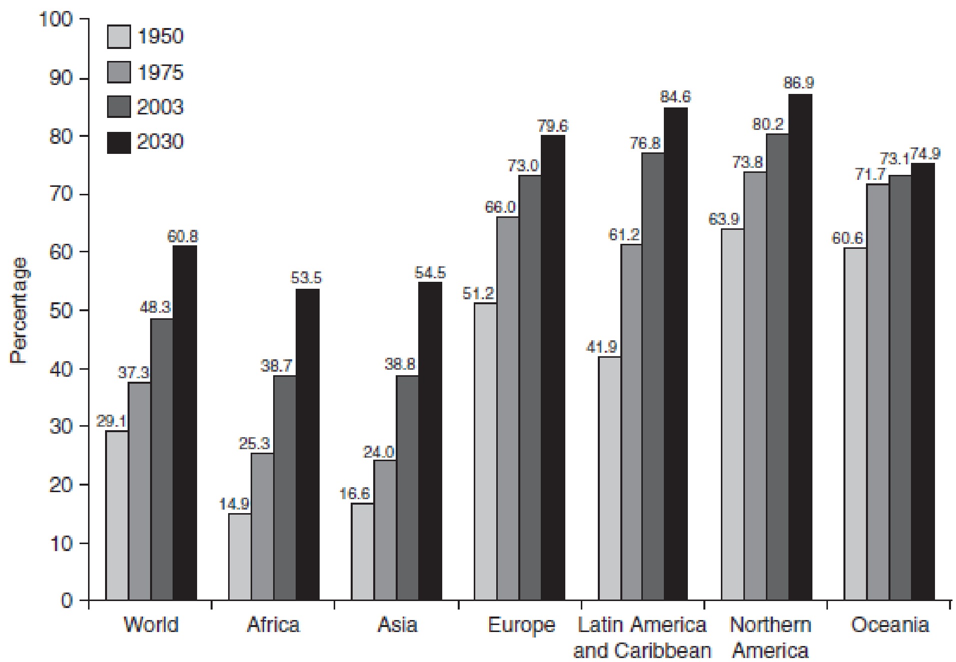


Figure 1: Projected population in urban areas (Droege, 2008).

It is interesting to observe that solar energy harvesting strategies are not often incorporated into the design of buildings considering the vast amounts of solar energy available. The city of Toronto, on average, receives approximately 1305kWh/m^2 of solar radiation on the ground (Natrual Resources Canada, 2008), yet reliance on fossil fuels for the operation of buildings is undeniably dominant in the built environment with very few signs of converting to alternative sources. Availability of oil is abundant, but not infinite. This means that there will come a time when alternative sources of energy must be obtained. Solar energy is infinite and unlike fossil fuels, Torontonians insatiable appetite for energy can go without consequence.

There are barriers when it comes to the utilization of solar energy in the built environment. The overshadowing of adjacent structures is leading to built environments that are receiving little to no solar activity. Solar radiation travels through 93 million miles of space before reaching the earth's surface. It is within only the final few hundred feet that it is being blocked from buildings, preventing this radiation from becoming a useful source of energy (Miller, Hayes, & Thompson, 1977). With inadequate amounts of solar radiation reaching building surfaces, the implementation of solar strategies is futile leaving society reliant on conventional, and often harmful, energy sources.

The operational energy of buildings is consuming much of the overall energy demand within the built environment (fig. 2) and it is this aspect of energy consumption which must be addressed. As per (Knowles, 2003), *"we grow cheap and maintain expensive"* which suggest that owners do not want to invest the high capital cost of solar technology during construction even though it will reduce energy consumption (and therefore cost) over the service life of the building.

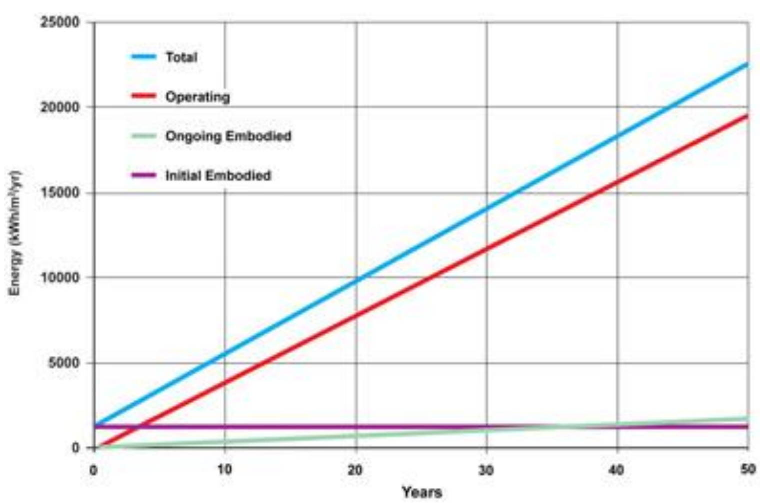


Figure 2: The overall embodied energy of a building over the life span (Cole & Kernan, 1996).

The scope of this thesis is to explore the potential of harvesting solar energy by implementing design parameters which will increase property owner's access to solar radiation. The access to solar radiation will allow designers and planners of the built environment to optimize development that contributes to a solar city. It is important that designers are aware of the location of the sun and how it will affect their building, and just as importantly, how it will affect adjacent buildings. It has been suggested by (Fitch, 1999) that the difference between the south facade and the north facade of a building is comparable to buildings that are located 1500 miles apart. Designing to be solar ready will not only benefit owners and developers by the reduction of energy costs, but benefit all by the reduction of harmful greenhouse gas emission that are created by our cities.

"The battle to ensure that our planet remains a hospitable and sustainable home for the human species will be won or lost in the major urban areas"

-Maurice Strong (Director General- 1992 Rio Earth Summit)+

Problem Statement

With the increasing need to incorporate renewable energy generating systems in urban areas, where population density and consumption are highest, scientists, engineers, urban designers and architects must look at the potentials that exist in urban locations such as the city of Toronto. Even though the amount of solar energy received on horizontal surfaces in Toronto is considerably higher than Berlin, Toronto's installed photovoltaic capacity per capita is only roughly three percent of Berlin (City of Toronto, 2007). The City of Toronto relies heavily on natural gas for energy generation where 63% of all energy is from natural gas and a mere 0.6% is generated from renewable sources (fig. 3) (City of Toronto, 2007).

In addition to other obstacles, the 'right-to-light' policy can be an increasing concern in urban areas, especially in growing urban environments. Although Canada once had a "right to ancient light" legislation in the 1800's when British Common Law was adopted, these laws were rescinded in the 1900's in response to urban planning needs (City of Toronto, 2007). Presently, Canada is the only industrialized nation that has not addressed the rights of property owners to the solar energy falling on their property (ibid). The City of Toronto's city planning division, policy & research office was contacted by the author to inquire about the status of the right to light issue within Toronto. A representative from the office explained that currently the City of Toronto is not working towards legislation or policy for access to solar radiation.

Although the majority of Canada's energy is being produced by hydropower, Ontario's installed capacity of energy generation is still reliant on coal (12%), nuclear (31%), and oil and gas (25%) (Ontario Ministry of Energy, 2010) and approximately 20% of Ontario's electric power is consumed within Toronto (City of Toronto, 2007). As of 2010, 77% of Toronto's electricity was generated by nuclear, oil and gas, and coal (Ontario Ministry of Energy, 2013).

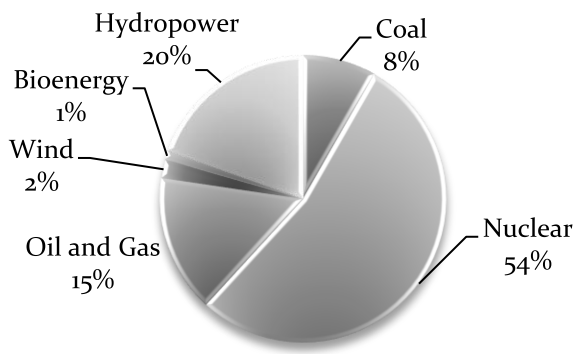


Figure 3: Toronto's electricity generation as of 2010 (Ontario Ministry of Energy, 2013).

These non-renewable energy sources have claims to be environmentally conscious or economically feasible, but with the deterioration of the environment in the unstable condition it is currently in, there is a dire need to divert even the cleanest of non-renewable sources.

Figure 4: (Left) 172 million gallons of petroleum were approximated to be discharged into the water before it could be stopped (Canadian Broadcasting Corporation, 2011).
(Middle) CO_2 Emissions from a coal fired power plant (Bellona Environmental Team).
(Right) The Fukushima Daiichi Nuclear Power Plant in Japan was destroyed by an earthquake causing concerns of nuclear contamination to nearby land (The New York Times, 2011).

Nuclear energy can be characterized as being clean as long as it is not disrupted by unusual occurrences such as the earthquake which destroyed the Fukushima Daiichi Nuclear plant (fig. 4) in Japan causing the potential for a nuclear disaster (The New York Times, 2011). Coal is abundant in Canada making it economically feasible, but burning coal releases toxins (fig. 4) such as carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxide (NO_X), and other airborne particles into the air that ultimately cause health issues to those exposed (Union of Concerned Scientists, 2012). The consequences of drilling for oil are widely known due to the highly publicized oil spill caused by British Petroleum (B.P.) that sent approximately 172 million gallons of crude oil into the Gulf of Mexico (fig. 4) (Canadian Broadcasting Corporation, 2011). With these toxic and non-renewable sources of energy comprising of the majority of Ontario's energy supply, it is overwhelming to observe the distance the construction industry must now progress in order to reduce the negative effects it has endured.

Many dense urban areas are faced with the problem of increasing energy demand and decreasing energy supply. If we can provide at least portion of required energy (both electricity and hot water) that is harvested on site, it will surely contribute to relieving pressure and demand on the grid, especially during peak times. It will also contribute to decentralization of conventional energy supplies, which can be vulnerable at times, as in the blackout that paralysed North East of America's continent in August of 2003. In his book "Electric water: The emerging revolution in water and energy" C.C. Swan poses the following question:

> *"Which is more efficient, a system that consumes more than half the energy it generates in machinery stretched out over the landscape, or a system that consumes a tiny quantity of steel and silicon to produce electricity from a roof only feet from the toaster?"* (Swan, 2007)

To summarise, today, the major Canadian city of Toronto, is not utilizing the untapped, free, and infinite supply of solar energy. Part of the reason for this lays in existing regulations and urban planning. This thesis will explore what can be done about Toronto's potential for onsite solar energy harvest by looking into the most prevalent urban morphologies that exist within Toronto.

Why Solar Energy?

There are many renewable energy sources that should be considered during the development and implementation of built environments. It is estimated that among hydropower, biomass, geothermal, wave-tidal, and solar energy, the current global energy demand can be satisfied 3078 times over by combining all of these energy sources (European Renewable Energy Council, 2010). Solar energy alone can theoretically provide up to 2850 times the current energy demand (fig. 5), making it the renewable energy source with the greatest potential (ibid). In only one hour, more solar energy will reach the earth's surface than will be consumed by the human race in one year (Suzuki & Boyd, 2008). The solar incidence of a building may exceed the energy consumption with the use of both passive and active solar systems (e.g. day lighting, solar thermal, etc.) (Solar Building Research Network, 2010).

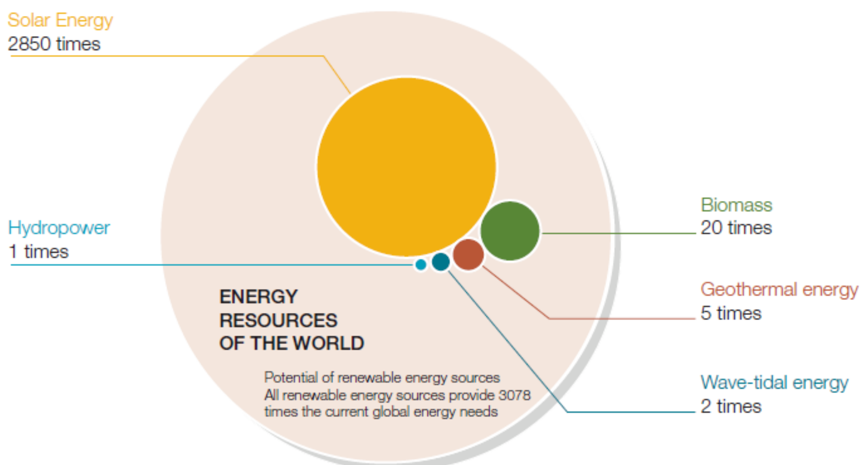


Figure 5: Theoretical potential of renewable energy sources (European Renewable Energy Council, 2010).

Active solar technology uses mechanical devices such as photovoltaic panels and solar thermal systems. An active solar system can be installed on the roof or wall of a building or can act as an integral part of the building envelope. Active systems are used to generate electricity, hot water for heating or domestic hot water use, or can be used for solar cooling.

A passive strategy is utilizing solar energy in its simplest form. Both direct and non-direct solar energy can be utilized in the built environment. Solar energy, allowed to penetrate the interior surfaces of our buildings, can be used to heat spaces. Using fenestration to allow direct and non-direct daylight into the interiors of buildings will minimize the need for electrically generated lighting. Passive strategies rely on strategically placed fenestration, overhangs, and other architectural features as to not cause overheating in the hot summer months, or inadequate amounts in the cold summer months. The main limitations to utilizing passive solar strategies is the ongoing development of the built environments which cause overshadowing limiting the amount of daylight reaching the interiors of buildings.

The following features have been developed by (Gennusa et al, 2011) as to why solar thermal and photovoltaics are suitable to installation within cities:

- Minimal maintenance,
- Negligible noise pollution (minimal moving parts),
- Reduces the need for foreign energy sources such as oil,
- Lack of pollution through service life,
- Components are installed easily,
- Components can be integrated into building envelopes reducing the needs for conventional envelope material,
- Photovoltaics can be easily integrated into local electricity grid.

The current state of the solar industry seems promising with nations across the world eager to lead the way of renewable energy sources. Government incentive is fuelling solar manufacturing to research and develop more efficient and ecological friendly products. This is a positive outlook for solar technology in the future to use less energy during manufacturing, generate more energy over its service life, and cause less harmful effects to the earth when disposed.

Feed-In Tariffs

As with many industries, the solar industry is heavily influenced by financial aspects. Reduction in greenhouse gas emissions and decreasing the dependence on oil is a secondary factor to the solar industry in North America. Government incentives and feed-in tariff programs are essential to boost the economy and generate awareness of solar energy. It is equally important that these programs are designed to not establish an industry reliant on incentives. It is not possible to have incentives permanently established. At some point in time the incentives or feed-in tariffs will have to be revoked and the industry must become self-sufficient. Feed-in tariffs provide a time frame for all those involved in the process of implementing solar strategies (architects, financiers, manufacturers, distributors, contractors etc.) in order to become familiar with the entire process from inception to installation.

The Ontario government implemented the "Green Energy Act" in 2009 where feed-in tariff incentives have been offered to Ontario residents and businesses to invest in renewable energy. With solar energy potentially becoming profitable, it is interesting to observe the lack of involvement by Ontario residents and building owners.

Energy Prices

With the finances of solar technology weighing so heavily on whether building owners will implement solar products, the price of energy has a major impact. Canadians are fortunate that electricity rates are among the lowest in the world. Ontarians pay between 6.2¢ CAD and 10.8¢ CAD/ kWh (Ontario Energy Board, 2012) where in Germany electricity prices are 0.35¢ CAD/kWh and in Denmark 0.40¢ CAD/kWh (Europe's Energy Portal, 2012). With energy prices so low in Ontario, the initial capital costs of solar projects will take much longer to become profitable for developers/owners. It seems evident that these financial figures are the major contributor as to why Berlin has 97% per capita more solar installations than Toronto (City of Toronto, 2007).

Although cost is the leading factor in the renewable energy industry, the imperativeness to implement renewable energy sources is the reductions of GHG emissions. Canada should seek inspiration from organizations such as the European Commission, where it is clearly stated that an achievement of implementing renewable energy is to cut GHG emissions (European Union, 2012). Whereas on the Ontario FIT website, the background information discusses financial and technical aspects of renewable energy installations (Ontario Power Authority, 2010). It takes much navigation through the Ontario FIT website before GHG emissions is addressed.

City of Toronto

Demographics

The city of Toronto has a population of 2.48 million people, covers 641km^2 and is the largest city in Canada (City of Toronto, 2012). The coordinates of Toronto are 43°40'12"N and 79°22'12"W (A View On Cities, 2012) and it receives an insolation level of 1305kWh/m^2 annually on horizontal surfaces (Natural Resources Canada, 2007). Although Toronto is located within a cold climate, insolation levels are comparative to warm climate locations such as Rio De Janeiro, Brazil (Natural Resources Canada, 2007).

As with most major cities, Toronto is comprised of varying urban morphologies with some buildings reaching heights of nearly 300 meters. Toronto has a population density of 4149.5 people per square kilometer which is among the highest in Canada (Statistics Canada, 2011). The core of the city is mainly dominated by high rise buildings and as the city expands outwards the morphology changes to a mix of mid-rise and residential neighborhoods consisting of single detached dwellings with varying height. Within only a few kilometers from the downtown core (which is being classified at the intersection of Bay & King) a morphological transformation from the highest buildings in Canada to a single detached dwelling is apparent. Three varying morphologies, which are i) morphology #1- high-rise towers ii) morphology #2- mid rise buildings, and iii) morphology #3- single detached dwellings are within a 4.35 kilometer radius of one another, were each investigated in this study.

The housing market in Toronto is dominated by apartment buildings with 37.8% of Torontonians living in apartment buildings with five or more storeys, 27.3% of Torontonians living in single detached houses and the remainder living in either semi detached houses (7.2%), row houses (5.6%), duplexes (4.4%), apartment buildings under five storeys (16.6%) and other dwellings (0.2%) (City of Toronto, 2006).

Morphologies

In order to accurately assess Toronto's stance in being a solar ready city, three specific areas were investigated which vary in building morphology. The morphologies are i) high rise towers ii) mid rise buildings, and iii) single detached dwellings will be looked at and are within a 4.35 kilometer radius of one another. For the purpose of this research, the definition of high-rise, mid-rise, and low-rise buildings is not classified as a per floor annotation. Instead, each morphological term will be used to define a specific type of community as follows:

<u>Morphology #1 - High-rise downtown towers- Bay St.& King St. W. (fig. 6)</u>

The intersection of Bay and King is arguably Toronto's busiest and most densely built area. Known as the Financial District, this area has many high rise buildings including the four tallest buildings in Canada. First Canadian place is the tallest at 298.10 meters, followed by Scotia Plaza at 275 meters, Canada Trust Tower at 260.91 meters, and Commerce Court West at a height of 239 meters (Emporis, 2012).

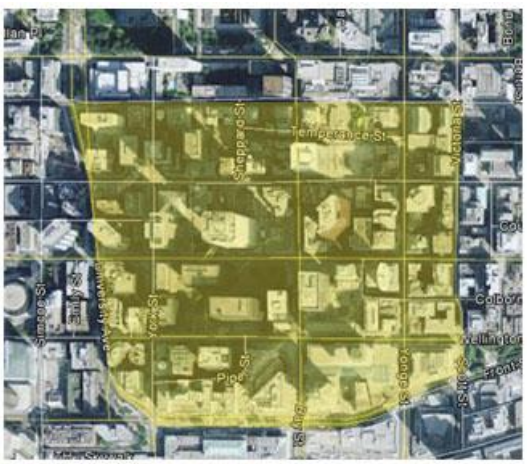


Figure 6: The intersection of King St. W & Bay St. A well known intersection in downtown Toronto will be classified as the high-rise area.

<u>Morphology #2 - Mid-rise main street buildings- King St. W. & Bathurst (fig. 7)</u>

This area comprises of mid rise buildings varying from 2.8 meters buildings to 52.6 meters. It is comprised of small businesses, hotels, restaurants, shops and numerous small offices, but it is rapidly changing. New buildings constructed here are mixed use: mid-rise (8-15 storeys) residential condominium buildings with the commercial functions at the street level.

Figure 7: The intersection of King St. W. & Bathurst. This area will be classified as mid-rise.

Morphology #3

North-south oriented low-rise single family houses on Cowan Ave (fig. 8)

This area was chosen due to its relativity to the north-south orientation. The street is slightly off the north axis by approximately 15°. Cowan Ave is comprised of single residential buildings (some duplexes and four-plexes) but the height of the buildings do not exceed 8.3 meters.

East-west oriented low-rise family houses on Thorburn St. (fig 8)

This area was chosen due to its relativity to the east-west orientation. The street is slightly off the east axis by approximately 15°. Thorburn St is comprised of single residential buildings, duplexes, and fourplexes.

Figure 8: Cowan Ave./ Thorburn St. - This area will be classified as north-south neighbourhood low-rise. (Thorburn St. is show in yellow, Cowan Ave. is shown in red).

In a study that compared a typical suburban house to multi-unit high-density residential building, it was concluded that low density housing is 2-2.5 times more energy and greenhouse gas emission intensive (Norman, Maclean, & Kennedy, 2006). The study included the associated energy of infrastructure, building operation and transportation of citizens. The report provides an interesting paradox scenario where as density increases, access to solar radiation, transportation energy, and operational energy decreases. The low rise buildings of suburbs will typically have more direct access to solar energy and can therefore utilize solar energy more efficiently. However, the transportation and operational energy is higher in the suburbs which creates an interesting debate to which morphology has a smaller carbon footprint.

Toronto's Current Zoning & Urban Planning Outlook

The City of Toronto has a definition for their urban design objectives which is (City of Toronto, 2012):

> *Good urban design is an essential ingredient of city building. Toronto should strive to be beautiful, vibrant, safe, and inclusive. Each new building contributes to the overall urban design of the city. The City's streets, parks and public spaces are key shared assets that require special design attention.*

Nowhere in this definition is energy mentioned. Urban design is a practice that will affect cities for decades, if not centuries, in the future since many buildings and infrastructural designs are intended to last many years. For this reason, it is irresponsible for the City of Toronto to neglect to include energy as a dominant factor in a definition for urban design.

It is more economical and efficient to develop communities that are generated by renewable energy sources rather than single buildings. The government of Canada has developed the ecoACTION community development project with the intent to develop communities that reduce energy consumption at a community level. There have been four EQuilibrium Communities Initiatives developed by Natural Resources Canada and the Canadian Mortgage and Housing Corporation (CMHC) across Canada; i) The Station Pointe community in Edmonton, Alberta ii) Ampersand in Ottawa, Ontario iii) Ty-Histanis in Tofino, British Columbia and iv) Regent Park in Toronto, Ontario (Canada Mortgage and Housing

Corporation , 2012). Each community exemplifies how energy consumption can be reduced by approaching the issue at a community level and is an initiative that municipalities should refer to during the development of future communities.

Toronto's Sustainability Outlook

The city of Toronto has published a Sustainable Energy Plan titled "Energy Efficiency and Beyond Toronto's Sustainable Energy Plan" (City of Toronto, 2007). The report was developed by the City of Toronto with the assistance from consultants, public stakeholders, professionals from the energy industry, various agencies, boards, and commissions and envisions a 21% energy reduction by 2030. The program addresses Toronto's current energy usage along with a short, medium, and long term plan to offset fossil fuel generated energy with renewable sources. As stated in the report, Toronto's vision for sustainability is as follows:

> *"Toronto will become a world leader in the sustainable use of energy from local, clean and renewable sources. It will strive to achieve energy self-sufficiency.*

Further in the report, the City of Toronto states its objectives one of which falls into the scope of this thesis:

> *"Maximize energy efficiency in Toronto's buildings and infrastructure"*

A major issue that is experienced in existing built environments is the infrastructure that is in place. The report (ibid) expects infrastructure to last between 60-80 years which means that in order to develop a community that utilizes renewable energy is a slow process of "grandfathering" must occur. The report states this well with a suggestion for action:

> *"Toronto's new buildings need to be models for what is possible in energy efficiency, in order to help owners of existing buildings learn how to integrate these features."*

Finally, in the City of Toronto's Sustainable Energy Plan's "solar section" (page 46), the needs for solar access within the city are addressed:

1) provincial regulation through the building code;

1) a property owner's legal covenant with neighbours;

3) or municipal regulations

This touches on the solar access legislation and how zoning regulations or by-laws must be put in place in order for Toronto's built environment to fully exploit the solar energy that falls on each of its buildings. Investigating legislation and policy which revolves around the concept of solar access is huge undertaking and is not within the scope of this thesis.

The City of Toronto has initiated small solar projects throughout different parts of the city to encourage the use of solar energy. "Solar Neighbourhoods" was initiated in Toronto and had a goal of installing one hundred residential solar thermal systems. The solar thermal systems were installed on various residential buildings throughout Toronto's east end.

Although an attractive title, the objectives of solar neighbourhoods were not to reduce energy consumption. The final report barely touches on GHG reductions, which is estimated at 60 tonnes per year. The key objectives of this initiative largely revolved around marketing, financing, contractor awareness for build ability, and public awareness of incentive programs. Although these attributes are all positives for the community, energy awareness to the home owner is a critical objective that is absent from the solar neighbourhood program. The following are the key objectives of the study (Toronto Atmospheric Fund, 2010):

1. Achieve a critical mass of residential solar thermal installations in a concentrated area of the city.
2. Test a variety of community-based marketing methods and messages.
3. Design and test financial incentives and zero-interest financing options.
4. Flush out barriers to residential solar thermal installation and initiate responses to these barriers.
5. Leverage public interest in solar energy to support overall home energy efficiency retrofits.
6. Provide insights for a potential city-wide residential solar thermal installation program.

The goals that have been set by the City of Toronto are definitely a step in the right direction, but lack the depth necessary to alter the way a city generates energy. The objectives tend to lean towards economics and not the reduction of GHG emissions.

Canadians are fortunate to have excess amounts of energy at a very low price rates. Hydro-electric power, coal, and natural gas plants provide plentiful amounts of energy which Canadians are exploiting. Since energy is so abundant, and, therefore, inexpensive, Canadians are not aware of the excessive amounts of energy being consumed. The city of Toronto receives similar radiation levels to warm climate cities such as Rio de Janeiro (Natural Resources Canada, 2012), yet solar energy is still widely ignored. It is a lifestyle that Canadians have become accustom to. Energy is being wasted and because it is inexpensive and excessive, financial repercussion are minimal. If Canadians were slightly more energy efficient in their daily lifestyle with the combination of utilizing renewable energy, than GHG emissions could be decreased drastically.

Location, Climate, and Natural Conditions

Toronto is considered to be a cold climate city with at least 3000 heating degree days at an 18°C base (Straube & Burnett, 2005). Being a cold climate can be beneficial to utilizing solar energy since it has been proven that some Northern European areas can utilize solar energy as effectively as Southern climates (Porteous & MacGregor, 2005). Northern climates can utilize solar energy more efficiently than Southern climates because southern climates will not use solar energy for heating but for electricity generations and possibly cooling whereas Northern climates can utilize solar energy for heating, cooling, and electrical generation (ibid). There is an opportunity for the city of Toronto to exploit solar energy for energy generation, heating and cooling.

CHAPTER 2

Literature Review: Solar Access In Urban Environments

Solar rights can be dated back to the 2^{nd} and 3^{rd} centuries A.D. where the Greeks and Romans designed cities and buildings to utilize solar energy using passive strategies (Borimir & Perlin, 1980). In ancient Egypt, architects observed and utilized the relationships between the sun and the buildings they designed (Alzoubi & Alshboul, 2010). The design of buildings were relatively simple, the south side was built using transparent materials to allow solar radiation into the interior during the winter and the use of eaves and overhangs were used to prevent overheating during the summer.

