IMPLEMENTATION OF SOLAR STRATEGIES WITHIN DIFFERENT URBAN LAYOUTS

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ABSTRACT

This work presents the process of solar strategies implementation on the neighborhood scale. A novel methodology is developed that initially uses a data collection matrix to record various features of neighborhood archetypes required for energy modeling. This work then selects three distinct neighborhoods in Canada based upon different attributes related to building type. Various tools and resources such as GIS, censes data, and building codes are used to gather the matrix data for these three neighborhoods. Subsequently, energy modeling of these neighborhoods is carried out using EnergyPlus to analyze their energy performance. Upon the identification of suitable solar surfaces, various solar strategies will be proposed and simulated by using PVSyst.

Keywords: Neighborhood archetypes; data collection matrix; energy modeling; energy analysis; solar strategies.

1. Introduction

More than half of the world's population lives in urban areas since 2007, resulting in the development and growth of different sectors of the economy, significantly increasing the urban energy demand, as well as an urge to a change in the fuel mix (Madlener & Sunak, 2011). With the recent advances in technology, new methods to generate and conserve energy have surfaced, and others became more viable to be installed. One of the biggest challenges public authorities are facing is to decrease the use of fossil fuel and rely more on a renewable energy-based source. Renewable sources of energy, especially solar, are turning into a key component in designing new energy efficient buildings that aim at achieving net zero energy status. Energy efficiency is the condition of using less energy while maintaining the same level of performance (Beckett, 2018). While this objective is feasible on a building scale, it is more challenging on a neighborhood scale. The urban design has a major influence in the energy demand of buildings and transport (Hachem, 2016).

As a step towards developing strategies of solar net zero energy neighborhoods, the International Energy Agency (IEA) Task 63: Solar Neighborhood Planning developed a matrix to catalog different patterns of neighborhoods, classifying them by neighborhood types and use, street layouts, building designs and several other neighborhood parameters. This matrix is employed to standardize energy simulations on large scale. Having this in mind, this paper aims to investigate selected solar strategies that have an effective impact on the energy consumption of different types of neighborhoods.

2. Methodology

The methodology is divided into four phases. Initially, a broad analysis of the urban patterns of the selected area to study is needed to identify repetitive layouts that can be used as a representative of a typical neighbourhood. After validating that the selected neighbourhood to study has a common urban layout, the second phase of the methodology comes in-place. It includes the development of 3D models to extract data, based on georeferenced mapping. Moreover, different data to input in the energy model should be collected via regional census, building codes and other relevant sources. The matrix is developed to compile relevant neighborhood archetype data for energy modelling needs to be filled. This data will be then used to establish the energy models for three neighborhoods. Finally, some solar strategies to these three neighborhoods will be proposed. Since this methodology is applicable for existing neighbourhoods in this study, the matrix acts as an innovative tool that eases the analysis process of both existing and new neighbourhoods.

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2.1. Urban Patterns

The very first step when selecting a neighbourhood to evaluate its energy performance is to find if the urban pattern is a representative of the usual layout present in the region where it is located. This is an essential step in order to validate the developed model to a baseline that is compatible to a typical neighbourhood, otherwise the energy simulation might not have an accurate reference.

For the presented case study, based on different street layouts displayed in the IEA Matrix, the three selected neighbourhoods' layout were compatible to at least five other neighbourhoods across Canada, having the same characteristics, such as: conventional and tilted grid, variants of attached and detached houses, similar type of construction and rooftop, and other details. The analysis was made using the mapping software Google Earth Pro, making the visual evaluation a key tool for this study.

2.2. Selection of neighbourhoods

Using the matrix described below, three neighborhoods are selected and analyzed for the comparison, in different regions of Canada. A crucial part of selecting regions is the availability of data. The study counts on data of community profiles and energy standards collected from reliable sources, such as Statistics Canada (2016) and Natural Resources Canada (2019), to structure and support the simulations of neighbourhoods. The first neighborhood, East York, located in Toronto, Ontario (43.689275°, -79.337520°), climate zone 5, is a conventional neighborhood with low-rise buildings composed with only detached houses. The second neighborhood, Saddle Ridge, located in Calgary, Alberta (51.128769°, -113.930133°), climate zone 7A, is a mixed of detached and attached houses, presenting also low-rise buildings and a mix of conventional and curvilinear grid layout. Finally, the third example, Mount Pleasant, located in Vancouver, British Columbia (49.258019°, -123.105317°), climate zone 5, is a mixed neighborhood with high-rise buildings, multi-family, as well as detached single-family dwellings. Just a small portion of the area is selected to be analyzed within the neighborhood and serve as a sample of the presented urban design to ease the simulation process.

2.3. Neighbourhood data collection matrix

The proposed study presents a Matrix developed by IEA Task 63 - SubTask A (International Energy Agency, 2021) to assist in the data input when simulating energy efficiency of larger urban areas. The matrix is a spreadsheet that allows input data of neighborhoods' characteristics, divided into five general categories: (A) Type of Neighborhood, (B) Neighborhood Building Structure and Passive Design, (C) Solar Energy Generation, (D) Energy Systems, (E) Miscellaneous Information, and (F) Simulation Outputs. In every category, several items are listed to collect information of different types of neighborhood archetypes, such as: street layout, green areas, density indicators, building type, block design, usage type, roof design, façade characteristics, geometry, shading devices, and others. These archetypes are then simulated, and their energy performance is compared.

