The Impact of Urban Morphology and Construction Standards on the Energy Consumption of Neighborhoods

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Abstract for Masters

The impact of urban morphology and construction standards on the energy consumption of neighborhoods

Azin Sanei

With the growing urban population, energy consumption and the CO_2 emission of cities are constantly rising, and thus, it becomes important to address the cities' energy use. Multiple factors are important for urban scale energy consumption, mainly urban design and construction standards. Urban design and choice of morphology design are considered influential factors in urban scale energy consumption. This study tries to understand the impact of urban morphology and construction standards on urban scale heating and cooling demand by evaluating two case studies in two districts in Montreal, Canada. One of the case studies is in downtown Montreal; buildings have different height variations in this case study, while the second case study represents a neighborhood with uniform heights. Both case studies are different in density and surface-to-volume ratio. Previous studies have shown that morphological parameters significantly affect radiation received on external surfaces, affecting energy consumption. On the other side, building compactness, construction, and insulation standards are important factors in reducing energy consumption. To run the energy simulations, a software workflow was developed where the geometry of buildings is modified using Rhino and imported to Grasshopper; the energy simulation for the buildings was completed using a combination of plugins of Ladybug tools which uses OpenStudio, EnergyPlus, and Radiance as backend engine.

To understand the effect of radiation on cooling and heating loads, two window locations are studied, showing 15% changes in heating loads when the windows are on one side of the buildings and 4% changes in heating loads when windows are located on both sides of the buildings in different orientations. Based on previous studies, two main morphological parameters are selected for a neighborhood to study. This study investigated the influence of orientation and surface-area-to-volume ratio (S/V represents changes in density and simplification in the model) for an as-build and multiple defined scenarios. Besides these morphological parameters, five different construction types using ASHRAE standards are selected, and heating and cooling demand are calculated for all the 330 models. Then the approximate solar potential for the models is calculated considering how much energy in all the models can be produced and covered by photovoltaic (PV) panels on roofs. Results indicate that even not ideal morphological design with very good insulation standards could produce 1.3 times more than the energy needed. In contrast, the best morphological model with a not insulated scenario will cover around 0.6 times the energy loads. The load calculation results show that the morphological parameters change the heating and cooling demand by a maximum of 45%. The results also show that when the insulation properties are modified to meet the statutory requirements of energy codes and even beyond the energy codes, a reduction of almost 80% in heating/cooling demand can be achieved. Thus, the results show that although morphological parameters are important in energy consumption and radiation received on surfaces, for example, if the surface-to-volume ratio changes significantly, the effects of construction standards are far more relevant for urban scale heating and cooling loads. To expand

the conclusion, this study can be continued in the future by studying different case studies in different climate zones.

Acknowledgments

I would like to express my deepest gratitude and respect to my supervisor, Professor Ursula Eicker, who is a wonderful human being and an amazing professor. I consider myself lucky to had the chance to learn from her; she supported me in my research and always was a source of encouragement and motivation. I also want to thank Dr. Pillar Alvarez and Dr. James Bambara for their support along the way.

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Chapter 1: Introduction

Referring to the 2018 Revision of World Urbanization Prospects, more than 43 megacities will be created by 2030 as the population grows and the rural population shifts to urban areas [1], which means more buildings in urban areas are needed daily. The buildings and construction sector are responsible for 36% of final energy usage and 28% of overall CO_2 emissions [1]. In 2019 CO_2 emissions from the building sector hit a record of 10 $GtCO_2$. This record is due to various reasons, such as increased heating and cooling demand, construction emissions, and extreme weather events [1].

One of the ways to reduce extreme climate events and climate changes is to reduce CO_2 emissions. Reducing the carbon footprint in cities is a big mission for developed and developing countries. Each city must care about the environment besides sustaining and improving its citizens' social and economic aspects of life. For this purpose, the designing a city, these goals should be considered by pursuing a more ambitious level in urban master planning compared to traditional urban design plan development [2]. Reducing carbon dioxide must be one of the main goals in urban development for urban planners. This goal can be achieved on an urban scale by using more sustainable energies [3]. To achieve this, reducing the energy demand in urban design, covering the energy demand (as much as possible) with renewable energy sources, and optimizing the amount of fossil fuel used on an urban scale, are proposed [2]. In countries that have already started fighting environmental issues, considering renewable energy and optimizing the use of fossil fuels as much as possible is becoming a must [4].

One of the first stages of decarbonizing the building sector is establishing an efficient urban development infrastructure and design. Urban development starts with the early-stage design stage with the conceptual design process. Defining limitations and establishing requirements by environment and performance happens in this stage [5]. Part of this is about the location, orientation, and other physical design parameters of the buildings on the urban scale known as urban morphology. Urban morphology can not be only designed based on environmental parameters as there are limitations in design like height limitation, typology limitations set by the municipality, or even the existing neighborhood [6]. Moreover, some of these morphological parameters affect the thermal comfort of pedestrians and the overshadowing of buildings [7].

Urban development should consider environmental potential and design in a way to maximize this potential. In this way, urban morphology is a prerequisite for using renewable energy in the cities; the most suitable renewable energy for urban integration is solar energy [8]. Besides this, an efficient design with optimal morphological parameters can control energy loads.

Solar Energy, or in other words, radiation, affects energy consumption by heating the spaces while it can be used as a source of energy to reduce fuel consumption. The solar radiation reached by the earth per year is around 1.08×10 8 G.W. [9], which is about 6000 to 10000 times more than average energy consumption worldwide; in other words, 0.01 percent of received solar energy can cover all energy needed on earth [10]. Not all of the radiation received on earth is convertible to energy as the solar radiation combines direct (beam), diffuse solar radiation, and reflected/Albedo solar radiation [11]. In the environment and urban design for solar energy capture, all three components, direct, diffuse, and reflected radiation, are important [12], [13]. Still, direct solar radiation is the type of radiation considered in renewable energy systems [10]. The availability of solar energy and its potential to use in the building sector depends on environmental parameters (site climate) and controlled and planned architecture and urban design [6]. Site climate cannot be controlled, so to use solar energy and its potential as maximum as possible, it is needed to do urban development as carefully as possible

Reducing energy loads, meaning less usage of energy and less CO2 emissions, by officiant design with the help of selecting optimal design parameters is critical in urban environmental design. Maximizing the use of solar energy in building forms and minimizing heat loss by dense and compact urban morphology (mostly in cold countries in Europe) are the two most used strategies for urban energy-efficient design [14]. The urban morphology and all aspects of urban development should be considered carefully. Urban design, landscape design, orientation, landscape, and site design can be obstacles to solar radiation potential with trees, landscape, and location of buildings [15], [16]. Based on the previous studies, orientation and compactness (mostly focused on density) are the most important factors in urban energy-efficient design. Orientation controls shadings, solar heat gain received, and overheating [17]; compactness has a major effect on heat loss control as well as causing shading and overshadowing, which might limit the potential for solar retrofitting on the facades using renewable energy [18]. Compactness also can be defined as how much area is in contact of the outside, like detached and attached buildings. Surface to volume ratio, the area of external surfaces divided into heated volume, is one of the most effective parameters to study. This parameter in the neighborhood scale represents urban adjacencies and solar access simultaneously [6].

On the other side, construction, insulation standards, and the airtightness of buildings play an important role in retrofitting and controlling energy consumption in new buildings. Choosing the right construction for new buildings or retrofitting the existing building is one of the cost-effective ways to control cooling and heating loads. A good design integrated with the right selection of construction ensures the project reaches a high-performance scenario [19]. A very good insulated building prevents heat loss and saves energy [20].

Although previous studies provided insight into the importance of mentioned factors, they all embody limitations and simplifications in their calculations. First, to check the geometrical and morphological parameters, most previous studies created hypothetical or simplified scenarios and studied the role of different parameters in those scenarios. Considering simplified scenarios will not show the true effect of morphological parameters. Second, construction and materials control energy consumption and might overcome the morphological effects, which in previous studies are not considered. Therefore, there is a lack of information about overviewing the effect of detailed morphological parameters and comparing it to a simplified one.

Meanwhile, considering different construction with different U-values helps to understand if morphological parameters are important in all cases or if the right choice of construction can compensate for other factors. Besides, most studies reviewed these factors in single buildings, while these parameters might act differently on the neighborhood scale. Examining real neighborhoods and designing different morphological scenarios, this research proposes an analysis and comparison between simplified models and detailed urban developments, considering different types of insulation.

1.1 Research objectives:

To address the gaps mentioned above, the main objectives of this thesis are as follows:

- To study and identify the most important geometrical parameters in buildings' energy consumption on a neighborhood scale.
- To evaluate energy consumption in real neighborhoods and study the selected spatial parameters and their effect on a case study. This step helps future energy-efficient urban development and design.
- To study the construction's effect on energy consumption on a neighborhood scale and compare it with the geometrical effect

1.2 Research hypotheses and assumptions:

- The available solar irradiance influences heating and cooling demand of the buildings
- Construction, building insulation standards, schedules, window to wall ratios impact heating and cooling demand.
- The same construction, building programs, and schedules are considered for all the buildings in the neighborhood to study the effect of parameter changes.
- Window-to-wall ratio and window properties are considered the same for all the buildings. This helps the radiation be influenced by geometry and shading, not window properties.

1.3 **Thesis outline:**

Chapter 2 reviews previous studies' fundamentals about geometrical parameters and their effect on performance indicators. This chapter consists of two main sections, first a short overview of the previous studies, and second describing each of the parameters and evaluating which one is the most important one in a cold climate to be selected in this study. Chapter 3 presents a review of available UBEM methods and software. This chapter reports the urban scale's methodology and workflow of energy calculation. The general approach and workflow applied in each research stage are defined after defining the current methods and software limitations for energy calculation in a neighborhood.

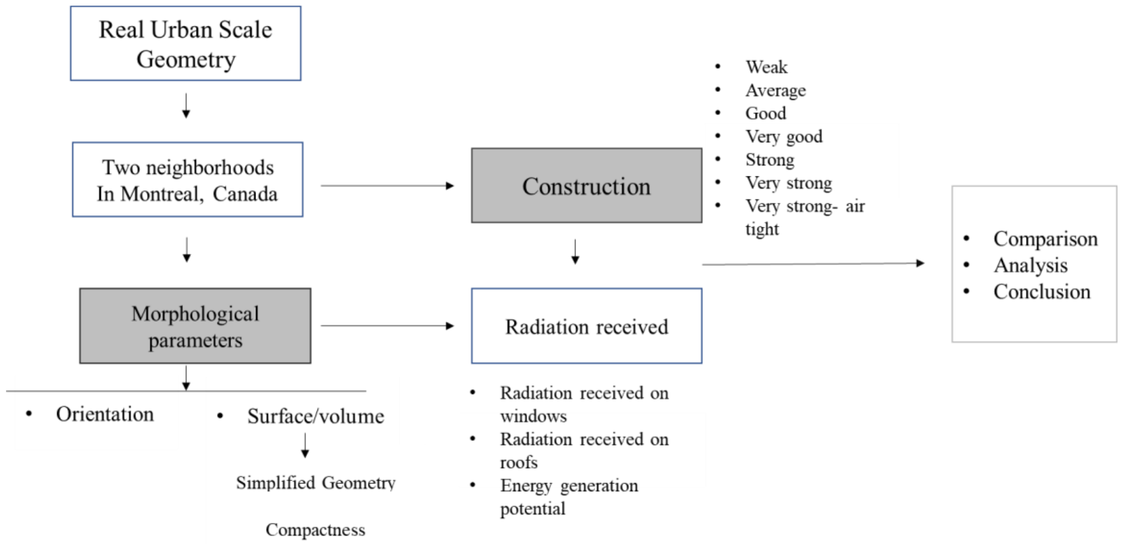


Figure 1-1, Chapter 4 general workflow

Chapter 4 (Figure 1-1) discusses the various scenarios based on the parameters defined in the chapter. These parameters are construction, location of windows, rotation, and surface-to-volume ratio (parameters selected as the most important spatial on an urban scale). Multiple simulations are done to overview the effect of these parameters modeled. Five construction scenarios were applied in each scenario from the construction library of selected software inspired by ASHRAE standards. In total, energy consumption in more than 330 models is calculated. After that, renewable energy generation for each scenario is calculated to see how energy demand can be covered. Chapter 5 summarizes the conclusions, showing how morphological parameters behave. Orientation significantly affects heating loads when there are windows on one side of each unit (buildings), while for both windows, the changes on heating demand are not significant. Heating demand changes by a maximum of 45% in sparse and dense scenarios; these changes might vary to 20% based on the type of construction. Construction standards can reduce almost 80% of heating demand. Moreover, chapter 5 proposes recommendations for future studies.

Chapter 2: Literature review

This chapter outlines previous studies' main elements about urban morphology parameters, construction, and insulation and their relation to energy consumption and solar potential in neighborhood and building scale. This chapter has three sections: 1- overview of solar energy and why it is important in morphology; 2- define neighborhood 3- overview of morphology parameters effective in urban energy consumption. Generally, this chapter tried to overview previous studies and outline current studies' existing limitations while categorizing the most morphological parameters effective in energy consumption.

2.1 Solar Energy:

The solar radiation reached by the earth per year is around 1018 kWh, which is about 6000 to 10000 times more than average energy consumption worldwide; in other words, 0.01 percent of received solar energy can cover all energy needed on earth [10]. Not all radiation on earth is convertible to energy because solar radiation combines three different types of radiation: direct (beam), diffuse solar radiation, and reflected/Albedo solar radiation [11]. In the environment and urban design for solar energy capture, all three components, direct, diffuse, and reflected radiation, are important [12], [13]. Still, mostly direct solar radiation is the type of radiation taken into account in renewable energy systems [10]. Understanding that how much solar energy is useful for energy use is affected by climate and geographical location (site climate) and the design of the buildings (architectural and urban) [6].

There are many ways to assess performance for solar energy potentials like solar thermal yield, solar radiation, photovoltaic generation, and the load match index [21]. The solar radiation received on a surface is influenced by various factors and geographical parameters like location, climate, and atmospheric conditions [22] or design factors and morphological parameters [23]. Harvesting solar energy means considering roof-integrated photovoltaics and roof solar thermal collectors [18]. Solar energy potential can be used in buildings via passive and active strategies. An active solar design converts solar radiation to electric and thermal energy, including solar photovoltaic or thermal collectors. In the meantime, a passive approach captures and employs solar energy with no need for any mechanical or electrical system to move the energy [24].

2.1.1 Geographical location:

The solar radiation received on a surface is influenced by factors and geographical parameters like location, climate, and atmospheric conditions [22]. First, Geographical location affects the solar radiation at each point. Geographical coordinates (showing the north-south position) and latitude show the geographical location of each point on earth. Higher latitudes will receive lower solar radiation, while it is more near-equatorial[25]. Climate and atmospheric conditions are affected by geographic conditions, seasons, and times of the day because they all impact the sun's position sky [11]. By mentioning the condition of the sky, it means the sunny or cloudy sky will impact having direct or diffused solar radiation [26]. The topography also affects the radiation received on the ground because it might block the radiation with rough trains, different elevations, and slopes [27].

2.1.2 Design Factors:

Building and urban design factors impact solar potential because they control the interaction between buildings. Solar radiation affects urban and architectural energy design. Careful early-stage design considering solar radiation influences energy consumption. All the design factors should be considered during urban developments. Design factors include urban design, site plan design, neighborhood, and individual Building shape, including all effective spatial factors, opaque and glazed ratio surface areas of the buildings [23].

2.1.3 Urban Morphology:

The "Urban morphology" phrase is used a lot in this study, so it's good to look at its definition. Different studies and research offer many definitions for "urban morphology." Still, it mainly refers to "the physical urban form" [28]. Many studies refer to this meaning -urban morphology study- manipulated physical geometries in a neighborhood scale to see the effect on energy consumption [28], [29]. Some studies consider urban morphology to connect a city's technological aspect to its formal aspect while considering geometrical studies as district study [23]. Urban morphology is one of the most important parameters effective on solar energy on the urban scale; that's why Solar Urban planning has emerged [30]. In solar urban planning, the main focus is solar potential in urban areas [31].

2.1.4 Building geometry:

Building geometry affects energy consumption and solar access in different ways, and many parameters define geometry as 'geometry' is a very general definition. It optimizes solar potential; for example, if one building is rectangular with elongation toward east-west is known to be very energy efficient in cold climates. Configuration of the shape-like layout, the surface-to-volume ratio, floor-to-area ratio, and so many other parameters control the solar potential of surfaces [6].

Configuration of the shape-like layout, the surface-to-volume ratio, floor-to-area ratio, and so many other parameters control the solar potential of surfaces [6].

2.2 neighborhood

First, it is good to overview what is known as a neighborhood; a neighborhood is known as a group of buildings in a district; this district can be in a city, rural area, or a village. Normally, this group of buildings is geographically related [32]. An Energy-efficient neighborhood is a type of neighborhood designed based on generating renewable energies [33]. Neighborhoods can be categorized in different ways:

- Based on purpose: residential, commercial or mixed-used
- Based on density: low, medium, and high density
- Based on the location: urban, rural
- Based on transportation: vehicle oriented, walkable

In urban design science, different methods are categorized based on the type of neighborhoods; these methods help to do energy-oriented early urban design [34]. The urban areas are categorized into four groups based on their scale: the regional scale (less than 100–200 km across), the city scale (less than 10–20 km), the neighborhood scale (less than 1–2 km), and the street scale (less than 100–200 m [8]

2.2.1 Solar Neighborhoods design:

The solar neighborhood is planned to achieve solar design techniques (active & passive) and help reduce energy demand and carbon footprint in all the buildings [32]. Low-density residential solar neighborhoods show an influence on building and façade orientation, aspect ratio, and window-to-wall ratio more than other factors in this category; the shading effect and elements causing shading on the facades are very important [6]. Hashem investigated the reduction of GHG emission and energy consumption in mixed-used neighborhoods; the results show the importance of the type of buildings (townhouse, detached house, apartment, …) and their usage (office, retail, supermarket, …). In the end, the ratio of the land area to overall build is suggested to be between 23 to 32%. [6]

Advanced strategies are recently designed to make net-zero energy neighborhoods; usually, two strategies are used adding high-performance systems measures or maximizing renewable energy generation. Usually works on low-density and small-scale neighborhoods [35]. Different energy systems and thermal collectors are required to apply net-zero energy strategies to large-scale urban areas, like thermal storage and heat pumps. The large-scale urban planning will be involved with systems design [36].

2.1 Metrics

Different metrics measure energy or solar potential on the urban scale. A short review of these metrics is presented below. Most of these metrics are measured to reduce energy loads or increase the chance of using renewables. Heating and cooling loads are the main metric in most studies.

2.1.1 Sky view factor:

The sky view factor is considered a value to measure solar access among buildings; it can be measured on the ground or on building facades. Chatzipoulka et al. showed that for specific density, the ground's average (mean) SVF is affected by open spaces between the buildings, known as mean street width; this factor does not represent the SVF of facades. The mean SVF of facades mostly represents the height of the buildings and adjacencies. [37].

2.1.2 Solar irradiation:

Irradiance is the sum of light energy from one thing hitting a square meter of another thing in a moment. Solar irradiation is the power per unit area received from the sun.

In urban design, solar irradiation helps calculate the solar thermal collectors and photovoltaics integrated with buildings. Mohajeri et al. calculated annual solar irradiation in different compactness. They reported that increasing solar thermal collectors, photovoltaics, and passive solar heating could change from 20% to 3, 85% to 49%, and 21% to 4%, respectively. And for the roofs, building-integrated photovoltaics and solar thermal collectors decreased from 94% to 79% and from 100 % to 95 %, respectively [18].

2.1.3 Urban Heat Island:

The Urban Heat Island (UHI) effect is a concern mostly in Mediterranean climate zones. Some parameters like shading, density, canyon width, vegetation, and landscape are important for controlling this metric. Envi-met and energy plus are the most used software to measure this metric. Salvati [38] investigated the urban heat island effect in Spain, one of the densest cities discovered that UHI intensity increases the sensible cooling load of residential buildings by around 18%–28%. Urban heat islands can increase electricity consumption in the summer months [39].

2.1.4 Wind airflow

Wind airflow is one of the renewable energy sources; in some climate zones, it is important to calculate wind potential. Moreover, wind airflow might cause an increase in heating loads in cold climates. Gros, 2016, analyzed different district densities and their relation to solar irradiation and wind velocity; the results showed that in a hypothetical scenario located in France, wind velocity could increase up to 80%, while solar irradiation lowers to 7%.

2.2 Morphology indicators:

In this section, the morphological parameter of neighborhoods that are known as effective on urban scale energy consumption is introduced.

2.2.1 Site design:

Landscape and site design can be obstacles to solar radiation potential with trees, landscape, and buildings located. This effect will be more in the cold season by reducing the solar potential [15], [16].

2.2.2 surface to volume (S/V)

The surface-to-volume ratio is the ratio of external surfaces to the heated volume, and it's a factor that defines heat gain and heat loss [40]. S/V or surface-to-volume in buildings is a better predictor for describing heating and cooling load on a neighborhood scale than ASV, PA, and Orientation [41]; this parameter is a very comprehensive parameter that so many others can be a subgroup of this parameter. This parameter shows how other parameters can affect each other; for example, in comparison with the influence on the energy use of NE-SW blocks than N-S blocks, the S/V ratio has more impact on the first group[14]. Compactness can be a subgroup of S/V in the case of attached and detached buildings.

2.2.3 Compactness

Density has been defined differently in urban and blocks scale. Still, it is mostly calculated as compactness or building density: the ground floor area of the building divided by the land area or the number of buildings divided by the neighborhood area. Compactness can be a subgroup of surface-to-volume ratio if the attached buildings are compared to detached buildings. The shading effect of buildings is very important in energy-efficient design, and density affects this directly [42]. Site coverage is one of the parameters related to compactness, but it does not carry the exact meaning of building density. As all these parameters are very much related, I overviewed them in the same part.