With solar energy being a major contribution of light and heat, it was a necessity for residents to have access to solar energy. The Greeks had a very informal law system where solar rights were not addressed, leaving building vulnerable to overshadowing. The Romans however addressed the necessity for solar radiation and provided legislature to ensure occupants receive adequate amounts (Borimir & Perlin, 1980). Each building was allocated a reasonable amount of buildable space on a lot as to not overshadow adjacent buildings. At this time, there were no calculations to determine adequate amounts of solar radiation. In the case of legal action being filed, the judge or arbitrator would decide what a reasonable amount of light was (ibid).

An example of urban design for solar access is the region of Acoma Pueblo, which is a Native American community near Albuquerque, New Mexico, USA. Acoma Pueblo used thoughtful placement of buildings in quite advanced urban design to ensure that residents were receiving adequate solar radiation in the winter and minimal amounts of radiation in the summer. As can be seen in fig. 9 buildings were laid out to ensure that solar radiation would penetrate the thick masonry walls to store energy during the day. This well planned concept of building-height to shadow-area is believed to be the initial conceptions of the "solar envelope" (Knowles, 2003) which will be discussed later in this section.

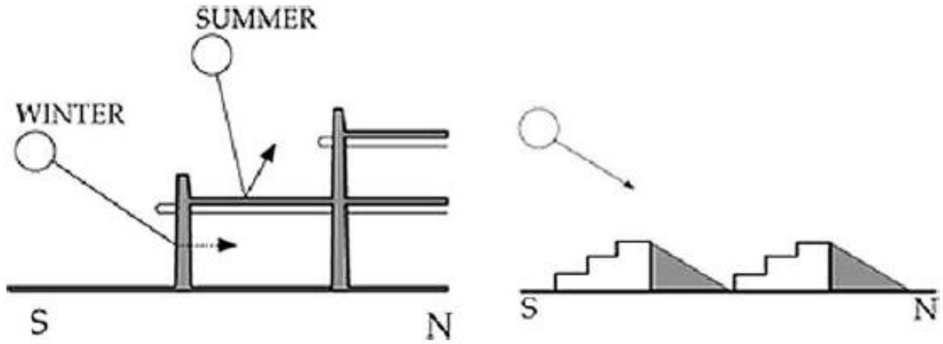


Figure 9: Acoma Pueblo's solar design (Knowles, 2003).

The right of light concept is evident in the skyline of New York City. In 1916 the increasing number of high-rises buildings was preventing the sun and wind to penetrate into the deep urban canyons that were being created. Therefore, the first solar zoning law in the United States was issued in New York City. Since skyscrapers were becoming extremely common due to the ability for developers to gross tremendous revenue through the leasing of office space, more and more skyscrapers were being constructed in the increasingly dense area of Manhattan. The bulkiness of these skyscrapers was becoming an issue since light and air were not being permitted to reach street level. Therefore the setback law was issued where after a certain height of a building was reached a setback must occur. The setback of the building was determined by the width of the street in which it is being built. If a building uses twenty-five per cent or less of the lot area, than set backs were not required, and no height restriction would be issued (Columbia University, 2003). This zoning by law shaped New York skyscraper as many of the buildings constructed in this era reflected these requirements. Fig. 10 displays two buildings in New York that depict the era of the right to solar access.

There has been much published about right of light policy with very little ever being enforced. On a global scale, most countries have some sort of historical solar right legislation which have been updated to current zoning requirements (City of Toronto, 2007). Before the zoning initiative in New York City, Canadian law had a right to ancient light legislation in the 1800's when British Common Law was adopted (ibid). This legislation was rescinded to accommodate the needs of urban design in the beginning of the 19th century leaving Canada with no legislation in regards to solar access.

Figure 10: (Right) Nelson Tower on 34th street and 7th Avenue in New York City (Columbia University, 2003). (Left) Rockefeller Center in New York City (The Midtown Book).

A leading complication with the development of a universal right to light legislation is the ability to determine what constitutes adequate solar access. Percy Waldram, a surveyor and lighting engineer, is a well known expert in the field of solar access and has developed the most common method to determine if adequate sunlight is achieved within a room of a building. Waldram's work was completed during the first half of the 20th century and is still widely used today (Chynoweth, 2004). Over the years of investigation and development of right of light scenarios, Waldram summarized the main importance of adequate sky lighting of an occupied space as (Bickford-Smith & Francis, 2007):

1. For health and legal purposes, occupants are entitled to an adequately lit room.
2. Skylight that is entering an occupied area must be direct and not from artificial sources or reflection,
3. For measuring the adequacy of skylight in an occupied space, the human eye is not a trustworthy source.

Although the Waldram theory of right of light has been the basis of many legal court cases, there have been many authors that have criticized his 0.2 per cent theory, which depicts that 0.2 per cent of the hemispherical sky can theoretically light the room in question (Francis, 2008). A paper published by (Defoe & Frame, 2007) questioned the method and outcome of Waldram's finding regarding the levels of light which deem solar rights. Further research by (Defoe, 2009) determined that Waldram's findings were incorrect and that a level of 0.5 per cent should become the standard for solar right legislation. These conflictions reflect the scientific nature of the right to light policies which are not a topic of research in this paper; however was included to exhibit the subjectivity that can surround solar right policies.

A common method of addressing solar access rights is by using the solar envelope. The idea of the solar envelope was introduced in the 1970's by architect Ralph Knowles, a professor at the School of Architecture at the University of Southern California. The solar envelope is defined by (Knowles, 2006) as the "*volumetric limits to development that will not shadow neighbours*". The solar envelope (fig. 11) is imaginary boundaries within a site that permits a building to be constructed within these limits (Knowles, 2006) . This prevents overshadowing on neighbouring buildings during critical times (ibid). Solar envelopes coincide with shadow fences (fig. 12) which described by (Knowles, 2006) is an imaginary fence that extends upward from a property line to give volume to the solar envelope.

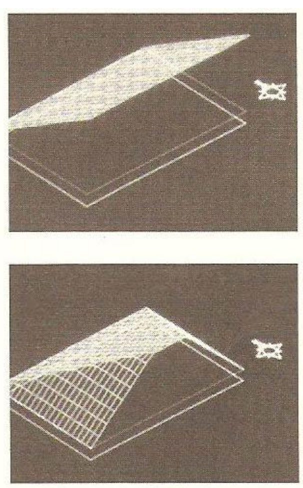


Figure 11: The solar envelope. Above is the solar envelope at noon on December 21st. Below is the solar envelope with different periods of the year to develop a completed solar envelope (Knowles, 2006).

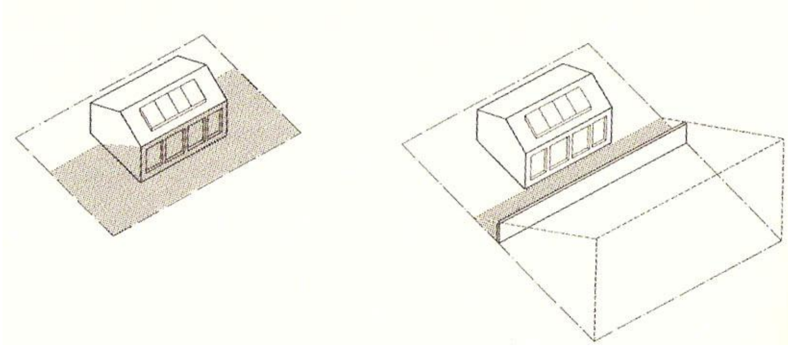


Figure 12: (Left) A site without the solar envelope or solar fence. (Right) A site with a solar envelope and solar fence (Knowles, 2006)

The department of architecture at the University of Southern California, and under the supervision of Ralph Knowles, developed a solar neighbourhood and underwent a 10- year study of the theoretical model (fig. 13). The residential buildings were designed within the confines of the solar envelope as well as municipal zoning laws and building code requirements. This design permits four hours of daylight during the winter months and eight hours of sunshine during the summer months (Knowles, 2003).

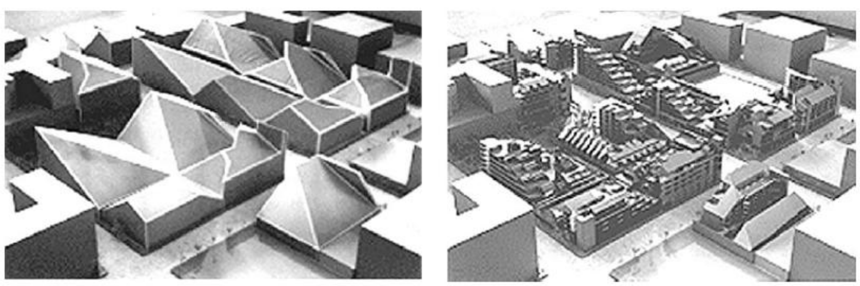


Figure 13: Housing project which permits a minimum of 4 hours of sunlight to each dwelling. (Left) Conceptual design using the solar envelope (right) fully designed buildings with architectural features (Knowles, 2003).

With the development of the solar envelope, solar access has been given to all buildings that are designed within these limitations. Solar radiation is not important only to create energy, but also through the use of natural lighting. Strategically placed glazing can introduce adequate amounts of daylight into the room which decreases the use for artificial lighting fixtures (energy conservation instead of energy generation). There are physical and psychological benefits to having access to natural day lighting in a work environment. Health, mental well being, productivity and motivation can all be increased if natural lighting is provided to workers (Menzies & Wherrett, 2006).

With much controversy surrounding the right of light concept, it is critical to assess what can be done to ensure buildings are given access to solar radiation. (Eisenstadt, 1982) suggests easements, restrictive covenants, subdivision ordinances, nuisance, permit systems, state statutes and zoning ordinances. As with any type of legal restrictions given to designers, it will inevitably come with disadvantages. (Eisenstadt, 1982) has provided some advantages and disadvantages to legal actions taken to provide solar access:

Table 1: Advantages and disadvantages to solar access by zoning

Advantages	Disadvantages
Zoning ordinances reflect local communities which mean they are adaptable to local weather conditions and the needs of local communities.	As zoning is changed or land use patterns updated, it could negative affect the use of solar collectors.
Zoning can be flexible and adaptable on a community basis.	Solar access can become very technical which may restrict smaller municipalities from issuing them.
Zoning can change as time progresses. Advancements in technology or methodology of solar access can be adaptable by updating zoning.	Provisions for variances are not uncommon in zoning ordinances. It must therefore be predicted that some variances that are awarded may shade solar collectors where legal action may be issued by the owner of the solar collectors.
Zoning can protect both existing and potential solar collectors.	
Zoning is a well established way of providing guidance to development. Solar methods may be somewhat unknown in some areas but the overall knowledge of zoning provides expertise in planning scenarios.	
Established zoning would prevent delay for solar proposals.	

There have been studies completed in cities around the world testing the right of light theory with the use of high rise buildings. Solar access in dense urban environments can be broken down into three criteria which are openness at ground level, daylight factor on building facade, and PV potential (Cheng et al, 2006). In an approach to determine these three factors in a densely built environment, the authors proposed four different urban design methods to determine which would provide the most solar penetration (ibid.). The configurations consisted of randomness and uniformity in the vertical and horizontal directions, as can be seen in fig. 14.

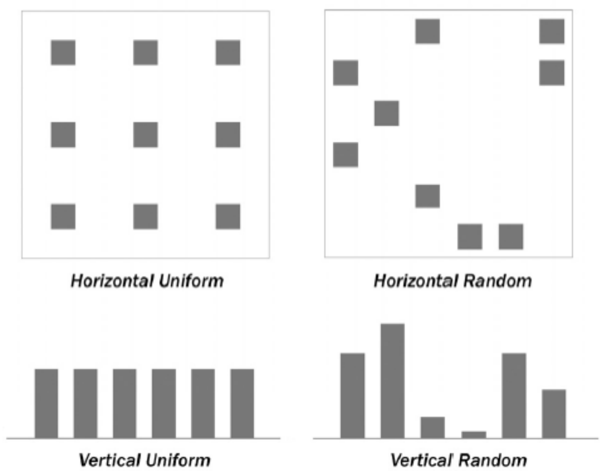


Figure 14: Configurations used for analysis of solar access (Cheng, Steemers, Montavon, & Compagnon, 2006).

The study found that horizontal randomness (fig. 15) is the most important design aspect of dense urban environments to maximize solar absorption on the building facade. The floor area does not need to be altered, but non-uniformity in the layout of buildings allows solar radiation to penetrate more area than if buildings are constructed along perpendicular orientations.

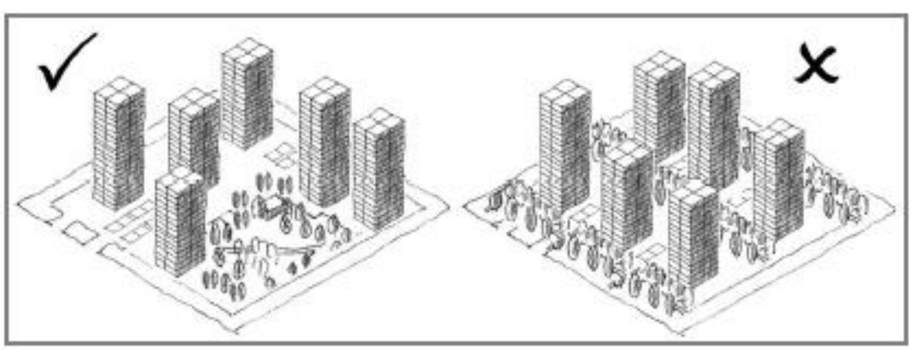


Figure 15: Horizontal randomness (Cheng, Steemers, Montavon, & Compagnon, 2006).

Building higher with less of a footprint, again without losing gross floor area, provides more openness and allows sun to penetrate into open spaces (fig. 16).

Figure 16: Taller and lower coverage of site compared to buildings with larger footprints (Cheng, Steemers, Montavon, & Compagnon, 2006).

Vertical randomness (fig. 17) was determined to provide more solar radiation due to the openness of the configuration.

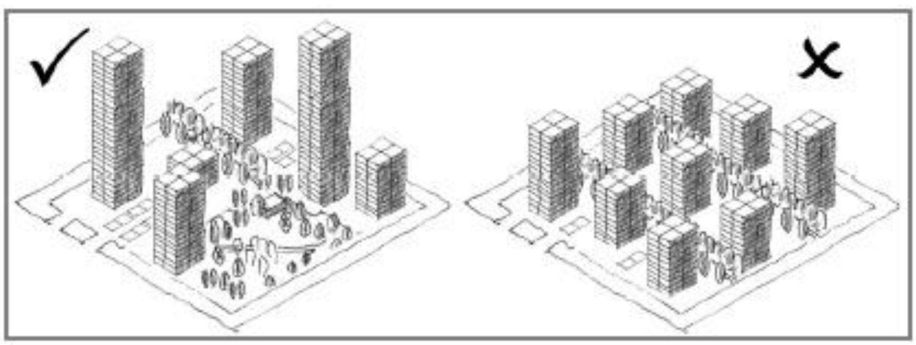


Figure 17: Vertical Randomness (Cheng, Steemers, Montavon, & Compagnon, 2006).

The theoretical urban designs shown above provide useful information in how urban design morphologies can promote or prohibit the use of solar energy. The city of Toronto, generally speaking, is not very diverse in the vertical or horizontal randomness. Fig. 18 is an elevation of King St. W looking north and fig. 19 is an elevation of Yonge St. looking west. These figures depict a relatively similar roof line which dissipates from the core urban areas. The horizontal layout (fig. 20) also depict relative uniformity. Using the models developed by (Cheng et al, 2006) simulation will be run to determine how Toronto could have benefitted by utilizing the "randomness" in the vertical and horizontal directions.

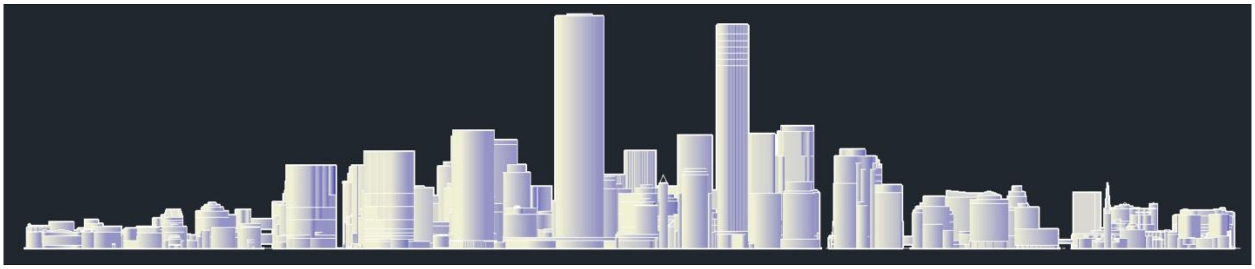


Figure 18: Elevation of King St. W. looking north.

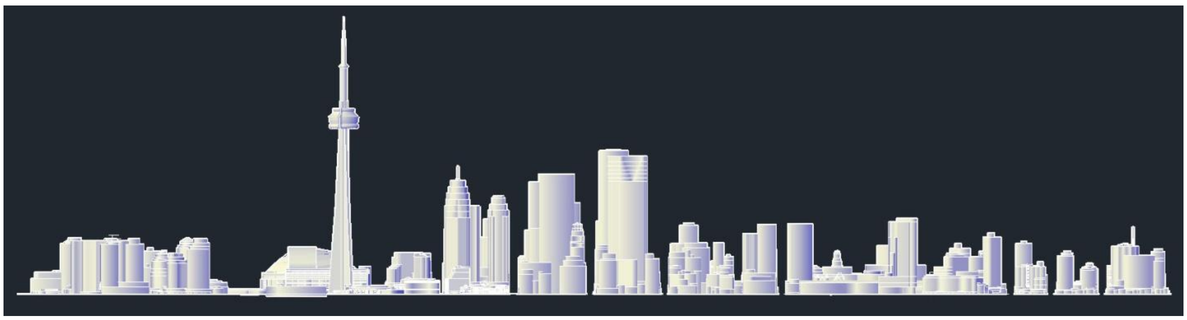


Figure 19: Elevation of Yonge St. looking west.

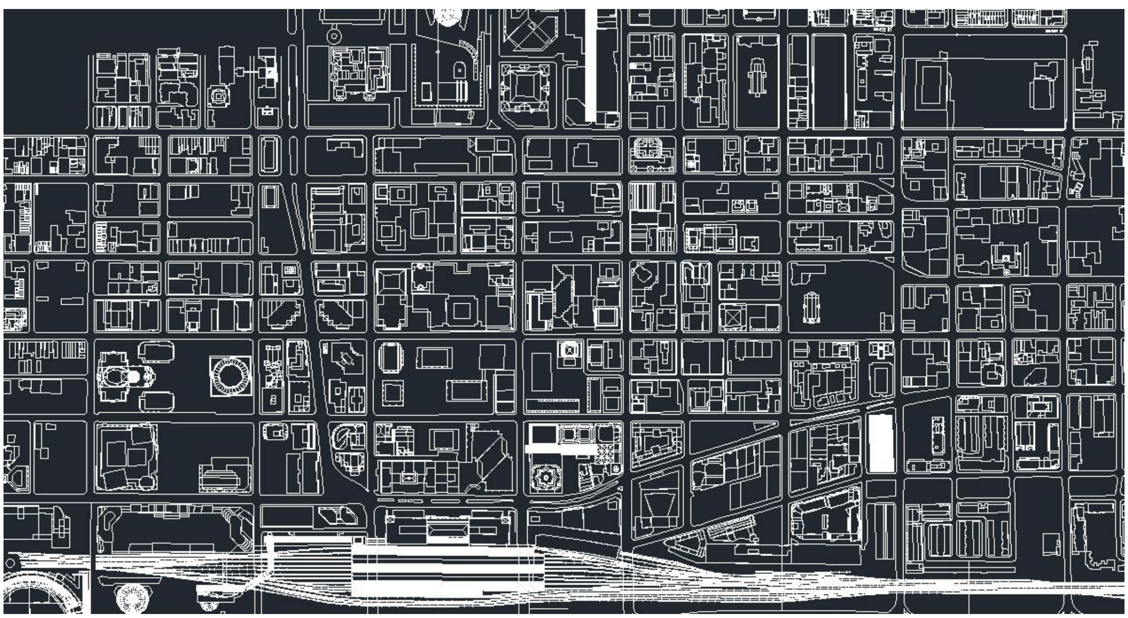


Figure 20: Plan view of Toronto's downtown.

A residential solar block (RSB) was developed by (Okeil, 2010) where the shadowing of buildings would occur only in open space (fig. 21). The intent of this theoretical environment was to maximize the built-up volume without casting a shadow on adjacent buildings. The RSB was oriented on NE, SE, SW, and NW coordinates and reaches peak height in the middle of the building.

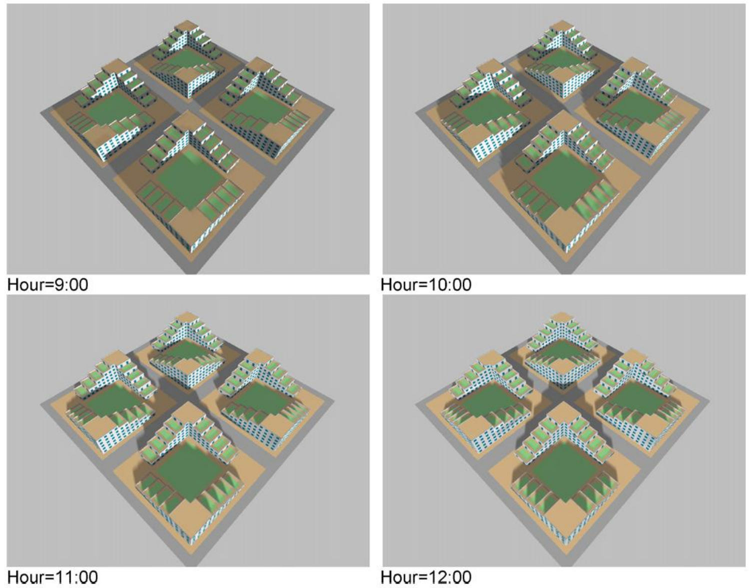


Figure 21: Shadows from 9:00-12:00 in December (48 degree latitude) (Okeil, 2010).

Furthermore, RSB's were compared to other formations and it was concluded that the solar radiation in winter increased in comparison to the linear and block urban form (fig. 22) all of which offer the same gross floor area. In December, the NE, SE, SW, AND SE facades facing 45° on the RSB received 67% of direct solar radiation whereas the same surfaces on the linear form received 60.1% and block form received only 47.8%.

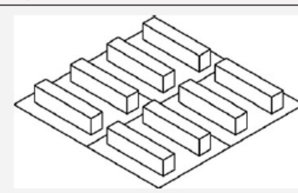
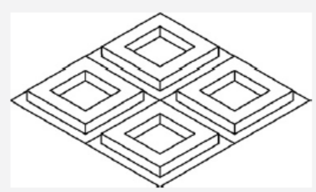
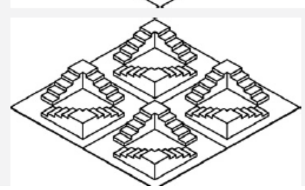
Module parameters		Layout (2 × 2 modules)
Urban form: linear		
Module size: 76.8 m × 76.8 m Building length: 60 m Building height: 15 m Street width: 26.4 m, 16.8 m Foot print/module: 1440 m² Surface area/volume: 0.28	Total area: 5898 m² Building width: 12 m Court: 60 m × 26.4 m Orientation: 0°, 45°, 90° Floor area ratio: 1.2	
Urban form: block		
module size: 76.8 m × 76.8 m Building length: 60 m Building height: 9 m Street width: 16.8 m Foot print/module: 2304 m² Surface area/volume: 0.2	Total area: 5898 m² Building width: 12 m Court: 36 m × 36 m Orientation: 0°, 45° Floor area ratio: 1.17	
Urban form: RSB		
Module size: 76.8 m × 76.8 m Building length: 60 m Building height: 3–15 m Street width: 16.8 m Foot print/module: 1840 m² Surface area/volume: 0.31	Total area: 5898 m² Building width: 12 m Court: 36 m × 36 m Orientation: 45° Floor area ratio: 1.1	

Figure 22: The three types of urban block forms used for simulation (Okeil, 2010).

In Tel Aviv, Israel a newly constructed neighbourhood was not designed with consideration for solar radiation. The newly constructed area was then investigated by (Capeluto et al, 2006) and theoretically redesigned to utilize solar energy. Solar radiation was permitted to reach the first floor of the building as well as a one meter area on the adjacent sidewalks. Fig. 23 displays how the same area can be designed with keeping solar rights and actually increasing the floor area ratio rates. This study was conducted using angular section lines to create a solar envelope which defined the buildable space within lot area (fig. 23 & fig. 24).

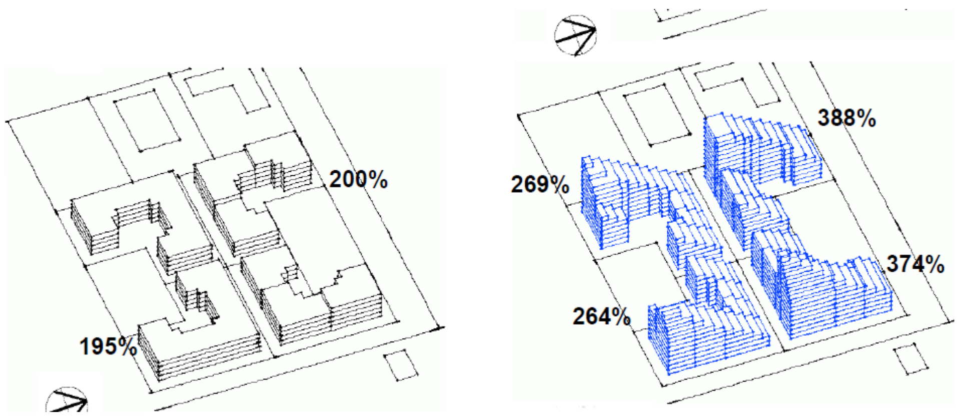


Figure 23: (Left) The constructed residential area in Tel Aviv. (Right) The theoretically redesigned residential neighbourhood which achieves a much higher concentration of solar radiation (Capeluto, Yezioro, Bleiberg, & Shaviv, 2006).

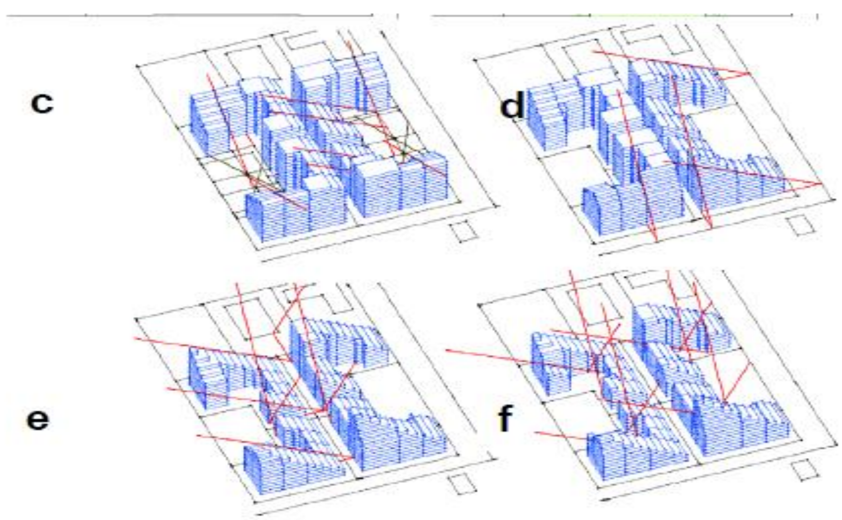


Figure 24: Using angular section lines to develop a solar envelope within site limits (Capeluto, Yezioro, Bleiberg, & Shaviv, 2006)

A study developed by (Kanters & Horvat, 2012) investigated how urban building forms will affect the amount of energy that can be generated by solar energy. Only the surfaces which received a benchmark insolation value of 650 kWh/m²/year were recorded since anything less would not be ideal for active system integration. Surfaces that received this benchmark value could potentially generate 100 kWh/m²/year, using a 15% efficient PV panel, or 250 kWh/m²/year using a 38% efficient solar thermal system. Results from this study depict that when solar energy is accounted for in newly designed urban areas, a significant amount of energy can be generated. In the urban forms which are comprised of low rise building (fig. 25, 1A-1D) a significant amount of energy demand could be satisfied by solar energy. The building formations which are comprised of high rise buildings (fig. 25, 5A-5D), seen a solar potential decrease by as much as 75%.