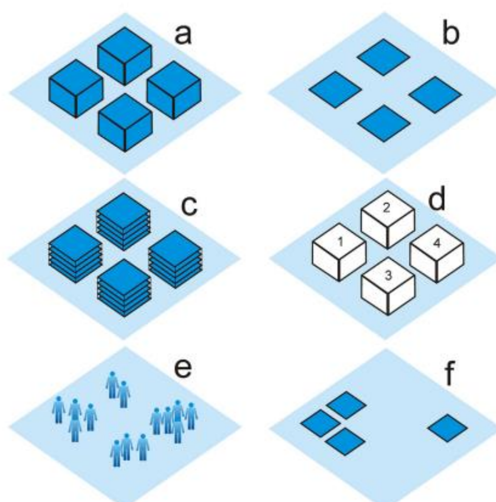


Figure 2-1: different indicators of urban compactness ". (a) Volume area ratio, (b) Site coverage, (c) Plot ratio, and (d) Building density, (e) Population density, (f) Nearest-neighbour ratio." [18]

Density is one of the indicators of compactness Figure 2-1 shows six different types of compactness on the urban scale. The volume area ratio (a) is the entire building's volume divided by the total area of the block or neighborhood. This indicator mostly shows the height of the buildings. Site coverage (b) is the proportion of the neighborhood filled by buildings; its difference with plot ratio (c) is that the total area of all building floors is calculated in plot ratio. Density (d) is the number of buildings in a neighborhood divided by the total area of the neighborhood, and at the end, population density (e), which is the number of people in that neighborhood considering the area of the neighborhood [18].

Density can influence energy consumption and solar radiation received on the façades and ground. Increasing compactness from a dispersed neighborhood to a compact one affects solar radiation received by 30% to 40% [18].

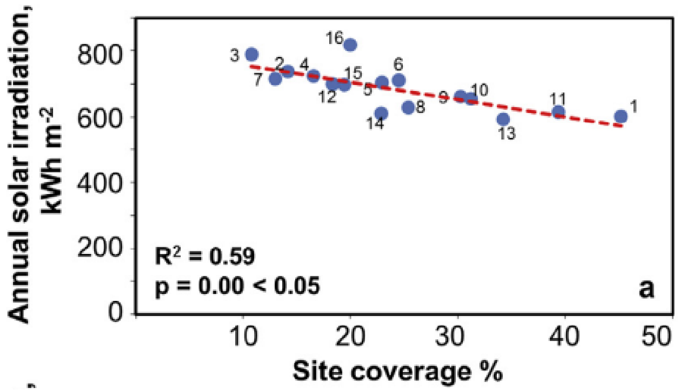


Figure 2-2: Annual solar irradiation and site coverage Relation, study for16 different neighborhoods [18]

Compactness has a major effect on causing shading and overshadowing, which cause a limited potential for solar retrofitting on the facades. Mohajer et al. suggested that density-related standards should be met in the early-stage design process. To increase the solar potential for urban scale, optimal compactness can help harvest more and have good solar potential.

One of the parameters to measure the neighborhood's solar radiation access is the Sky view actor. Chatzipoulka et al. revealed a correlation between density and average sky view factor on the ground with a very clear negative correlation, following the same way on the sky view factor on facades [37].

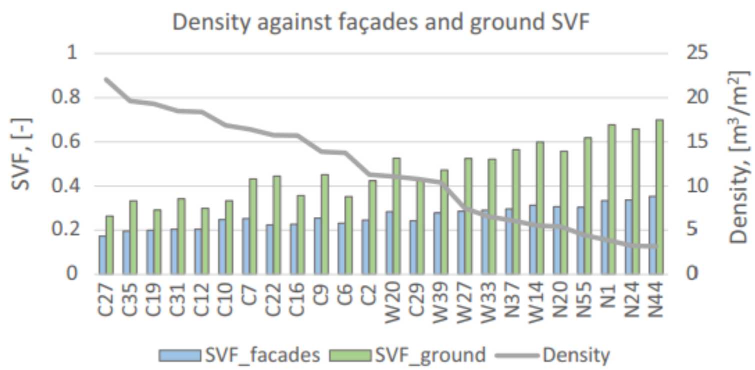


Figure 2-3: Density [m^3 /m^2], mean SVF values, of façades and ground, in 24 urban forms, [37]

Density also affects urban air temperature because of the shading effect and airflow between buildings; it can decrease or increase [42]. Javanroodi et al. l; investigated the effect of Density and typology in ventilation and energy potential of dry climate. The energy consumption of one target building in around 1600 different urban models showed 10 to 15 percentage changes in cooling and ventilation demand [43].

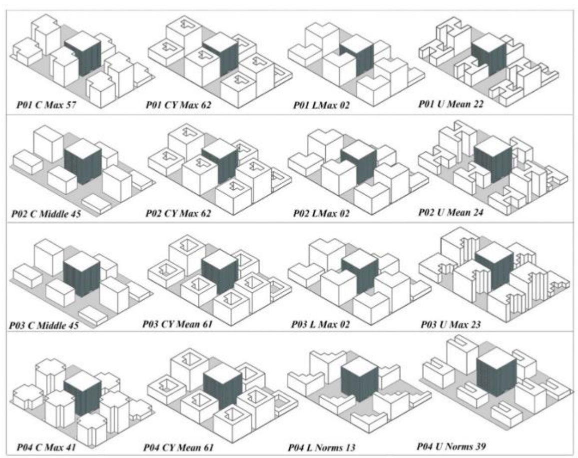


Figure 2-4: Urban morphology around one target building

the urban configuration chosen in four urban patterns and urban building form, [43] Mohajeri et al. working in Geneva City (Switzerland), found that the urban compactness affects the solar potential of the facades more than the roof [18]. Besides ventilation, airflow in an urban environment and its relation to density is important [44]. Gros et al. reviewed airflow, indoor temperature, and energy demand by reviewing two "density on urban scale" models. Referring to this study, urban Density can affect up to 80% of wind velocity, while solar radiation will affect around 7% [44].

Overviewing real data like electricity usage is also a metric to study energy consumption in buildings. Li et al. surveyed an overview of the real relation between energy consumption and urban morphology. The data of 534 households in 46 different neighborhoods were studied. Density and urban configurations like trees and shaders were explored. The results indicated that tree shade plays a significant role in electricity bills and urban heat islands increase by density. At the same time, it does not show a clear relation between winter electricity and density [39]. Zhou et al. studied the effect of urban morphology on one single building. They considered the effect of the surrounding neighborhood on one building. The results indicated that the heating load in the downtown area with more density is 1.5 to 5 percent less than in sparse areas in the suburb, while the heat island effect rises to 1% [45].

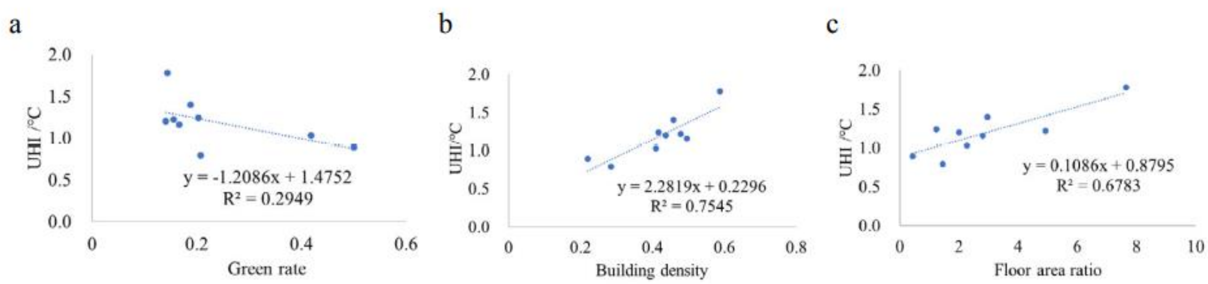


Figure 2-5, relation with urban heat island effect and urban morphology around a single building [45]

2.2.4 Orientation:

Orientation of the buildings is considered one the most important factors in energy-efficient design. Elongation of the buildings affects radiation, which controls overheating or solar heat gain received [17]. In urban design, orientation is important because it defines solar potential on all surfaces and shading that can control heat stresses in the summer. Other geometrical parameters can affect this parameter, such as the height-to-width ratio [7]. Orientation can save up to 105% of annual energy consumption [46]. It also determines how intense the radiation is for a neighborhood [18]. On the other hand, orientation defines the availability of solar radiation on urban canyon surfaces, which can bring comfort or discomfort to pedestrians walking on sidewalks [7] because this orientation in a very dense neighborhood might not be related to cooling loads [41]

Orientation impacts the effect of all other morphological parameters. That's why it is considered one of the most important factors of energy-efficient urban design. For example, blocks with E-W orientations generally show low energy consumptions in all typologies, or S/V is more effective in blocks oriented in NE-SW and not much effective if blocks are oriented N-S [14] Chatzipoulka et al. overviewed multiple neighborhoods in London to see the effect of morphological parameters on Sky view factor, to be able to compare the parameters they rotated the models (real urban models) to be in the same direction for the rest of the study [37].

For solar radiation, the effect of orientation is more significant. Mohajeri et al. simulated annual solar radiation kWh m^2 received on roofs and facades of 16 neighborhoods in Geneva with different densities and orientations. The results show the dependency of density and orientation. If the neighborhood were close in density, they had similar solar radiation. In contrast, annual solar radiation is always less than a not compact neighborhood in compact neighborhoods, even if the neighborhood is favorable oriented [18].

2.2.5 The area of the shadow cast on building surfaces (ASV)

The area of the shadow cast on building surfaces affects solar potential, affecting the potential of renewable energies [47]. So many studies focused on this factor to calculate solar potential or thermal comfort measures in hot and dry climates [48], [48], [49]. Oh, et al. overviewed five real districts in Seoul, Korea, and found out that ASV, or the area of the shadow cast on building surfaces (especially roofs in winter), is critical to energy consumption [41].

2.2.6 The ratio of perimeter to the area (P.A)

Perimeter to the area (P.A) is used as a single building and urban scale morphological metric. This metric does not offer a visible relation to heating and cooling load while it describes lighting better [41].

2.2.7 The aspect ratio of the blocks or buildings (length/width)

The aspect ratio or division of length over width can be referred to as a building or a block in urban design. This parameter is mentioned as one of the important parameters in the solar potential for an urban scale. Li et al. overviewed the effect of density, site coverage, azimuth, and aspect ratio of the individual buildings in hypothetical urban models. The study separately focused on Solar thermal (S.T) and Photovoltaic (P.V). The study shows that increasing the aspect ratio increases the solar potential eventually.

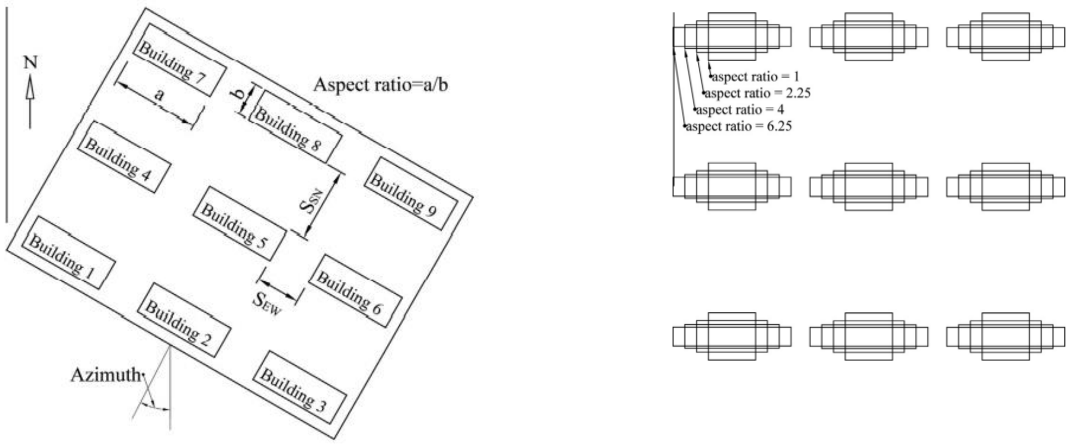


Figure 2-6: One of the scenarios in "Solar potential in urban residential buildings" by Li et al. [50].

2.2.8 The ratio of obstruction height to canyon width (H.W.)

The H.W. factor means "the maximum ratio of obstruction height to canyon width in its direction" [41]. This factor can be defined for each direction separately, like HWNbuildings, meaning height to canyon width north side. ASV (area of the shadow cast on building surfaces) and H.W. (Ratio of obstruction height to canyon width) both consider the effect of direct light on analysis[41].

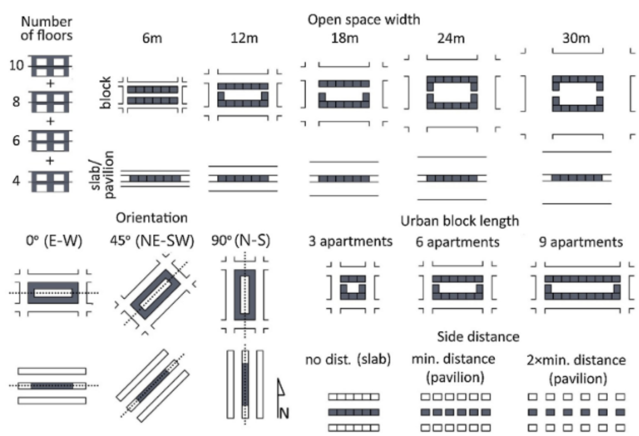


Figure 2-7, Open space width, block length, and orientation used to generate urban forms [14]

Vartholomaios argued the effect of orientation, block length, side distance, w/h ratio, and S/V ratio for hypothetical scenarios (Figure 2-7). It acknowledged the effect of all parameters on each other and mentioned that depending on the orientation and compactness, W/H could have different effects on KWh/M^2 energy; for example, in compact models, W/H has a limited effect.

2.3 Simulation software:

Here I covers the simulation software used on similar studies. Not all of the software introduced in this chapter are focused on energy calculations as energy performance measurements related to urban morphology are a vast range of data, including radiation, CFD, LCA, and thermal comfort.

The need for various advanced models has been developed for building energy modeling. Although so much software runs single building energy calculations, retrofitting in the urban scale is becoming important daily. Turning neighborhoods to energy-efficient models is a priority to reduce energy consumption, reduce CO_2 levels and simultaneously increase the chance of using renewable energies. Thus, the need for energy evaluation on a large scale increases. Many methods and simulation software developed to help to solve this problem. Software evaluating energy consumption on a large scale is usually known as UBEM (Urban Building Energy Modelling). UBEM usually simplifies some calculations and assumptions to offer faster simulation time. Level of complexity accuracy is always a challenge for a user [63].

2.4 Measuring urban morphology parameters:

Energy performances for buildings and neighborhoods can be measured differently; the most used energy performance indicators are usually categorized in solar, airflow, thermal comfort, loads, and life cycle. More categories are introduced in Figure 2-8.

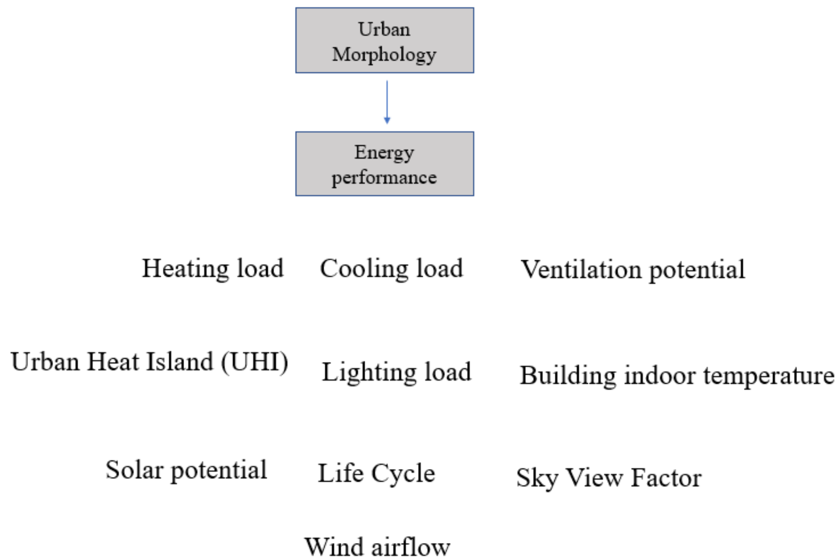


Figure 2-8, most used energy performance indicators related to urban morphology

2.4.1 Heating load and Cooling load:

The heating load is the amount of heat energy added to the room to keep the temperature within acceptable limits. The cooling load is the amount of heat energy that needs to be extracted (cooled) from space to keep the temperature within acceptable limits [52]. The impact of urban morphology on urban energy demand is not much investigated compared to other performance indicators. Chen et al. [53] investigated urban morphology indicators, Vegetation Index, and Built-up Index (including building height, plot area, and building volume), and their effect on heating and cooling demand. This study revealed that energy demand and UMIs (urban morphology indicators) have a significant spatial relation [53].

2.4.2 Ventilation potential:

Urban morphology helps ventilate cities; from old times, cities were designed to capture wind or guide it to exit. Ventilation corridors can decrease pollution and the heat island effect. Gu et al. showed a direct effect between ventilation potential and heat island intensity index [54].

2.4.3 Urban heat island (UHI):

When natural land is replaced with dense obstacles around us, such as pavement, buildings, and other surfaces that absorb and keep heat, urban heat island happens. Urban heat island affects air pollution levels and heat-related illnesses [55]. Studies show that urban morphology and especially density greatly influence the effect of the urban heat island. Especially developing urban blocks from low-density to high-density blocks affected ventilation performance. Zhou et al. studied the effect of urban morphology on one single building. They considered the effect of the surrounding neighborhood on one building. The results indicated that the heating load in the downtown areas with more density is 1.5 to 5 percent less than in sparse areas in the suburb, while the heat island effect rises to 1% [45].

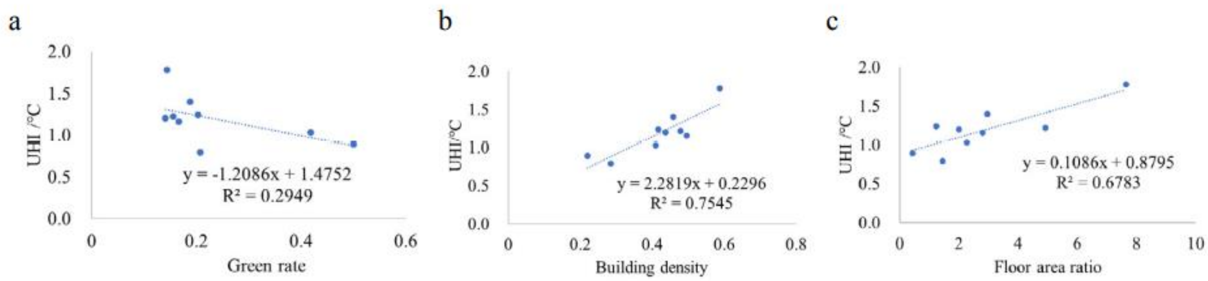


Figure 2-9, urban heat island effect and urban morphology around a single building [45]

2.5 Weather data construction standards

Weather data is an essential input in building performance, and solar energy simulations and Building energy codes are made to help buildings get as energy-efficient as possible. These codes are different for residential and commercial buildings. In this section, I will talk about what type of weather data and construction standard is used in this study.

2.5.1 Weather Data:

Weather data is an essential input in building performance and solar energy simulations. Weather data is usually a constant parameter underlying the simulation in the simulation process. Weather data is a dependent factor on the location of the simulation. Weather data includes "location coordinates, temperature, relative humidity, and solar irradiance; but can also include other parameters such as cloud coverage, precipitation, or illuminance [56]".

One year weather data is usually needed to run energy and solar radiation studies. Yearly weather data contains meteorological observation of one value for every hour based on ten years or more data and is called a typical meteorological year (TMY).

There are multiple types of Typical Meteorological Years (TMY):

- EPW (Energy Plus Weather Format)
- CLM (ESP-r weather format)
- WEA (Daysim weather format)
- DDY (ASHRAE Design Conditions or "file" design conditions in Energy Plus format)
- RAIN (hourly precipitation in m/hr, where available)
- STAT (expanded Energy Plus weather statistics)

These weather data (so-called typical) are based on previous periods. They don't represent future or climate patterns [57]. This study uses weather data from the energy plus website Official EPW (Energy Plus Weather Format). This weather data contains information from 1883 to 1996.

TMY (Typical Meteorological Year Data) data is used for a wide range of meteorological applications, so it contains a wide range of data such as:

Month: January as a start (1) and December as the end (12)

Day: the number of days in each month

Hour: considering 24 hours in every day, the first row on the table is from 12:30 am to 1:30 am on the first of January

Global irradiation: it's the amount of energy (irradiance) received on a horizontal surface on the earth

Temperature and wind speed: the average for one year.

2.5.2 Construction standards:

Building energy codes are made to help buildings get as energy-efficient as possible. These codes are different for residential and commercial buildings. These codes have different sections from construction to efficiency and characteristics of technologies used in the building. These codes can be mandatory or optional based on the location and type of the building. Codes usually offer standards for the building construction, heating, ventilation, and air conditioning (HVAC) systems; lighting; and service water heating systems [58].

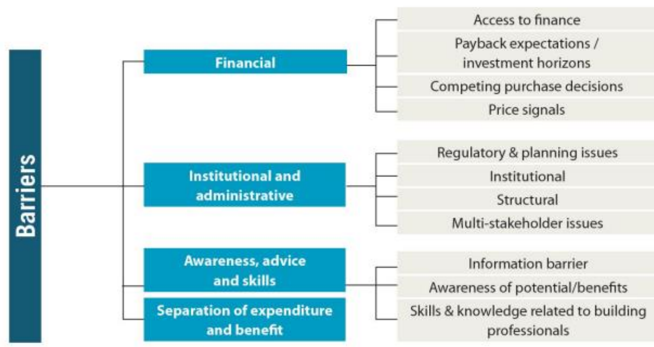


Figure 2-10, Barriers to use building energy codes [59] & [58]

Using codes and standards follows limitations; the build process might become more expensive (financial limitations), and more skilled forces must be presented while constructing (Figure 2-10). In America, The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) developed a standard for buildings in 1894. ASHRAE standards are updated so many times after that. These standards are made for different climate zones and different buildings. Also, independent statics and analysis of U.S. Energy Information Administration updated data table of U.S commercial buildings, including the number of workers, ownership, and occupancy, structural characteristics, energy sources and uses, energy-related building features, and more, the latest version of this report is issued on 2018 which estimated 5.9 million buildings [60], [61].