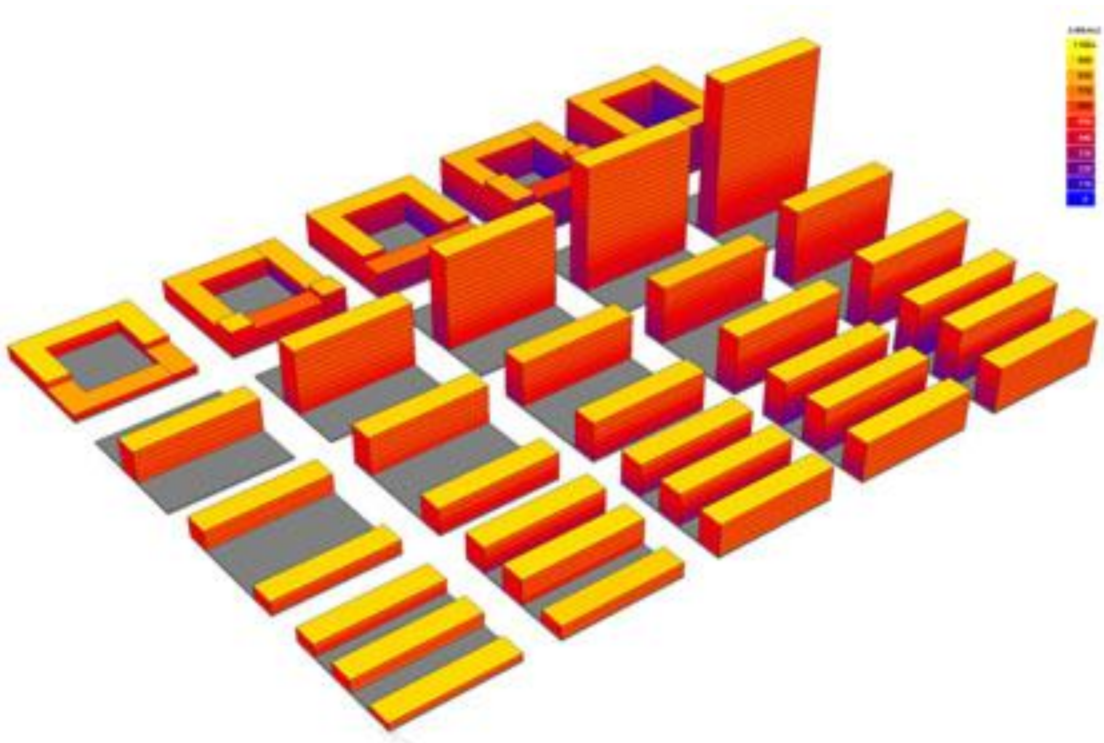


Figure 25: Geometry types in north-south orientation (Kanters & Horvat, 2012).

A master's thesis completed in the department of environmental applied science and management at Ryerson University by (Forgione, 2010) investigated buildings on the Ryerson campus to determine the insolation values of various facades. This thesis determined that by utilizing PV panels for the generation of electricity, only approximate 5% of the energy demand of Ryerson could be satisfied by solar energy. A similar thesis was developed by (Chow, 2012) revisited Forgione's methodology and workflow using different software tools and datasets. In this thesis, Chow investigated hourly PV electricity outputs and smart metering to gain useful information on the management of energy during peak hour demands. In both thesis it was mentioned that much of the roof and facade surface area was not being fully utilized due to mechanical equipment, building components, green roofs, and overshadowing from adjacent buildings. All of these obstacles contribute to the minimal potential for harvesting solar radiation for the use of energy. There are many obstacles that must be investigated to ensure that the solar system that is installed will receives adequate amounts of solar radiation to be deemed a contributing source of energy.

It is a difficult and overwhelming task to provide solar access to all buildings, particularly in already established built communities. Some methods that are suggested by (Littlefair, 1998) are:

a) National building regulations- This means having a basic set of principles or guidelines that can be adapted to each municipality. This is similar to building code requirements which are issued nationally than altered to suit the needs and specifications of each town or city.

b) Local planning laws- Zoning laws can be uniquely designed for any city and can address the needs of individual communities. For example, in an area where the construction is mainly new development, this provides an opportunity to propose more strict solar regulations than an existing built community.

c) Private legal agreements- A legally binding agreement that is prepared when a solar building is constructed and protects the solar access from future developments.

An example of implementing legal solar action is in Boulder, Colorado which has taken steps in a positive direction in terms of guaranteeing solar access to their residents. New developments (such as fig. 26) must incorporate the aspects of the solar fence (fig. 11). Even if a proposed residential building is not incorporating solar strategies. Those requirements are:

a) The layout must be within 30 degrees of east-west coordinates,

b) The roof structure must be designed to incorporate a minimum of seventyfive square feet of solar collectors or photovoltaic equipment,

c) Unimpeded solar access through ordinances or private covenants.

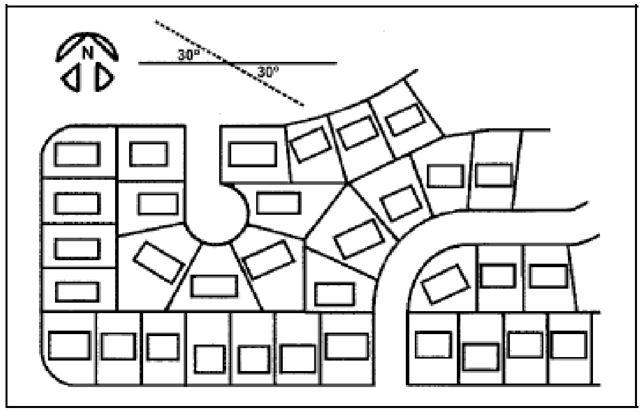


Figure 26: Solar siting in a proposed subdivision (City of Bouler Building Services Center, 2006).

The city of Boulder has ordinances to which developers must follow. A solar fence of either twelve feet or twenty-five feet must be provided to protect nearby buildings. This requirement is to ensure solar access for two hours on the shortest day of the year (December 21st) (City of Bouler Building Services Center, 2006). The city has divided the solar access planning into three areas which are designed to suit different scales of the built environment. The areas are:

a) Solar Access Area 1- Lots protected by a twelve foot solar fence,

b) Solar Access Area 2- Lots protected by a twenty-five foot solar fence,

c) Solar Access Area 3- Lots protected through the solar permit process.

Although the solar requirements that have been established in Boulder, Colorado are positive in theory, it is rather easy to be critical of these design parameters due to the developments in a city of this size. Boulder has a population of 97, 385 with approximately 42630 housing units on a land area of 24.66 square miles (U.S. Census Bureau, 2010). This allows developers to build on large plots of land which minimizes the chances of overshadowing and prevention of solar access from reaching nearby building facades. Boulder lacks the density of a major city, yet is proving that solar access through policy can be an effective approach to utilizing solar energy.

Similar to the suburban approach of Boulder Colorado, research has been conducted in a PhD thesis completed by (Hachem, 2012) at Concordia University. Investigated for the conditions of Montreal, Quebec, the intent of (Hachem, 2012) was to find out how three interconnected design aspects of shape, density, and layout (fig. 27) can affect the solar potential of neighbourhoods. The ultimate goal of this research was to develop a design methodology for solar optimized suburban communities.

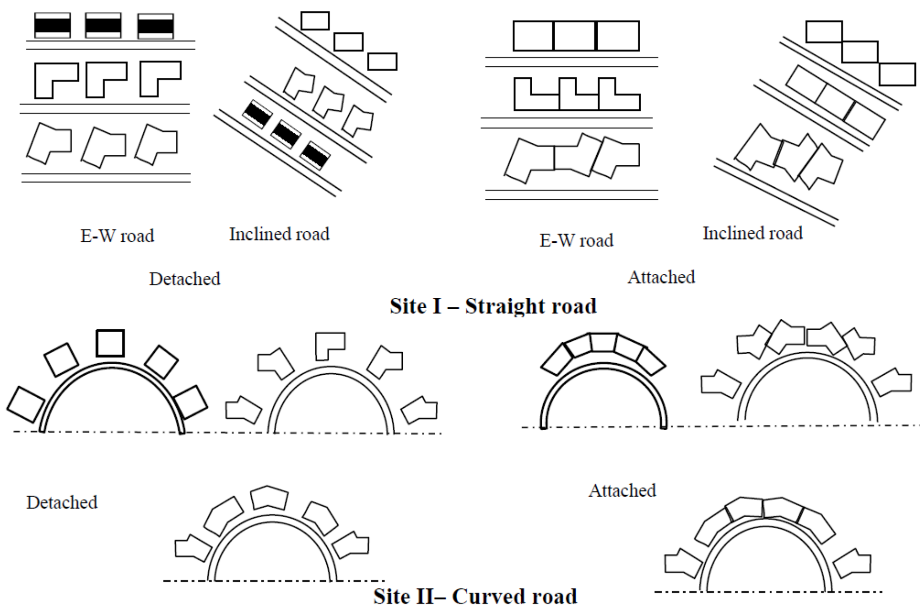


Figure 27: Sample configurations of suburban neighbourhood layouts (Hachem, 2012).

Any city attempting to establish right to light policies will have a unique approach within their respective regions. Other than physical and geographical parameters, zoning and building code requirements vary greatly from country to country, even region to region. There are some potential constraints for guaranteeing solar access in the urban context that can be applicable to all regions on earth as described by (Littlefair, 1998):

a) large obstructions,

b) uneven obstructions or various shapes,

c) non-optimal glazing orientation,

d) the building obstructing itself (overhang, extensions, courtyards).

There is also the issue of determining what a solar building is, and which types of buildings are legally obliged to acquire guaranteed solar access. If a building is visually displaying photovoltaic panels or a solar thermal system, is it then classified as a solar building? If a building is utilizing solar energy by the use of passive strategies (i.e. outfitting the south facade with glazing and strategically placed overhangs), it may not be considered a solar building since it does not appear to be utilizing solar energy from a public perspective. A paper by (Hestnes, 1999) defines a solar building as a building which uses a combination of passive strategies, active systems and photovoltaics which will not necessarily satisfy all the energy requirements. Small amounts of conventional energy may be necessary for day lighting or other miscellaneous equipment. Essentially, a solar building does not have to generate an excess of energy to produce a net zero building. It is also stated by (Hestnes, 1999) that a solar building can utilize optimal facades to serve multiple solar functions. A highly exposed south facade or rooftop can utilize solar energy to satisfy hot water needs as well as electricity by using a combined photovoltaic/solar thermal system. Combination systems are a highly innovative systems which utilize solar radiation simultaneously for the generation of electricity and hot water. A research project by the International Energy Agency, IEA Task 35: PV/Thermal Solar Systems, investigates combination systems and provides analysis, case studies, and product development on combination systems (Solar Heating & Cooling Programme International Energy Agency, 2010).

The concept of a solar building not needing to generate net zero energy is further validated by the European Commission of Energy. In 2010, a directive was adopted by the European Union which stated that buildings must be designed to be nearly net-zero which is defined as (European Comission of Energy, 2010):

"nearly zero-energy building" means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby;

Other organizations will define a nearly net zero energy building quite differently. The Federation of European Heating and Air-Conditioning defines both nearly net zero buildings and net zero buildings as consuming 0 kWh/m^2a of primary energy (Federation of European Heating, Ventilation, 2012). The difference between a "nearly zero-energy building" and a "net zero energy building" is that a net zero energy building will generate a surplus of energy. This surplus of energy will be delivered to the municipal energy supply where it can then be used by other buildings.

(Littlefair, 1998), has developed arguments against how a solar building can be defined:

a) Any building, not just those designed to be solar, benefit from solar radiation,

b) It can be difficult what constitutes a solar building,

c) Construction of a solar building could have negative effects on the value of adjacent land,

d) An existing building may become a solar building many years after construction by the retrofitting of solar technology.

The points that are stated by (Littlefair, 1998) provide some context to how a "solar building" can affect nearby buildings. For example, a building that is constructed in a developed area can negatively affect adjacent buildings by overshadowing them. If a single building is ideally designed to utilize solar radiation (i.e steeply angled roof due south to mount PV panels) may cause heavy overshadowing on buildings located directly north. Overshadowing is caused by a surface that is designed to utilize solar energy. This type of scenario develops the issue of how the built environment must be arranged as to not design solar buildings solitarily, but instead how buildings can be designed in order to develop a solar community.

Much of the published research on solar rights provide guidelines and requirements in the development of new residential sub-divisions or theoretical dense urban environments. There has been little research completed in regards to what can be done in existing urban environments to alleviate the dependence on artificial means of heating, cooling and lighting. Existing built environments dominate our world and the infrastructure that is in place will last beyond the life span of any researcher who hopes to change that. Therefore, there is a need to develop ideas and guidelines that can have a relatively quick impact on accessing solar energy in urban environments without jeopardizing the quality of the architecture and development of our cities.

Definition of a Solar City

An important aspect of this thesis is determining if Toronto is in fact a solar city. In order to determine if Toronto has potential to be a solar city; a solar city must be defined. A solar city cannot be determined by the amount of solar radiation that it receives or it becomes a variable of geographical location. A solar city cannot be defined by the amount of solar technology installed because if than becomes a variable of economics. There are many complicated factors that lead to cities implementing solar strategies and it is a monumental task to determine what all of those factors are.

Citizens of Toronto are among some of the most energy demanding individuals in the world. Fig. 28 and fig. 29 display that Toronto's energy consumption compared to other major cities around the world. Toronto is Canada's largest city (by population) and is Canada's top energy consumer per capita and compares to some of the larger major cities such as New York, U.S.A. Since Toronto has such high energy consumption, it is imperative that the future development plans of Toronto implement solar strategies to offset as much non-renewable energy generation as possible.

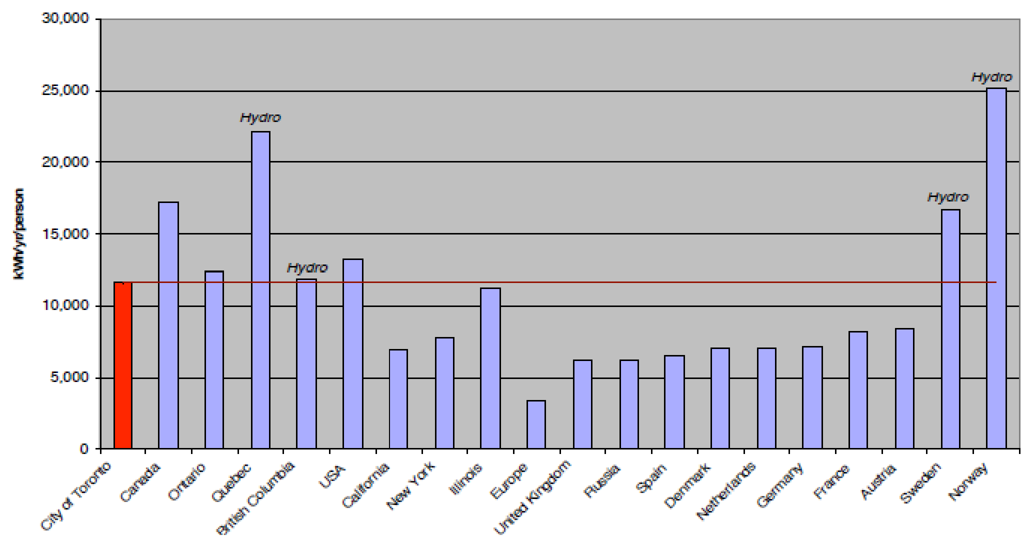


Figure 28: Energy consumption per capita in selected cities (City of Toronto, 2007).

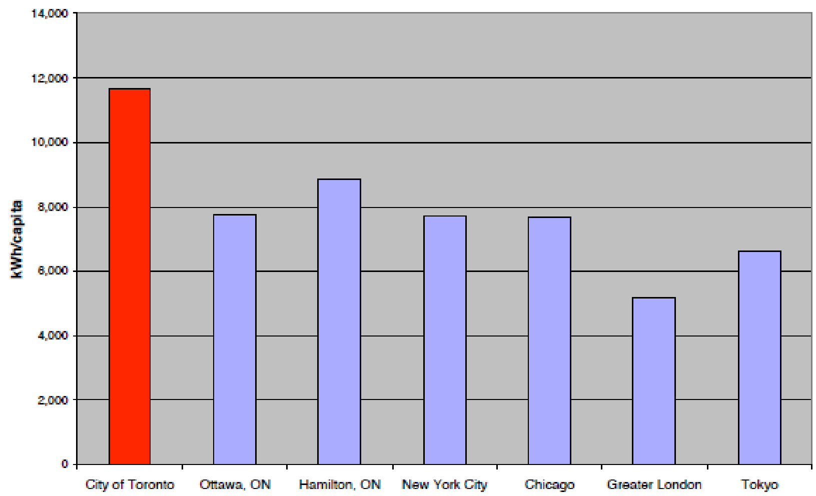


Figure 29: Energy use per capita in selected cities (City of Toronto, 2007).

There are multiple definitions of solar cities developed by organizations such as (Solar City, 2011), (Treberspurg, 2008), and (World Future Council, 2007). From these definitions, there are some interesting factors that intrinsically define what designers must consider when designing urban environments. (Solar City, 2011) plans to achieve community based energy generation to achieve a stabilized climate by the year 2050. (Treberspurg, 2008) believes a solar city should "*"create an exemplary model of energy efficiency and sustainable energy use"*. This definition also refers to a time frame and how the interests of energy efficiency evolves over time. The construction industry is constantly being introduced to new products, components, techniques, materials, etc. and therefore it is important that passive solar strategies are not overlooked by highly innovative and high-tech active components.

The (World Future Council, 2007) provides an ambitious definition of a solar city that is 100 per cent renewable, meaning no fossil or nuclear fuel is used in embodied or operational energy for any aspect of the city. Although extremely ambitious, it is unrealistic to expect this to become reality for many decades. The built environment is a deeply compiled arrangement of underground infrastructure, buildings, parks, roads, etc. In order to develop a city which uses 100% renewable energy (embodied and operational), our cities would have to be rebuilt in their entirety.

These are just some of the concepts that have been developed to define a solar city. A solar city can be subjective and indefinable term on a global scale. A city which implements solar panels on a few public buildings can theoretically claim itself as being a solar city, whereas cities such as Linz-Pichling, a small city in Austria where solar energy and other renewable energy sources were implemented at the earliest of design stages, can also be classified as a solar city.

A city needs essential aspects to function. Among these functions are the most basic of fresh air, fresh water, and sunlight. During the shortest day of the year, when heat is needed the most, buildings must be receiving adequate amounts of direct solar radiation. A city which can be defined as a solar city must provide several hours of direct solar radiation on the winter solstice. A city must be designed to which it's tectonics contribute to the use of solar energy. The development of a new city that can be designed specifically for the utilization of solar energy is extremely rare. Therefore, it is unrealistic to expect a city to generate 100% of its energy from solar radiation.

The planning of a "solar city" must undergo a paradigm shift in the ways it is designed and oriented. When high-rise buildings became possible with the knowledge breakthrough of structural engineering, cities began to look differently with the development of the skyline. A similar approach must be considered for a solar city. The city must transform itself, without compromising the quality urban design, to have the appearance of a solar city. Proper orientation, glazing locations, rotation, slopes, heights, and installations should be apparent in the buildings and depict a unique character to that city.

As research, development, design, construction, implementation, and utilization of solar technology become more common, it is encouraged that the term of a solar city be revisited to accommodate a given time period.   A definition that is developed today may very well be outdated in the near future. An exercise of this thesis was to develop an adaptable definition for the term "solar city":

> "A solar city is city which has a developed strategy for solar energy specifically for the built environment and all spaces formed by this environment.   The plan shall embrace and implement solar energy as design criteria during preliminary phases of design. A solar city will display the features of solar architecture ("form follows function").   The approach to the implementation of solar energy will create a unique character to each city and acts as a cornerstone for further urban development. Ultimately, a solar city

understands the potential for solar energy to become a contributing factor to the overall energy demand and reflects this concept into the design of its communities."

Research Objectives

Is Toronto capable of being a solar city? Is there potential for building facades and roofs to implement active solar strategies? Is the current built environment optimized to incorporate solar energy as a major contributor to the overall energy demand? If not, how do we make it happen?

Specifically, the research objectives of this thesis are to:

1) Investigate different morphologies in Toronto to determine if urban planning of Toronto has allowed property owners access to solar energy in order to integrate active solar strategies to building facades.

2) Is there a potential for the existing built environment of Toronto to harvest solar radiation?

3) With the results of solar access analysis, possible areas of improvement will be identified in order to make new developments solar ready.

Methodology

In order to respond to the research problem, the following will be completed; four specific areas in Toronto that are of interest for this research will be developed with the use of a 3-dimensional digital model. The following areas in Toronto have been chosen which vary in building morphology:

- High-rise downtown towers (Bay St.& King St. W.) (fig. 6)
- Mid-rise downtown main street buildings (King St. W. & Bathurst)(fig. 7), and
- North-south oriented low-rise single family houses on Cowan Ave (fig. 8)

- East-west oriented low-rise family houses on Thorburn St. (fig. 8)

These areas will be investigated utilizing a 3-d digital model and analyzed to determine insolation levels of facades and roofs. With the results from the solar energy simulation, new building formations will be proposed which are specifically designed to utilize solar energy.

Figure 30 provides a diagrammatic display of the methodology undertaken over the course of this thesis.

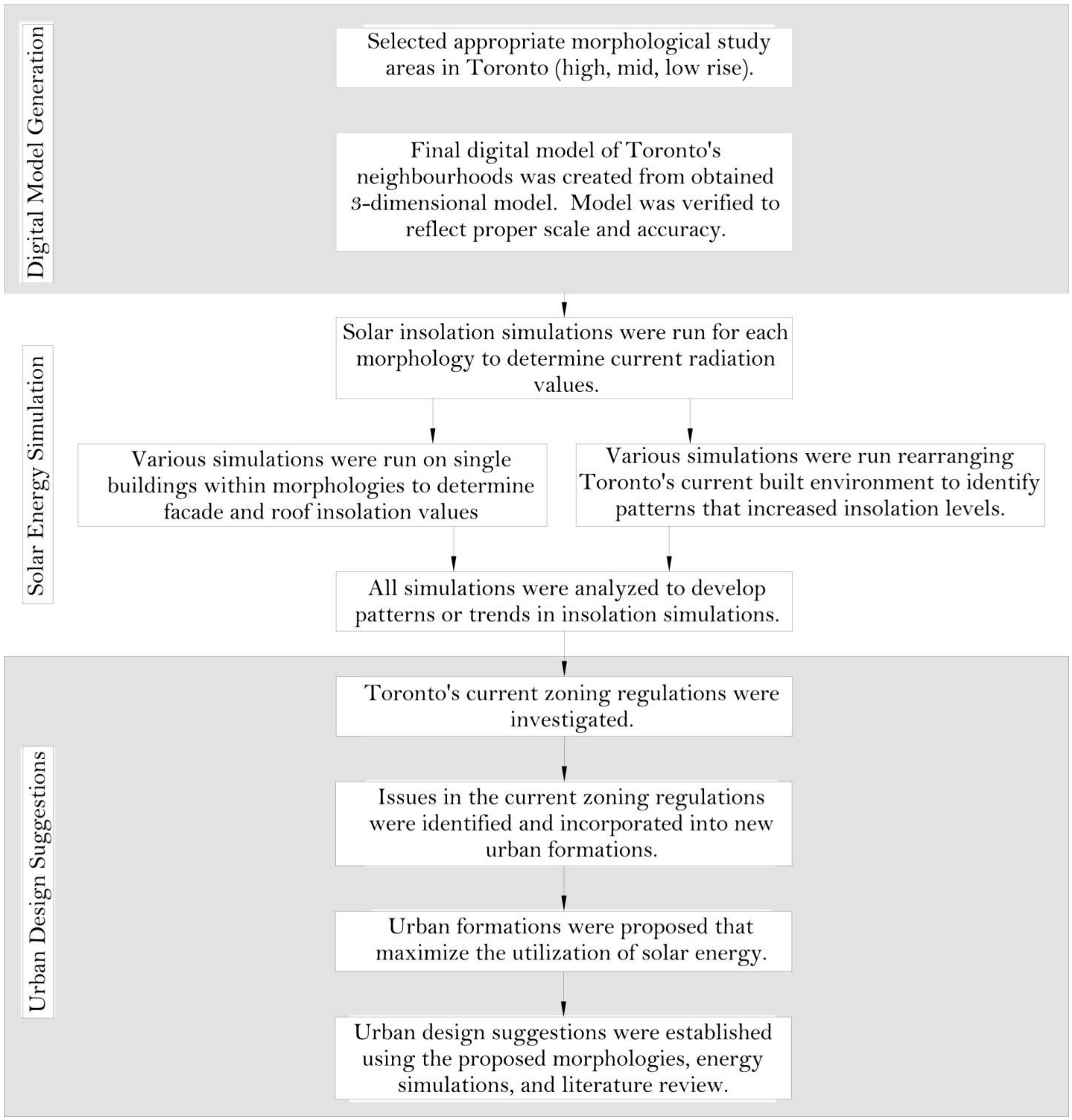


Figure 30: Diagrammatic depiction of methodology.

Energy Simulation Software

There are hundreds of software programs that are available for energy simulation of buildings (Attia, Beltran, Herde, & Hensen, 2009). There are software programs that resemble basic spreadsheets and there are some which allow the user to develop full 3d geometric models. Some software is more suitable than others but it is difficult to decipher which to choose when approaching the wide variety of available programs.

AutoCAD is the most commonly used modeling program in the architecture industry (Attia, Beltran, Herde, & Hensen, 2009). It is a very simple tool to learn although can become complex with many add-ons being available to enhance functionality. Autodesk Revit is a 3-dimensional based modeling program commonly used in conjunction with AutoCAD. Autodesk Vasari is a stripped down version of Revit which offers energy simulation functions. Vasari was used during the preliminary simulations because it offers a very simple user interface. Autodesk Ecotect provides numerous energy simulations types including solar access analysis. Ecotect provides visual solar radiation analysis as well as numerical output per facade.

Simulation results identified the preferable surfaces on buildings that are suitable for building integration of active solar systems. Simulations were completed using yearly accumulations using the units of kilowatt hours per meter square per year ($kWh/m^2/year$) or gigawatt hours per meter square per year ($GWh/m^2/year$). The simulation analyses can provide the data necessary to determine if Toronto can harvest solar radiation in order to offset non-renewable energy sources.

Limitations

Limitation of Energy Simulation Software

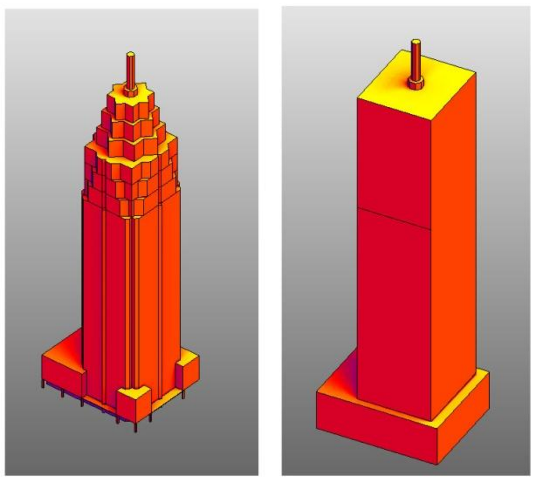
Software programs have been the main limitation for this research. There are many software programs available, both for modeling and simulation, with no single program being used consistently within the field of architecture. A report by (Horvat et al, 2011) identifies barriers architects are facing when attempting to implement energy simulation software into the EDP (early design phase)of buildings. The most common barriers that architects are experiencing with energy simulation software are: tools are too complex, tools are not integrated with CAAD tools, tools are too expensive and using the tools take too much time. Furthermore, a similar report surveyed architects and it was determined only 2% of those surveyed in this report felt satisfied with the digital tools that are currently available (Dubois, et al., 2011)

During the early stages of simulations, many difficulties were encountered with the size and detail of the digital model. When detailed models of each building were used for simulations, the software program could not compute the many surfaces of buildings and would cease progress of the simulation. For this reason, the digital models had to be redrawn with simple geometry in order to eliminate as many surfaces as possible. Since the redrawn digital mass model is not an identical representation of Toronto's built environment, solar simulations will possess some margin of error.

One of the questions raised during the early stages of this study is how detailed models of buildings will compare to mass models of buildings. In order to determine the margin of error that is experienced with converting the detailed model to a mass model, many comparisons of single detailed buildings and mass buildings was analyzed. This comparative calculation provided a margin of error of approximately 20% than can be applied to each solar insolation simulation. The models that are shown in fig. 31, 32, and 33 are some examples of the detailed geometry versus the mass geometry and results are shown in Table 2.

Table 2: Detail model vs. Mass model

Figure #	Insolation Level (MWh/year)		Surface Area (m^2)		Surface Area Difference (%)	Insolation Difference (%)
	Detail	Mass	Detail	Mass		
Fig. 31	20,269	30,686	71,858	56,648	22	34
Fig. 32	13,146	12,466	29,130	32,239	10	5
Fig. 33	12,997	9,553	38,240	25,989	33	27



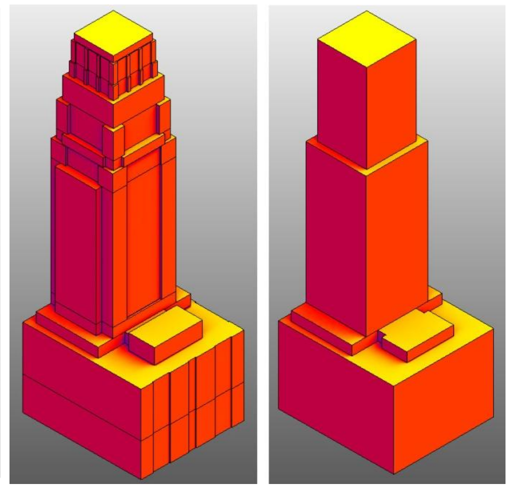


Figure 31: (left) Detail model vs. mass model #1.
Figure 32: (right) Detail model vs. mass model #2

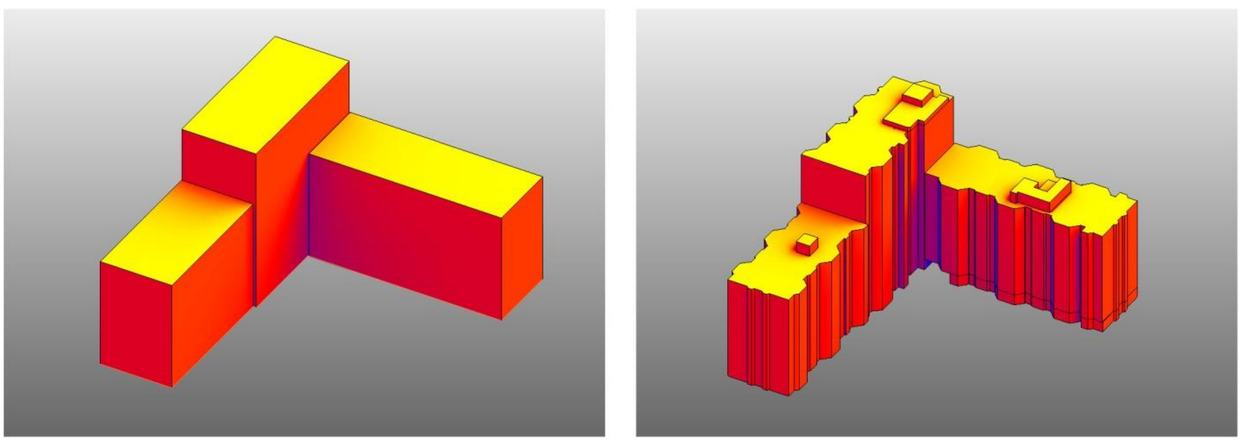


Fig. 33: Detail model vs. mass model #3.

Furthermore, the simulation process revealed more limitations and difficulties through both modelling and computing solar energy simulations. The two simulation software programs that were used for the analysis were Autodesk's Vasari and Ecotect, with modeling being completed in Autodesk's AutoCAD and Revit. Both simulation software programs offer a solar radiation analysis option where the surfaces of the mass models are simulated to determine the solar insolation received over a given time period. When this operation was performed, results drastically differ displaying a lack of consistency between the currently available simulation software. Although a common digital model was used for simulation in both software programs, varying results were achieved. The discrepancies pose numerous questions to software developers and since results from each analysis were different, it is difficult to decipher which is correct and questions the validity of the software. Accuracy is of uncompromising importance with simulation software, and until a reliable simulation tool is available for architects, all results must be analyzed critically.

It seems typical that energy simulation software lacks the ability to build a 3-dimensional model, and conversely, modelling software lacks the ability to perform accurate and meaningful energy simulations encouraging the transfer of files between programs. The incompatibility between software, even when they are developed by the same company, remains inadequate with vital data being lost through the export and import of files. Both Vasari and Ecotect offer import and export functions from modeling software such as AutoCAD or Revit, although it is not uncommon that this seemingly simple task generates unnecessary conflicts or errors. After a time consuming and laborious task of generating the 3-d models in AutoCAD, the same model had to be redrawn in Revit in order to achieve a file that is suitable for export into the solar simulation software. The ability to utilize a single digital model would prevent errors or inconsistencies and also reduce labour since up to 80% of the effort in preparing an energy simulation goes into the geometric description of building (Bazjanac, 2001).

After much time spent investigating and experiencing the available software, the final simulations were completed using Autodesk's Vasari and Ecotect. The mass models were built in Autodesk's AutoCAD and Revit where they were than exported as a “mass model .gbxml”. This file could then be opened by Ecotect (not imported) and used for solar radiation analysis. Figure 34 is a diagrammatic display of the software programs used over the course of this thesis.

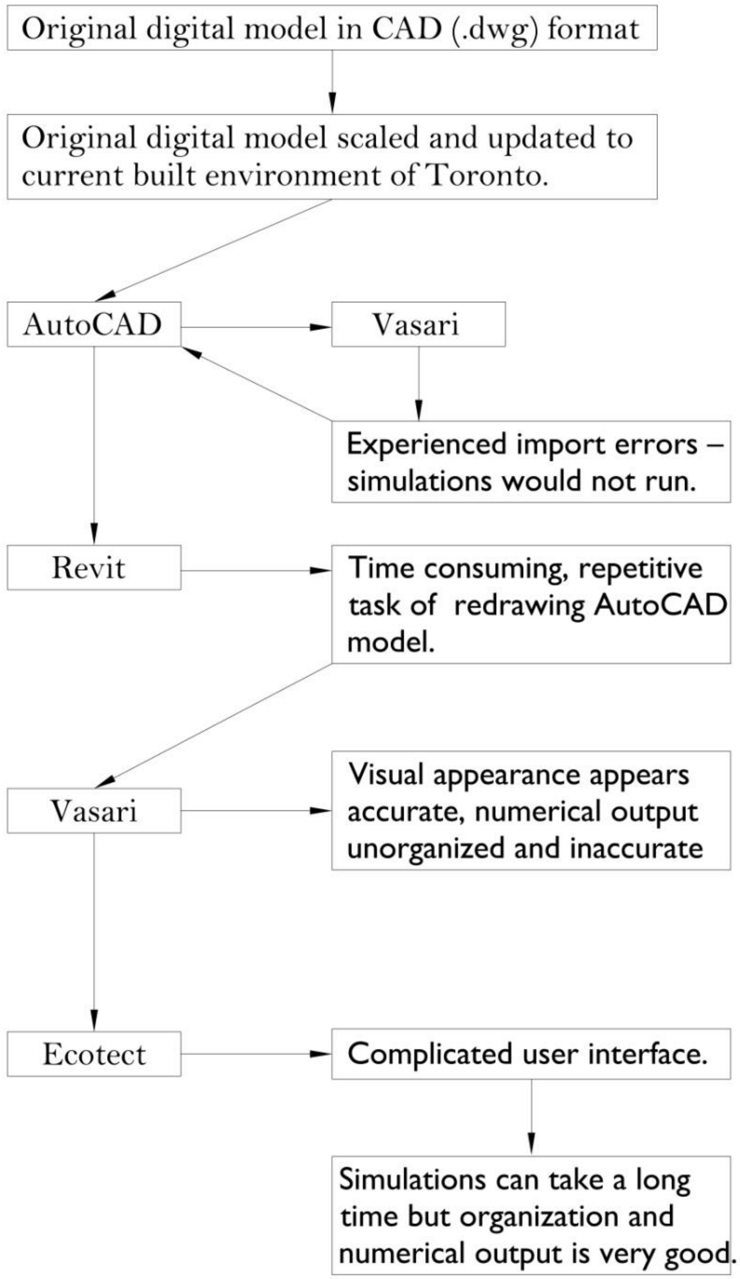


Figure 34: Diagrammatic depiction of the software process.

The barriers that were faced can be further validated with research conducted by the (U.S. DOE, 2011) which determined that building performance simulation software tools tends to be developed for engineers and not architects. Since 1997 approximately 389 energy simulation software tools were developed with only 35 intended for the architectural community (ibid). The users for many of these energy simulation programs are mainly researchers, physicists, and experts who value empirical validation, analytical verification, and calibration of uncertainty (Attia et al, 2009).

Weather Files

The accuracy of the simulations relies heavily on the data within the weather file. The weather file provides the software with all the vital data of a city that calculates the insolation levels. During the progress of this thesis it was determined that the weather files provided by Ecotect for the city of Toronto was incorrect. In fig. 35 there are two figures, one which has a flat roof and the other which has a sloped roof at an angle of 45 degrees due south. The insolation reading on the flat roof is reading higher than the insolation level on the sloped roof which logically cannot be correct. Toronto has a geographic location of 79.19°E and 43.65°N (Natural Resources Canada, 2012) where it is evident that a sloped surface will receive higher solar radiation than a flat surface. According to (ibid) a flat surface will receive approximately 1350.5 kWh/m^2/year and a sloped surface can receive 1669.5 kWh/m^2/year.

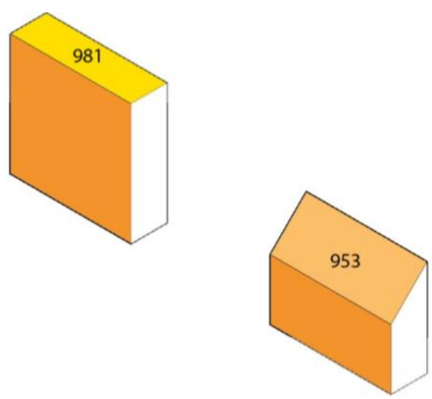


Figure 35: Inaccurate insolation simulation with the weather file from Ecotect.

A new weather file was imported into Ecotect in order to determine a proper insolation reading. The weather data was downloaded from (Department of Energy, 2012) and the identical model from fig. 35 was re-simulated and is shown in fig. 36. The results appear logical using the new weather data and the sloped surface received a higher level of insolation as initially expected. These insolation values also coincide with the data that was retrieved from (Natural Resources Canada, 2012) where an insolation level of 1305kWh/m^2/year on horizontal surfaces is recorded for the City of Toronto.

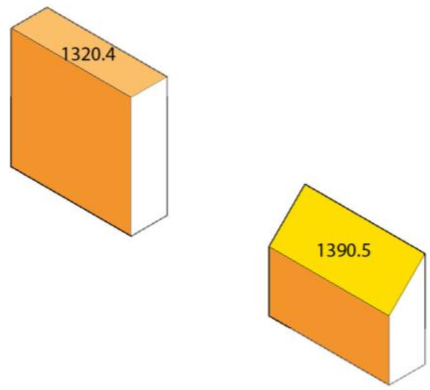


Figure 36: Accurate insolation simulation with weather file from (Department of Energy, 2012).

Vegetation

Although not a factor in morphology #1 or #2, morphology #3 has many trees that overshadow roofs and facades. The location of trees and other vegetation was ultimately unknown and the task of inserting vegetation into the digital model on the large scale of this research would have been a tedious and cumbersome task. If it was possible to determine the location of trees and other vegetation, the many surfaces of these components would surely lead to errors or ceasing of the simulation software. As mentioned prior, there were numerous errors with the large scale model of buildings and adding vegetation would only lead to a more error prone simulation.

Limitations Summary

With many limitations experienced, it should be noted that the modeling and simulation process rarely reflects a real world scenario and therefore simulations are not 100% accurate. This can be common for all scales of simulations, whether it be a single building or a mass model. Particularly on a scale of the model used for this research, meticulous overview of the digital model and comparative analysis to aerial and street images was completed to ensure relative accuracy between digital models and real world environments.

The overall process of modeling and performing solar simulations of the morphologies was a difficult task. Many complications were experienced that dramatically increased the time necessary to model and simulate the morphologies. Adequate simulation software still does not exist which is being addressed in the new IEA Task 51: Solar Energy and Urban Planning, specifically sub task B: Methods and processes for solar energy in urban planning.

CHAPTER 3

Preliminary Simulation Results

During the initial stages of urban design, urban designers will look at the existing conditions of the area. Physical objects such as infrastructure, roads, railways etc. are easily observed where natural parameters such as sun and wind patterns can be overlooked (Droege, 2008). This section will investigate altering morphologies using the existing buildings by rearranging them into a different building arrangements. The results will then be compared to the current built environment to determine if simple rearrangement of buildings increase insolation levels.

Current Built Environment

Table 3 displays the insolation levels for the current built environment of each morphology in Toronto. Each morphology was simulated (fig. 37, fig. 38, and fig. 39) in its current state with an overall insolation value.

Table 3: Average Insolation Value For Current Built Environment.

Figure #	Morphology	Overall Insolation Value (kWh/m²/year) of building envelope area
Fig. 37	Morphology #1	205 KWh/m²
Fig. 38	Morphology #2	323 KWh/m²
Fig. 39	Morphology #3	349 KWh/m²

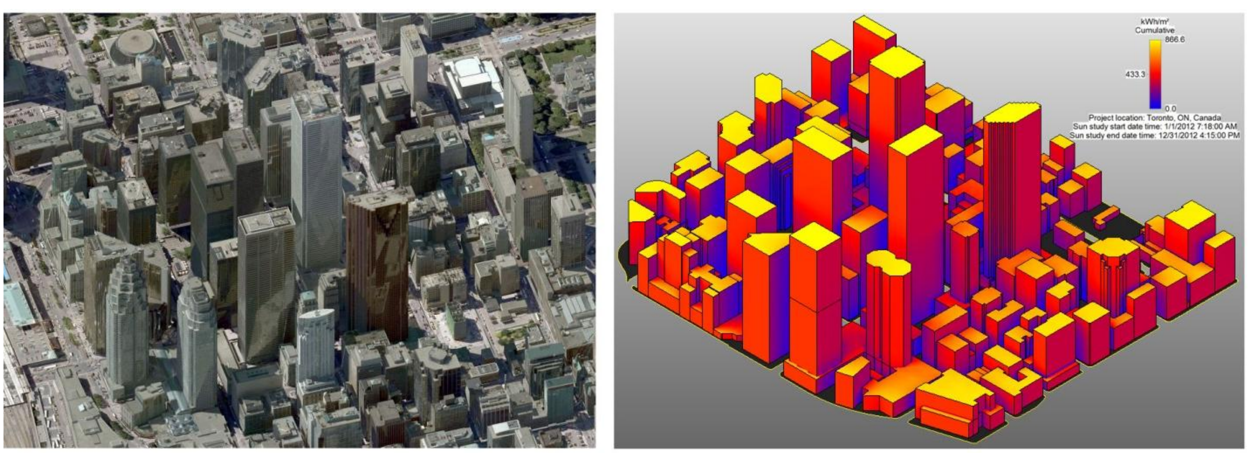


Figure 37: (left) Aerial image of Bay St. & King St. W. (right) Solar simulation of Bay St. & King St. W.

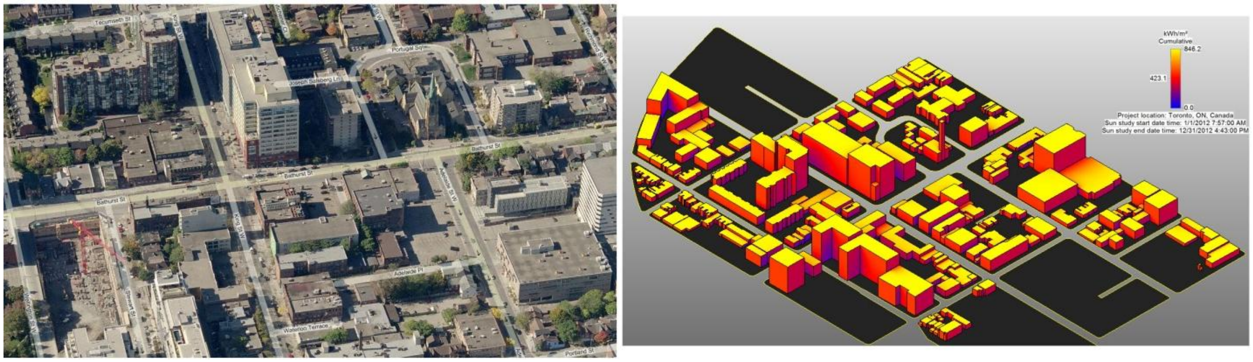


Figure 38: (left) Aerial image of Bathurst St. & King St. W. (right) Solar simulation of Bathurst St. & King St. W.

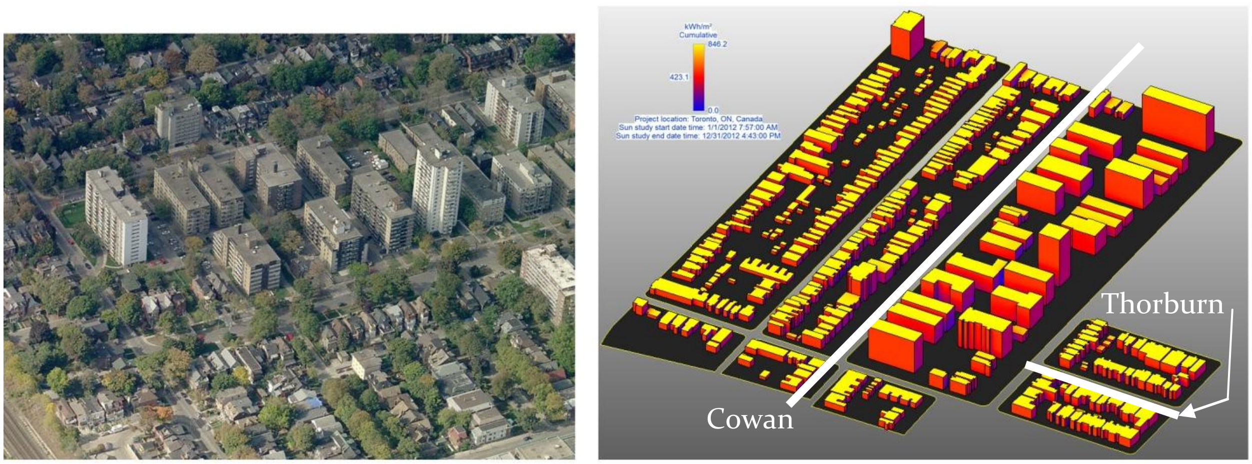


Figure 39: (left) Bird's eye aerial image of Cowan Ave (north/south orientation) & Thorburn (east/west orientation (right) Solar simulation of Cowan Ave. & Thorburn St. E.

The preliminary simulation resulted in lower than expected insolation levels (200-350 kWh/m²/year in comparison to 1320.5 kWh/m²/year which Toronto receives annually (Natural Resources Canada, 2012). This is due to how Ecotect includes all facades into analysis, even those which do not receive direct sun exposure such as north facades and then averages the solar insolation output. Software limitations prevented only south and roof facades from being simulated. The process of choosing only south and roof facades on a large digital model is very time consuming and error prone since each surface must be chosen individually.

Morphology #1 received the lowest insolation level with 205 kWh/m²/year due to the high level of overshadowing that occurs. Morphology #2 and #3 received similar amounts of annual solar radiation with 323 kWh/m²/year and 349 kWh/m²/year respectively. Overshadowing is less of an issue with morphologies #2 and #3 since they do not contain high-rise structures and higher insolation levels were expected.

Isolated Building Investigation

To investigate how overshadowing can deter the utilization of solar energy a building located in Commerce Court (which is located in the middle of the Financial District) (fig. 40) in downtown Toronto was investigated due to the surrounding context of high-rise buildings. The building is a single floor building measuring approximately 43 meters x 43 meters offering 1,849m^2 of flat roof that is free of mechanical units and other interfering components that typically hinder the installation of solar systems.

Figure 40: Aerial view of Commerce Court in downtown Toronto.

Fig. 41 displays a solar simulation of the building free from surrounding context and a solar simulation in its current state. The simulation was completed to investigate how overshadowing of high-rise buildings affects adjacent buildings. The following energy generation can be calculated for each scenario (assuming 15% efficiency for a PV panel):

<u>Isolated Building:</u>

1320.5 kWh/m^2/year x 1,849m^2 x 15%P.V. = 366,240 kWh/year

(enough energy to completely satisfy the energy demand for 24 apartment units)

<u>Building With Context:</u>

291.6 kWh/m^2/year x 1,849m^2 x 15%P.V. = 80,875 kWh/year

(enough energy to completely satisfy the energy demand for 5.33 apartment units)

A flat and component free roof (i.e. mechanical units, skylights, vents, walkways, green roof) is a ideal location for the installation of solar systems and as can be seen in the above calculations, the solar potential is reduced 4.5 times by the surrounding high-rise buildings. This is the worst case scenario in a dense environment such as Toronto, but was included to display the affects that high-rise buildings can have on its surroundings.

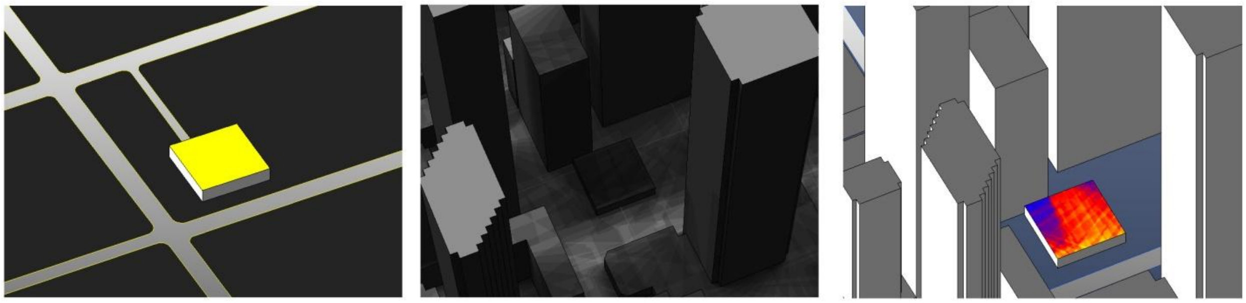


Figure 41: (left) Commerce Court in isolation, (center) shadow study of Commerce Court, (right) Solar simulation of Commerce Court with current context.

One of the tallest building in Toronto is First Canadian Place (Emporis, 2012) which can be seen in fig. 42. The entire south facade of the building was simulated and receives 4.2GWh/year of solar energy (which is enough energy to completely satisfy the energy demand for 42 apartment units) . There is heavy overshadowing on the lower portion of the building as can be seen in fig. 42 (right). The surface area was analyzed and it was determined that 81% of the total energy (3.4GWh/year) was received in the top 30% of the building. Therefore, only the top 24 storeys (of 72 total storeys) are of adequate insolation levels to facilitate active solar strategies. This simulation exemplifies the problematic issue of implementing solar strategies into dense urban environments.

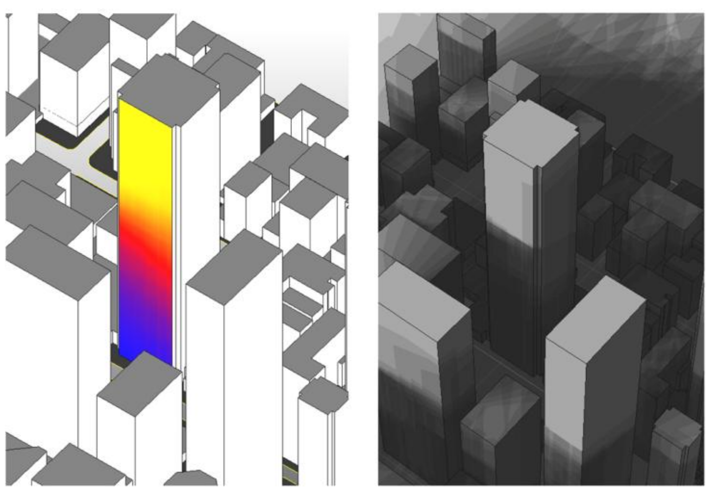


Figure 42: (left) Solar simulation of First Canadian Place, (right) Shadow study of First Canadian Place.

Vertical and Horizontal Randomness

As demonstrated in other studies and specifically in (Cheng et al, 2006) showed that arranging buildings with horizontal and vertical randomness permits higher insolation levels. The approach of vertical and horizontal randomness was applied to the three morphologies of Toronto as an investigative measure to determine if higher insolation levels could be achieved.

The difference between the study developed by (ibid) and the presented morphologies in this thesis is the use of gross floor area (GFA). For example, in the same study five separate single storey buildings with 100m² GFA each, could be rearranged into a single building with five floors each having a 100m² GFA. But, the digital mass models which are used for this research are simple mass boxes where the software does not detect floor areas.

Since the simulation software does not detect GFA the morphologies were only horizontally rearranged since vertical randomness is not possible. High-rise, mid-rise, and low-rise buildings were randomly mixed in each morphology to investigate how insolation levels on surfaces would differ.

Table 4 explains the details of the randomness used and the simulation results from morphology #1.