In Canada, the first national building code is developed by Natural Resources Canada. They developed the Model National Energy Code for Buildings (MNECB) in 1997. In 2011 the file got updated and renamed to National Energy Code for Buildings (NECB). And after that, NECB 2015. In Canada, many standards are developed or inspired based on the available examples, such as ASHRAE [62].

2.5.3 CFD Software:

Computational Fluid Dynamics (CFD) Software can help calculate microclimate effect assessment in urban scale [64]. So many studies focused on the relation of wind flow, natural ventilation and heat removal, and urban morphology. The top software used in these studies is ANSYS Fluent, SOLENE-Microclimate, and OpenFOAM.

2.5.3.1 OpenFOAM:

OpenFOAM is free, open-source CFD software. OpenCFD Ltd has developed this software since 2004 [65].

2.5.3.2 SOLENE-Microclimate:

Density and urban morphology can affect airflow on an urban scale. Different software for these types of studies is used, like EnviBatE and SOLENE-Microclimate [44]. SOLENE-Microclimate (Figure 2-11) considers nonsteady building thermal behavior focus on outside airflow and radiation study (short and long wave) [66]. The advantage of this software is that it works on an urban scale, and urban planning impacts like soil, greenery, etc., can be considered in the model.

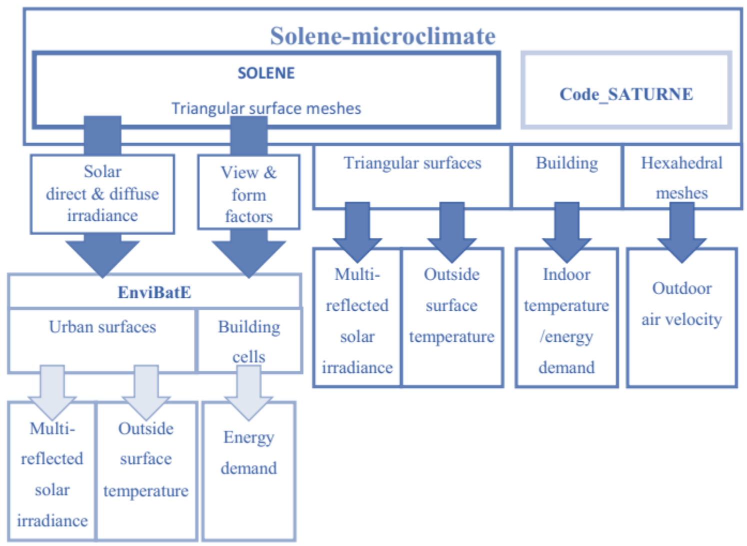


Figure 2-11, Data exchange flowchart of SOLENE-Microclimate and EnviBatE

2.5.4 Radiation and Solar Access:

Radiation and solar access can affect environmental planning; it is important to calculate solar access inside and outside buildings. The specific type of software focused on this type of analysis.

2.5.4.1 Radiance:

Radiance is a well-known software used in multiple studies to overview solar availability or solar access inside and outside buildings. "Radiance is a suite of programs for analyzing and visualizing lighting in design [67]." Greg Ward, the developer of this tool in 2018, was awarded "The Daylight Award" for his work. Time and sky conditions with detail can be defined in Radiance. For all the geometry, shaders, and definitions about the color, opacity, or transparency, the reflection of the material at a very detailed level can be defined [68]. Radiance plugins are installed in different software. Ladybug tools [69] use Radiance as the simulation engine for daylight and raytracing engines. Sketchup has a similar plugin, Su2rad [70], that can be installed as an extension, so many engineers can use it. Sketchup is an easy-to-understand 3D modeling software [71]. Chatzipoulka et al. studied solar availability on the urban scale on facades and the ground using Radiance raytracing.

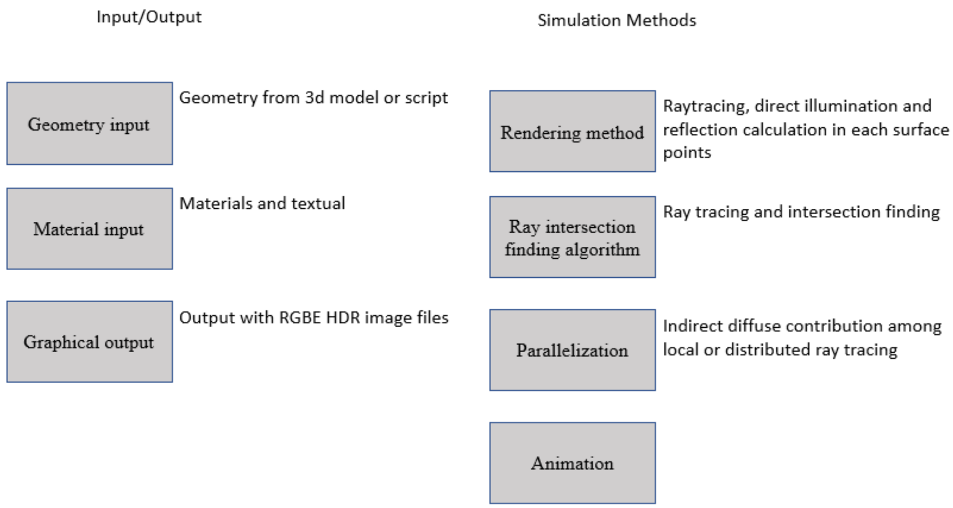


Figure 2-12, Structure of RADIANCE tool [68]

2.5.4.2 Urban Multi-scale Environmental Predictor (UMEP):

UMEP is an open-source GIS-based tool. It asses urban climate performance indicators. Using UMEP, users can illustrate heat and cold waves and understand the impact of green infrastructure, the effects of buildings on human thermal stress, and solar energy production [72]. UMEP allows interaction with the spatial environment with QGIS, a GIS open-source platform [64]. So it can be used for studies related to urban form and urban morphology and asses solar energy production.

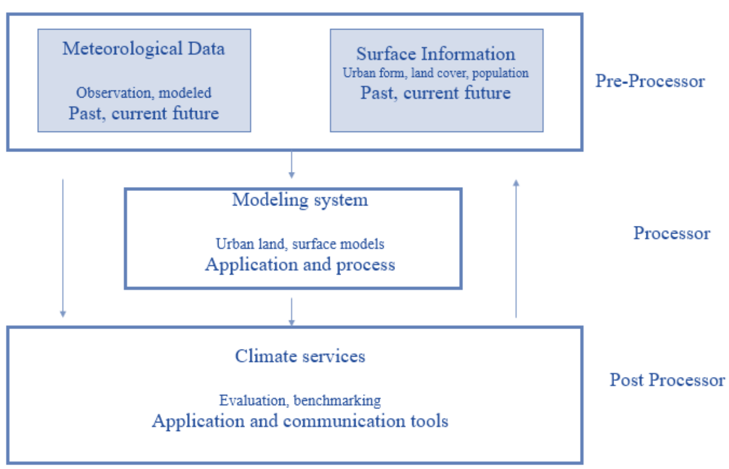


Figure 2-13, Structure of UMEP software [72]

Because of the connection that UMEP has with the GIS tool, urban morphological parameters can easily be calculated. UMEP has documented a user guide that gets updated regularly [73]. Urban land cover, sky view factor, wall height, land cover fraction, and so many spatial factors can be calculated using UMEP with the help of the Q-GIS application [73].

2.5.4.3 CitySim:

CitySim is a software described to help urban energy planners make better, more sustainable, and energy-efficient decisions[74]. It was developed in C++ code in 2009. CitySim gets wether data and is very accurate in radiation analysis. It can consider radiation, shading, and raytracing[74]. This software can calculate a few buildings to thousands. Li et al.; studied the effect of some parameters on the solar potential of residential buildings with different densities, and all the study was performed with CitySim [50]. The radiation analysis is validated by inter-model comparison with Radiance and heating, and cooling demand is validated using the BESTEST validation procedure[75]. The software is made by the Solar Energy and Building Physics Laboratory (LESO-PB) of EPFL.

2.5.5 Summery

After reviewing morphological parameters affecting energy consumption, the short conclusion can be: "the study's goals define what the best parameters to overview in each study are." Most studies indicated that urban morphology significantly impacts the heating and cooling demand of each building. Based on the literature presented, the basic and important spatial parameters on urban scale studies are surface-to-volume ratio (S/V) and density. These parameters represent the relation of buildings with surrounding space and other buildings [14]. Not only heating and cooling load but outside thermal comfort or even wind velocity and airflow get affected by Density [44]. Oh, et al. [41] presented a comprehensive table of effective geometrical parameters in urban development. And found out that S/V. (surface to volume ratio) is the most effective heating and cooling load element in urban energy consumption.

Solar availability is one of the well-known indicators on urban scale to measure solar availability, which is effective in energy consumption. Chatzipoulka et al. l. worked on the real geometry of London and investigated the solar availability in façades of buildings and on the ground, which is helpful at the pedestrian level. This study revealed that Mean outdoor distance, site coverage, rotation, and urban complexity influence the solar accessibility of open spaces. Rotation (direction), building density, and building height were affected by the solar accessibility of building facades [37]. Morphological parameters can affect each other, and their importance is based on the study's goal, climate, and assumptions. Vartholomaios overviewed the effect of multiple urban scale morphological parameters (orientation, S/V, W/H, block length, side distance). The conclusion showed that all parameters are effective, some on some occasions more effective than others, but orientation affects all very significantly, S/V and W/H [14]. Mutani et all [51] created a bottom-up workflow to evaluate the energy balance of residential buildings in Turin, They used GIS as the tool and concluded that urban compactness is the most important and after that, building shapes and open spaces between the buildings (H/W) and surface to volume ratio are critical parameters in energy consumption. At the end they observed the effect of parameters on each other, for example how orientation effect surface to volume ratio. They also had a topic about simplification of the models and how it can fasten the simulation time.

What is noticeable in the studies is that most of these studies only focused on morphological parameters. Recent studies also are focused on occupancy modeling. Lack of data in comparison have of the morphological parameters and construction standards on urban energy consumption is visible. This thesis uses highlighted parameters to see the construction effect on an urban scale with geometrical (morphological) parameters. Orientation and the surface-to-volume ratio. These parameters are selected as the mostly are known as the most effective parameters in urban energy consumption (**Error! Reference source not found.**). As mentioned, density can be a subgroup of S/V, and most studies found it a very important. To see the effect of S/V and density, scenarios are designed as detached and attached to represent both parameters. The metrics in this study are heating and cooling loads while considering radiation.

Chapter 3: Methodology

The basic idea behind this research is to study the real (existing) urban morphology, understand and measure morphological parameters, evaluate the effect of each of them with different insulation standards, and understand the best solution to cover energy consumption with renewable energy.

To understand this goal, multiple steps are needed to consider, in this chapter. Previously in literature review chapter I overviewed simulation software available and construction standards.Here, I go over the construction standard used in this study plus software used in this study, beside explaining developed methodology.

3.1 Construction standards:

This study uses two codes as a reference: ASHRAE (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers) and CBECS (the Commercial Building Energy Consumption Survey). NREL (The National Renewable Energy Laboratory) accepts the software default values. NREL is the U.S specializes in researching and developing renewable energy, energy efficiency, energy systems integration, and sustainable transportation.

Building program assumptions are based on the standard available for a midrise apartment (Ladybug Tools 1.3.0., ASHRAE standard 2015, CBESC pre-1980). Based on ASHRAE 2015 standard, the infiltration rate for a midrise apartment can be considered 0.105 Ach for airtight buildings and 0.525 Ach for leaky buildings here, I considered infiltration for average building for all the buildings.

Table 3-1, Buildings program assumptions

People (people/m^2)	0.0248	Lighting (W/m^2)	11.096192
Infiltration (Ach)	0.315	Electric equipment W/m^2	6
Ventilation rate (Ach)	0.302	Gas equipment	non
Cooling set point (° C)	22	Heating set point (° C)	25

The case studies are a part of Montreal. The first scenario is from a neighborhood where most buildings are midrise apartments and midrise commercials, and the second scenario is where there are few high-rise buildings. This study tries to understand the effect of urban morphology and construction on heating and cooling demand. Other influential factors on heating and cooling demands are considered the same, such as window-to-wall ratios and type of buildings. A similar window-to-wall ratio (40 %) is assigned to all buildings and construction for all assumed similar.

In this study, five categories of construction standards are examined. Different iterations are created with walls, floors, and windows for the five-construction standard studied. The construction standard is categorized into five groups: weak, average, good, very good, strong, and very strong.

Table 3-2, building's construction assumptions

	R-value		U-value
	Exterior walls m^2K/W	Exposed floor and roofs m^2K/W	Windows W/m^2K
Weak	1.13	3.44	5.7
Average	1.8605	3.44	4.68
Good	3.58	5.55	2.68
Very good	10.56	10.66	1.75
Strong	16.12	16.019	1.07
Very Strong	26.58	26.69	0.6

The construction standard related to exterior walls, exposed floors, and windows are categorized into four groups: weak, average, good, very good, strong, and very strong.

There are different standards for construction used in different buildings. These construction standards sometimes are called libraries. Libraries are a range of standard cards defined based on the type of buildings, year of construction, and climate zones.

3.2 Software used in this study:

3.2.1 UMI:

The Urban Modeling Interface (UMI) is a sustainable design platform designed and developed with MIT sustainable design lab team. This platform evaluates building performance indicators and environmental effects.

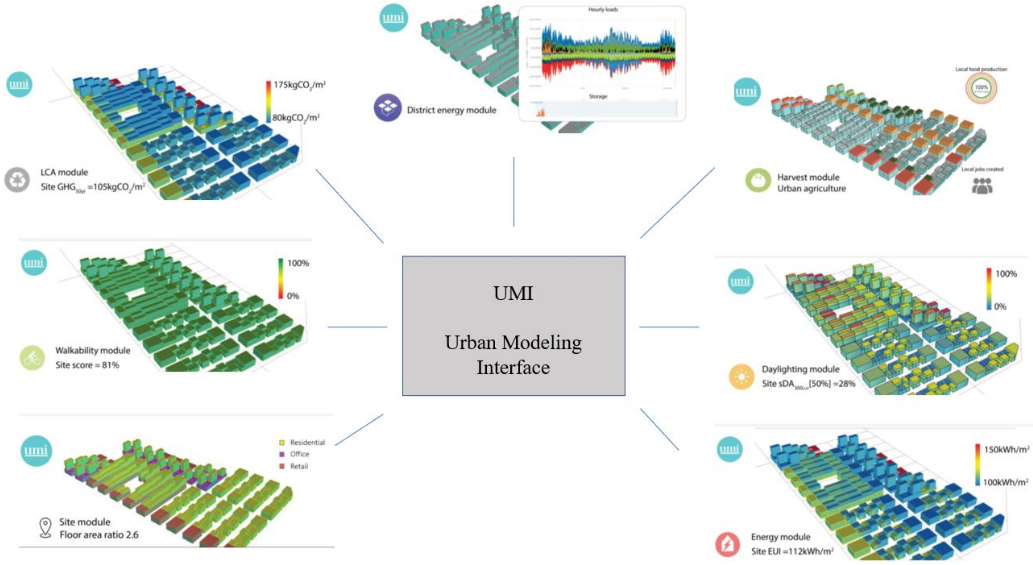


Figure 3-1, Urban Modeling Interface Platform performance indicators [76]

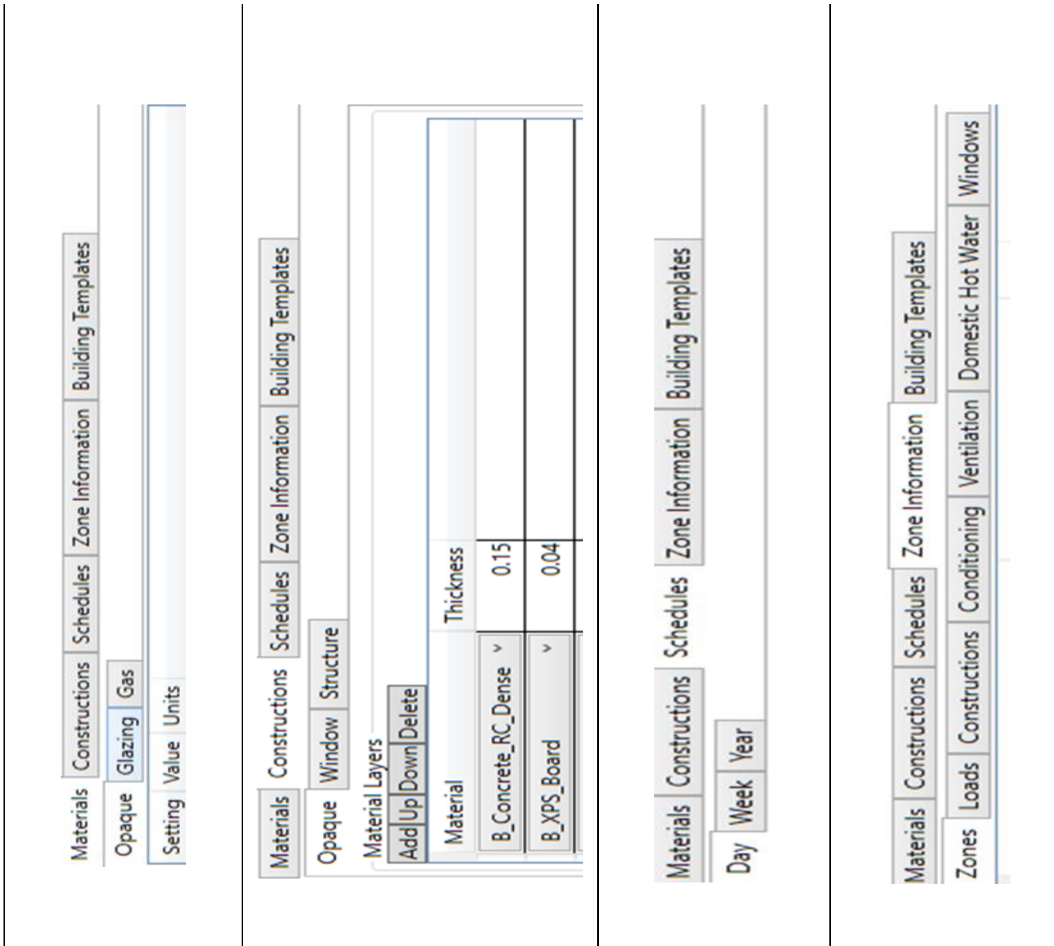
These platforms allow users to evaluate a neighborhood from different aspects: operational and embodied energy use, neighborhood walkability, access to daylight, urban food production, and district-level energy supply analysis [76].

This platform uses the energy plus engine as the simulator engine and Rhinoceros 3d (Rhino) as the design environment [77]. Targeted users are "urban designers and planners, municipalities, utilities, sustainability consultants and other urban stakeholders "[76].

Based on my experience UMI interface is so simple to use. When the geometry is ready in Rhino 3d, users can define the closed geometries as buildings and start making templates for different neighborhood scenarios.

Figure 3-2 shows the main sections of UMI tools. In the Material section (Figure 3-2-A), it is possible to define materials in detail, density, roughness, specific heat, and more. As shown, cost estimation is also part of the detailed input information and embodied carbon and energy, which helps early-stage LCA estimation (Figure 3-1).

In the Construction section (Figure 3-2-B), users can set layers of materials and define customized construction for windows, structures, and other parts of buildings like a roof, walls, façade, floor, interior floor, and more. Schedules can also adjust and customize occupancy, domestic hot water, and more. In the Zone Information section (Figure 3-2-D), all conditioning inputs can be inserted like setpoints, Cop, heating and cooling schedule, heating and cooling capacity, and infiltration information, and the user is allowed to define to use or not use the mechanical ventilation and economizer.



A	B	C	D

Figure 3-2, main template section of the UMI tool

Generally, UMI has a wide range of input that the user can define. It also generates the .idf file in the processing folder that users can check for understanding default values, which are many in my idea.

Some of the advantages of using UMI, based on my experience working with this interface, is that

- Simplification in the calculation (shoebox model)
- Easy to insert parameters
- Adjustable construction details and schedules (equipment, occupancy, ventilation, infiltrations, and more.)