Table 4: Randomness Test For Morphology #1. (Current Built Environment Insolation Level - 205 KWh/m²/year)

Description of New Morphology	New Overall Insolation Value (kWh/m²/year) of building envelope area
Five of the highest buildings removed.	226
Highest buildings rearranged to be in the middle.	212
Randomness #1 (Rearranged Tall Buildings)	204
Randomness #2 (Rearranged Tall Buildings)	
Buildings arranged from highest to lowest (higher buildings to the south of lower)	212
Buildings arranged from highest to lowest (higher buildings to the north of lower)	219
Randomness #3 (Random arrangements)	209
Randomness #4 (Random arrangements)	211

None of the randomness tests in morphology #1 increase insolation levels significantly enough to be considered a viable option for the City of Toronto. The density and height of the buildings caused heavy overshadowing in each pattern which ultimately resulted in no positive results. In any arrangement that tall buildings are placed with such density, it should be expected that overshadowing will prevent insolation levels from increasing.

The same concept of randomness was utilized in morphology #2 and #3 with negligible improvements. In morphology #2, the buildings were rearranged in similar methods that were utilized in morphology #1. In morphology #3, the height of the buildings is relatively uniform since it is a residential neighbourhood, therefore rearranging the buildings was not a viable option. The results from morphology #2 can be seen in Table 5 and results from morphology #3 can be seen in Table 6.

Table 5: Randomness Test For Morphology #2. (Current Built Environment Insolation Level - 323 $kWh/m^2/year$)

Description of New Morphology	New Overall Insolation Value (kWh/m^2) of building envelope area
Randomness #1 (Rearranged Tall Buildings)	322
Randomness #2 (Rearranged Three of the Taller Buildings)	330
Randomness #3 (Rearranged buildings)	320
Tallest buildings were rearranged to be in the middle	331
Buildings arranged highest to lowest with highest buildings on the south.	331

Similar to morphology #1, morphology #2 seen minimal increase in insolation levels. The investigative approach to applying the randomness concept to morphology #2 is not a viable option for the City of Toronto. The density of this area is somewhat high which results in overshadowing no matter how the buildings are randomly rearranged.

Table 6: Randomness Test For Morphology #3. (Current Built Environment Insolation Level - 349 kWh/m²/year).

Description of New Morphology	New Overall Insolation Value (kWh/m²) of building envelope area
Every other building was deleted.	370
grouped three buildings into one for all buildings.	346

The concept of randomness is unrealistic for morphology #3 since nearly half of the houses were removed to increase insolation, but results were negligible. In a city that is as populated as Toronto, it is not a viable option to remove this many residential buildings.

Preliminary Simulations Conclusion

The preliminary simulations were completed in an attempt to identify areas which have the most potential to utilize solar energy. Multiple simulations were completed with geometric attributes being altered. In nearly all simulations there was a negligible increase in the insolation levels. This can conclude that the current state of the City of Toronto is not optimized to take advantage of solar energy harvesting for energy generation.

Due to the limited functionality of the solar energy simulation software and the design of the digital model, all further solar energy simulations comprises of only a small area within each morphology. This allows each new morphology to have some context since the digital model reads the south most facades as having no overshadowing registering a very high and inaccurate insolation level (fig. 43).

Morphology #1 was deemed to be unrealistic for varying building formation due to the high demand of square footage to maximize gross floor area for profit. Lots in the core of major cities are developed to the maximize floor space in order for owners to maximize profits. This results in minimal opportunity to focus on solar design. Other renewable energy sources such as wind power may be preferable due to the wind that is generated by deep urban canyons created by neighboring high-rise buildings, but is not within the scope of this research

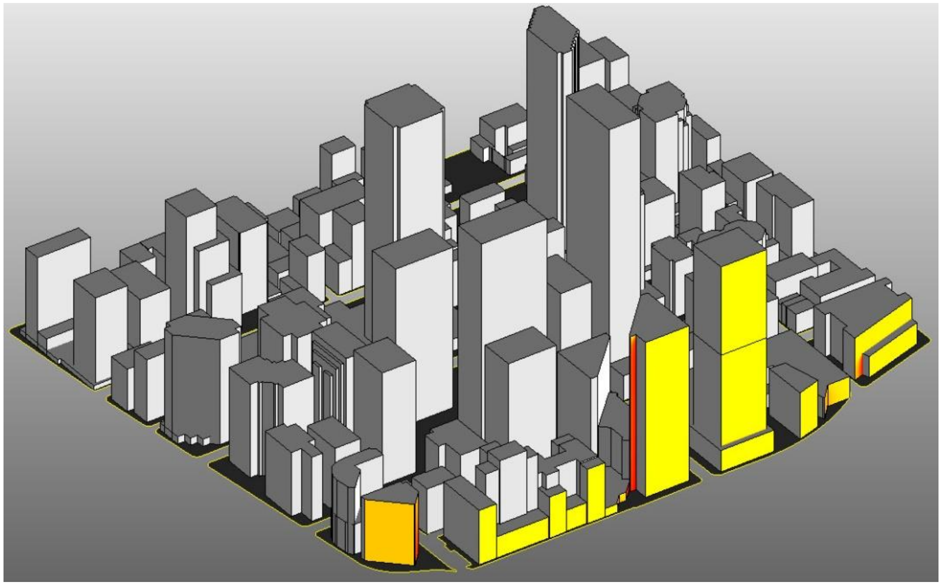


Figure 43: The surfaces simulated in this figure receive inaccurate insolation levels due to the south side not experiencing overshadowing.

Morphology #3 did not see as drastic of increase in insolation with only a 9% increase in the north/south orientation and a 6% increase in the east/west orientation. Morphology #3 showed very little fluctuation in insolation levels due to the limited building sizes that is permitted in residential neighborhoods. The proposed morphologies for this area did not exceed 10 meters in height and the building's foot prints were similar to the current built environment of approximately 4.5 meters wide by 15.25 meters deep. With these restrictions it is difficult to manipulate the existing built environment without violating building practices and zoning bylaws to accomplish higher insolation levels. The current area of morphology #3 achieved an overall insolation level of 324 kWh/m^2/year in the east/west orientation and 338 kWh/m^2/year in the north/south orientation which only slightly exceeds the more vertical built environments of morphology #1 and #2. Vegetation also plays a crucial role in residential neighborhoods but was not involved in the simulation process due to the complexity and ultimately unknown locations of trees or other overshadowing factors. Large trees, which are both common and desired in residential areas, will cast shadows on any type of building formation during the high intensity summer months ultimately lowering insolation levels on any design typology.

Morphology #2 offers the opportunity for buildings to display architectural individuality and solar ready design. Square footage is not as demanding as the high rise morphology #1 and vegetation and zoning limitations are not as restrictive as in the residential area of morphology #3. The critical elements of mid rise morphologies will be maintained as to not alter the essence of the intended design, such as the corridor type street level front that is often occupied by retail space or restaurants. An area such as morphology #2 offers the "main street" character that is often desirable for residential, retail, and commercial spaces. A "main street" typology consist of all the needs necessary for residents such as retail, grocery, public transit, green space, etc. that are accessible without the use of an automobile.

Figure 44: King. St. E. & Bathurst St.

CHAPTER 4

Urban Configuration Development

The area of King St. W. and Bathurst St. (fig. 45) is a rapidly developing community with multiple active construction sites providing the area with many new mid-rise buildings.

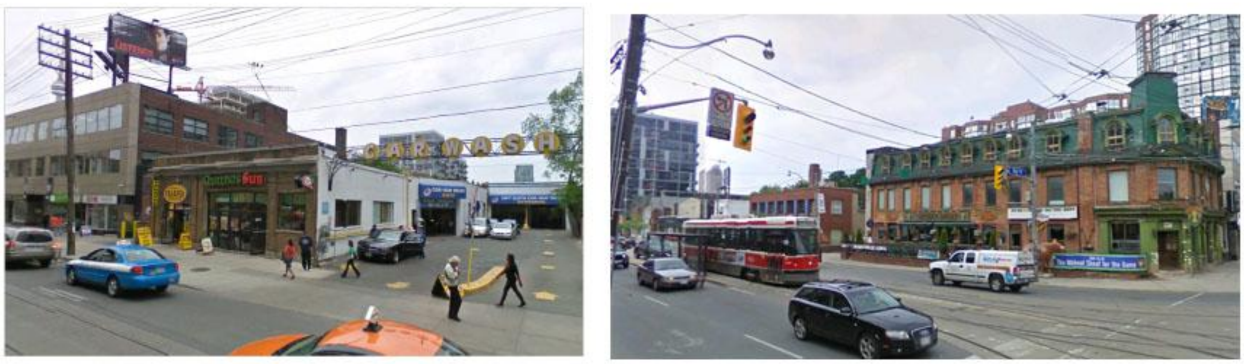


Figure 45: Photo of the small buildings near the intersection of Spadina St. and King St. W. (left looking southeast towards the intersection) (right looking southwest towards the intersection).

Since the area is experiencing such rapid development, the low-rise buildings in the main intersection of this area were removed from the digital model (fig. 46) in order to simulate new building formations that comprise of mid-rise buildings. Multiple simulations using very simple geometric mass models were completed using varying patterns to investigate which building formations maximize insolation levels.

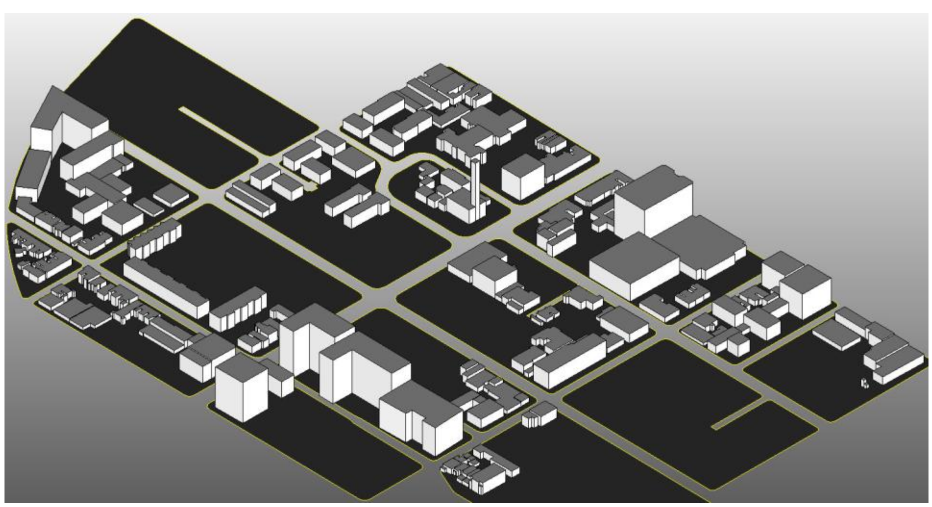


Figure 46: Morphology #2 with buildings removed for study area.

The flat storefront typology which is common to this area was maintained and new formations were placed at the edge of each street. The width of the buildings does not exceed 15 meters which approximately represents a double loaded corridor of a residential building. Anything deeper than 15 meters would not permit solar access to the exterior, preventing passive solar systems from being utilized, and may violate building code regulations such as fire escape routes. Building height does not exceed 50 meters which is the maximum height of the current built environment and maximum buildable height permitted by zoning requirements. The floor to floor height is 3 meters.

A basic site analysis is provided in fig. 47 which displays general information about the site location and layout for proposed building configurations. There are six building configurations that were generated using altering geometric features such as slope and height differential. These building configurations were developed to investigate how urban forms correlate with insolation values. The building configurations are numbered starting at the top left reading right to the bottom right. The configurations are numbered starting at number one and ending at number six. A compass rose is provided with north pointing up, and a winter and summer solar path displays the course of the sun at winter and summer solstice.

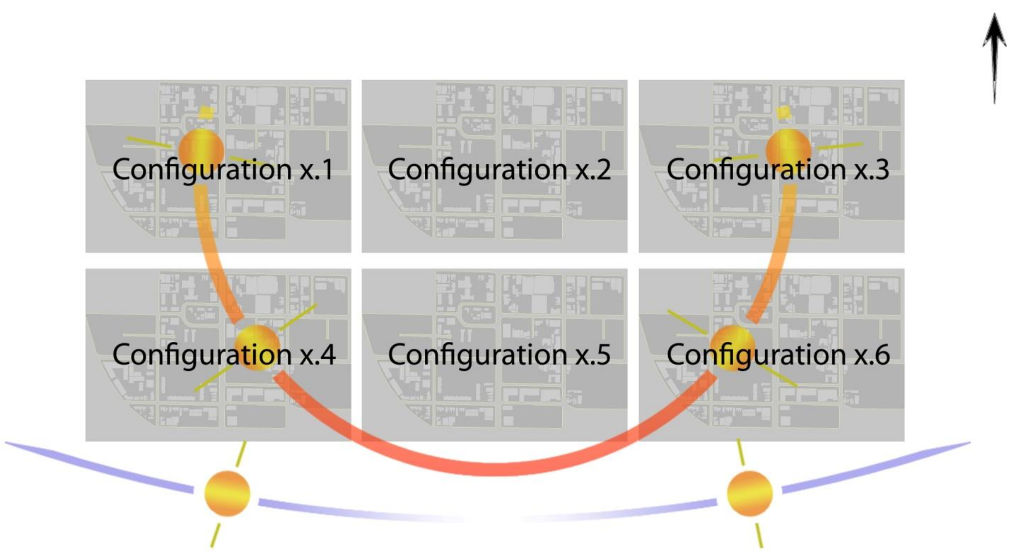


Figure 47: General site analysis, and the six proposed configurations.

The assumptions were made as follows: the unit used for recording energy generation levels is GWh/year, a variation of KWh/year, a common unit for energy consumption. To accurately compare building formations, the potential energy generation is being calculated by determining the overall average insolation level and multiplying it by the surface area of the facades. This generates the amount of solar energy which the building receives.

The average Toronto apartment as of 2010 was 78.7 square meters (Toronto's Condo Blog, 2011) and the average energy consumption of a Canadian apartment is 197 $kWh/m^2/year$ which includes space heating, water heating, appliances, lighting, and space cooling (Natural Resources Canada, 2012). This results in an approximate annual energy demand of 15,504 kWh/year or .015GWh/year for an average Canadian apartment. The approximate energy generation of a typical apartment unit has been included for contextual purposes.

Due to Toronto's geographical locations, only the south facade and roof surfaces will be simulated since it is these surfaces which receive the majority of solar radiation. Furthermore, due to overshadowing from the neighbouring buildings, it can be assumed that active solar strategies will not be utilised on the lower portions of facades. To determine which surfaces are suitable for active solar integration, a benchmark insolation value was developed.

This concept of a benchmark insolation value is referenced from (Kanters & Horvat, 2012) which was mentioned on page 27 and will be utilized for the City of Toronto. A benchmark insolation value of 700$kwh/m^2/year$ has been set. This number was determined as a minimum insolation level that could potentially generate 105 kWh/m2/year (building envelope area), if a 15% efficient PV panel is installed. Since the average apartment unit energy demand is approximately 200$kWh/m^2/year$ (floor area), based on the Statistic Canada (Natural Resources Canada, 2012), potentially 50% of the overall energy demand can be satisfied by PV panels.

The six initial configurations can be seen in fig. 48 and were designed with the height of the building not exceeding the width of the street, which is 30 meters, as to not cause heavy overshadowing of buildings due north. In formation A.1 each building is 50 meters long x 30 meters high x 15 meters wide and generated a potential energy level of 10.52 GWh/year. In formation A.2 the buildings on the north remained the same size and the buildings on the south are only 15 meters high which resulted in a slight increase in the energy generation level to 10.74 GWh/year. In formation A.3 a “stepping back” formation was utilized and resulted in an energy level of 10.11 GWh/year. Energy levels in formation A.5 and A.6 decreased slightly, but there was a large increase in insolation levels in formation A.4 which is due to the sloped surfaces. The surfaces are rotated at a 45° due south which is the ideal angle to maximize the efficiency of active solar strategies for the location of Toronto (43°40'12"N)

Formation A

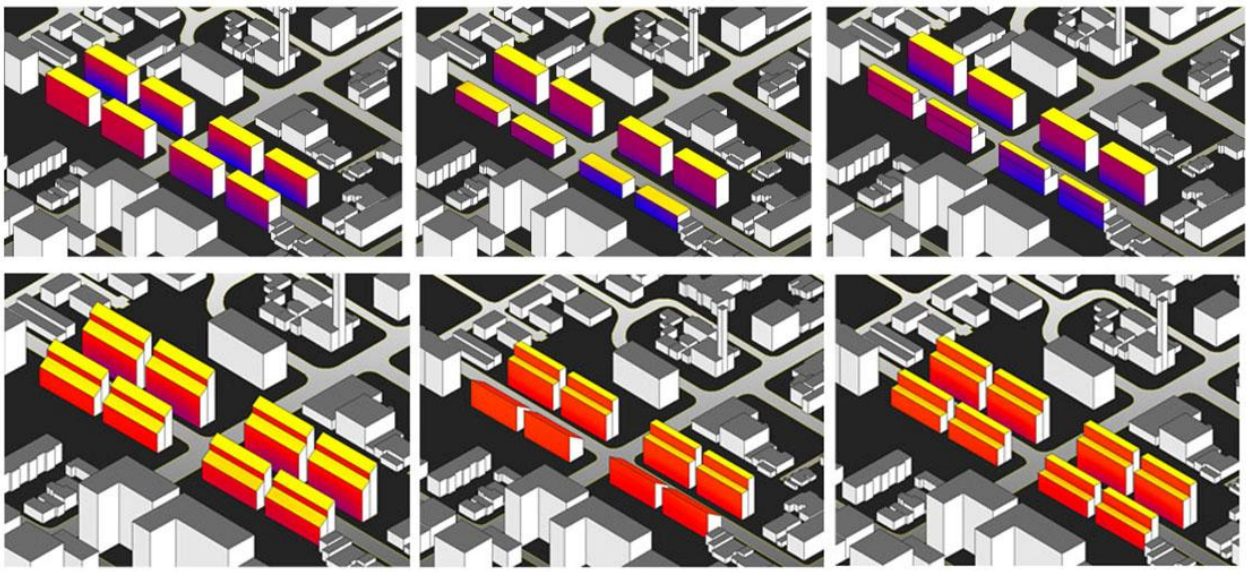


Figure 48: Formation A: (top left) Formation A.1, (top middle) Formation A2. , (top right) Formation A.3, (bottom left) Formation A.4, (bottom middle) Formation A.5, (bottom right) Formation A.6.

Table 7: Simulation Results - Formation A - Preliminary Building Formations

Formation	Insolation Level (kWh/m²/year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/year)
Formation A.1	837	60,000	12,571	10.52
Formation A.2	833	12,890	12,890	10.74
Formation A.3	815	51,000	12,408	10.11
Formation A.4	993	52,520	11,714	11.63
Formation A.5	806	48,922	11,618	9.36
Formation A.6	856	46,200	13,550	11.6

It was determined that it is not reasonable to compare new formations to the current built environment of morphology #2. As can be seen in fig. 45 the buildings on the south side of King St. W. are very low (fig. 45 is looking south from the north side of King St.(left) and looking southwest towards the intersection of King St. W and Bathurst St. (right)) and this is allowing the south facade of the buildings on the north side of the street to receive nearly maximum insolation levels. The highly desired land along King St. W. is currently being occupied by a small car wash, and other privately owned small businesses. For this reason, it is expected that the future built environment of this intersection will be developed to maximum zoning allowances for developers to earn maximum profit.

The formation seen in fig. 49, which is being referred to as the base case, where building height is maximized as per zoning requirements. Although this is the economically feasible solution, it leads to a built environment that neglects critical design features that can incorporate solar energy. New building formations were developed that are similar to that of the base case in order to represent a reasonable real world development.

Figure 49: Simulation with new formation designed to the maximum zoning height (base case).

The base case receives an average insolation level across the south facade and roof of 820kWh/m^2/year. The base case has a GFA of 102,000 m^2, a surface area (south facade and roof only) of 26,400m^2 and energy generation potential of 13.87GWh/year (equivalent to provide power to approximately 139 apartments). The parameters of the base case are used throughout the following formations since the maximum buildable area is a viable prediction for the future development of this area.

For all new formations, the building foot print was not adjusted from the base case, which was 50 meters long by 15 meters wide. In formation B, each building was raised until the building on the north side of King St. reached the maximum building height of 50 meters (fig. 50).

Formation B

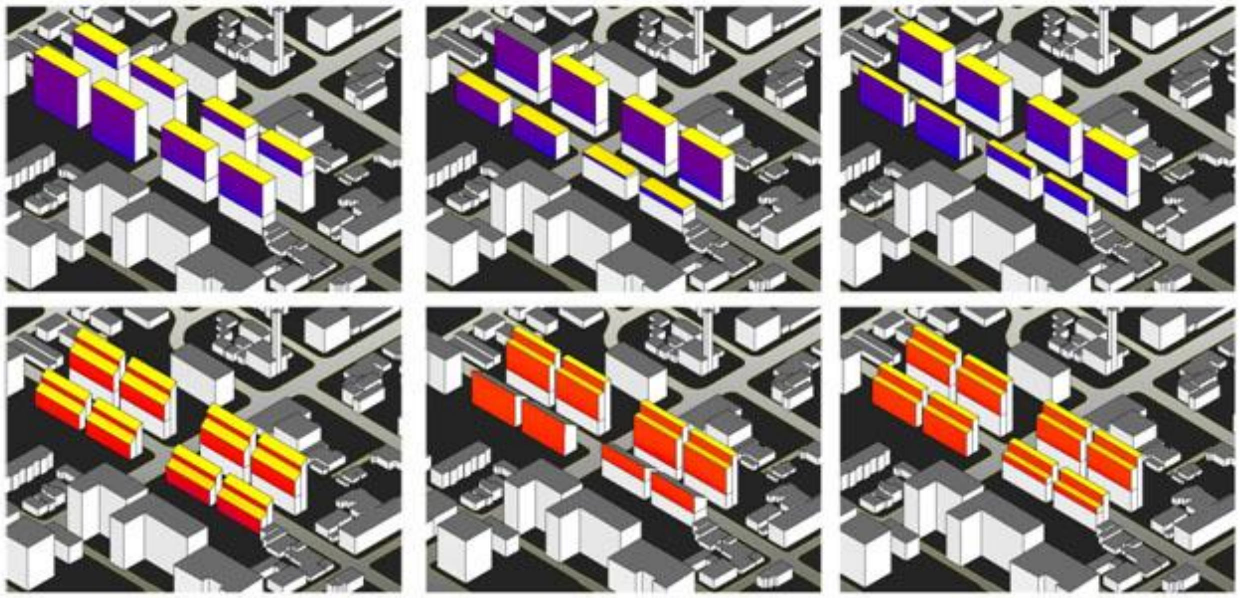


Figure 50: Formation B: (top left) Formation B.1, (top middle) Formation B.2. , (top right) Formation B.3, (bottom left) Formation B.4, (bottom middle) Formation B.5, (bottom right) Formation B.6.

Table 8: Formation B - New Building Formations With Increased Floor Area

Formation	Insolation Level (kWh/m²/year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/Year)
Formation B.1 (Base Case)	820	102,000	16,910	13.87
Formation B.2	820	75,000	16,748	13.73
Formation B.3	812	78,000	16,160	13.12
Formation B.4	1008	63,214	13,800	13.91
Formation B.5	803	72,238	14,760	11.85
Formation B.6	843	70,000	16,400	13.83

Other than in Formation B.4 there was a slight decrease in energy generation levels in all of formation B. As the building height increased, the energy generation decreased which is due to the overshadowing created by the increased building height. Since formation B.4 was developed with a sloped roof at 45° to maximize solar absorption, this formation seen an increase in potential energy generation.

It is interesting to observe that energy levels in formation B.1 (base case) were higher than most of the other proposed formations. The reason is that the surface area which recorded an insolation value of at least 700/kWh/m^2/year was higher in formation B.1 than any other formation. The exposed rooftops of formation B.1 provided unobstructed access (ignoring building components such as mechanical equipment) to direct solar radiation, where in some of the other formations this was not the case. The south facades of the north buildings in formations B.2-B.6 were permitted to receive much more insolation than formation B.1 however, formation B.2-B.6 could not generate as much energy because the energy intensity decreases on surfaces that are tilted to 90° compared to surfaces that are horizontal (Natural Resources Canada, 2012).

To increase the exposed surface area, but to not cause overshadowing, new formations were proposed that maintained maximum buildable area of 102,000m^2. Proposed formation C was developed by subtracting floors from the southerly building and adding them to the northerly building. This will violate the zoning ordinance for this area (which is addressed in the "Urban Design Suggestions" section) but this formation still satisfies the population density as GFA is not being decreased. Each building has a foot print of 50 meters long by 15 meters wide, a floor to floor height of 3 meters and a GFA not less than 102,000m^2. Formation C can be seen in fig. 51 and simulation results are shown in table 9.

Formation C

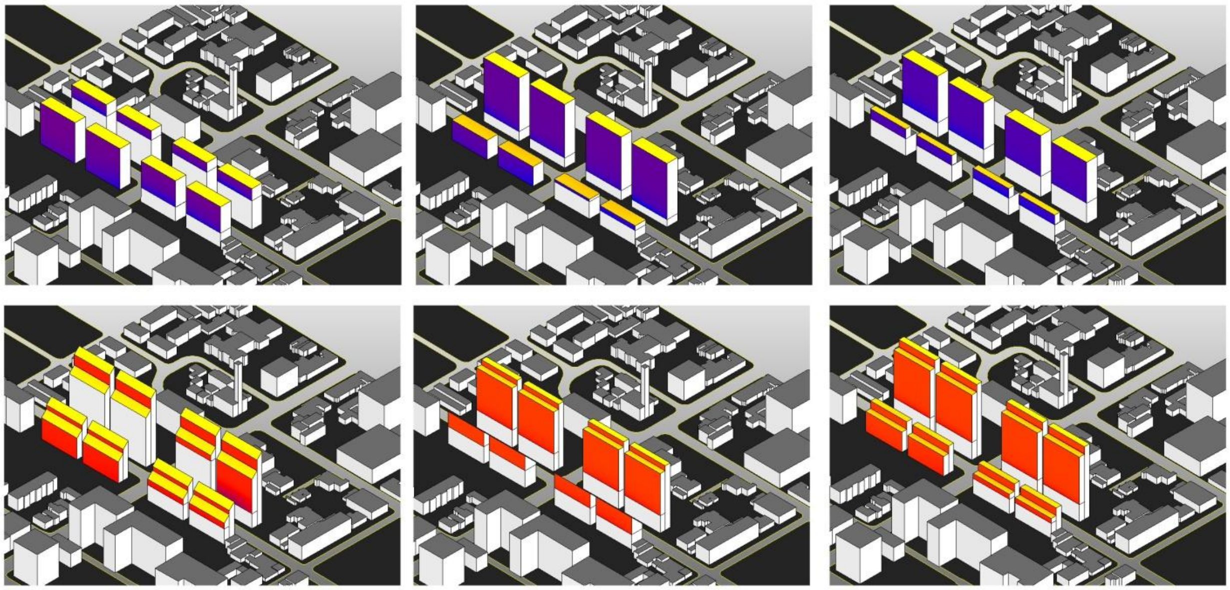


Figure 51: Formation C: (top left) Formation C.1, (top middle) Formation C.2. , (top right) Formation C.3, (bottom left) Formation C.4, (bottom middle) Formation C.5, (bottom right) Formation C.6.

Table 9: Formation C New Building Formations With Maximum Gross Floor Area

Formation	Insolation Level (kWh/m²/year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/year)
Formation C.1 (Base Case)	820	102,000	16,910	13.86
Formation C.2	809	102,000	22,147	17.9
Formation C.3	797	102,000	20,806	16.58
Formation C.4	961	104,141	15,208	14.6
Formation C.5	803	102,894	19,990	16.05
Formation C.6	822	103,600	23,550	19.52

As can be seen in Table 9, potential energy generation levels increased from the previous formations due to the increased exposed surface area. The more exposed surface area provided, the more solar radiation can be absorbed for the generation of energy. Formation C.2 and formations C.6 experienced the largest potential energy which is because of the large exposed surface area that is facing south. It is interesting to note that formation C.4 which utilizes a the sloped roof (45° due south) had the lowest energy generation yet the highest average insolation level. The high peak of the sloped roof causes overshadowing on the buildings due north causing less surface area to record an insolation value of 700/kWh/m²/year which limits usable space for active solar installations.

The considerable downside for the formations presented in formation C (fig. 51) is that the building height of the northerly building is reaching heights of 80 meters, which far exceeds the zoning limitations. Although it may be beneficial for the small contextual area of the main street (in this case, King St)., it causes overshadowing for the building located directly north and, therefore, greatly diminishes the urban quality of that city block.

In an attempt to amend this issue, the new configuration derived from rearranging formation C to allow solar radiation to penetrate more surface area was developed. The "randomness" design criteria was mentioned on page 22, and the vertical and horizontal randomness and was proven to be an effective design criteria by (Cheng et al., 2006) For each formation, a lower building and a higher building were relocated with one another, which is being classified as vertical randomness. This produced a formation that had two high buildings and two low building on the north and south side of King St. The new formation D can be seen in fig. 52.

<u>Formation D</u>

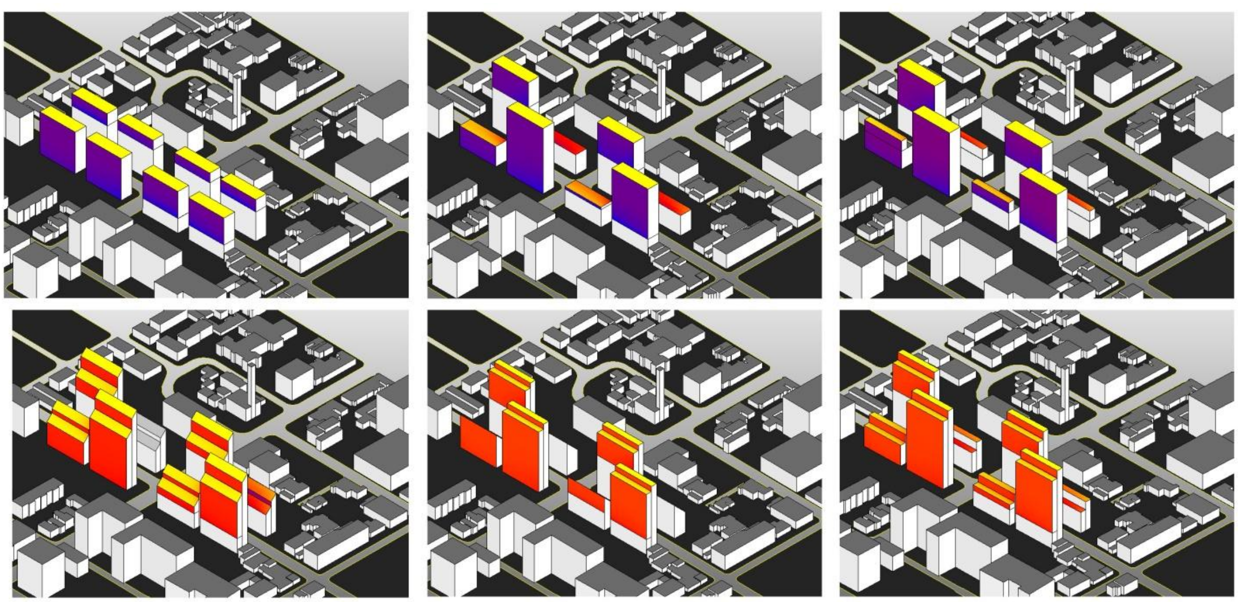


Figure 52: Formation D: (top left) Formation D.1, (top middle) Formation D.2. , (top right) Formation D.3, (bottom left) Formation D.4, (bottom middle) Formation D.5, (bottom right) Formation D.6.

Table 10: Formation D - New Building Formations With Maximum Gross Floor Area (Utilizing Vertical Randomness)

Formation	Insolation Level (kWh/m^2/year) of building envelope area	Gross Floor Area (m^2)	Surface Area (Surfaces >700 kWh/m^2/year) (m^2)	Potential Energy (GWh/Year)
Formation D.1 (Base Case)	820	102,000	16,910	13.86
Formation D.2	801	102,000	18,414	14.75
Formation D.3	802	102,000	17,221	13.81
Formation D.4	933	104,141	18,976	17.7
Formation D.5	802	102,894	16,111	12.92
Formation D.6	813	103,600	19,548	15.9

Formation D (fig. 52) seen slight decreases in energy levels from formation C in all formations except formation D.4, which seen an increase of 3.1 GWh/year. The randomness concept opens up the formations and allows solar radiation to penetrate more surface area, yet in some formations overshadowing now becomes an issue. The higher buildings that are now located on the south side of King. St. are causing large shadows on buildings due north. The reason that formation D.4 seen an increase of energy generation levels is because it is the only formation that has a sloped surface facing south. Since a sloped surface can maximize solar absorption, it is the only surface that can experience some overshadowing yet still generate meaningful amount of energy. The other five formations experience overshadowing on horizontal or vertical surfaces which caused many surfaces to record an insolation level below the benchmark of 700kWh/m^2/year.

Looking a bit deeper into the randomness concept and finding out how these configurations would work in broader context, formation D was duplicated and placed directly behind. All geometric criteria has been doubled to see how it would affect overall energy generation The randomness concept, that was utilized in Formation D, and developed by (Cheng et al., 2006), was again used in new formation E. Fig. 53 displays the new formation E.

Formation E

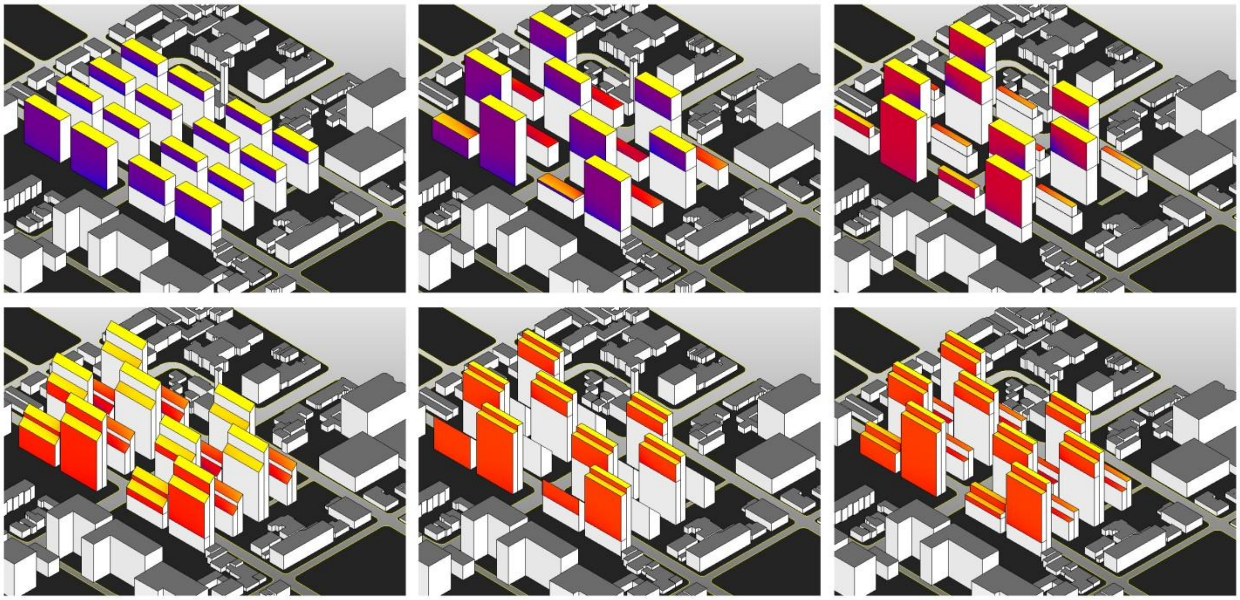


Figure 53: Formation E: (top left) Formation E.1, (top middle) Formation E.2., (top right) Formation E.3, (bottom left) Formation E.4, (bottom middle) Formation E.5, (bottom right) Formation E.6.

Table 11: Formation E - New Building Formations With Maximum Gross Floor Area (Increased Buildings x2)

Formation	Insolation Level (kWh/m²/year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/Year)
Formation E.1	834	204,000	28,252	23.56
Formation E.2	806	204,000	30,228	24.3
Formation E.3	809	204,000	27,538	22.28
Formation E.4	947	208,282	29,390	27.83
Formation E.5	812	205,788	23,670	19.22
Formation E.6	818	207,200	28,950	23.7

By doubling the surface area, it was expected that energy levels would increase by approximately twofold. In all configurations, an approximate increase of energy levels was by a factor of 1.5 from formation D. Formation E.4 is not generating a significant amount of energy compared to all other formations despite utilizing a sloped roof angled directly towards the south. The high pitch of the roof caused much overshadowing of the lower floors in the buildings located directly behind. Although insolation levels peaked in formation E.4, reaching levels of approximately 1378kWh/m²/year, the limited surface area limited the energy generation level significantly.

An attempt to increase energy generation in formation D and E was to use randomness in the vertical direction. The results were disappointing with energy generation levels fluctuating very little from formation C. In the new formation F randomness in the horizontal direction was added to the randomness in the vertical direction. The buildings were randomly scattered in order to fit the existing context (fig. 54) and open up the formation to allow solar radiation to penetrate more surface area. The new formation F can be seen in fig. 55.

Figure 54: (left) Formation with buildings in line. (right) formation with buildings staggered by 25 meters.

Formation F

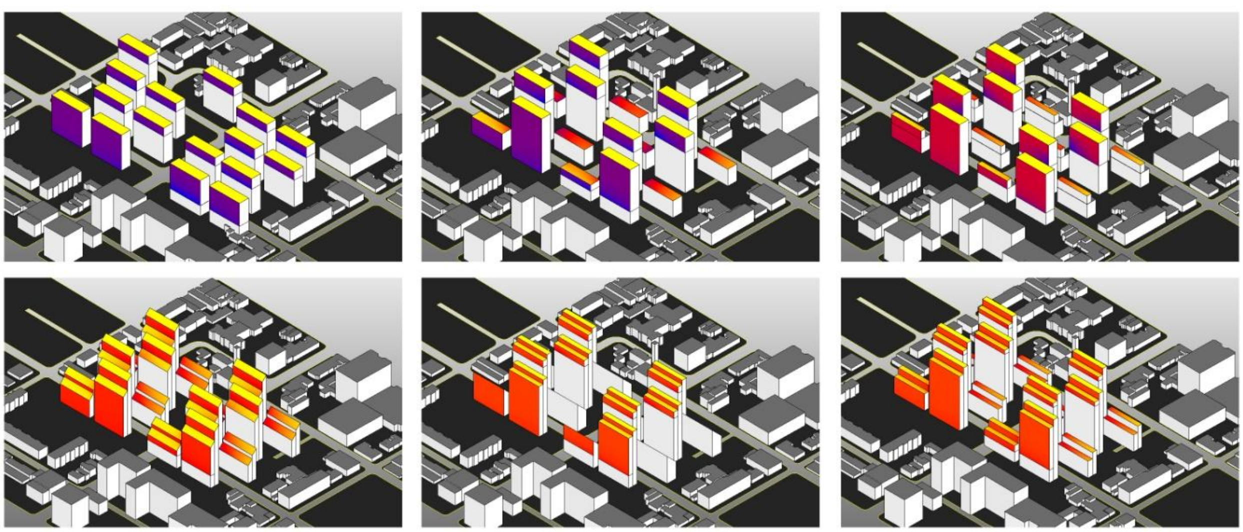


Figure 55: Formation F: (top left) Formation F.1, (top middle) Formation F.2., (top right) Formation F.3, (bottom left) Formation F.4, (bottom middle) Formation F.5, (bottom right) Formation F.6.

Table 12: Formation F - New Building Formations With Maximum Gross Floor Area (Increased Buildings x2) Utilizing Horizontal and Vertical Randomness.

Formation	Insolation Level (kWh/m²/year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/year)
Formation F.1	829	204,000	29,013	24.05
Formation F.2	824	204,000	26,180	21.57
Formation F.3	810	204,000	23,957	19.4
Formation F.4	951	208,282	28,695	27.28
Formation F.5	830	205,788	20,061	16.65
Formation F.6	825	207,200	25,740	21.23

In the majority of the formations above, there was a decrease in energy generation levels. Formation F.4 did see a large increase of 9.47Gwh/year which can be contributed to allowing more solar radiation to penetrate the sloped roofs. The horizontal randomness allowed slightly more solar radiation to reach more surfaces, but only formation F.4 could benefit from this. Since formation F.4 has sloped surfaces, even small amounts of additional solar energy that penetrates these surfaces can be utilized more efficiently than flat or horizontal surfaces. Since all other configurations experienced slightly more insolation on flat or horizontal surfaces, the energy could not be efficiently used and was reflected in the non-increased potential energy generation levels.

For horizontal randomness to be an effective design criteria in this scenario, more land area would be required that can allow the buildings to be further spread apart. The more space that is between each building, the less overshadowing becomes an issue. Since the area of King and Bathurst is an existing context, the movement of buildings was restrictive. Although theoretically the study area could have been expanded, it was decided that the removal of anymore buildings would not represent a real world scenario.

A final formation (formation G) was developed where buildings were rotated in order to open up the formation to allow the solar radiation to penetrate more surface area. The formations geometry, GFA, or slope were not altered, the middle buildings were simply rotated 90° (fig. 56)

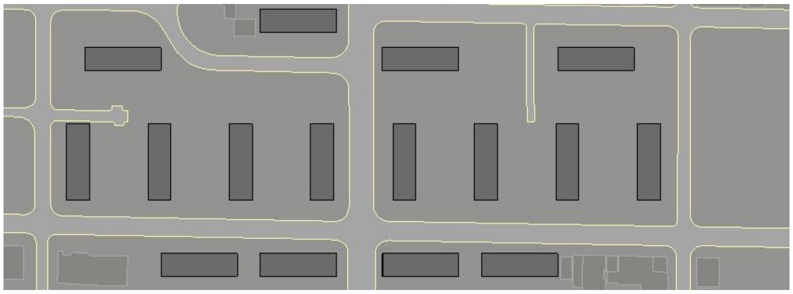


Figure 56: Buildings in the middle two rows were rotated 90°.

Formation G

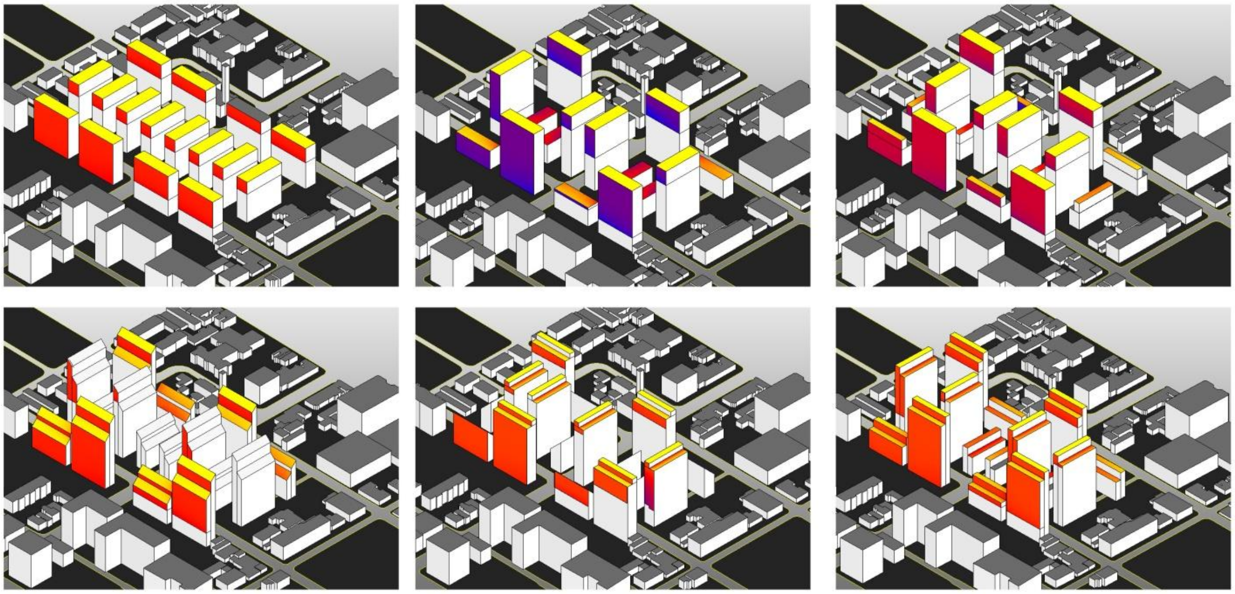


Figure 57: Formation G: (top left) Formation G.1, (top middle) Formation G.2., (top right) Formation G.3, (bottom left) Formation G.4, (bottom middle) Formation G.5, (bottom right) Formation G.6.

Table 13: Formation G: New Building Formations With Maximum Gross Floor Area (Increased Buildings x2) Utilizing Horizontal ,Vertical Randomness, and Rotation

Formation	Insolation Level (kWh/m²/year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/year)
Formation G.1	829	204,000	25,327	21
Formation G.2	776	204,000	25,638	19.93
Formation G.3	765	204,000	23,363	17.87
Formation G.4	791	208,282	20,000	15.82
Formation G.5	788	205,788	21,943	17.29
Formation G.6	723	207,200	24,736	17.88

Energy generation was lower in formation G because of the low surface area facing the south direction. When the buildings were rotated, the large facade that were due south for all of the other formations are now facing east and in some cases reducing the surface area by 50%. It is surprising that the decrease in surface area in formation G still generated comparable energy levels to formations E and F. By rotating the interior buildings, the formation opened up by allowing solar radiation to penetrate surfaces with higher intensity which leads to the comparable energy generation levels.

To determine the effectiveness of rotating the interior buildings, the south facades of the most northerly situated buildings were analyzed for comparison (fig. 58). The formation with the straightly orientated buildings (formation E.1) received an energy generation level of 5.6GWh/year, where the formation with the rotated buildings (formation G.1) received an energy generation level of 6.25GWh/year. A significant difference of 0.65 GWh/year (or enough energy to completely satisfy 43 apartment units) clearly displays that rearranging building orientation to open up the formation can contribute to utilizing solar energy more efficiently.

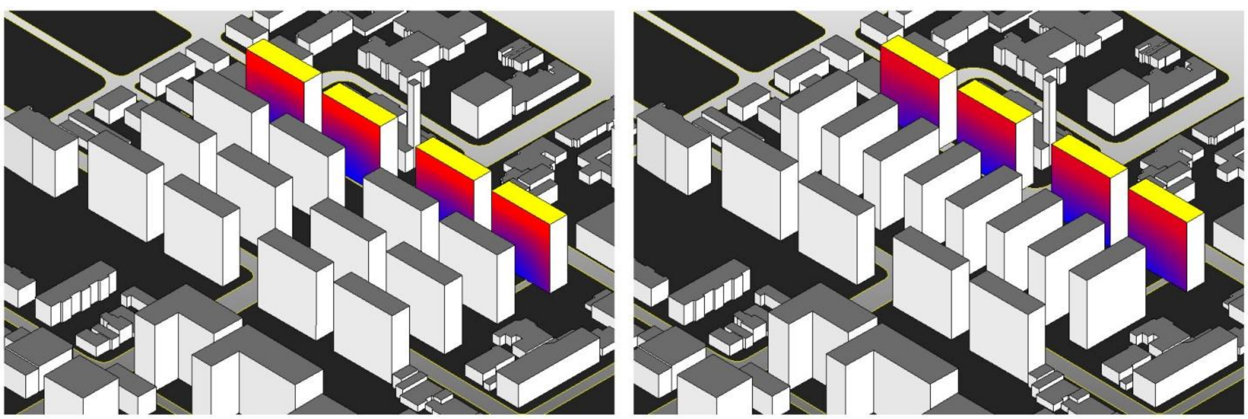


Figure 58: (left, formation E.1) building formation using similar buildings. (right, formation G.1) building formation with center buildings rotated 90°.

Community Scale Energy Generation

All of the simulation for formation A-G were completed by using separate buildings and adjusting the geometry, slope, randomness, and rotation. Although there are preferable formations, there were few formations that distinctively provided a higher energy generation value compared to the rest. The fluctuation between simulations was not as high expected when undertaking this research and therefore a more unique formation was approached to increase the energy generation levels.

When an urban formation is developed of individual buildings there is no way to resolve the issue of overshadowing. The sun is constantly changing course throughout the year and inevitably overshadowing will occur at some point restricting the utilization of solar energy for the purpose of energy generation. To minimize overshadowing on adjacent facades, a single building was developed that depict formations A-G that are simulated throughout this section. Fig. 59 displays three buildings that are designed which possess similar characteristics to the base case (fig. 49).

Formation H

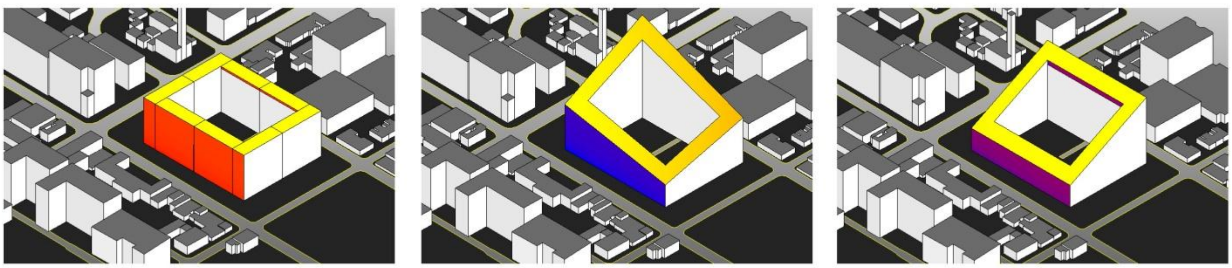


Figure 59: Formation H: (left) Formation H.1, (middle) Formation H.2., (right) Formation H.3.

The six buildings of the base case (fig.49) were rearranged to form a single building. The parameters of the base case (height, width, and length) are identical to formation H.1 with a GFA of 102,000m^2. Using formation H.1 as a template, formation H.2 was developed by increasing the northwest corner of the building to 75 meters and the southeast corner of the building was reduced by a factor of two (25 meters). Formation H.2 was also inspired by the residential solar block (RSB) (Okeil, 2010) which was mentioned in the literature review (fig. 21). The RSB was specifically designed so that shadows would fall in open space and not on building facade. The study by (Okeil, 2010) was designed in a theoretical environment, whereas formation H.2 is being placed on a built environment which means that overshadowing will occur on some building facades.

Formation H.3 is another alteration of formation H.1 and also maintained the GFA of the base case of 102,000m^2. The north facade was stretched so the building is 75 meters high and the south edge of the building is 25 meters. The results of the new formation H are shown in table 14.

Table 14: Formation H - New Building Formations Utilizing Larger Buildings

Formation	Insolation Level ($kWh/m^2/Year$) of building envelope area	Gross Floor Area (m^2)	Surface Area (Surfaces >700 $kWh/m^2/year$) (m^2)	Potential Energy (GWh/Year)
Formation H.1	860	102,000	13,000	11.18
Formation H.2	1327	115,210	11,850	15.72
Formation H.3	1208	101,486	10,708	12.94

Formations H.2 and H.3 recorded very high insolation levels but an overall energy generation level that was not as high as some of the single building formations. The reason for the lower energy generation and the high average insolation level was the decreased surface area. The roof area remained the same, but the usable facade surface area was drastically decreased due to the formation of the box. Not having as much wall surface are due south reduced the available area for solar installations ultimately lowering energy generation values.

Similar to formations E,F, and G where the building area was doubled to investigate the energy generation on a larger scale, formation I provides two box formations possessing similar parameters in terms of GFA ($204,000m^2$). The duplicated box formations were placed within a city block to investigate if overshadowing becomes an issue and how it would affect energy generation potential.

<u>Formation I</u>

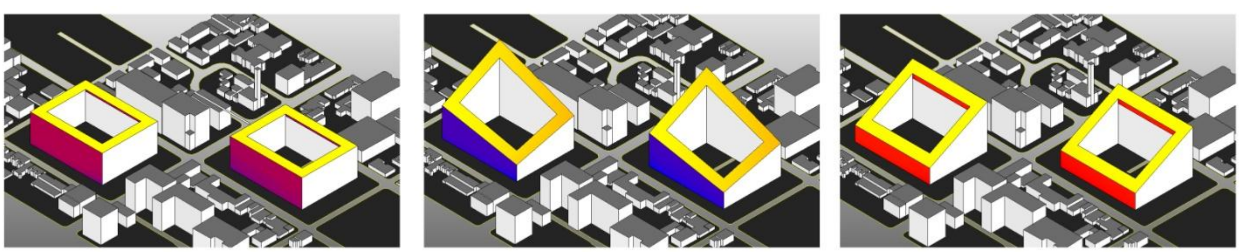


Figure 60: Formation I: (left) Formation I.1, (middle) Formation I.2., (right) Formation I.3

Table 15: Formation I - New Building Formations Utilizing Larger Buildings (Increased x2)

Formation	Insolation Level ($kWh/m^2/Year$) of building envelope area	Gross Floor Area (m^2)	Surface Area (Surfaces >700 $kWh/m^2/year$) (m^2)	Potential Energy (GWh/Year)
Formation I.1	862	204,000	26,000	22.41
Formation I.2	1324	230,420	23,700	31.4
Formation I.3	1208	202,972	21,416	25.87

Formation I.1 and I.2 provide more energy than any other formation. Formation I.2 can provide 31.4GWh/m^2 which is 3.57GWh/m^2 higher than the closest single building formation with a GFA of 204,000m^2 (formation E.4). Although the roof surface in formation I.2 is sloped towards the southeast and the roof in formation I.3 is sloped directly south there is still a much higher energy generation level in formation I.2. This occurred because of the increased facade surface area that was created by extending the northwest corner of the building higher. This facade area experiences an unobstructed view towards the south which allowed maximum levels of solar absorption and increasing the overall energy generation.

As mentioned earlier, and similar to the single building formations, there will be overshadowing directly north of the building since the north wall is now reaching heights of approximately 75 meters. The difference between the box formations and the single building formations is the amount of land necessary to construct these buildings. The amount of land needed to construct the 16 single buildings of formation F.1 is 39,000m^2 whereas the amount of land necessary to construct the two box formations is 26,000m^2. This means the population density can be achieved on less amount of land. This allows the box formations to be spread further apart than the single building formations and if planned accordingly, overshadowing can be minimized. The higher density permitted formation I to be constructed on opposing corners of the intersection where this was not possible with the single building formation.

To investigate overshadowing that will occur if the box formation is placed in multiple locations, formation J was developed (fig. 61). Formation J mimics the box formation H.2 and H.3 since they were the formations that generated the most energy. The formation was copied four times and placed on each side of the intersection at King St. W and Bathurst St.