- Perfect for early-stage design step to have an understanding from energy to life cycle to walkability
- Give a clear picture to urban energy-efficient designer
- Very fast calculation time

Materials | Constructions | Schedules | Zone Information | Building Templates

Opaque | Glazing | Gas

Setting	Value	Units
Conductivity	1.75	W/mK
Cost	0	
Density	2400	kg/m3
Embodied Carbon	0.24	kgCO2/kg
Embodied Energy	2.12	MJ/kg
Substitution Rate Pattern	1	
Substitution Timestep	100	
Transportation Carbon	0.067	kgCO2/kg/km
Transportation Distance	500	km
Transportation Energy	0.94	MJ/kg/km
Moisture Diffusion Resistance	50	
Roughness	Rough	
Solar Absorptance	0.7	
Specific Heat	840	J/kgK
Thermal Emittance	0.9	
Visible Absorptance	0.7	

Figure 3-3, defined materials by the UMI tool

As a user who worked with this software, UMI has some limitations and drawbacks. Here I mentioned a few of them:

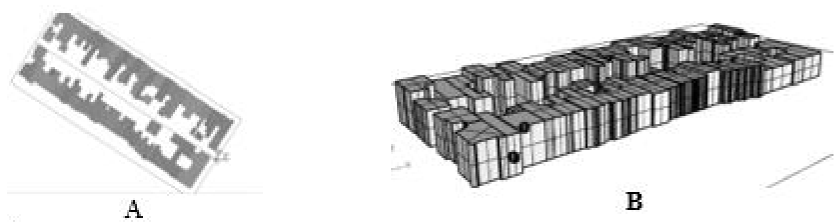
- So many default values on the background (you'll find it in the .idf file)
- The simplification process is not so clear in all aspects, but there are articles that you can refer to and understand how the simplification is done for the shoebox. Still, more factors like adjacencies and errors are not clear.
- Every time you run a project, you'll get a different number.
- 5 to 10 percent changes in results are normal because of the simplification strategy.
- You'll get a result even if there is a minor problem; for example, the user will get an answer anyhow, even if the geometry has some errors. After overviewing the geometry, I noticed there were some problems with geometry.
- There are limitations on how many buildings you are running (UMI limit)

- Adjacencies of the buildings are not considered in the simulation process (so far and based on a few sample files that I run)

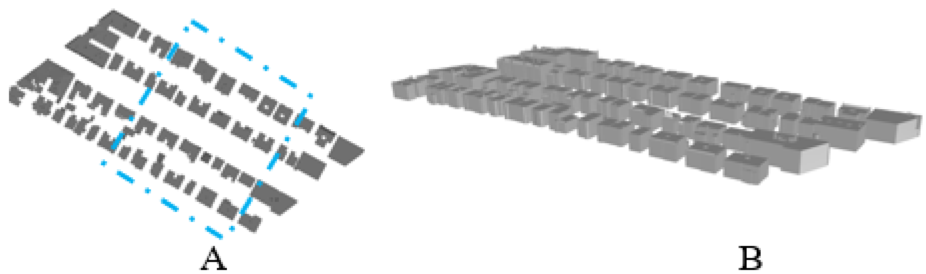
- It's an early-stage design software, so mix-use buildings; detailed windows location is not possible to define. Users can define a continuous window-to-wall ratio for each side.

3.2.1.1 Case study for UMI:

UMI was selected as the software for this study to examine the case studies. After multiple examinations and simulations, some errors were found, so I proceeded with another software. One of the main merits of using UMI is getting the results for individual buildings; this software also provides radiation calculation, with the same run of calculating the loads, saving much time for the user. Here I calculated heating and cooling demand, and the general pattern of heating and cooling was correct approximately but not the most accurate; also, for individual buildings, there were some cases where the data was so off that the main problem was defining the adjacencies of the buildings to their neighbors. The case study ran with UMI is what is known as SC1 in the next chapter.



SC1



SC2

Table 3-3, first case studies used for UMI calculations Layout, (B) perspective

I calculated energy loads and radiation for eight different orientations and two types of construction standards for both case studies. Table 3-4 shows sample bar charts of the results I got using UMI. Table 3-5, A-2-a shows that although the trend of heating loads looks correct for E, F, J & G, the trend does not look real; later, by calculating the results with another software (Ladybug), this trend follows the cooling loads.

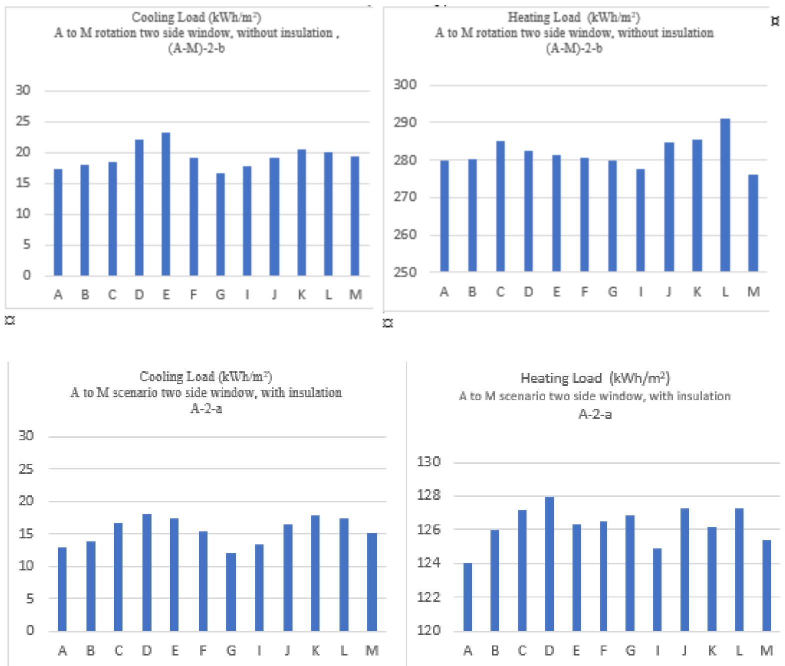
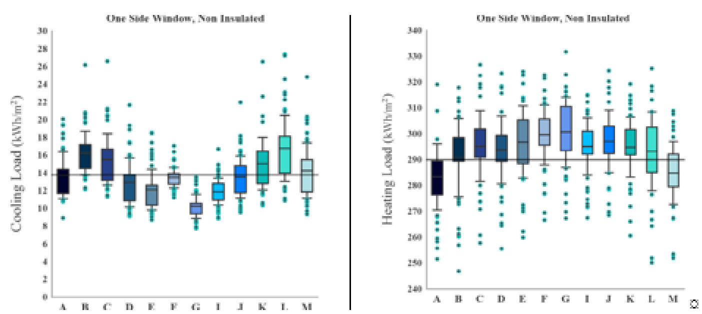
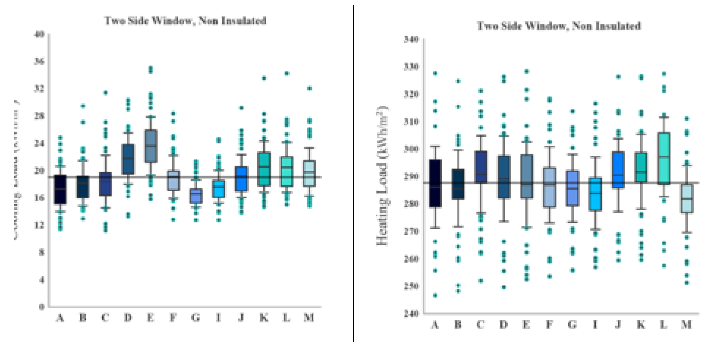


Table 3-4, Sample of UMI results for heating and cooling loads, A to M are orientation every 30 degrees

Also, considering looking at single building results, so many buildings were out of the range here that more than four results are omitted as an error to draw these diagrams:



(A)



(B)

Table 3-5, UMI, single building results for a neighborhood scale calculation

(A) one side & (B) two side window scenarios

These calculations for one and two-side windows and highly insulated and not insulated scenarios for 12 different orientations (48 cases) are not presented in this thesis as there were not many interpretations possible. In the next step, calculations for different density scenarios were also performed.

The results of different density scenarios showed that if the blocks are completely attached and the walls between them exist; buildings are going to be recognized as individuals without adjacencies (a & e), while if we attach the buildings and remove the walls between them the heating and cooling loads suddenly decreases significantly (b & c), this shows the adjacencies are not recognized by the software. Besides all this, with every simulation, there is a chance of a 5 percent error, which would make the comparison a bit difficult.

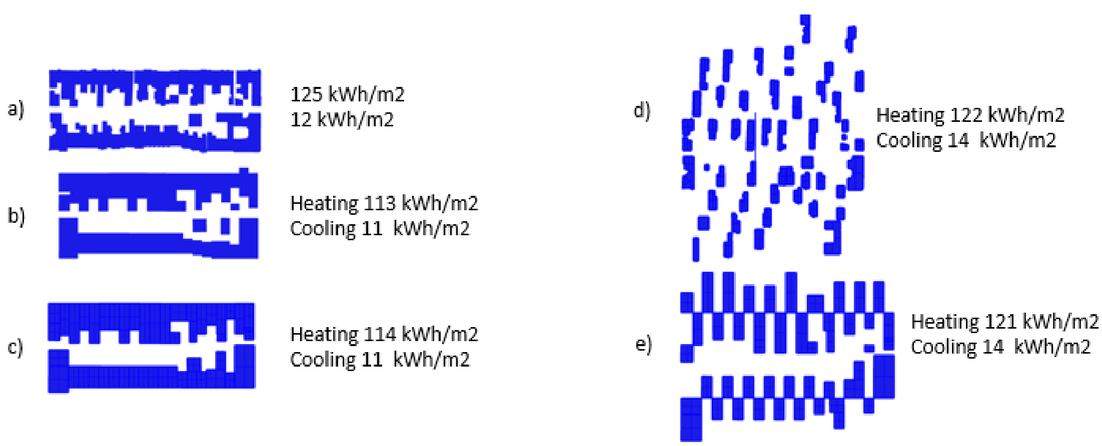


Figure 3-4, density scenarios and the heating and cooling demands

3.2.2 Ladybug tools:

Ladybug tools is a package of different applications that connects multiple software to let the user measure environmental design and its impacts. Among all the environmental software available in the market, Ladybug tools are known as one the most comprehensive ones, connecting 3D Computer-Aided Design (CAD) interfaces to a host of validated simulation engines.

This package has multiple plugins; each is connected to different engines in the background. Users can do block-coding and use this interface to connect multiple engines, giving users a wider range of possibilities.

For example, radiance is the engine working in Ladybug tools as the main engine to calculate radiations and solar analysis. This engine can be connected to energy plus or airflow calculations. Figure 3-5 indicates different software and engines that are connected through Ladybug tools.

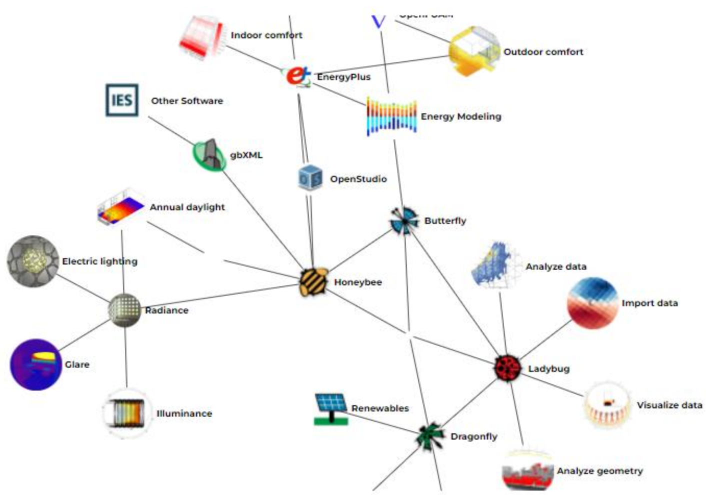


Figure 3-5, Ladybug tools flow chart [69]

In this study, Honeybee, Dragonfly, and Ladybug plugins are used. Honeybee connects the geometrical model to the energy plus engine (using open studio) to calculate energy consumption (here, cooling and heating loads). Ladybug connects the model to the Radiance engine to calculate radiation received on the windows and the roof. This study uses this strategy; the steps are presented thoroughly in the next chapter. Ladybug tools is a package of developing interfaces: following the updates is a must for the users. In the last versions, this package could not solve urban scale calculations. However, in the last two versions, urban scale calculations and defining scenarios for simplified urban scale calculations are added to this platform. GeoJSON files that are open standard format designed to represent simple geographical features and their non-spatial attributes can also be imported to this package. This package has different plugins that here I will introduce shortly:

By importing EnergyPlus weather files (.EPW), users can get different analyses, which helps early-stage design. This plugin supports radiation and solar studies as well as outdoor comfort studies.

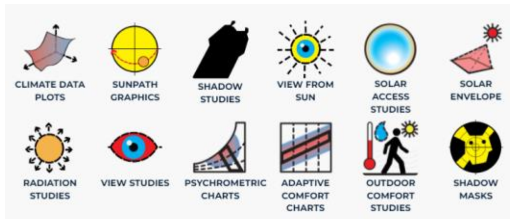
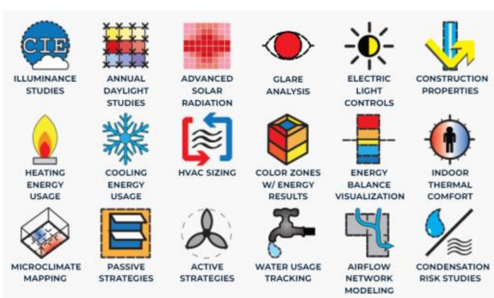


Figure 3-6, Ladybug plugin [69]

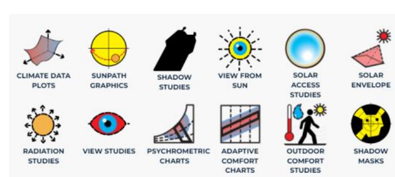
3.2.2.1 Honeybee:

Honeybee connects the model to Radiance and Energyplus (OpenStudio) engines. These plugins help users run detailed daylighting and thermodynamic calculations, Figure 3-7-A. It connects Grasshopper/Rhino CAD environment to these engines [78].



(A)

(B)



(C)

Figure 3-7, Honeybee plugin (A), Dragonfly plugin (B), Butterfly plugin (C) [78]

3.2.2.2 Dragonfly:

Dragonfly's main role is to run energy models in district scales with abstracted building geometries. District scale models can be translated to detailed Honeybee models so that the model will be run with OpenStudio and EnergyPlus engine [79]. Also, Dragonfly models can be run with URBANopt, a platform known for urban scale energy modeling by NREL [80]. More features are shown in Figure 3-7-B. I found some limitations and points interesting to record while using Ladybug tools. The first one is: using the Multiplier component in the Dragonfly plugin, which makes the multizone calculations possible for individual buildings and increases the simulations time by decreasing the accuracy of the results, and the second is defining the exterior roofs, which was not possible in the version that I used in this study and at the time of submitting this document the new version solved this problem, and at the end adjacencies in the urban scale model in detailed Honeybee energy calculations.

3.3 Workflow and methodology:

The general workflow is described in detail in Figure 3-8. There are limitations in most software and tools related to urban scale energy modeling. Ladybug tools can connect multiple engines to work together on one platform (Grasshopper). In this study, Rhino is used as the visualized platform and grasshopper as the visualized coding platform.

The geometry extracted from the municipality of Montreal is presented in 3D models (.CAD) and GML files. Here GML files (LOD,1) are used in a model that does not have windows or any geometrical details; by using Grasshopper parametric modeling, windows are added to the geometries and convert the model to LOD 3, which can be used to early-stage energy calculation assessments.

Different models are defined using the extracted footprint and the height of the individual buildings in Rhino.

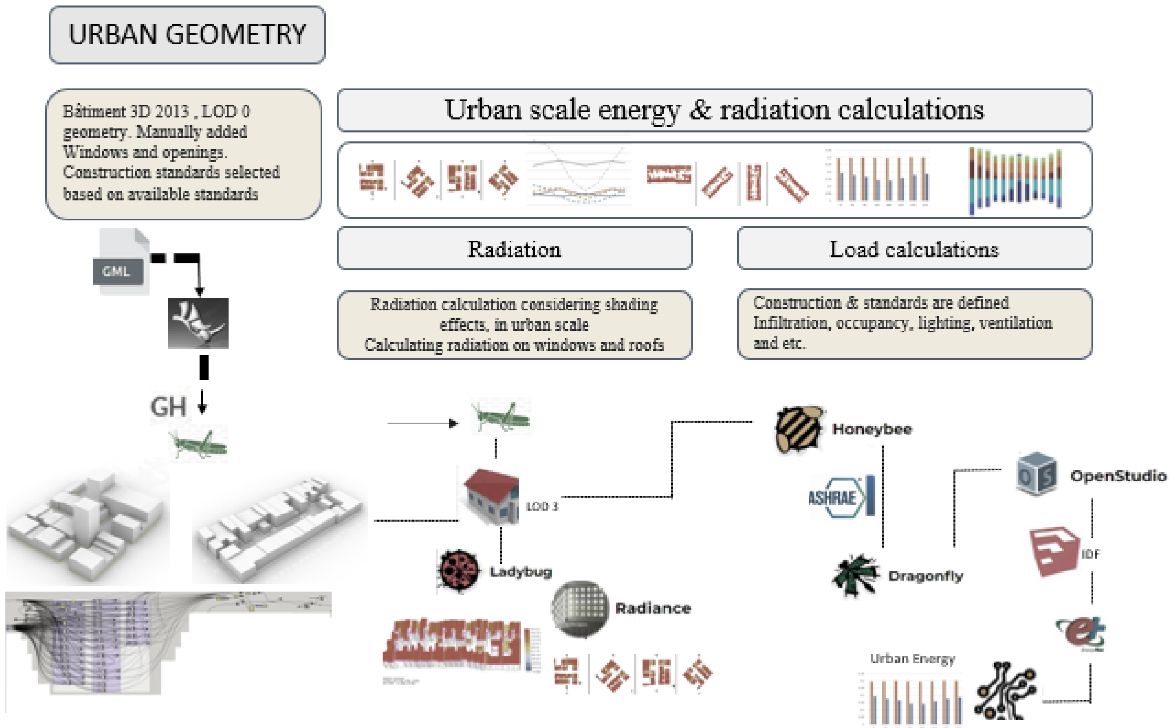


Figure 3-8, workflow used in this study

After defining the geometries and scenarios, using Radiance engine radiation on roofs and windows is calculated. Radiance can calculate radiation for different duration, daily, hourly, monthly, or yearly. Here annual radiation is calculated to see the relation between annual heating and cooling loads.

The Honeybee is a plugin in the Ladybug tools package; as explained above, the biggest responsibility is making the geometry ready to be transferred to energy calculation engines. Here construction standards, occupancy, plug loads, infiltration, and ventilation standards are defined using default ASHRAE standards. It is good to mention that Honeybee helps define and modify the values. I also used automated calculations, using grasshopper parametric abilities for each morphological scenario to change construction scenarios and orientations.

Chapter 4: Simulation

Chapter four goes over the case study and different simulations and calculations. Different parameters based on the previous chapters are going to be evaluated. The case studies are real neighborhoods located in Montreal, Canada.

4.1 Making ready the Case study:

In this section, two neighborhoods in Montreal are selected to study. Neighborhoods are a mix of different buildings, mostly attached. The geometry of this neighborhood is downloaded from Montreal's municipality website, which offers GML and .3dm files [81]. This study overviews the neighborhood's existing situation. Spatial parameters of the case study are studied to understand the effect of each of these parameters on their urban-scale energy consumption.

Some assumptions are considered in this study:

1. The available solar irradiance influences the heating and cooling demand of the buildings
2. Construction, building insulation standards, schedules, and window-to-wall ratios impact heating and cooling demand.
3. The same construction, building programs, and schedules are considered for all the buildings in the neighborhood to study the effect of parameter changes.
4. Window-to-wall ratio and window properties are considered the same for all the buildings. This helps the radiation be influenced by geometry and shading, not window properties.

4.1.1 Geometry:

Montreal's municipality website presents 3D models of most of the neighborhoods in the city. Currently, Available geometries are in GML, Mesh 3Ds, and dwg format. These formats need modification to become readable in Rhino. The first step is to convert them to a suitable format.

4.1.1.1 Limitations:

Possible usable geometries should not be in the Mesh model; after converting the GML file, all the geometries are in Mesh and not usable for energy calculation. In this case, all the geometries should be remodeled again in Rhino. As this process is so time taking, parametric coding can help. In this section, I made a Grasshopper code to extrude the ground floor in the height of the building.

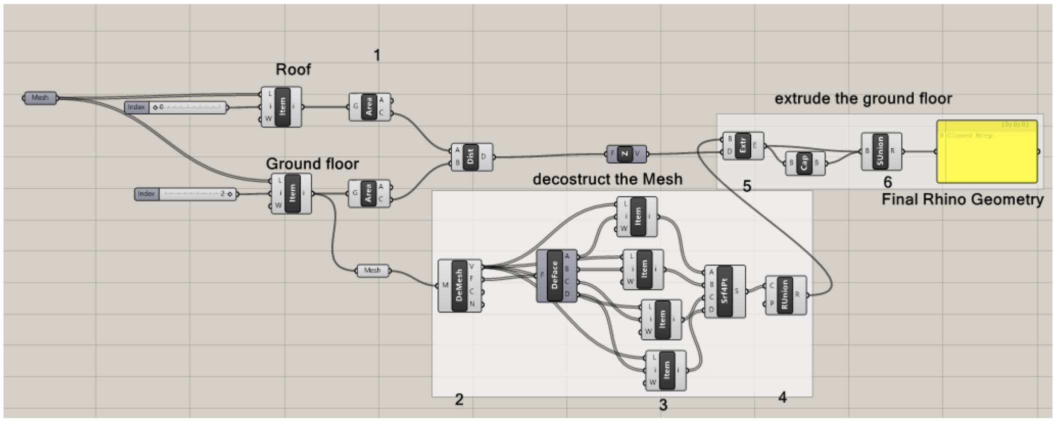


Figure 4-1, Converting Mesh to Surface in Rhino, with Grasshopper Coding

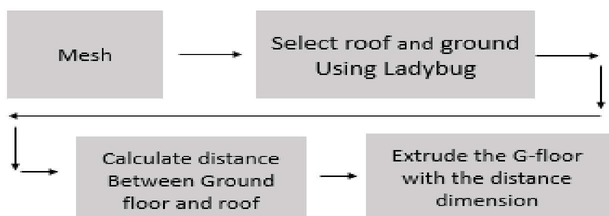


Figure 4-2, Converting Mesh to Surface in Rhino, with Grasshopper processes

1- Importing the Mesh in Grasshopper, categorize elements (roof and ground floor) and find the distance between them to use for extrusion.
2- Deconstruct Mesh and divide it to vertex and faces.
3- Reconstruct surfaces with the help of vertexes.
4- Reunite all the surfaces.
5- Extrude the surface.
6- Close the surface.

This process can be repeated on multiple geometries; this algorithm is helpful for this section's automation process.

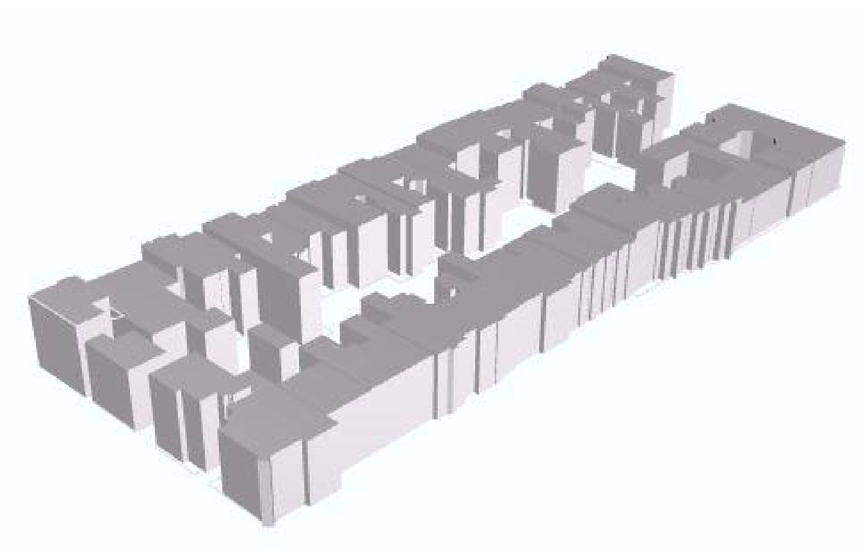
4.1.1.2 Construction Standards:

Building energy codes are made to help buildings get as energy-efficient as possible. As presented in the Methodology chapter, Chapter 3, Building program assumptions are considered based on the standard available for a midrise apartment (Ladybug Tools 1.3.0., ASHRAE standard 2015, CBESC pre-1980). 0.3 Ach is the infiltration, and 40% WWR is considered for all the buildings.

In this study, five categories of construction standards are examined, and all are explained in the Methodology chapter Table 3-1. Different iterations are created with varying walls, floors, and windows for the five-construction standard studied. The construction standard is categorized into five groups: weak, average, good, very good, strong, and very strong. They are explained in the Methodology chapter Table 3-2.

4.1.2 Case study introduction:

Two case studies were selected for this study. Montreal has different neighborhoods with different urban morphology. The first case study (Figure 4-3) is selected from famous neighborhoods in the city called Plateau Montreal; the second case study (Figure 4-4) is located in Downtown Montreal.



Plateau Montreal
City block

The number of buildings in the study: 46

The average height of buildings: 13.6 m

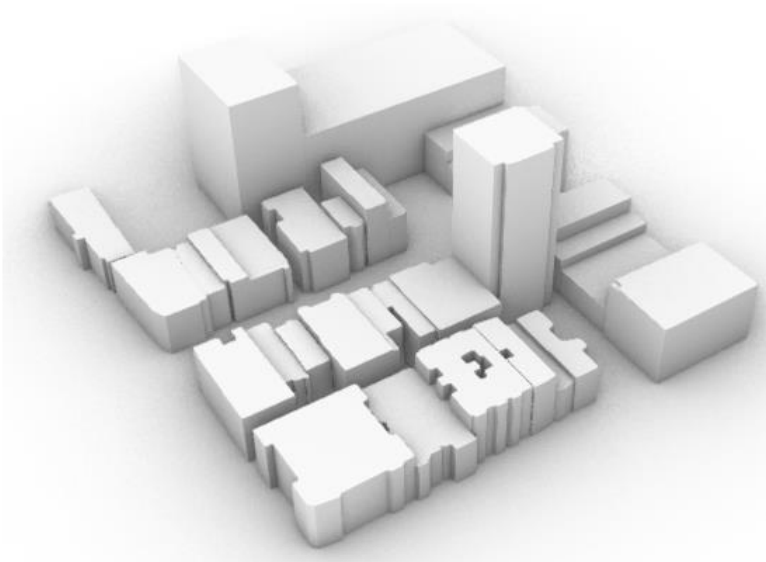
Highest Building: 16.5 m

Lowest Building: 7.3 m

Total area: 27,368 m^2

Approximate block size: 80 m *170m

Figure 4-3: Case Study one, SC1-r, Plateau Montreal



Montreal downtown
City block

The number of buildings in the study: 33

The average height of buildings: 19 m

Highest Building: 60 m

Lowest Building: 9 m

Total floor area: 100,150 m^2

Approximate block size: 160 m *150 m

Figure 4-4: Case Study two, SC2-r, Montreal downtown

4.1.2.1 Scenarios:

Different geometrical alternatives are designed to observe the effect of spatial parameters in the rest of the study. As mentioned in the literature review, spatial parameters affect radiation received, heating, and cooling demand. This study selects orientation and surface-to-volume ratio (simplification and compactness) among all spatial parameters. These parameters influence radiation and shading received on surfaces; for each of these parameters, one scenario is designed, and radiation is calculated. Geometrical simplification is selected for the surface-to-volume ratio effect because most urban scale studies consider simplified geometry.

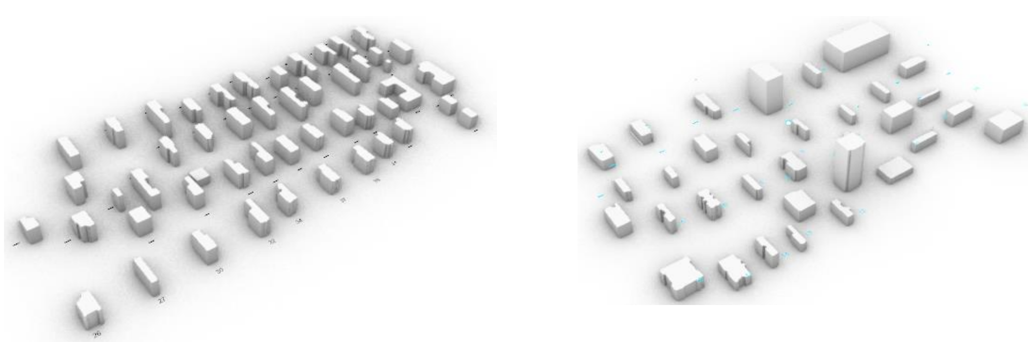
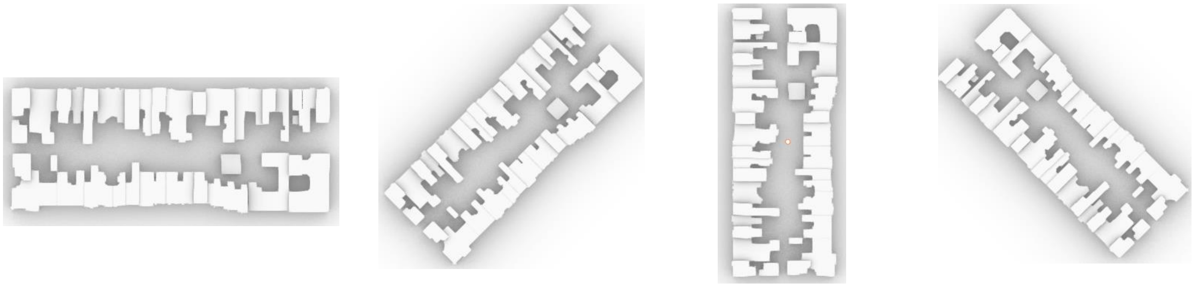
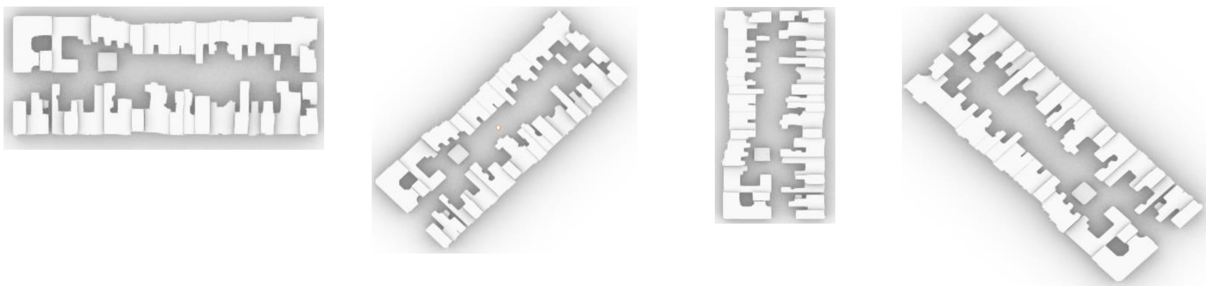


Figure 4-5: Geometrical alternatives effective on density SC1-sp and SC2-sp

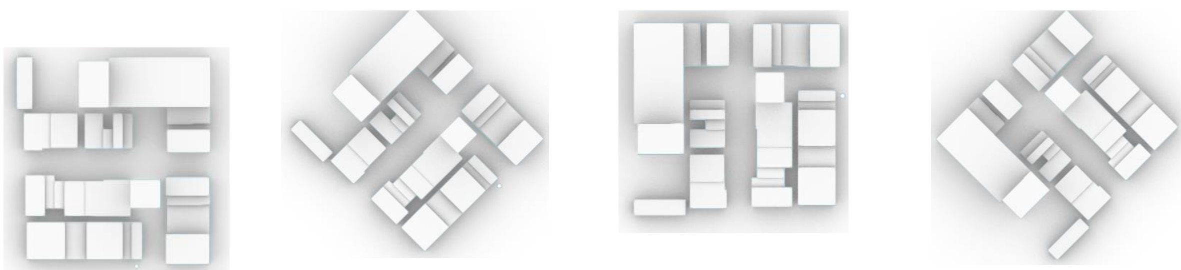


0 ° 45° 90° 135°

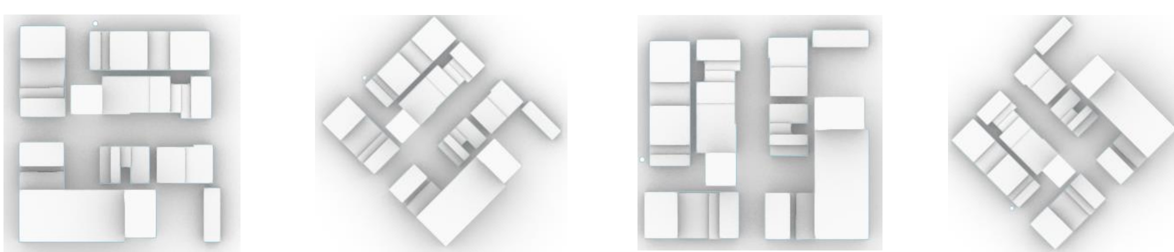


180° 225° 270° 315°

Figure 4-6: SC1-r orientation alternatives

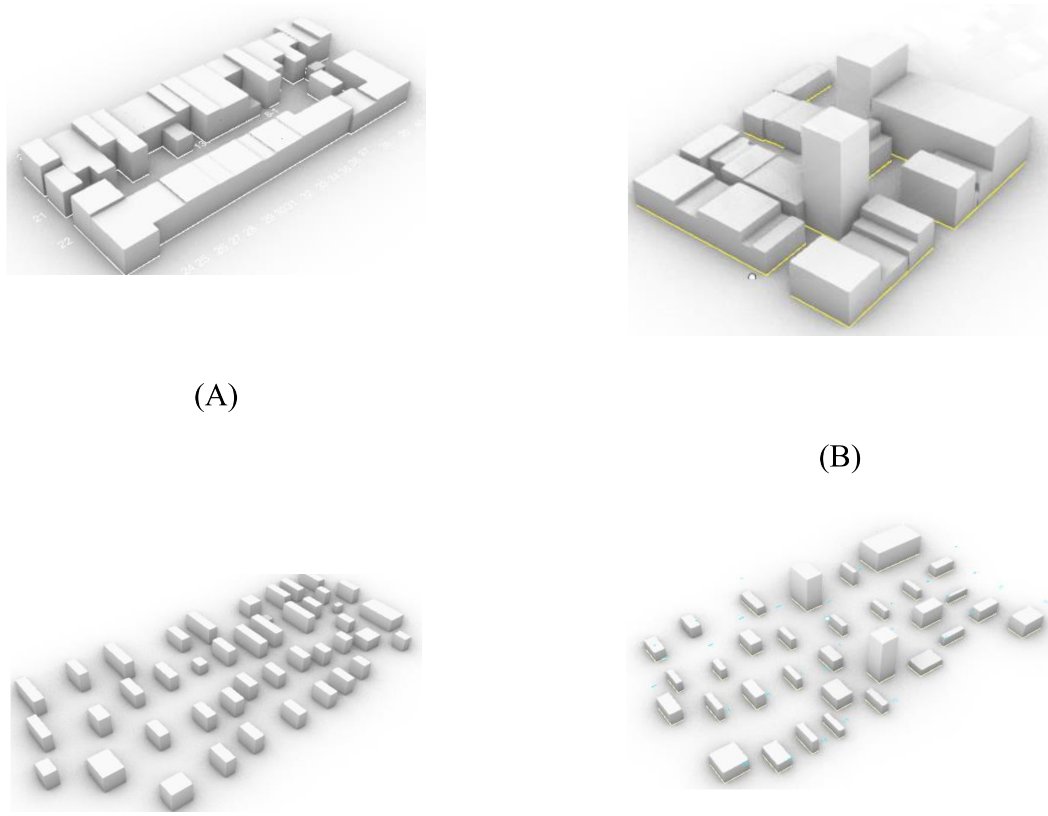


0 ° 45° 90° 135°



180° 225° 270° 315°

Figure 4-7: SC2 orientation alternatives



(A)

(B)

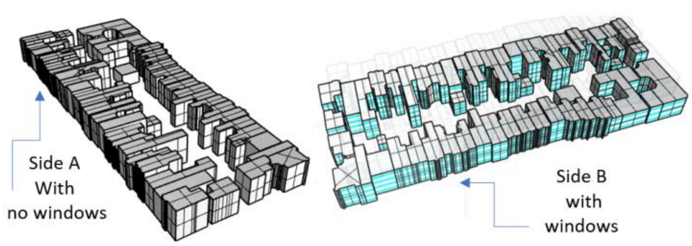
(C)

(D)

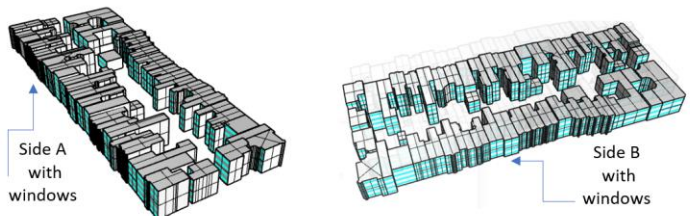
Figure 4-8: Simplified geometry effective on for SC1 & SC2: (A) SC1-s (B) SC2-s (C)SC1-sp-s (d) SC2-sp-s

4.1.2.2 Windows:

The 3D geometries extracted from the municipality of Montreal have limited data availability and do not offer window locations in buildings. As the presence of windows is effective in energy demand, to control this effect and understand the geometrical effect in future scenarios, WWR and the location of windows are considered the same for all the buildings. Two main alternatives are defined for both scenarios; Figure 4-9 shows options for scenario one, the Plateau Montreal model.



(A)



(B)

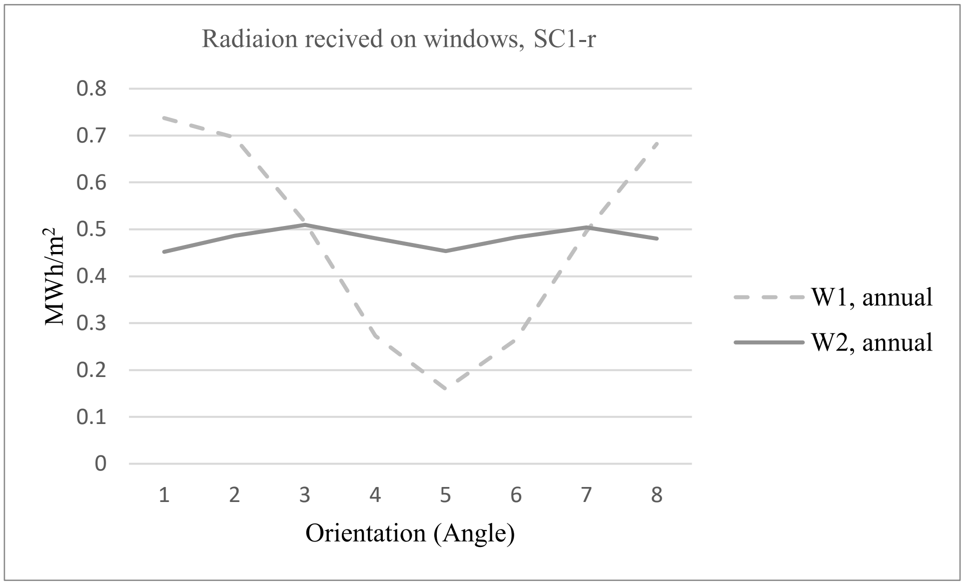
Figure 4-9: Window location alternatives: (A) one side window (B) both side windows

Windows determine energy demand for two reasons. First heat loss and second radiation received which helps heat the spaces. An uninsulated window may allow more heat loss and radiation, ultimately increasing the cooling demand in summer and heating demand in winters. There are two ways to locate windows (Figure 4-9) for the Plateau Montreal scenario; basic calculations for one side window are calculated (Table 4-1). The diagrams show the comparison between one single side window and two side windows applied in the case study. By observing the radiation received in the single-side and two-side windows scenario, although total radiation received inside the buildings is higher in the two-side scenario, the radiation changes based on orientation in the one-side window scenario are higher than in the two-side scenario.

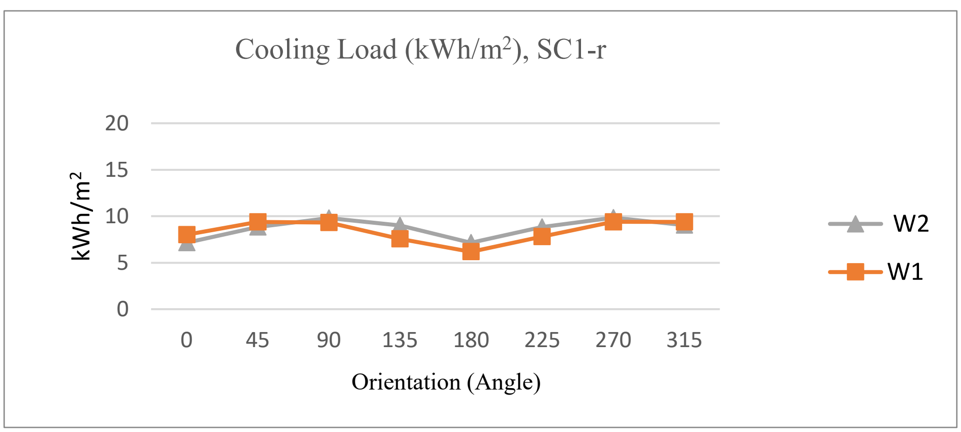
Also, heating and cooling changes show that in the single side window, there is almost a 13% (around 20 kWh/m2) difference in heating load in a different orientation. In comparison, in the two-side windows, there are almost only 1 % changes in heating loads. It can be observed that cooling loads act similarly in both scenarios.

Table 4-1: SC1-r, single and double side windows, existing situation

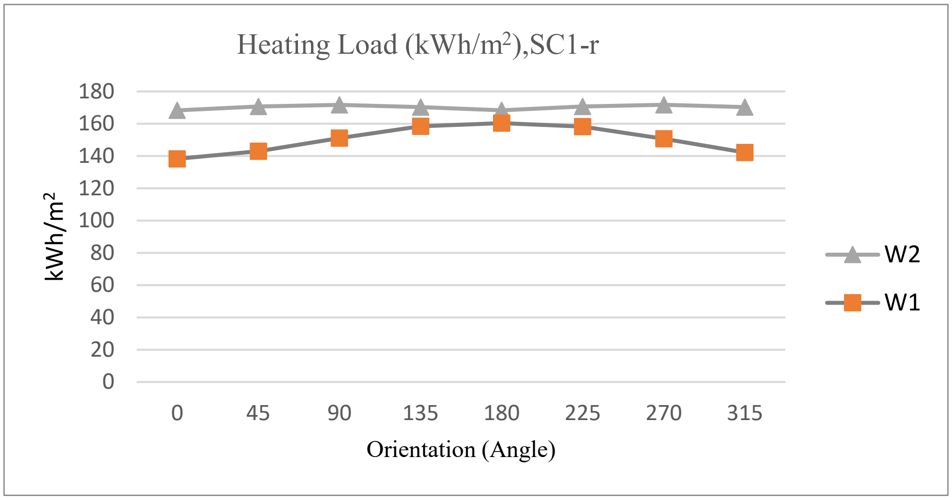
A) Radiation on windows (MWh/m2) B) Heating load (kWh/m2) C) Cooling load (kWh/m2)
W1 = single side window   W2= two side windows



(A)



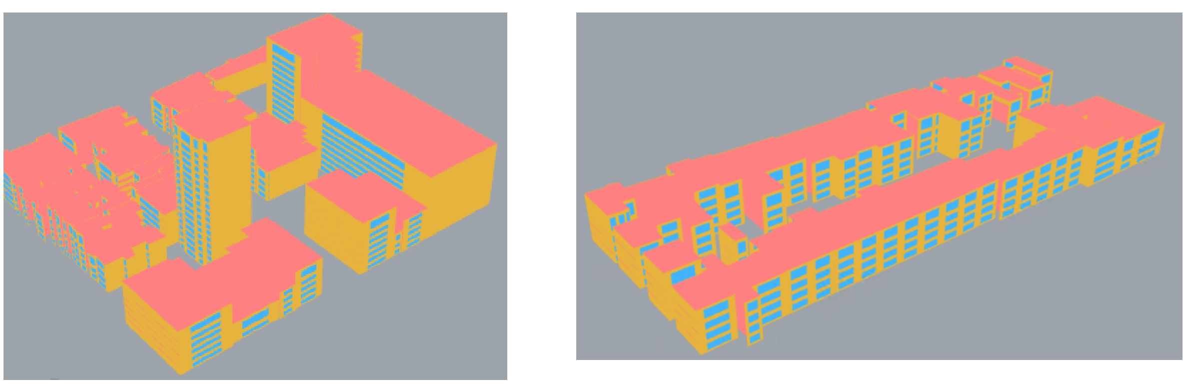
(B)



(C)

The case study here is selected to show a scenario where the windows are on the two sides of the building, as all observed real-world scenarios had the window distribution on two sides of buildings. The two side windows are closer to the existing situation.