Formation J

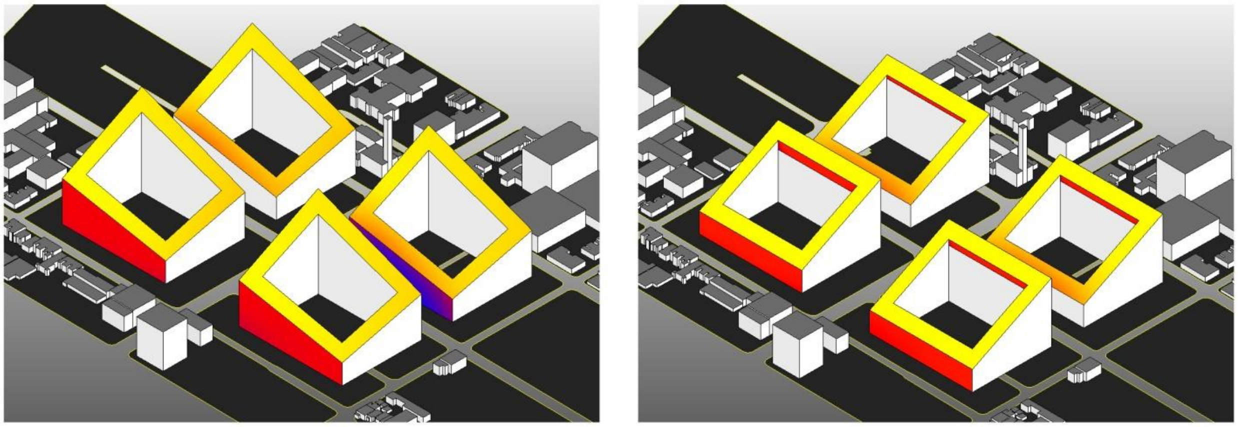


Figure 61: Formation J: (left) Formation J.1., (right) Formation J.2.

Table 16: Formation J - New Building Formations Utilizing Larger Buildings (Increased x2)

Formation	Insolation Level (kWh/m²/Year) of building envelope area	Gross Floor Area (m²)	Surface Area (Surfaces >700 kWh/m²/year) (m²)	Potential Energy (GWh/Year)
Formation J.1	1323	460,840	41,848	55.44
Formation J.2	1200	405,944	39,972	47.9

Formation J.1 was a duplication of formation H.2 and seen a 76% increase in energy generation. Formation J.2 is a duplicate of formation H.3 and experienced an energy generation increase of 54% from formation H.3. The box formations can generate more energy due to the less overshadowing that occurs when compared to the single building formations.

Shadow Studies

A shadow study is presented in fig. 62, fig. 63, and fig. 64 for formations F.1, J.1, and J.2. The image on the left is the shadow range experienced for the entire day on the summer solstice and the image on the right is a shadow range experienced on the winter solstice.

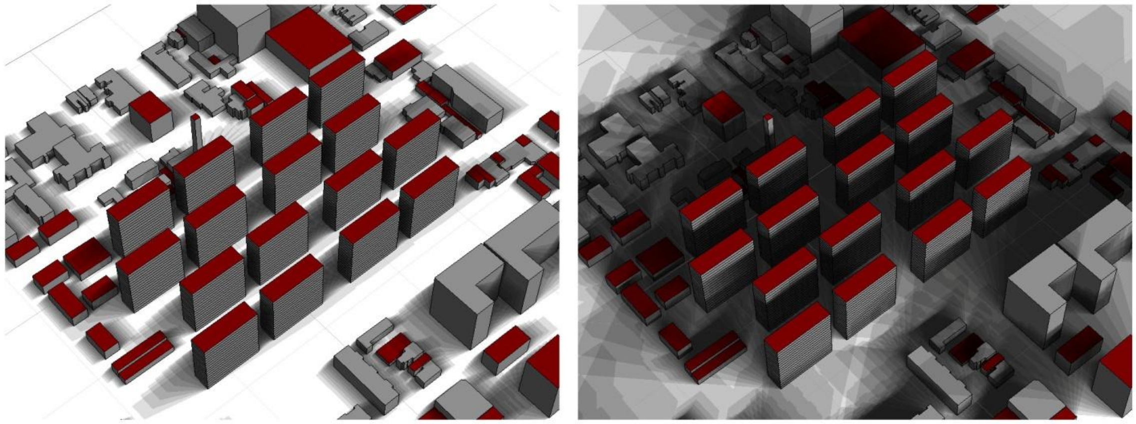


Figure 62: Formation F.1 shadow study. (left) Shadow range on summer solstice, (right) Shadow range on winter solstice.

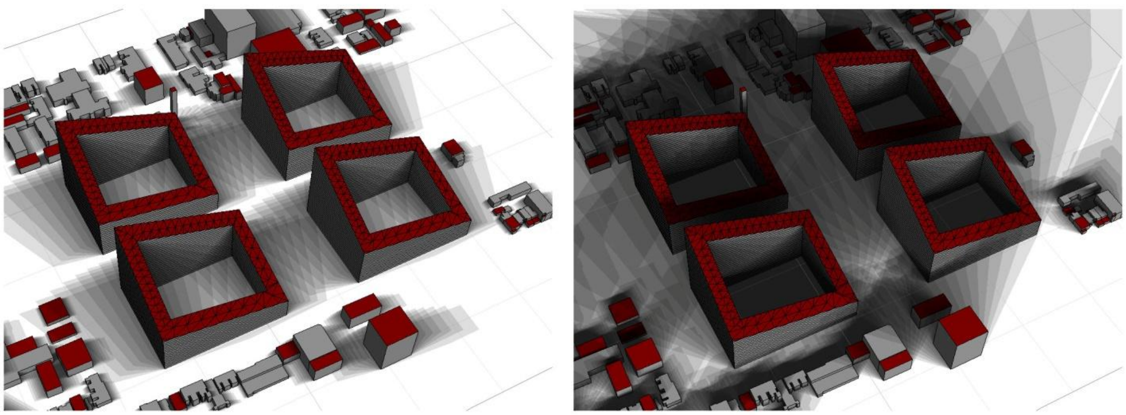


Figure 63: Formation J.1 shadow study. (left) Shadow range on summer solstice, (right) Shadow range on winter solstice.

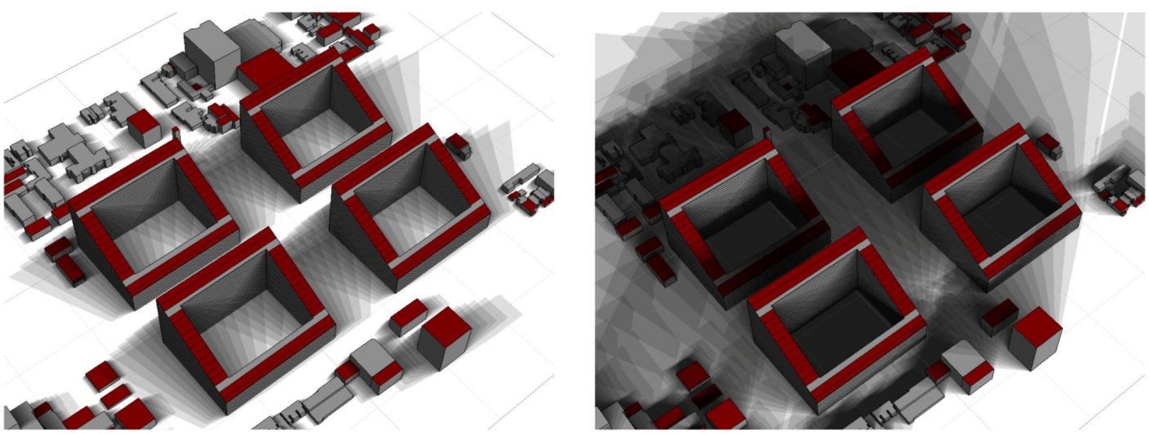


Figure 64: Formation J.2 shadow study. (left) Shadow range on summer solstice, (right) Shadow range on winter solstice.

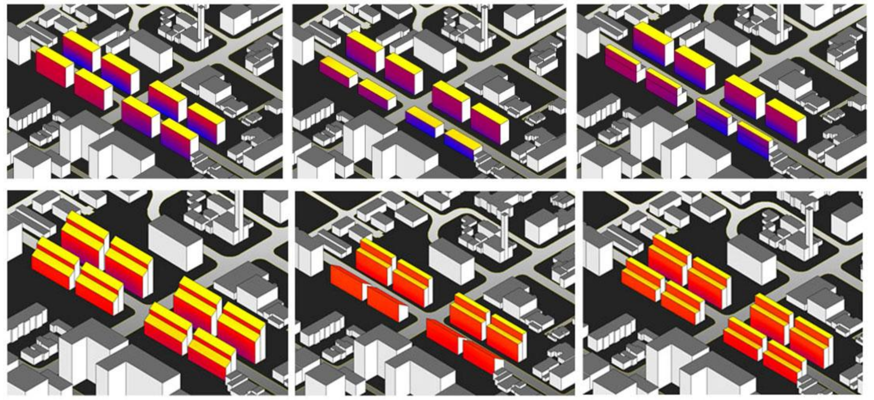
During the summer solstice, overshadowing is not an issue in the single building formation where much of the roof and south facade see much unobstructed solar radiation. But, during the winter overshadowing becomes a major issue as nearly all south facade surface area is overshadowed.

Conversely, the box formations see some overshadowing in the summer and some overshadowing in the winter. The difference is that the overshadowing is less intense and permits the solar absorption on surface area to accumulate constantly throughout the year. This yearly accumulation, which is much more evident in the box formation, is important since energy generation levels that are being recorded for this research are taken annually. Being able to accumulate large amounts of solar radiation during the summer months is good, but not difficult to achieve, and issues of energy storage arise. Recording steady insolation levels all year round is the goal since solar radiation is desired more in the winter than the summer.

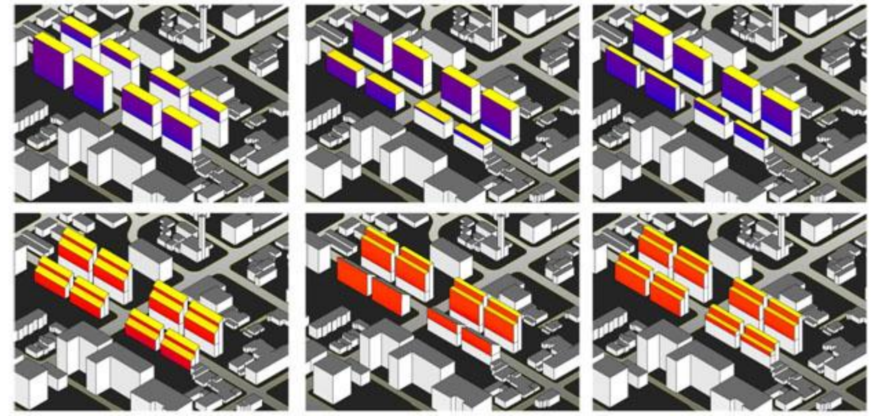
Building Formations Analysis

Due to the large number of formations developed through this section, a summary sheet of formations has been presented on the following page. This page provides each proposed formation along with the figure number. Following on page 84 is a summary table (Table 17) with each formation and the potential energy generation.

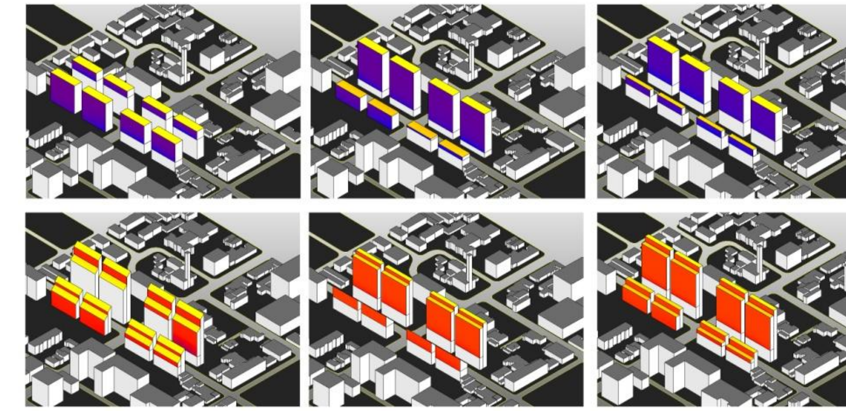
SUMMARY OF BUILDING FORMATIONS



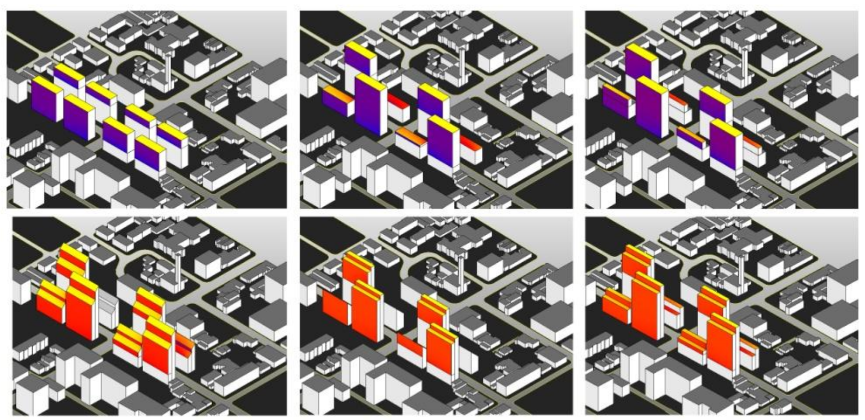
Formation A
Figure 48



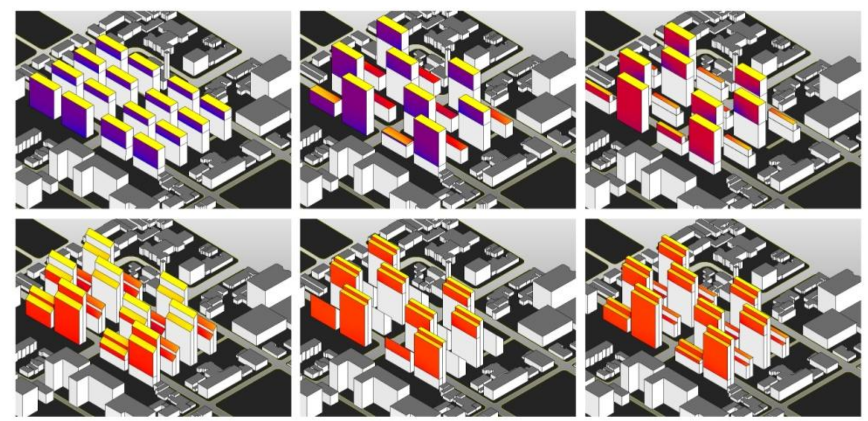
Formation B
Figure 50



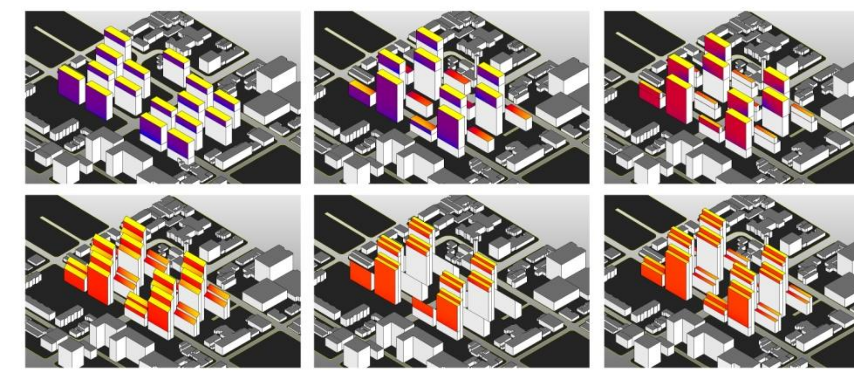
Formation C
Figure 51



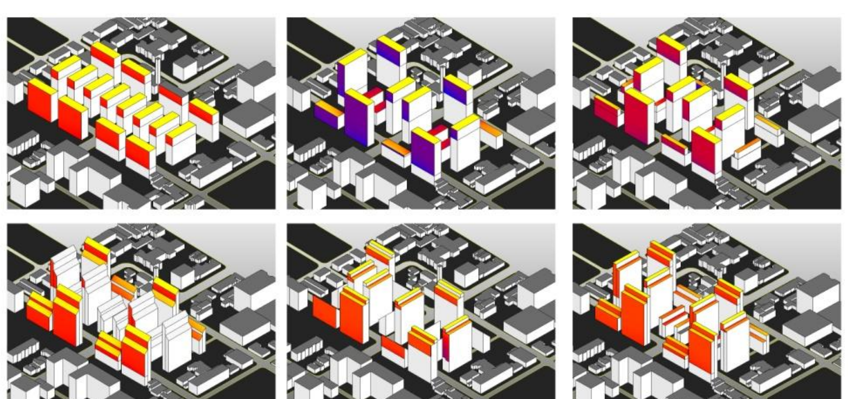
Formation D
Figure 52



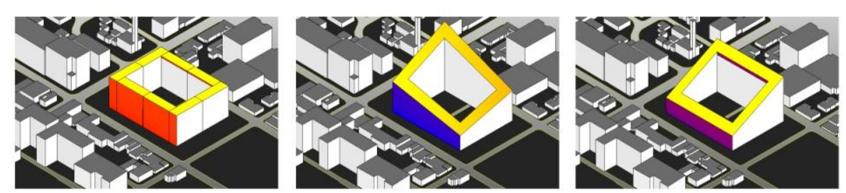
Formation E
Figure 53



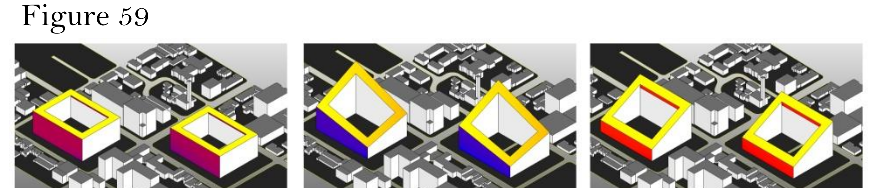
Formation F
Figure 55



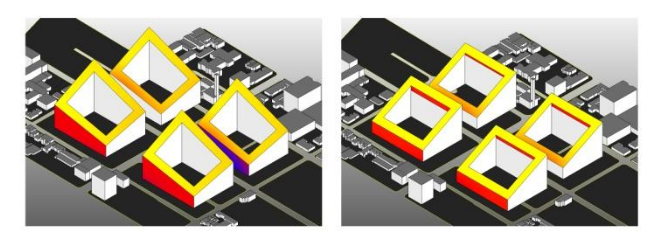
Formation G
Figure 57



Formation H
Figure 59



Formation I
Figure 60



Formation J
Figure 61

Table 17: Summary of Formations

Formation	Potential Energy (GWh/year)	Formation	Potential Energy (GWh/year)	Formation	Potential Energy (GWh/year)
Preliminary Building Formation		Duplicated Single Building Formation (204,000m²)		Box Formation	
Formation A.1	10.52	Formation E.1	23.56	Formation H.1	11.18
Formation A.2	10.74	Formation E.2	24.3	Formation H.2	15.72
Formation A.3	10.11	Formation E.3	22.28	Formation H.3	12.94
Formation A.4	11.63	Formation E.4	27.83	Formation I.1	22.41
Formation A.5	9.36	Formation E.5	19.22	Formation I.2	31.4
Formation A.6	11.6	Formation E.6	23.7	Formation I.3	25.87
Formation B.1	13.87	Formation F.1	24.05	Formation J.1	55.44
Formation B.2	13.73	Formation F.2	21.57	Formation J.2	47.9
Formation B.3	13.12	Formation F.3	19.4		
Formation B.4	13.91	Formation F.4	27.28		
Formation B.5	11.85	Formation F.5	16.65		
Formation B.6	13.83	Formation F.6	21.23		
Single Building Formations (102,000m²)		Formation G.1	21		
		Formation G.2	19.93		
Formation C.1	13.86	Formation G.3	17.87		
Formation C.2	17.9	Formation G.4	15.82		
Formation C.3	16.58	Formation G.5	17.29		
Formation C.4	14.6	Formation G.6	17.88		
Formation C.5	16.05				
Formation C.6	19.52				
Formation D.1	13.86				
Formation D.2	14.75				
Formation D.3	13.81				
Formation D.4	17.7				
Formation D.5	12.92				
Formation D.6	15.9				

The simulation process displayed which building formations are preferable for the integration of solar strategies. Multiple formations were developed with varying geometry, height, rotation, and horizontal and vertical randomness. The building formations that consisted of six single buildings seen fluctuations of energy generation levels, but there was rarely a formation which received drastically higher energy generation than others. Not until the box formations were developed that energy generation levels began to increase.

In fig. 65, formations C and D which maximized zoning limitations were compared. The yellow line depicts the formations with the four lower buildings on the south and four higher buildings on the north (formation C, fig. 51), where the red line depicts the vertical randomness with high and low buildings on both the north and south side (formation D, fig. 52). Each formation follows a similar potential energy generation pattern, other than configuration #4 which utilizes the sloped roof. Configuration #4 seen much higher energy levels in the randomness formation, than in the straight formation. The randomness allows the solar radiation to penetrate more surfaces by opening up the building layout, whereas the straight formation overshadows much of the lower part of the building due north.

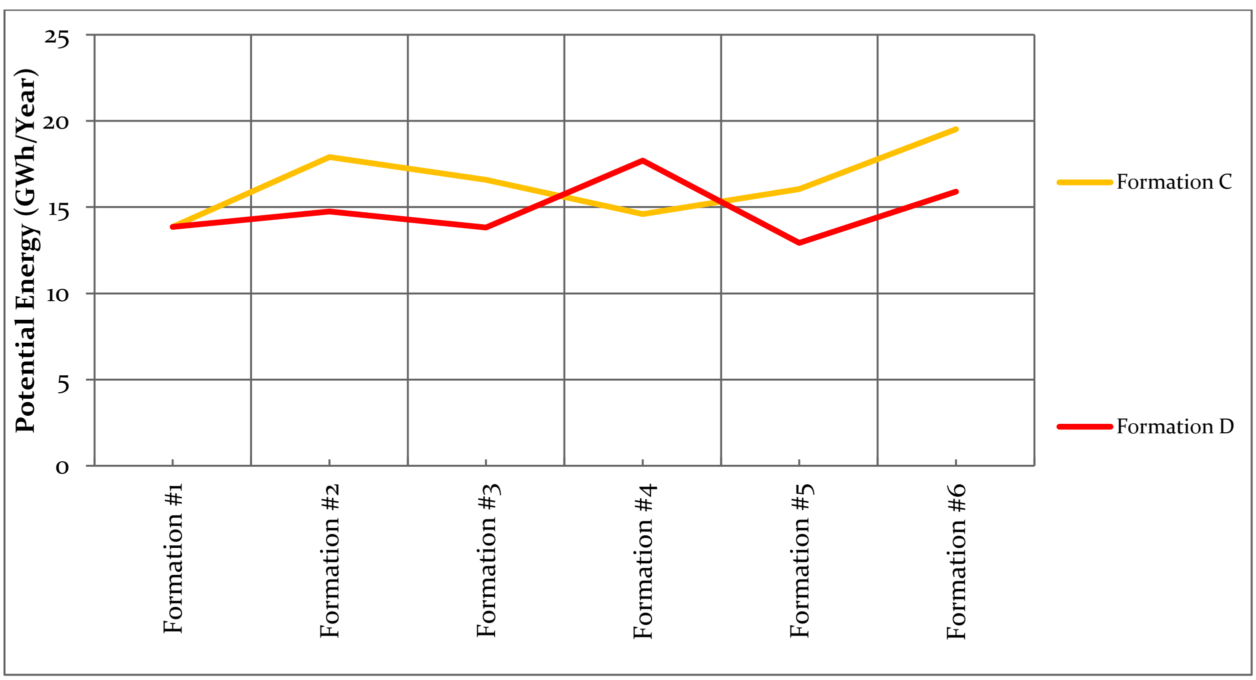


Figure 65: Energy potential for formations with 102,000m² GFA (maximum zoning height allowance) (Formations C and D)

A shadow study shown in fig. 66 clearly displays the overshadowing that is occurring. In the formation that has the smaller buildings in front (fig. 66 left), there is heavy overshadowing on the lower 50% of the building due north, rendering them useless for solar installations. When the buildings are alternated (fig. 66 right), this allows the full south facade of the higher buildings to receive maximum amounts solar radiation.

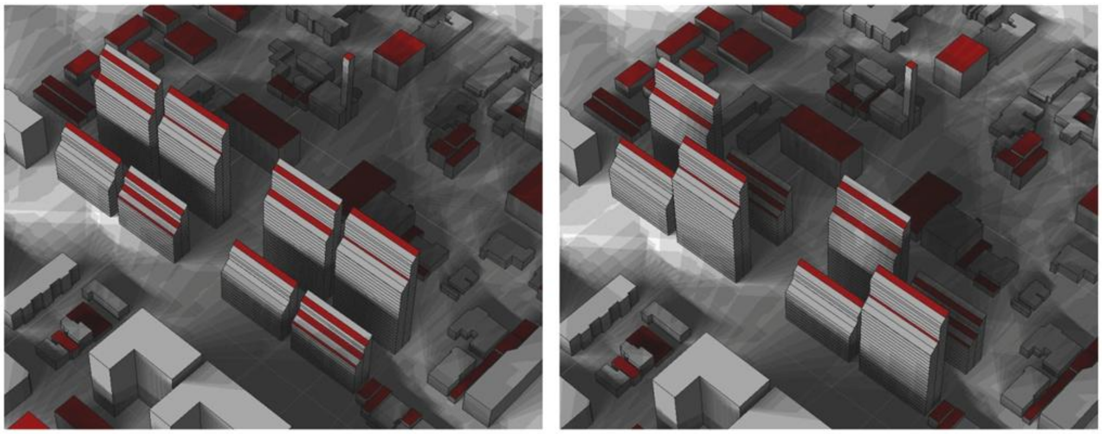


Figure 66: (left) shadow study of formation C.4, (right) shadow study of formation D.4.

Other than formation D.4, the straight formation generated more energy than the randomness formation. The randomness formation created much overshadowing over the smaller buildings due north (fig. 67), in many cases it provided an insolation level on surfaces not over the bench mark value 700kWh/m²/year on roofs and south facades. This resulted in a building that is rendered useless in terms of utilizing solar energy for the purpose of energy generation. More land area would have been beneficial for the randomness concept. The tight restrictions of the built environment did not permit enough separation between the buildings.

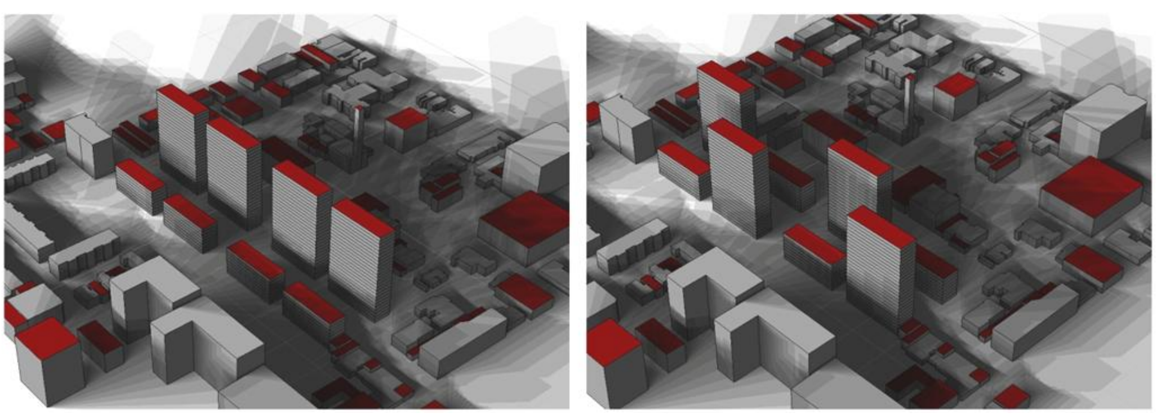


Figure 67: (left) shadow study of formation B.2, (right) shadow study of formation C.2.