The location of windows for both case studies is selected as shown in Figure 28; as shown in the picture in the scenario Downtown Montreal, it is not to place windows in the same direction for all windows, so some of the buildings have different orientations than others. In SC2, few buildings have windows in different orientations as the urban morphology had limitations about applying all windows in the same location for all the buildings.



(A)

(B)

Figure 4-10: window location in case studies: (A) SC2-r (B) SC1-r

4.1.2.3 Total scenarios diagram:

In total, 330 models are generated by mixing the simplification, density, and orientation; Figure 4-11 shows how the models are made from a mix of options.

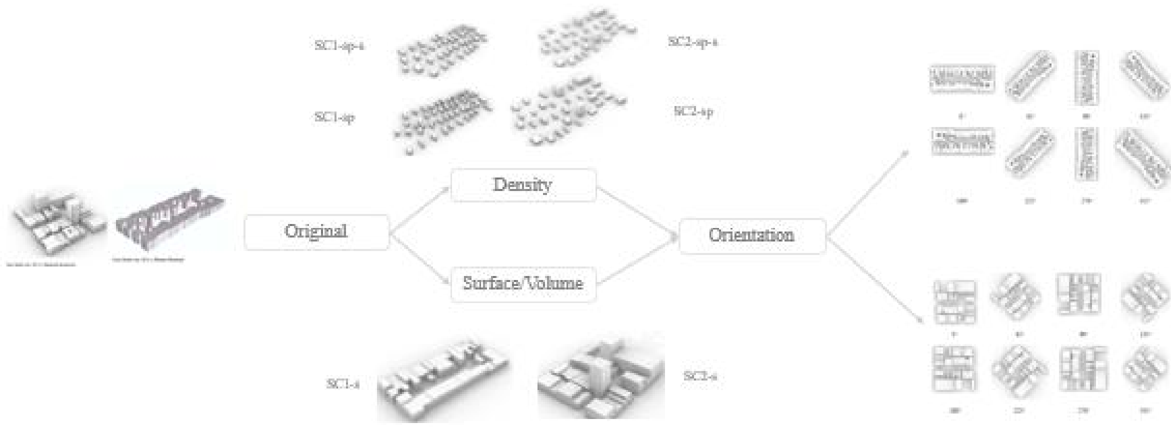


Figure 4-11: Alternative designs based on spatial parameters

4.2 Main parameter studies

The investigation of each parameter and its effect on the models are presented in the rest of the chapter.

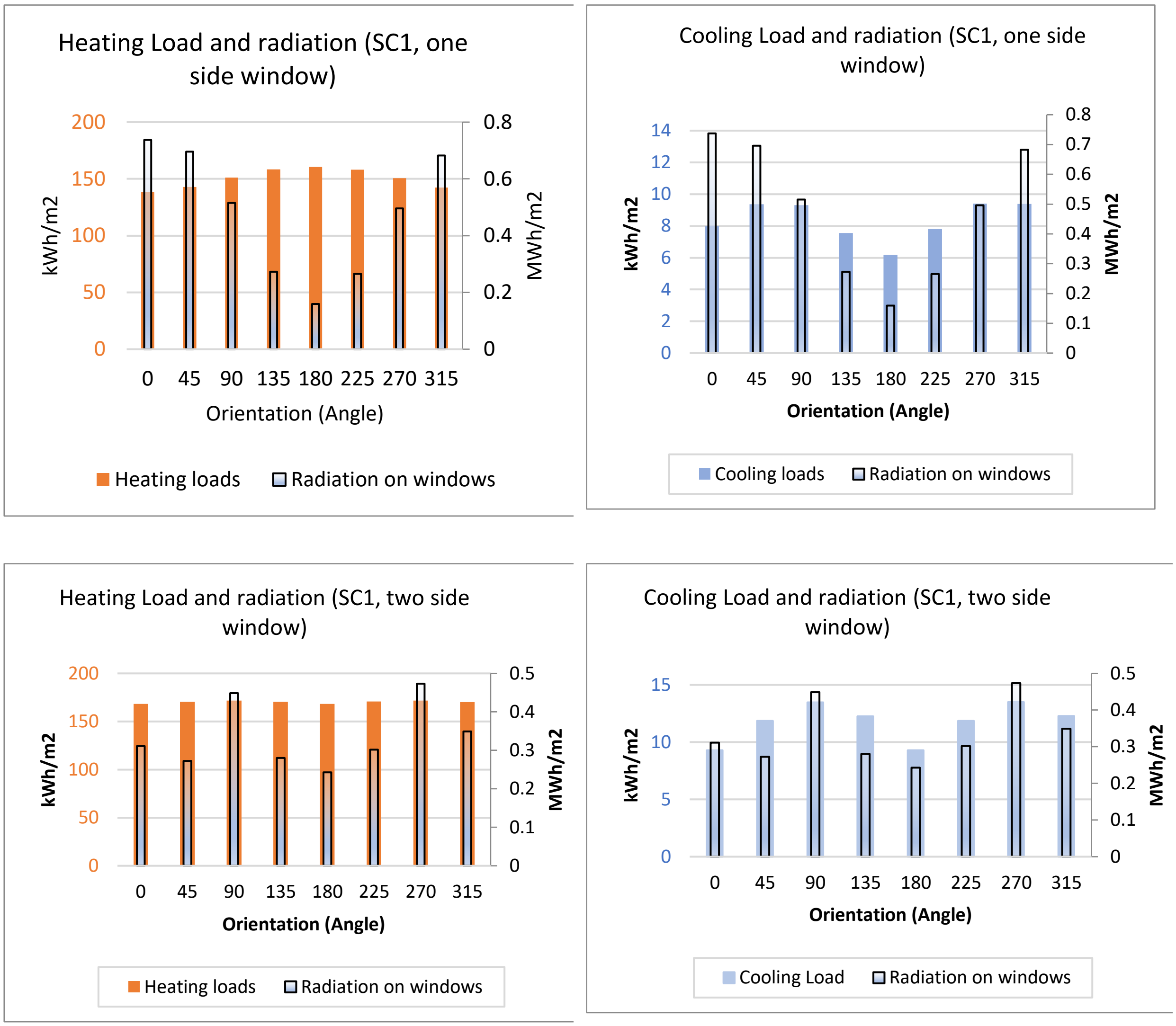
4.2.1 Orientation:

Orientation in urban design is considered a parameter that is not only important but also affects other parameters' behavior. This factor defined radiation received on buildings and shading effects on the urban scale. For example, the basic rule for the urban environmental design of a cold climate is to consider block overviewing to the south to get as much radiation as possible.

In this study, the first parameter to be overviewed is the location of the windows. As mentioned, WWR, construction, and type of windows are selected similarly in all the neighborhoods' buildings.

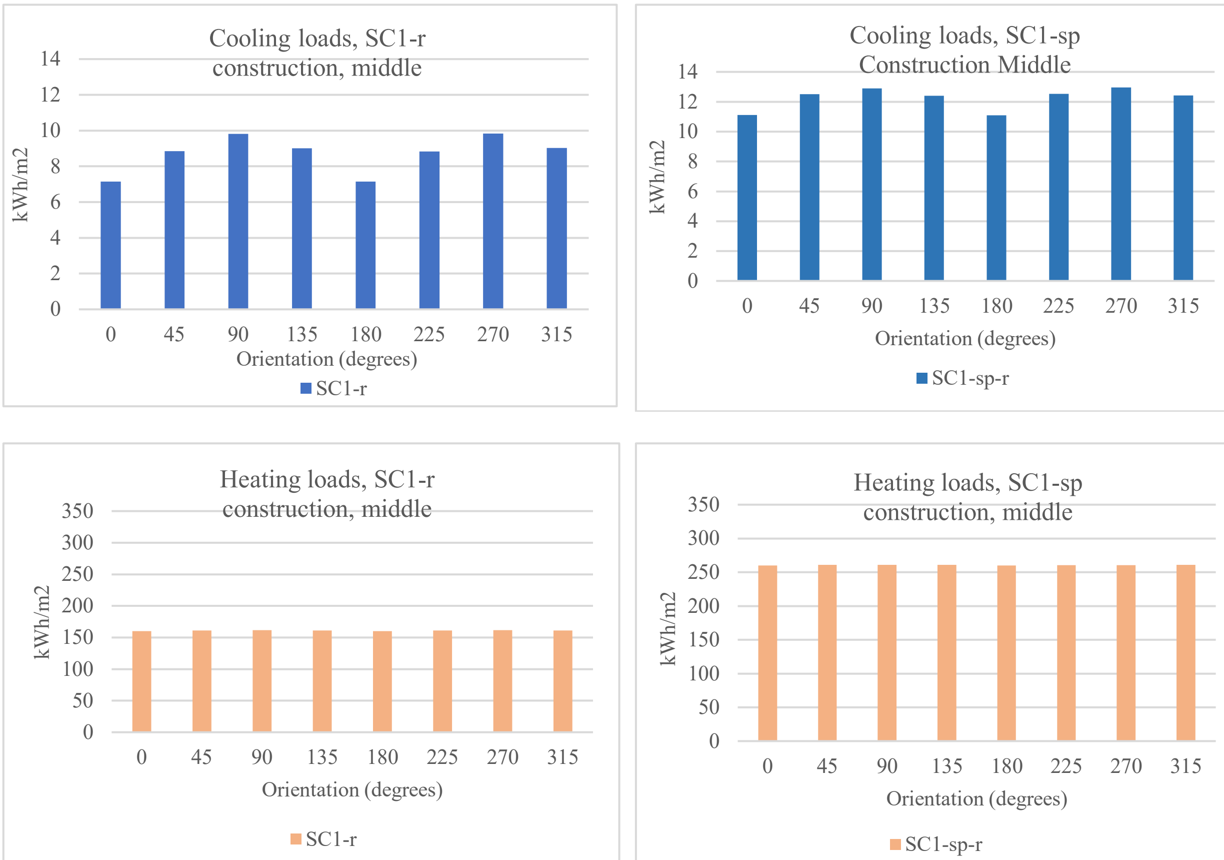
As the orientation is directly related to radiation received, limited calculations on the SC1 with a one-side window and two-side windows (Figure 4-9) are compared. Although in all the calculations for the rest of the study, two-side windows are selected as the option to proceed with, here, to observe the effect of radiation, some simulations consider one-side windows are overviewed (Table 4-2).

Table 4-2: radiation, cooling & heating demand SC1 for one-side and two-side window location



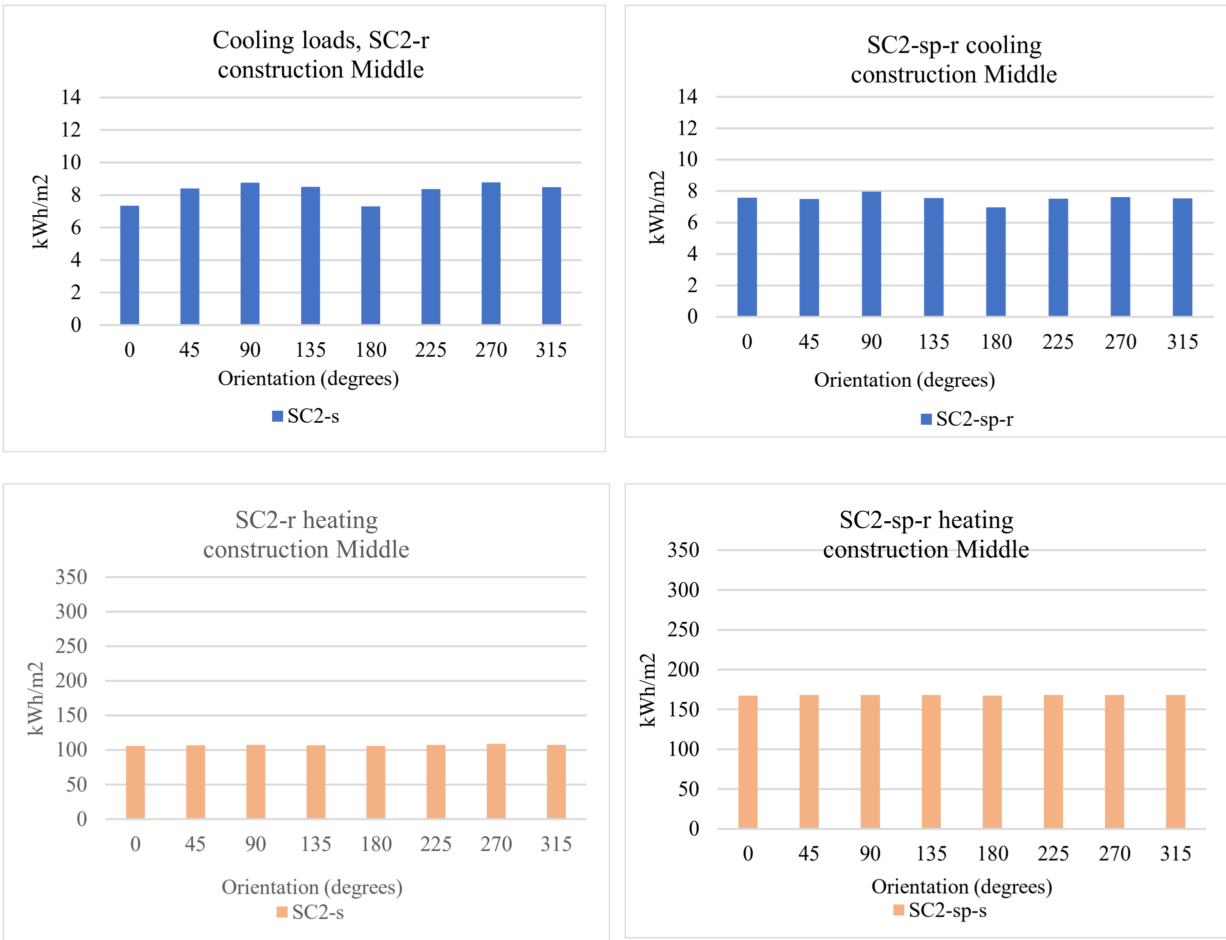
Radiation received on windows (MWh/m^2) and heating and cooling demand (kWh/m^2) are illustrated in Table 4-2. Cooling loads continue the same trend in one-side and two-side window scenarios. The cooling loads change around 36% to 34% in both scenarios. The changes observed in radiation in both cases account for around 60 to 80%; the main difference in these diagrams is in heating loads. In a two-side window scenario, changes in cooling loads are around 33%, while heating loads only change around 4% in different orientations. Considering the insulated scenario, the changes in heating loads decrease. In the one-side window scenario, the changes in cooling loads are similar to the other scenario, while changes in heating loads are almost three times more, reaching 13%.

Table 4-3: orientation, SC1



To overview the orientation, the effect works similarly in different scenarios; SC1 and SC2 in dense and sparse models are simulated, and the same construction is considered in all the models; 32 cases from the total of 160 models are calculated, presented in Table 4-3 & Table 4-4. The changes in heating loads look very similar in dense and sparse models, while the difference in cooling loads reduces in the sparse model.

Table 4-4: orientation, SC2



To conclude, orientation is more effective if there is only one side window in the building or units inside; when it comes to windows in different locations, heating loads do not see such significant changes by changing the orientation.

4.2.2 S/V:

To overview the surface-to-volume ratio, two different models are designed; "simplification" and "density."

4.2.2.1 Simplification

Simplification is a parameter that most urban studies use from it. Simulation of complex geometries is time taking. That is the main reason why urban scale simulations use simplified models. Here SC1 and SC2 are simplified (Figure 4-8). The changes in S/V of different models are between 1% to 14%, as the more the S/V changes are, the more the effect is.

The relation between simplification and construction is visible in the result table Table 7-1 & Table 7-2. Table 4-5 indicates that as the construction standards get more insulated, the effect of simplification on heating loads (that are dominating concern in this study) will get less.

For example, the final results of SC1-Dense simple & real comparison show that the simplification effect reduces as the construction gets stronger. The changes start from 9% to 7% by changing construction standards only; adding infiltration to the model reduces the effect to 4 percent.

Table 4-5: Simplification effect, comparison between SC1-dense-real and SC1-dense-simplified

type of construction	Angle	changes %	type of construction	Angle	changes %	type of construction	Angle	changes %
weak	0	9	good	0	8.70	Strong	0	8.034
weak	45	9.14	good	45	8.49	Strong	45	7.802
weak	90	9.13	good	90	8.46	Strong	90	7.803
weak	135	9.21	good	135	8.57	Strong	135	7.902
weak	180	9.34	good	180	8.69	Strong	180	7.998
weak	225	9.23	good	225	8.48	Strong	225	7.700
weak	270	9.23	good	270	8.439	Strong	270	7.66
weak	315	9.276	good	315	8.545	Strong	315	7.80
middle	0	8.851	Very Good	0	7.367	Very strong	0	7.57
middle	45	8.754	Very Good	45	8.38	Very strong	45	7.406
middle	90	8.767	Very Good	90	8.30	Very Strong	90	7.41
middle	135	8.814	Very Good	135	8.54	Very Strong	135	7.47
middle	180	8.891	Very Good	180	7.51	Very Strong	180	7.542
middle	225	8.836	Very Good	225	8.262	Very Strong	225	7.31
middle	270	8.849	Very Good	270	8.13	Very Strong	270	7.29
middle	315	8.852	Very Good	315	8.419	Very Strong	315	7.4
-	-	-	Very Strong-airtight	0	4.082	Very Strong-airtight	270	4.28

In the rest of the case studies, the changes in heating loads are different based on the simplification ratio. For example, the S/V in SC1-sparse-real is more than SC1-dense-real, which can be why simplification's effect on this model is around 11 to 15 percent.

In SC2, the same pattern can be seen in the construction and simplification, but the interesting point is the effect of orientation. Buildings in SC2 have different height levels, which is why in 90 degrees orientation, the effect is more than others for the shading effects. Without considering 90 degrees orientation, the simplification effect is between 4 to 5 percent, while considering orientation, this increases to 8 to 9 percent. For SC2 sparse models, the S/V changes to 13 percent, and the effect reaches 18% in the worst case (orientation & construction).

Table 4-6: Simplification effect, comparison between SC2-Sparse-real andSC2-Sparse-simplified

type of construction	Angl e		type of construction	Angle		type of construction	Angle	
weak	0	4.793	good	0	4.62	Strong	0	5.05
weak	45	4.588	good	45	4.27	Strong	45	4.56
weak	**90**	**8.878**	good	**90**	**8.27**	Strong	**90**	**7.80**
weak	135	4.476	good	135	4.06	Strong	135	4.30
weak	180	4.594	good	180	4.29	Strong	180	4.627
weak	225	4.504	good	225	4.13	Strong	225	4.38
weak	270	4.512	good	270	4.08	Strong	270	4.308
weak	315	4.677	good	315	4.38	Strong	315	4.691
middle	0	4.12	Very Good	0	5.60	Very Strong	0	4.745
middle	45	3.99	Very Good	45	4.84	Very Strong	45	4.367
middle	**90**	**8.487**	Very Good	**90**	**8.28**	Very Strong	**90**	**7.476**
middle	135	3.92	Very Good	135	4.46	Very Strong	135	4.167
middle	180	3.97	Very Good	180	4.99	Very Strong	180	4.416
middle	225	3.93	Very Good	225	4.58	Very Strong	225	4.231
middle	270	39.74	Very Good	270	4.40	Very Strong	270	4.177
middle	315	0.040763	Very Good	315	0.050404	Very Strong	315	4.47
-	-		Very Strong-airtight	0	0.04456	Very Strong-airtight	270	3.36

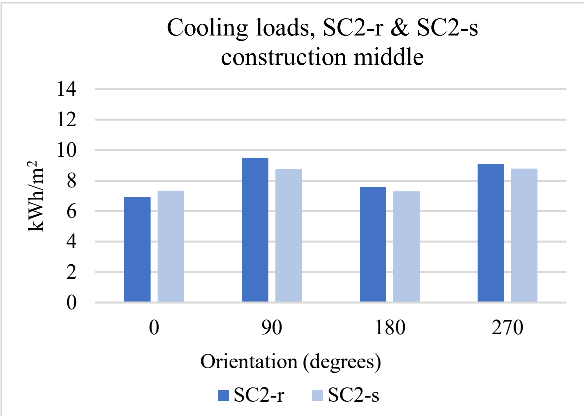
By a very strong and infiltrated construction standard, this effect gets to 4%. The trend of changes in one construction type (Middle) in different orientations is selected to illustrate.

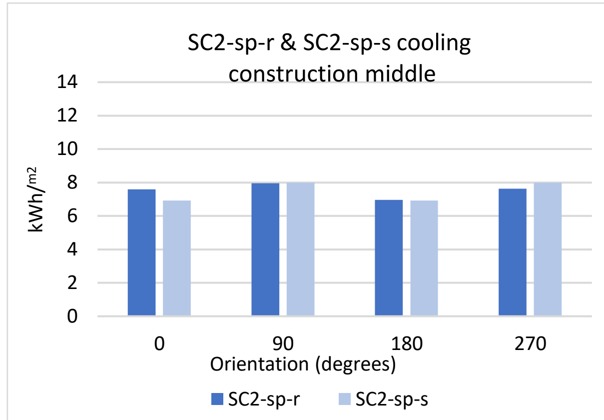
Table 4-7: S/V effect, Simplification, SC1

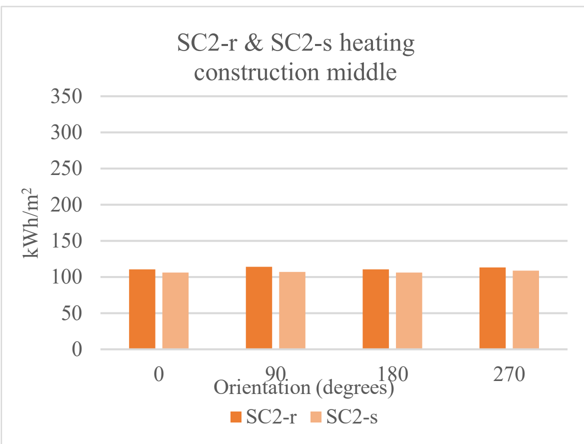
In SC1 maximum changes are in heating loads of Sparse scenarios; by simplification, S/V reduces from 0.47 to 0.4, and heating loads changes from 11 to 18 percent depending on its construction and orientation. For SC2, more changes occur in dense scenarios shown in Table 4-8, reaching 14%.

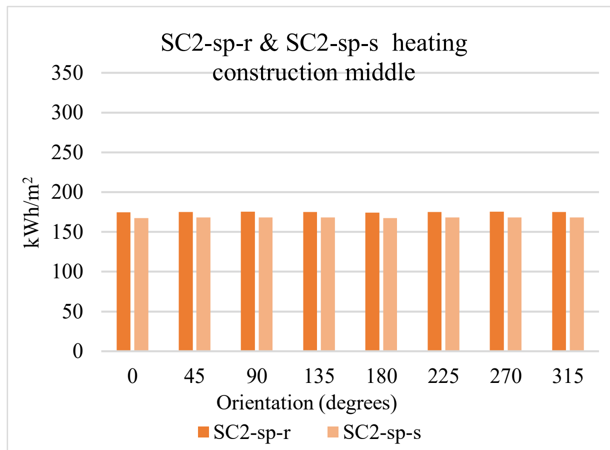
In total, if simplification does not make big changes in S/V, which in most neighborhoods is the same case, and due to that, heating and cooling loads will not face significant changes. Besides, the changes are more if the construction standard used in that neighborhood is not well insulated.

Table 4-8: S/V effect, Simplification, SC2









4.2.2.2 Density

Density is known as the most important parameter in urban environmental design. This parameter is mainly known as the most important one for two reasons: first, the radiation received, and then the area of the surfaces in contact with the outside (S/V). Here the buildings in two scenarios are attached and detached, and S/V changes in designed scenarios.

In comparison to sparse and dense scenarios in real geometries, ignoring what material and orientation each model is in, all the options show changes in heating loads between 36 to 39 percent when S/V is changed from 0.26 to 0.47. When adding a good infiltration rate to the model, heating loads decrease to less than 30 kWh/m^2 and decrease the density effect to 25%. Two types of constructions and four significant orientations are illustrated (32 cases) in Table 4-9 & Table 4-10 as a sample of all the models (160 cases) that are compared (Table 7-1 & Table 7-2).

Table 4-9: S/V effect, Density, SC1

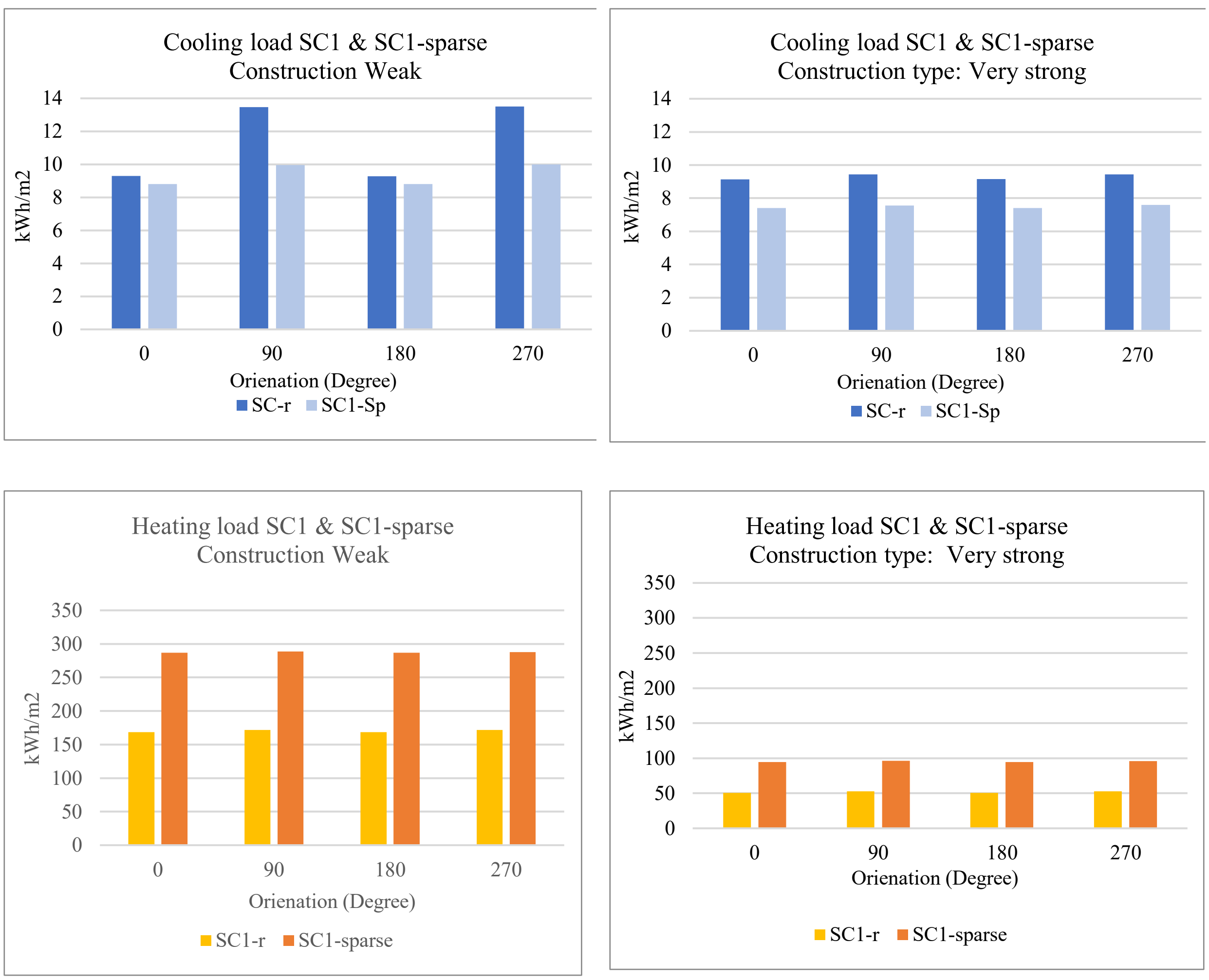
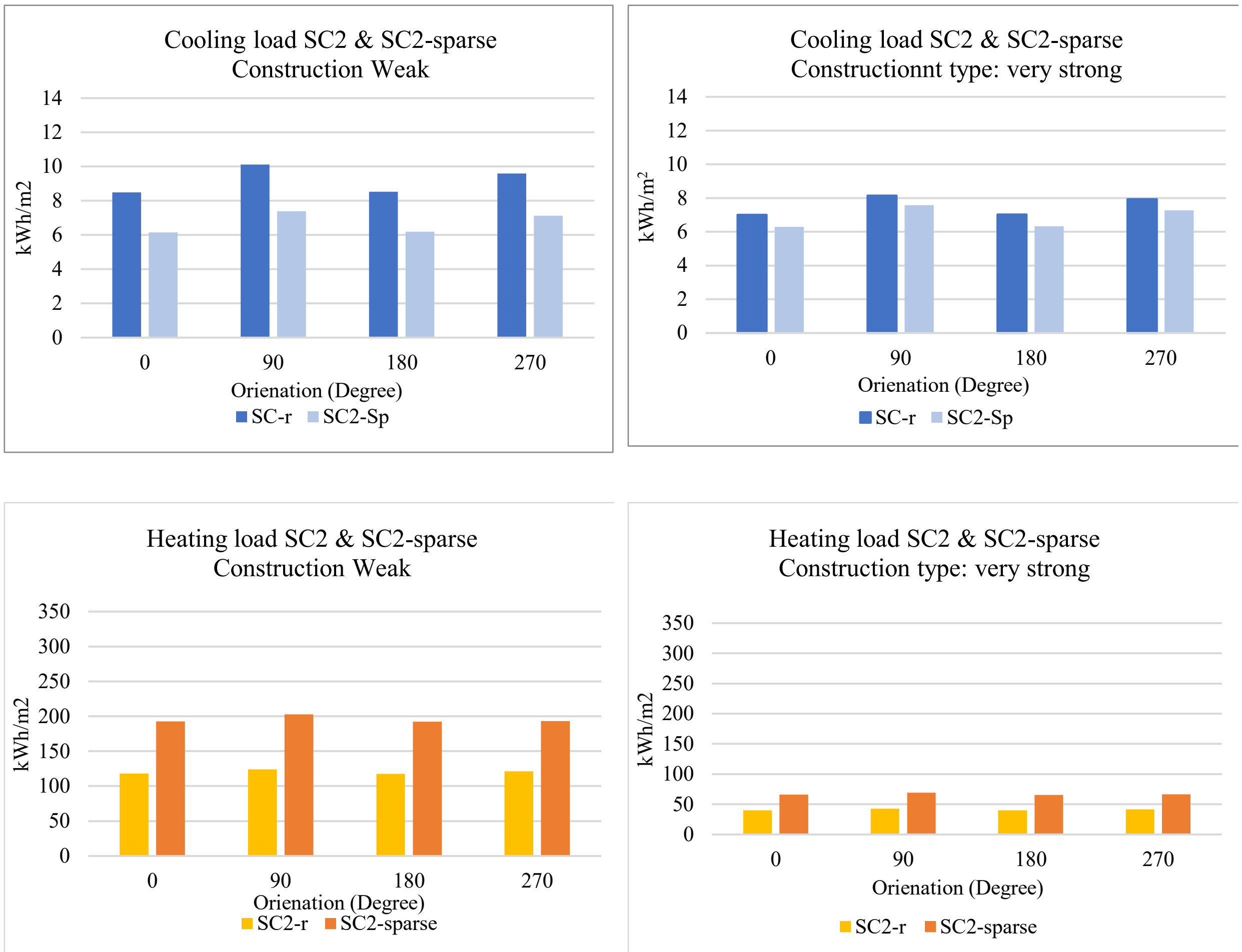


Table 4-10: S/V effect, Density, SC2



As the diagrams show, the density effect is less when the construction standards are more insulated. Also, as mentioned in S/V (Simplification) section, the orientation can increase this effect; at 90 degrees orientation, the density effect is a bit more, not so huge that it affects the calculation or design. In total, detached or attached buildings in a neighborhood is a very important design option for urban environmental design as this can affect energy consumption by 40%. However, this effect can be reduced to 20% by a smart choice of construction and infiltration rate.

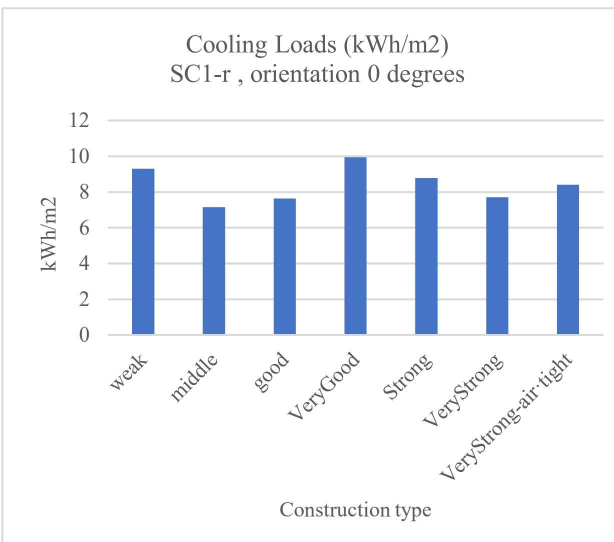
4.2.3 Construction:

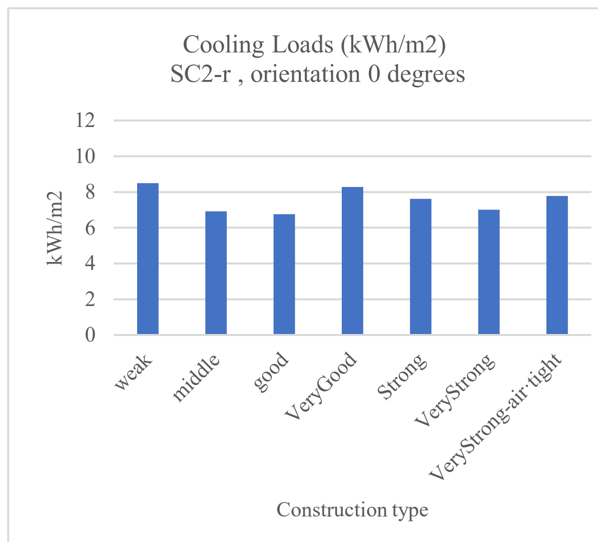
Construction standards are a parameter that is considered after building a neighborhood and urban design. Here the study observed construction standard effects and saw if this parameter can influence morphological parameters, measuring all the scenarios using defined construction scenarios that are introduced in the Methodology chapter in Table 3-2.

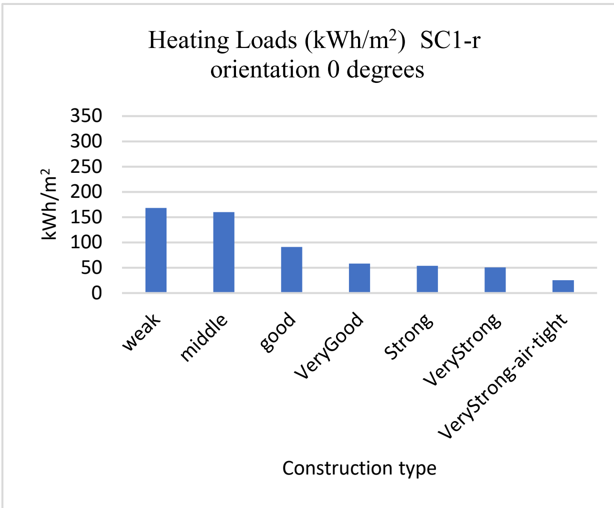
All the construction standards are taken from the Ladybug tools construction standards section. They are based on ASHRAE standards or inspired by them with minor modifications. What I didn't consider in the calculation is that the g-value of the buildings is not increasing linear, which caused ups and downs in cooling results; type of gas and solar transmittance of the glasses are different.

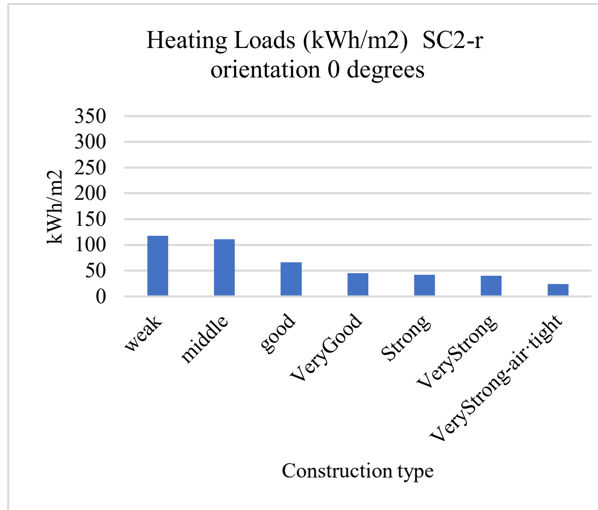
Table 4-11 shows the construction effect on heating and cooling loads; there are changes in cooling loads around 2 kWh/m^2 in both scenarios depending on what type of construction is used; what is noticeable here is that cooling loads are extremely dependent on total energy transmittance of the windows, on the other side, heating loads that are dominated in total energy consumption changes significantly. SC1 & SC2 heating loads decrease from 168 to 25 kWh/m^2 and from 117 to 24 kWh/m^2, almost up to an 85 % reduction in heating loads.

Table 4-11: Construction, SC1 & SC2 dense



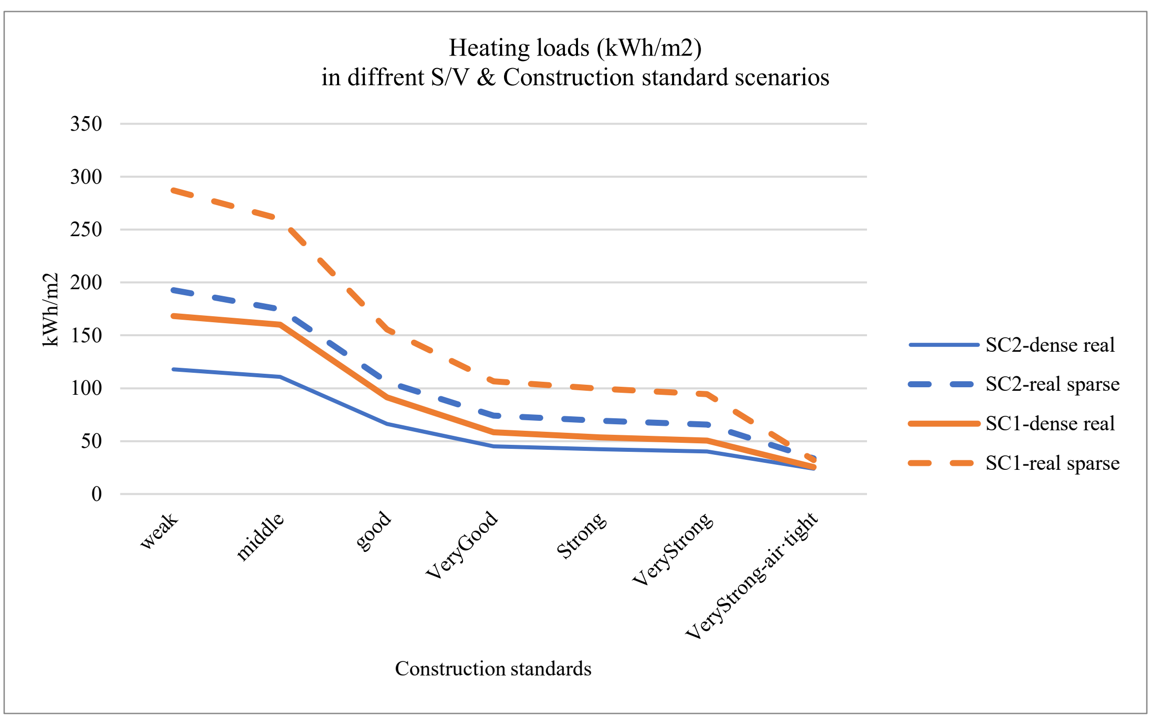






Among the morphological parameters, S/V (compactness) had a higher effect on cooling and heating demands; therefore, a comparison between S/V and construction standards is presented in Table 4-12. The construction standard can significantly decrease the heating loads, and infiltration plays an important role after a specific amount of load reduction. If more insulated standards are used in one building, a better infiltration rate will be defined most of the time.

Table 4-12: Construction, SC1 & SC2 dense

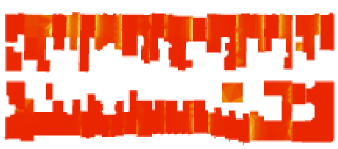


4.2.4 Renewable energy generation:

Part of urban environmental design is to maximize the chance of using renewable energy sources like installing solar panels and wind turbines. In this study, radiation is considered as the source of producing renewable energy. Urban design effect on radiation received on the roofs of each building, the radiation received on the roof of all scenarios are calculated (Table 7-4). However, here Table 4-13 & Table 4-14 only show the radiation received for SC1 & SC2 dense scenarios. An approximate evaluation of PV potential was calculated based on the radiation data for all the scenarios; about 10,000 MWh of roof solar irradiance approximately produces 1500 MWh of electricity.

Radiation received on the roof is very helpful in understanding the solar potential and how much energy from renewable energies can be produced. Table 4-13 shows radiation on the roofs in different orientations for SC1-r, and Table 4-14 shows radiation on the roof for SC2, where buildings' heights are different.