Fig. 68 displays the potential energy generation for formations with 204,000m² GFA or higher. The box formation exceeded the energy generation than either of the single building formations. This increase in energy generation can be directly related to the minimal overshadowing that is occurring in the box formations as well as the greater surface area of the roof. The slope of the roof on the box formations produces unobstructed solar access which allows maximum absorption of solar energy. For most of the box formations, less surfaces area was necessary to achieve a higher energy generation level.

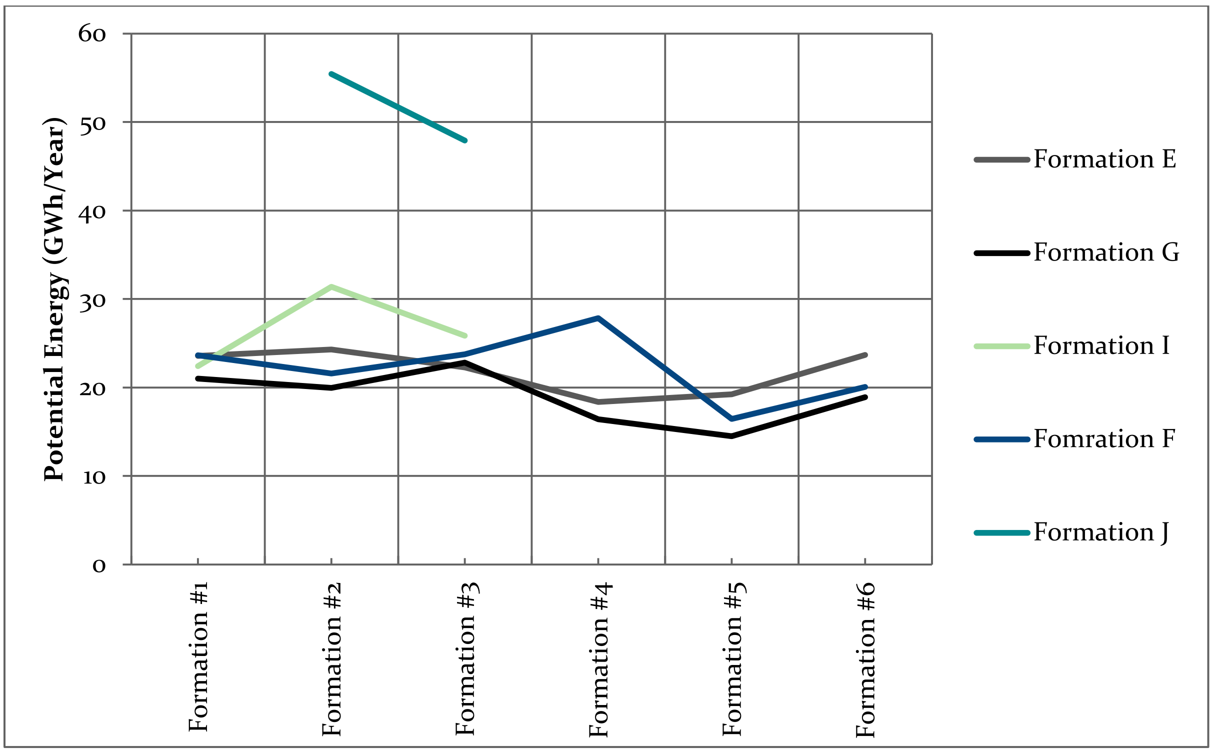


Figure 68: Energy potential for formations with 204,000m² GFA or greater. (Formations E,FG,I,J).

Fig. 69 displays the simulation results for all proposed formations. Generally, there was a similar pattern for the single building formations, with only few formations not following. This graph is included as a general overview of all formations and is not being used for analysis since many of the formations offer very different GFA. For example, formation A.2 offers only 13,000m² GFA where formation I offers 204,000m² GFA.

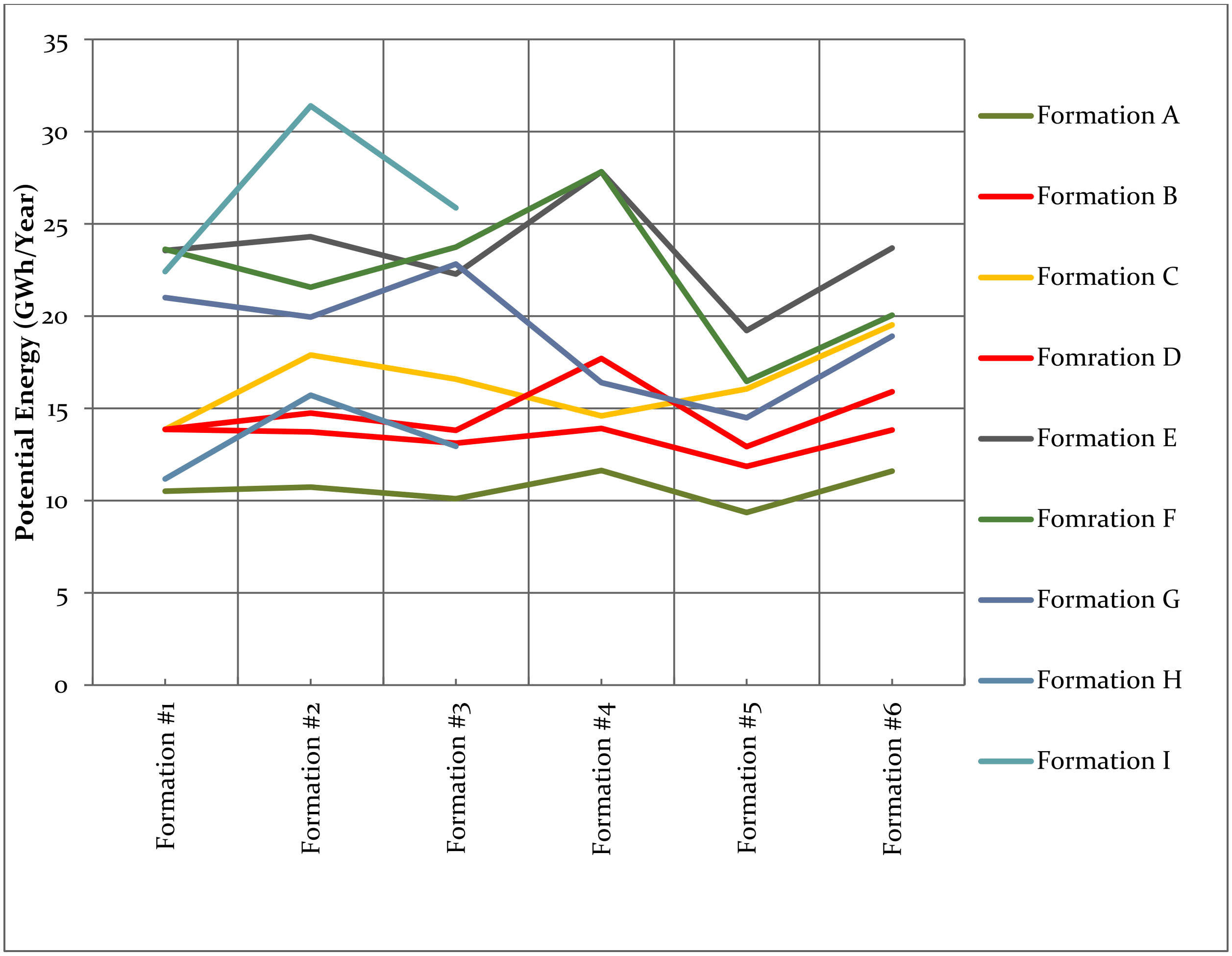


Figure 69: Energy potential for all formations.

For an accurate analysis of the proposed formation, fig.70 displays all morphologies with a GFA equal to, or higher than the base case (102,000m²). Single building formations C and D have a GFA of 102,000m² and are shown in red. Single building formations E, F, and G, have a GFA of 204,000m² and are shown in black. Box formations H and I have a GFA of 204,000m² and is shown in green. Box formation J has a GFA of 408,000m² and is shown in blue.

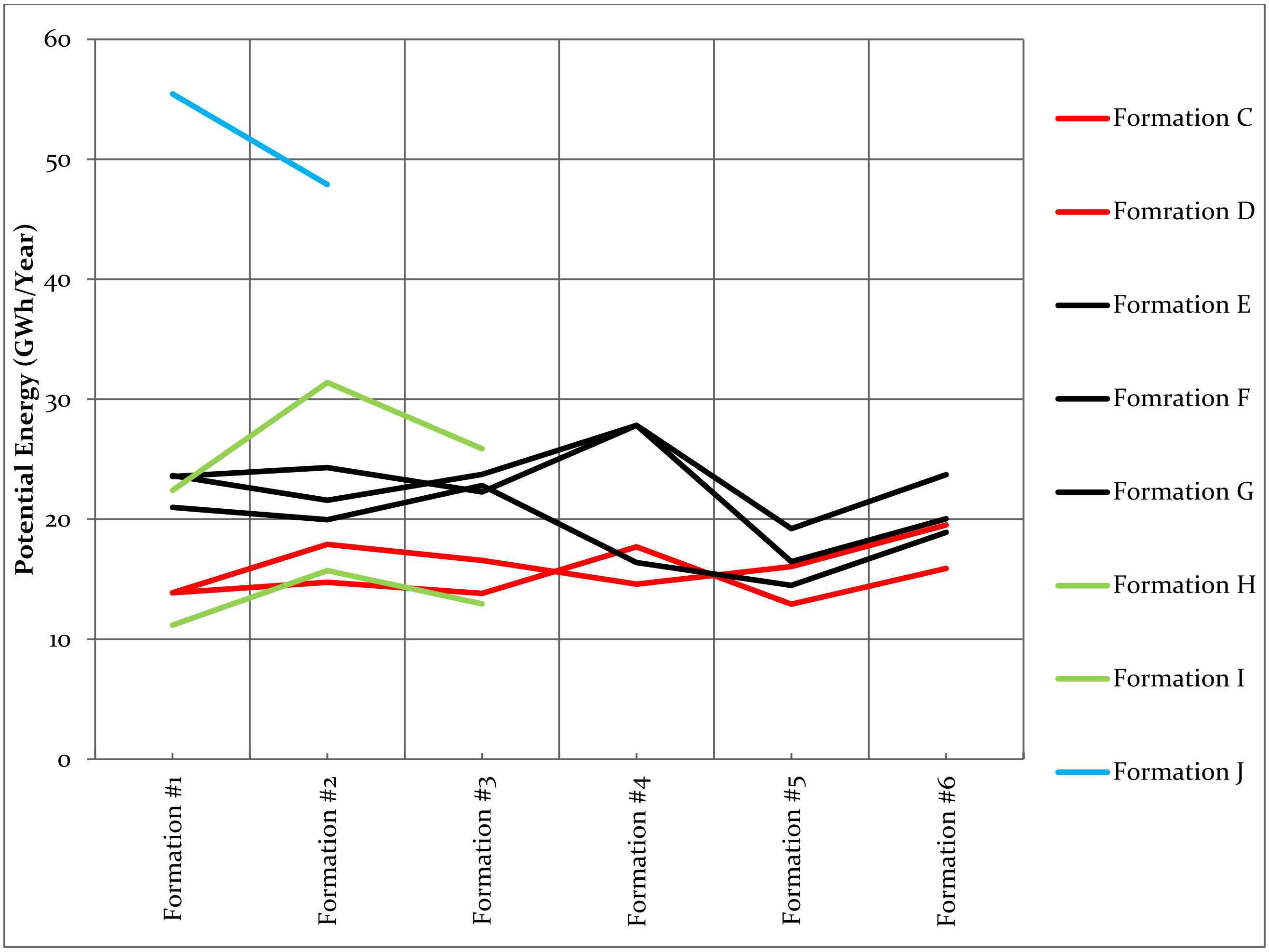


Figure 70: Energy potential for formations which have a GFA of 102,000m², 204,000m², or 408,000m².

When comparing formations with a GFA of 102,000m², the box formation of the same GFA does not stand out from the single building formations. But, when comparing the box formations with 204,000m² GFA to the single building formation with a GFA of 204,000m² there is a large increase in potential energy generation. This means that as more single buildings were added to the site, potential energy generation does not necessarily increase. When box formation buildings were added to the site, the potential solar energy generation increased.

In most cases, as more single buildings were added the potential energy generation decreased because overshadowing is more prevalent rendering much of the surfaces useless to generate energy. When more box formations were added, overshadowing is less of an issue because the box formations were capable of being spread out further since it took less land area to match the required GFA of the single building formations.

Urban Design Suggestions

Through the insolation simulations of the existing built environment and preliminary simulations it has already been determined that the currently built environment of Toronto is well suited to harvest solar energy. With the built environment of Toronto not optimized to accommodate solar installations it becomes an increasingly difficult challenge to begin implementing solar ready communities into this area.

Although south facing facades will receives peak amounts of solar radiation, the facades that are 30°± south will experience an approximately 12% less insolation level (Canada Mortgage and Housing Corporation, n.d.) . This allows flexibility within an existing built environment for designers to incorporate solar strategies. It can be difficult to incorporate solar strategies into existing environments due to infrastructure that was not designed to provide solar access to surrounding buildings. It is these very areas that are commonly being rebuilt and it is at this time that they must be grandfathered in to allow solar access to surrounding buildings in order to utilize solar energy in the future.

Building upon the concept of solar access are some design criteria which must also be considered when designing environmentally responsible structures. Four points stated by (Droege, 2008) , in order to develop a low energy urban area are:

1. The urban structure must optimize energy efficiency,
2. Minimal energy demand of the buildings,
3. The energy supply system must be efficient (i.e. minimal transmission loss),
4. Share renewable energy sources.

Each four of the points mentioned can be utilized in the city of Toronto in establishing new zoning ordinances. Criteria number one states that the building must optimize energy which coincides with criteria number three to minimize transmission loss. Solar energy is delivered directly to a building which minimizes energy transmission. Conventional electricity is generated at a site located kilometers away from the end use where transmissions losses can be contributed to old and often inefficient power cables.

Criteria number 4 states that renewable energy should be shared. Sharing energy does not necessarily mean that buildings must somehow be physically connected to one another by cables in which electricity can flow between the two buildings. Sharing renewable energy sources is exactly the intent of this thesis. Although, it is important to maximize solar energy potential on a single building, it is more important to ensure solar access to all buildings in a community so they too can utilize solar energy.

During the early design phases of buildings architects and planners must consider long term effects of the buildings and surroundings. A building owner or developer may not want to incorporate solar strategies at the time of construction but may be desirable decades later. This concept is widely referred to as being "solar ready". Solar ready can be defined as providing surfaces of the building being sloped or orientated towards the sun to maximize solar absorption or it can mean installing components such as cabling or piping so that active solar systems can be easily installed on the facades with minimal disturbance to the occupants.

A concept that is common in the construction industry are incentives. If a developer is planning to include some type of public space, such as a plaza or park, that benefits the general public they are than sometimes permitted to break zoning ordinances in that particular development. It is a reward for offering something to the public where in return a developer may be permitted to build higher or wider to increase profitable GFA. This type of incentive can become useful in developing communities to be solar ready.

This concept was used to develop formation C (fig. 51) where the buildings on the south side of the street were lowered in height and the buildings on the north side of the street were raised. The maximum building height in this area is 50 meters, but the south building is only 20 meters and the north building is 80 meters. This exchange of building area satisfies the maximum GFA, since no floor area was lost, and permits higher energy generation levels, which is exemplified in formation C.2 (fig. 51), where an additional 4.04 GWh/year was generated.

The box formation is an urban development which can offer many positive aspects to a community. The primary goal is energy generation, and solar energy can be exploited the best with the box formations H and I (fig. 59, fig. 60). The large formations also contribute large amounts of GFA so developers and building owners will not sacrifice rentable floor area. The box formations also provide a higher population density per the amount of land area necessary for construction. This means that more people can work or live in buildings that take up less land which can then be used for communal space such as parks or urban farming. The center of these of formations can also offer large amounts of green space which can also be utilized as parks or urban farming.

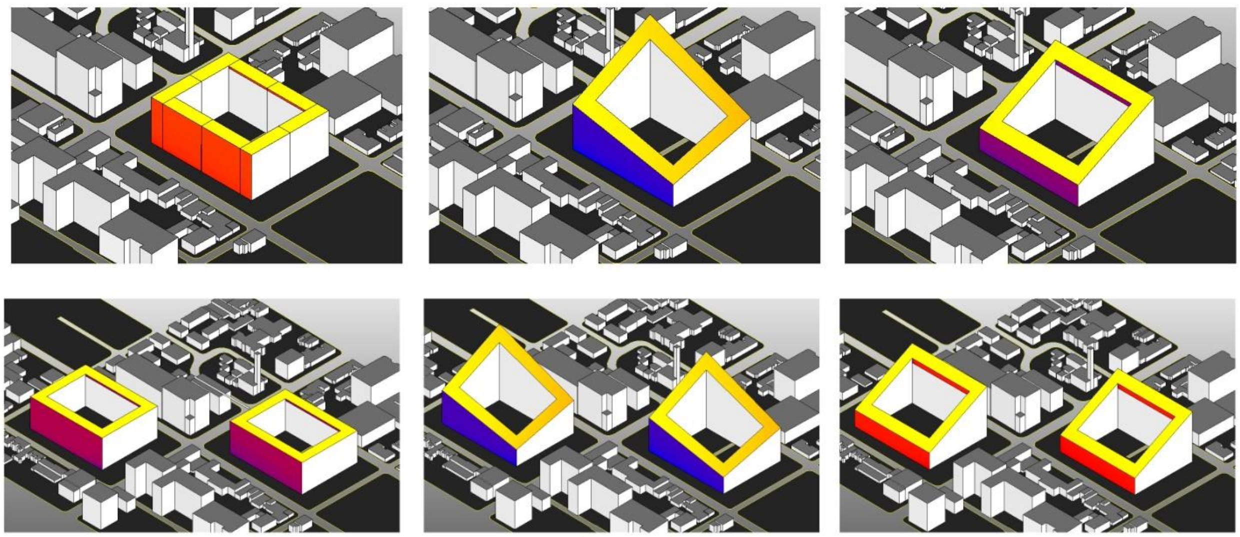


Figure 71: (above) formation H (below) formation I.

It is within the context of urban design regulations where major improvements can be made to enhance the implementation of solar energy into a built environment. Zoning regulations and limitations must be established to guide and assist designers rather than restrict them. Lenience with zoning can also be detrimental to solar design. As mentioned by (Eisenstadt, 1982) (on page 21), zoning provisions may cause overshadowing on past solar installations. Zoning and building code regulations cannot be a fixed set of documents. Each major alteration to a morphology must be investigated independently to see what type of affects it will have on existing buildings, newly constructed buildings, and future development.

CHAPTER 5

Conclusions

The results from this study display that the current built environment of Toronto is not optimized for buildings to fully take advantage of solar energy for the generation of electricity or hot water. There is always the opportunity for solar installations on the rooftops of higher buildings to utilize solar energy, but an overall solar simulation depicts that the built environment is not providing enough radiation to consider solar energy as a contributing source of energy.

The opportunity that the City of Toronto has, lies in the zoning ordinances and the development of the future built environment. Formations must be implemented similar to that of the formations developed in the "Urban Configuration Development" section. Architectural individuality and quality urban design is of uncompromising importance and should not be alternated in any form. If buildings are simply designed within the restrictions of the developed formations, similar to the solar envelope concept (fig. 11 & fig. 12), than designers are free to design within those limits. It is not an intention of the author to add another restriction to the designers, but instead provide design guidelines to enhance solar energy collection. The City of Toronto must also implement a zoning by-law system which allows incentives for the purpose of utilizing solar energy. If building heights exceeds zoning ordinances in an attempt to increase solar energy generation, an incentive or zoning by-law must be considered.

This research developed an in depth methodology as to how approach analyzing facades of buildings in built environments. Conceptually developed urban configurations have been proposed in order to ensure the methodology that was developed is functional. The methodology can be used by future students or researchers to further develop urban configurations which integrate solar strategies. The methodology can be adaptable to any location ensuring that weather files are used that are correct, and insolation results are compared to reliable sources such as solar data from the Natural Resources of Canada database.

The methodology that was undertaken in this study determined that the task of evaluating insolation levels in built environments, and proposing new building formations is a laborious and repetitive task that must be addressed in the development of future simulation software. Much of this research was spent experimenting with new software and developing an accurate method to transfer digital models from drafting software to energy simulation software. Even when this goal was accomplished, critical data was lost through the import/export process that compromised the accuracy of simulation results. For this reason all simulation results had to be reviewed and analyzed critically to ensure accurate analysis can be achieved.

The software does not function well with large models such as city blocks used for this research, and often results cannot be achieved. Many errors and freezing of the software leads to the conclusion that simulation software is intended for single building scales. This study shows that solar energy can be exploited more efficiently on a community scale, and unless architects and urban planners are given proper tools to utilize during the design phase, it is not practical to expect changes that are necessary to alter the way our communities utilize energy. It seems unrealistic that a similar methodology could be satisfactory in a real world scenario since so much time was wasted completing repetitive tasks and attempting to solve program errors and incompatibility between simulation and drafting software.

The proposed building formations in this study will not provide enough energy to completely satisfy the energy demand but can facilitate conventional sources of energy. In Canada, commercial/institutional buildings consume an average of 277kWh/m^2/year (Natural Resources Canada, 2012) which is among the highest in the world (City of Toronto, 2007). The box formation (formation J) has a GFA of 204,000m^2 and will have an energy generation level of approximately 56.51 GWh/year. If PV panels were installed to completely cover the surfaces that recorded an insolation value of 700kWh/m^2/year or higher, a total of 8.47GWh/year could be generated. This results in approximately 15% of the buildings overall energy demand could be compensated by solar energy. Although 15% seems low, it is a positive step towards relieving the reliance of non-renewable energy sources. Canadians must also become aware of the way we consume energy. If our buildings are designed to have higher thermal values, better air tightness, use energy efficient appliances, and occupants turn off lights and appliances when not in use than solar energy can be utilized to produce much more than only 15% of the overall energy demand.

It was determined that increasing building surface area to the south was just as important as providing solar access to buildings due north. In many of the single building formations, configuration #4 (sloped roof) did not see increased levels of potential energy generation. This was because the tall sloped roof caused overshadowing of the south facade of the building that was located directly north. Allowing all building surfaces to absorb solar radiation is a design principle that must be considered in new developments. Solar urban design is not solely about maximizing insolation levels on a single building, but providing adequate amounts of insolation to surrounding buildings.

Improvements are imminent in our built environment to satisfy at least a portion of overall energy demand with solar energy. Simple adjustments to the geometry, sloping of facades, or strategically organizing buildings can contribute to capturing the infinite and free sources of solar energy for the use of electricity or hot water. Although it is a huge endeavour to develop a built environment that acknowledges solar energy as a contributing factor to a cities energy needs, it is one that cannot be ignored. Cities are top energy consumers, are continually growing, and more energy will be necessary to satisfy energy demand. To decrease our reliance on conventional energy generating systems it is of uncompromising importance that alterations to our built environments are designed to accommodate renewable energy sources such as solar energy.

Recommendations for the Future Work

Issues related to legal framework: Solar access is directly related to legislation and public policy. When solar energy is taken away or obstructed by new construction it will undoubtedly become a legal issue, especially if expensive solar installations are incapable of generating energy due to overshadowing. Legal aspects coincide with the general theme of this thesis but were not part of the scope of research. Future work can investigate the legal framework revolving around guaranteeing property owners access to daylight.

Right-to-light and Right-to-solar energy: Along the same topic of legislation and solar access, is the comparison of right-to-light and right-to-solar energy. The difference lies in whether passive or active solar systems are being integrated into the building. Right to light focuses on implementing passive strategies where any amount of daylight which is permitted to penetrate building interiors is useful. This includes diffuse radiation which can decrease the need for artificial lighting. Whereas, right to solar energy means direct access to the radiation from the sun. Right to solar energy is important when integrating active solar strategies which require intense amounts of direct solar radiation in order to generate electricity or hot water.

The detailed model compared to the mass model is an issue that can be researched in future work. It was determined in this research that there is approximately a 20% margin of error when mass models are used instead of detailed models. As research of a solar ready community becomes more progressive and specific to a certain site, the research can focus on finely detailed digital models. This will result in more accurate simulations that can exemplify real world insolation levels and potential energy generation.

Market viability and feasibility of the solar ready building formations becomes an interesting issue. Toronto is currently experiencing a building surge with high-rise glass condominium type buildings being erected on many sites within he downtown area. The future may see different building types being developed as the market for high-rise glass condominiums will surely depress. There are also members of the community who prefer to live in a development which utilizes renewable energy sources. This can contribute to a marketable aspect for "solar ready" communities which can then advance the development of integrating renewable energy into our communities.

An example of where market viability becomes an issue within this thesis is formation C. Buildable space was removed from the south building and added to the north building. Although population density was not altered, the lot on the north of King. St. now becomes more valuable than the lot on the south of King St. Future research can investigate the issue of market viability and how this will affect the integration of solar strategies into our built environment.

The concept of the solar envelope was presented in this research as an urban design suggestion that the City of Toronto can utilize to integrate solar energy into new developments. The solar envelope is a conceptual idea which can de adaptable to any site to achieve varying results. Further research can adapt the conceptual idea of the solar envelope and design very specific envelopes to achieve scientific data. For example, a solar envelope can be designed to permit a certain variable of daylight hours to adjacent buildings (a right to light issues). A solar envelope can also be designed to permit a variable amount of insolation to adjacent buildings (a right to solar energy issue). Adapting specific solar envelope designs to sites across the city of Toronto can assist to ensure that buildings are guaranteed access to solar energy.

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This research has been part of a development for a larger research project, a proposal that has recently been approved to be a four year long project for the International Energy Agency Solar Heating and Cooling Programme (IEA SHC) Task 51: Solar Energy and Urban Planning. The objectives of Task 51 are to assist architects and urban planners to architecturally integrate passive and active solar systems to generate a large portion of energy from solar energy. The intended audience for Task 51 will be architects, urban planners, municipalities, energy consultants, academics, and other professionals involved in the design process.

Outcomes of This Research

Colucci, A. and M. Horvat, (2012), Making Toronto solar ready: proposing urban forms for the integration of solar strategies, 1st International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2012) San Francisco, July 2012, Energy Procedia, Volume 30, 2012, Pages 1090–1098, ISSN 1876-6102, Available at: http://dx.doi.org/10.1016/j.egypro.2012.11.122

Colucci, A. and M. Horvat, (2012), Can Toronto be a solar city? An analysis on solar energy potential in the city of Toronto, Proceedings of the *SASBE2012 - 4th CIB International Conference on Smart and Sustainable Built Environments*, Sao Paolo, Brazil, June 28-29, 2012.

A journal paper in preparation, aiming for submission at the end of March 2013, for the Special Issue on "Environment and Energy in the production of urban habitat" to be published in Architecture Research in Scientific & Academic Publishing ISSN 2071-1050.

This research will be presented at the Climate Change Technology Conference (CCTC) 2013 in Montreal, Quebec, Canada May 27-29, 2013.

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