Table 4-13: Radiation received on roofs in different orientations, SC1-r

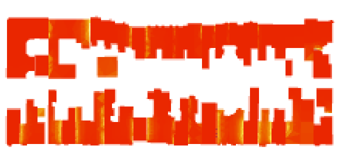


0 °
9436.2 MWh

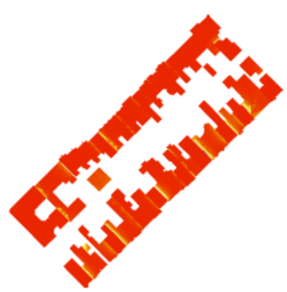
45°
9454.9 MWh

90°
9471.8 MWh

135°
9447.3 MWh



180°
9429.9 MWh

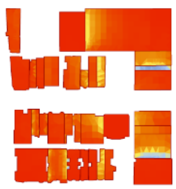


225°
9452.7 MWh

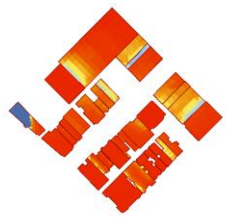
270°
9478.5 MWh

315°
9456.1 MWh

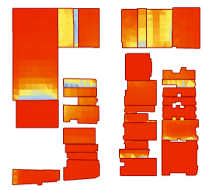
Table 4-14: Radiation received on roofs in different orientations, SC2



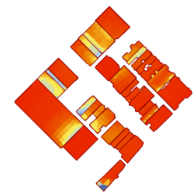
0 °
18287 MWh



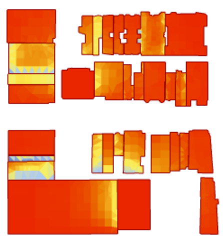
45◦
17628 MWh



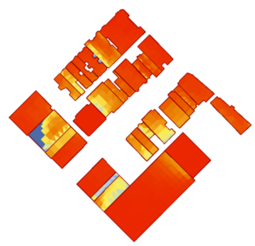
90◦
17814 MWh



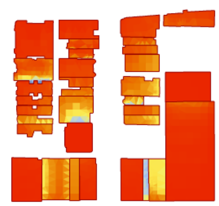
135◦
17381 MWh



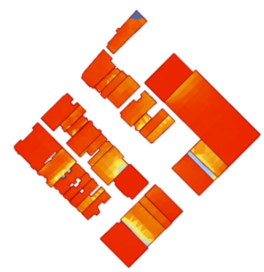
180◦
17410 MWh



225◦
17464 MWh

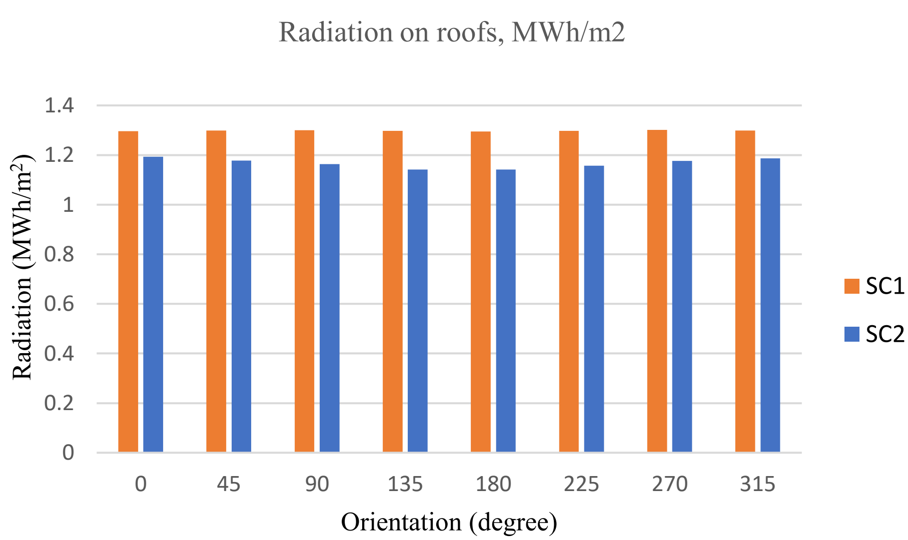


270◦
17464 MWh



315◦
18095 MWh

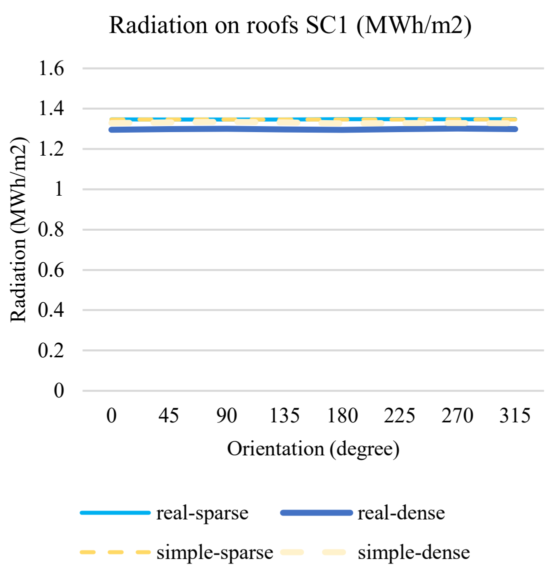
Table 4-15: Radiation comparison SC1 & SC2



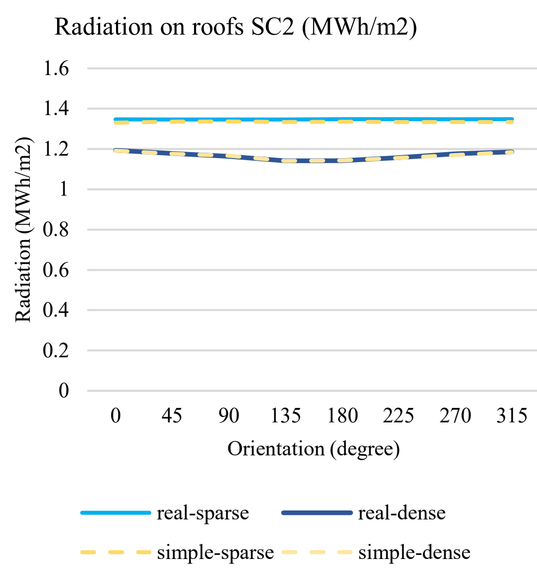
Radiation received on different morphological alternatives shows the scenario with similar heights receives almost 8 percent more than another one with different building heights; the radiation calculated (Table 4-15) shows that for SC1, all the buildings have similar heights, and there are no significant changes, around 3%, while in SC2, that there is a bit of height difference between buildings, there is the difference around 10% between dense and sparse model.

Table 4-16: Radiation received on roofs (MWh/m2)

(A) SC1-r, SC1-sp, SC1-s, SC1-s-sp (B) SC2, SC2-sp, SC2-s, SC2-s-sp



(A)



(B)

Radiation on the roof of different scenarios is calculated; sparse and dense models are compared; Table 4-16 shows that there are not many changes in radiation received on roofs in SC1 & SC1-sp while this radiation on SC2 & SC2-sp changes around 17%.

After automatically calculating the radiation of all models using Ladybug tools and heating and cooling of all 330 models, 6 top models are selected as a highlight to be presented here; the models are selected based on best and worst parameters.

The radiation received in the dense neighborhood scenarios oriented to 270 degrees is the lowest radiation on the roofs. By adding the weakest construction to the selected geometries and calculating energy generation and heating and cooling loads, both SC1-r & SC2 renewables can cover almost 0.6 times of energy loads.

By orienting the neighborhoods to 0 degrees, the radiation on the roofs became maximized. Adding the weakest construction standard to calculate heating and cooling loads, SC1-r and SC2-r can cover 0.4 times their energy needed from renewable sources; this can be increased by 1.5 & 0.9 for both scenarios. This table shows the importance of construction standards.

Table 4-17, renewable energy generation calculations

Title	Orientation	Construction	Density	Cooling (kWh)	Heating (kWh)	Energy needed (kWh)	Radiation on roofs (MWh)	PV potential (MWh)	Energy needed/ renewable potential	Cooling (kWh)	Heating (kWh)	Energy needed (kWh)	Radiation on roofs(MWh)	PV potential (MWh)	Energy needed/ renewable potential
Scenario				SC1						SC2					
Worst orientation + Dense+ worst construction	270	Weak	dense	13.49	171.75	2206643.73	9813.5	1472025	0.667	9.60	121.378	5362527.28	20823	3123450	0.58
Worst orientation +Dense + Best construction	270	very strong	dense	9.96	52.65	1095909.70	9813.5	1472025	1.343	7.93	41.743	3313039.931	20823	3123450	0.94
Best orientation +Sparse + worst construction	0	Weak	spare	10.0	287.97	3242956.001	9808	1471200	0.454	6.15	192.71	7033495.928	20768	3115200	0.44
Best orientation + Sparse + Best construction	0	very strong	spare	8.12	95.88	1477693.74	9808	1471200	0.996	6.29	65.739	3859077.60	20768	3115200	0.80
Best orientation + Dense + Best construction + airtight	0	very strong/i	dense	10.95	27.97	877467.46	9808	1471200	1.677	7.23	33.72	3088628.77	20768	3115200	1.00
Best orientation + Sparse + Best construction + airtight	0	very strong/i	spare	10.79	35.2	942346.20	9808	1471200	1.561	8.096	34.06	3126051.52	20768	3115200	0.9965

Chapter 5: Conclusion & Future work

This thesis investigates the impact of urban form on energy demand and puts it in relation to changes in building construction standards. Environmental urban design helps to reduce energy consumption and Co2 emissions as one of the first stages of decarbonizing the building sector to establish an efficient urban development infrastructure and design.

In chapter two, by overviewing the previous studies, orientation and surface-to-volume ratio (S/V) are selected as the most important morphological parameters to investigate. While overviewing the definition of multiple urban morphological parameters in chapter two, it is observed that many of the parameters are related, or some can be considered as a subgroup of others. Here, geometrical simplification and density are selected as subgroups of S/V. For simplifications, real geometries are changed in cubic shapes. I consider attached buildings to be detached to define density scenarios, so the neighborhood becomes sparse. For orientation, all case studies are also overviewed in eight different orientations.

Two real neighborhoods in Montreal, Canada, are selected as the case studies. The main difference between the neighborhoods is the building heights. One of them (SC1) has buildings with similar heights, while the second scenario (SC2) has buildings with different heights. Four different morphology models out of each scenario are developed (Real, Sparse, Simple & real, Simple & sparse), and energy demand in each of these models is investigated in eight different orientations.

On the other side, five different construction standards are defined. The construction standards are default material standards defined in Urbanopt/Ladybugtools, a tool that NREL approved. These construction standards are applied to all the geometries that are designed. To run the energy simulations, a software workflow is developed. The geometry of buildings is modified using Rhino and imported to Grasshopper; the energy simulation for the buildings is completed using a combination of plugins of Ladybugtools; this tool uses OpenStudio, EnergyPlus, and Radiance as backend engines. In total, energy consumption in more than 330 models is calculated. In addition, renewable energy generation for each scenario is calculated to see how energy demand can be covered.

After running all the simulations, the results show the same pattern in all the scenarios. SC1 and SC2 in dense and sparse models are simulated. Maximum yearly cooling loads are observed when neighborhoods are oriented towards 90 or 270 degrees, and minimum cooling loads are at 0 and 180 degrees. Heating loads do not change much if the building has windows on both sides, and if the buildings have one-side windows, heating loads are highest at 180 degrees and minimum at 0 degrees. Overall, window locations highlight the importance of orientation as a parameter in urban design. In the models with two-sided windows, heating loads do not see significant variation by changing the orientation, while the change in heating loads in the one-sided windows can vary up to 34%.

The simplification of geometries shows that parameters can impact each other's influence. For example, the effect of simplifying the geometries (simplification) increases by 3 to 4 percent if the model is oriented toward 270 degrees (orientation). In this study, the surface-to-volume ratio changes up to 13% by simplifying the geometries, and heating and cooling loads don't face significant changes. Simplifying the geometries is only effective when the buildings are not well insulated by 16%.

The next step is to compare the models when S/V changes significantly. The sparse scenarios are developed by changing the density by turning attached buildings into detached models. When the surface-to-volume ratio changes around 44%, heating loads change around 38%. Density's effect is influenced by orientation; for example, this parameter is more influential on heating loads if the neighborhood is oriented toward an angle that causes less radiation on the buildings (like 90 & 270 degrees). Furthermore, if a stronger construction standard is applied, the difference between dense and sparse heating loads reduces to 20%.

Changing the construction standards in different scenarios decreases heating loads up to 70% & 85% in different case studies. A comparison between scenarios with different S/V (density, as it is the most effective morphological parameter) and construction standards show that regardless of the morphological feature, all neighborhoods can reach a heating demand of less than 40 kWh/m2, by changing the construction type. Moreover, calculating the renewable energy potential shows the construction standard's importance. The radiation received on the roofs of the neighborhoods with the best orientation along with dense and sparse models can not cover more than 0.6 times the energy needed. On the other hand, if the best construction standard (beyond the energy codes) is used, and the neighborhoods are oriented toward an angle with minimum radiation in both dense and sparse scenarios, 0.9 to 1.5 times of energy will be possibly covered by renewable sources. Comparing the results of scenario one (Plateau Montreal) and scenario two (Downtown Montreal), shows the importance of S/V and compactness, as the results of heating loads in downtown scenario is always around 30% less than Plateau scenario.

This study compares the effect of construction standards and morphological parameters on the urban scale. Other morphological parameters can be studied, and their effect on each other might give new results. Although they are not known as effective as Surface-to-volume ratio, density, or orientation based on the literature review, it is good to overview some of them in future studies.

At first, UMI tools were used, which is a tool developed by MIT sustainable design lab in this study. Although this tool had many positive points, some limitations, such as the definition of adjacencies and the chance of getting different results in every run, were not a match for this study. So, choosing the best tool matching this study's requirements along the way became a challenge. This study used UMI and Ladybug tools, inspiring a study to compare different software tools in the future. Urban energy modelling software has limits and merits; users can share their experiences with other energy modelers to select the best tool based on their requirements. Also, this thesis's results and conclusions are limited to Montreal's weather data. Further studies can be conducted later by examining these parameters in other climate zones.

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Appendices

Table 7-1: Appendices - Scenario one , results

		SC1							
type of construction	Orientation	real-dense		real-sparse		Simple-dense		Simple-sparse	
	degree	cooling	heating	cooling	heating	cooling	heating	cooling	heating
weak	0	11.105	168.279	10.292	287.037	8.963	153.905	8.309	244.020
weak	45	12.508	170.632	11.869	288.399	11.566	156.328	9.395	245.483
weak	90	13.459	171.716	12.892	288.556	13.111	157.339	9.742	245.458
weak	135	12.401	170.352	12.244	288.221	11.909	155.978	9.373	245.272
weak	180	11.102	168.351	10.284	287.004	8.977	153.957	8.309	244.020
weak	225	12.520	170.728	11.869	288.078	11.591	156.288	9.395	245.483
weak	270	13.499	171.759	12.952	287.978	13.160	157.235	9.742	223.337
weak	315	12.432	170.315	12.270	287.933	11.928	155.857	9.373	245.272
middle	0	8.805	160.000	7.150	260.160	10.499	146.994	6.972	244.020
middle	45	9.693	161.277	8.844	260.867	12.200	148.295	8.669	223.465
middle	90	9.960	161.660	9.815	260.913	12.693	148.630	9.609	223.337
middle	135	9.690	161.027	9.012	260.920	12.094	147.983	8.807	223.451
middle	180	8.803	160.048	7.147	260.140	10.499	146.978	6.961	222.718
middle	225	9.701	161.320	8.828	260.643	12.200	148.222	8.662	223.465
middle	270	10.002	161.681	9.839	260.509	12.693	148.536	9.641	245.458
middle	315	9.715	161.005	9.035	260.710	12.094	147.911	8.839	223.451
good	0	7.629	91.449	7.194	155.642	7.491	84.127	7.197	132.194
good	45	9.881	93.645	8.887	157.029	9.751	86.316	9.050	133.714
good	90	11.369	95.007	9.956	157.821	11.181	87.591	10.101	134.375

good	135	10.345	93.503	9.086	156.914	10.182	86.122	9.227	133.581
good	180	7.628	91.441	7.198	155.626	7.498	84.124	7.197	132.194
good	225	9.885	93.602	8.905	156.771	9.756	86.283	9.050	133.714
good	270	11.397	94.938	10.006	157.323	11.193	87.549	10.101	134.375
good	315	10.373	93.452	9.093	156.658	10.192	86.094	9.227	133.582
VeryGood	0	9.940	58.274	8.875	106.472	9.658	53.555	8.919	89.106
VeryGood	45	13.331	61.850	11.849	109.321	13.062	57.067	12.058	92.085
VeryGood	90	15.817	64.294	13.981	111.490	15.450	59.361	14.121	93.985
VeryGood	135	14.019	61.669	12.253	109.170	13.693	56.814	12.558	91.908
VeryGood	180	9.933	58.205	8.869	106.452	9.660	53.506	8.919	89.107
VeryGood	225	13.354	61.731	11.856	108.989	13.066	57.019	12.058	92.085
VeryGood	270	15.868	64.159	14.070	110.857	15.452	59.331	14.121	93.986
VeryGood	315	14.010	61.612	12.287	108.834	13.677	56.828	12.558	91.908
Strong	0	8.783	53.605	7.312	99.561	8.656	49.619	7.591	83.855
Strong	45	10.605	55.703	8.805	101.197	10.497	51.672	9.188	85.543
Strong	90	11.629	56.873	9.709	102.163	11.459	52.756	10.023	86.352
Strong	135	11.110	55.573	9.082	101.084	10.973	51.503	9.492	85.423
Strong	180	8.786	53.565	7.312	99.539	8.659	49.598	7.591	83.855
Strong	225	10.621	55.622	8.816	100.949	10.500	51.645	9.188	85.543
Strong	270	11.661	56.780	9.764	101.715	11.463	52.735	10.023	86.352
Strong	315	11.126	55.525	9.109	100.842	10.963	51.503	9.492	85.423
VeryStrong	0	7.713	50.419	6.252	94.483	7.663	46.870	6.574	79.844
VeryStrong	45	9.132	51.918	7.399	95.595	9.101	48.338	7.795	81.001
VeryStrong	90	9.931	52.731	8.085	96.215	9.845	49.092	8.438	81.519
VeryStrong	135	9.439	51.799	7.563	95.470	9.376	48.196	8.026	80.878
VeryStrong	180	7.719	50.388	6.246	94.464	7.666	46.854	6.574	79.845
VeryStrong	225	9.150	51.854	7.400	95.409	9.107	48.317	7.795	81.001
VeryStrong	270	9.960	52.659	8.129	95.882	9.848	49.077	8.438	81.519
VeryStrong	315	9.436	51.763	7.599	95.294	9.366	48.196	8.026	80.878

Table 7-2: Appendices - Scenario two , results

		SC2							
type of construction	Orientation	real-dense		real-sparse		Simple-dense		Simple-sparse	
	degree	cooling	heating	cooling	heating	cooling	heating	cooling	heating
weak	0	8.491	117.862	6.156	192.710	8.535	99.802	6.923	183.472
weak	45	9.397	118.684	6.902	193.511	9.768	100.293	7.720	184.631
weak	90	10.124	124.048	7.382	202.687	10.199	100.305	7.997	184.692
weak	135	9.449	118.252	7.001	193.144	9.810	100.257	7.759	184.499
weak	180	8.533	117.419	6.198	192.314	8.534	99.873	6.923	183.478
weak	225	9.421	118.844	6.906	193.342	9.768	100.561	7.719	184.634
weak	270	9.601	121.378	7.130	193.420	10.199	101.677	7.997	184.692
weak	315	9.394	119.054	6.913	193.548	9.810	100.430	7.760	184.496
middle	0	7.385	110.630	6.961	174.702	7.333	106.062	6.021	167.498
middle	45	8.733	111.042	7.503	175.130	8.407	106.978	6.720	168.131
middle	90	9.514	113.913	7.964	175.634	8.759	107.164	6.944	168.049
middle	135	8.858	110.762	7.566	174.929	8.500	106.916	6.792	168.058
middle	180	7.598	110.360	6.960	174.432	7.300	106.121	6.020	167.502
middle	225	8.705	111.197	7.521	175.016	8.362	107.317	6.704	168.132
middle	270	9.099	113.274	7.631	175.505	8.788	108.811	6.958	168.049
middle	315	8.746	111.309	7.530	175.198	8.486	107.175	6.768	168.056
good	0	6.764	66.278	6.540	105.880	6.646	60.124	6.645	100.982
good	45	7.835	67.124	7.521	106.629	7.864	61.029	7.645	102.075

good	90	8.566	70.267	8.471	111.777	8.510	61.430	8.028	102.530
good	135	8.026	66.804	7.685	106.319	8.022	60.991	7.805	101.999
good	180	6.774	65.900	6.564	105.520	6.646	60.138	6.633	100.986
good	225	7.825	67.080	7.533	106.476	7.864	61.128	7.632	102.077
good	270	8.255	68.800	8.006	106.891	8.510	62.145	8.068	102.530
good	315	7.937	67.294	7.627	106.670	8.022	61.070	7.803	101.996
Very Good	0	8.279	45.195	7.982	74.115	8.158	41.219	8.024	69.960
Very Good	45	10.013	46.730	9.750	75.479	10.222	42.762	9.637	71.823
Very Good	90	11.281	49.409	10.706	79.534	11.374	43.614	10.288	72.948
Very Good	135	10.326	46.315	10.062	75.106	10.596	42.696	9.974	71.756
Very Good	180	8.306	44.736	8.019	73.643	8.158	41.223	8.023	69.965
Very Good	225	10.009	46.588	9.767	75.278	10.222	42.797	9.635	71.825
Very Good	270	10.760	48.458	10.641	76.305	11.375	44.062	10.380	72.947
Very Good	315	10.251	46.828	9.996	75.561	10.597	42.726	9.975	71.753
Strong	0	7.622	42.287	7.009	69.230	7.488	38.983	7.238	65.734
Strong	45	8.558	43.124	7.908	70.062	8.374	39.837	8.310	66.866
Strong	90	9.075	44.993	8.707	73.057	8.573	40.189	8.760	67.356
Strong	135	8.773	42.875	8.121	69.805	8.551	39.800	8.528	66.799
Strong	180	7.645	41.995	7.037	68.927	7.485	38.985	7.237	65.737
Strong	225	8.561	43.042	7.919	69.933	8.372	39.861	8.310	66.868
Strong	270	8.806	44.237	8.269	70.388	8.609	40.547	8.761	67.356
Strong	315	8.680	43.199	8.066	70.085	8.550	39.821	8.529	66.797
Very Strong	0	7.010	40.207	6.294	65.739	6.940	37.272	6.493	62.620
Very Strong	45	7.782	40.797	7.009	66.321	7.680	37.880	7.336	63.425
Very Strong	90	8.138	42.413	7.585	68.909	7.803	38.124	7.669	63.756
Very Strong	135	7.927	40.607	7.147	66.112	7.808	37.846	7.496	63.357
Very Strong	180	7.033	39.991	6.320	65.516	6.938	37.274	6.493	62.622
Very Strong	225	7.785	40.736	7.018	66.229	7.679	37.895	7.337	63.426
Very Strong	270	7.935	41.743	7.272	66.536	7.825	38.434	7.669	63.756

Very Strong	315	7.874	40.847	7.114	66.322	7.806	37.860	7.497	63.355

Table 7-3: Appendices - Scenario one , one side windows results

middle	0	7.999	138.277
middle	45	9.375	143.008
middle	90	9.306	151.183
middle	135	7.558	158.435
middle	180	6.173	160.381
middle	225	7.796	158.167
middle	270	9.402	150.641
middle	315	9.381	142.253

Table 7-4 : Appendices - radiation received on the roofs sparse models

SC2/sp	radiation (kWh)
0	20768000
45	20837000
90	20859000
135	20817000
180	20834000
225	20806000
270	20823000
315	20809000

SC1/sp	Radiation (kWh)
0	9808000
45	9809100
90	9808900
135	9808300
180	9812300
225	9813100
270	9813500
315	9810700