Filling data into the matrix is a process that should be thoroughly considered. Different tools can be used to fill the matrix, including mapping software such as Google Earth, Open Street Map, ArcGIS, and others that will combine with 3D modeling software, like SketchUp, AutoCAD, Rhino, and others to develop a model of each neighbourhood. With a 3D model in place, essential data to generate an energy model can be extracted from it, like floor and rooftop areas, shading analysis, window to wall ratio, and much more. A possible variation of around 5% from the is expected when generating geometries out of real buildings.

Some other data that are not extractable from the model (mentioned above) needs to be addressed, like demographics for instance. Reliable data sources, such as Census and Regional Building Codes are also alternatives that have being exploited. Further, these data can be used for energy simulation and accordingly suitable solar strategies can be implemented.

The flowchart shown in Figure 1 illustrates the overall process taken by following this methodology to analyze the energy performance of the case study neighbourhoods.

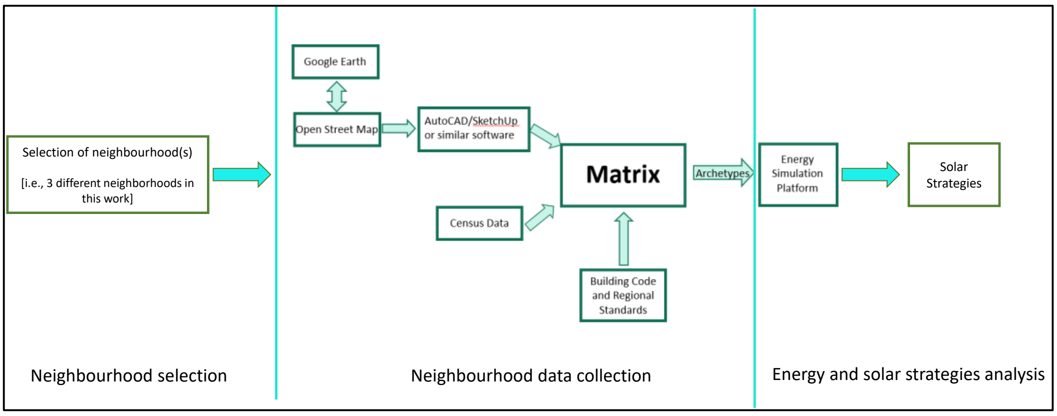


Figure 1 - Methodology Flowchart

2.4. Energy modeling

The third phase of this methodology consists of inputting all the collected data into an energy modelling software to create a comprehensive energy model of the neighbourhood. For this specific study, EnergyPlus is chosen, an energy analysis and thermal load simulation tool. In combination with EnergyPlus, SketchUp and the plugin Euclid also is used to due to the ease of modelling a 3D structure and the integration with other platforms. This plugin employs SketchUp's modelling platform to convert energy data input from the 3D model into an EnergyPlus-compatible energy model. Satellite pictures are utilized to compute measurements for the 3D modelling of the neighbourhood structures. Furthermore, Google Street View and 3D models from Google Earth are applied to model the rooftops of the structures as accurately as feasible.

The following assumptions are taken into account in the modelling of the neighbourhoods studied in this study:

a) The building shapes are based on the shape of the roofs.
b) Exterior walls are considered to be 1 metre offset from the edge of the roofs, resulting in an overhang.
c) Each floor is supposed to be 2.5 metres tall. Inside walls or any internal divisions of buildings were not considered.
d) Fenestrations were created based on street views if available, and if not, on the patterns of adjacent buildings.
e) In single-family structures, each home is a zone, whereas multi-family buildings include a zone for each unit and common area.
f) Electric furnace is the heating system assumed for the energy simulations of all buildings due to its commonly use in north American buildings.
g) The only enhancement studied and applied for the retrofit buildings is the building envelope.

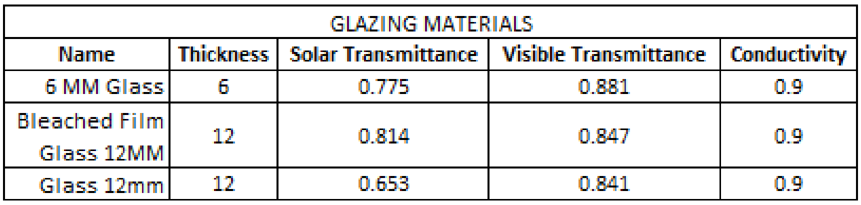
Following the modelling of the specified neighbourhoods, an IDF file is created to be further processed and analyzed with Energy Plus.

When running a simulation in EnergyPlus, a lot of parameters that have a significant impact, such as HVAC systems, construction materials, lighting and appliances average use, and others, must be properly considered. Therefore, all the assumptions are based on data from the census, government agencies, on standard buildings and systems, and the 2017 ASHRAE Handbook – Fundamentals (ASHRAE, 2017). Energy simulations considers the energy demand of thermal zones by different end-uses over a full year.

The simulations include five energy end-uses, which are also considered in the NRCan Comprehensive Energy Use Database (Natural Resources Canada, 2019). Those are: Space Heating, Water Heating, Space Cooling, Appliances, and Lighting. Aiming to reach net-zero energy status, the building envelope is designed in two different types of material: conventional and high performance. This allows a comparison of energy performance while assessing the average reduction in the energy demand, especially on space heating.

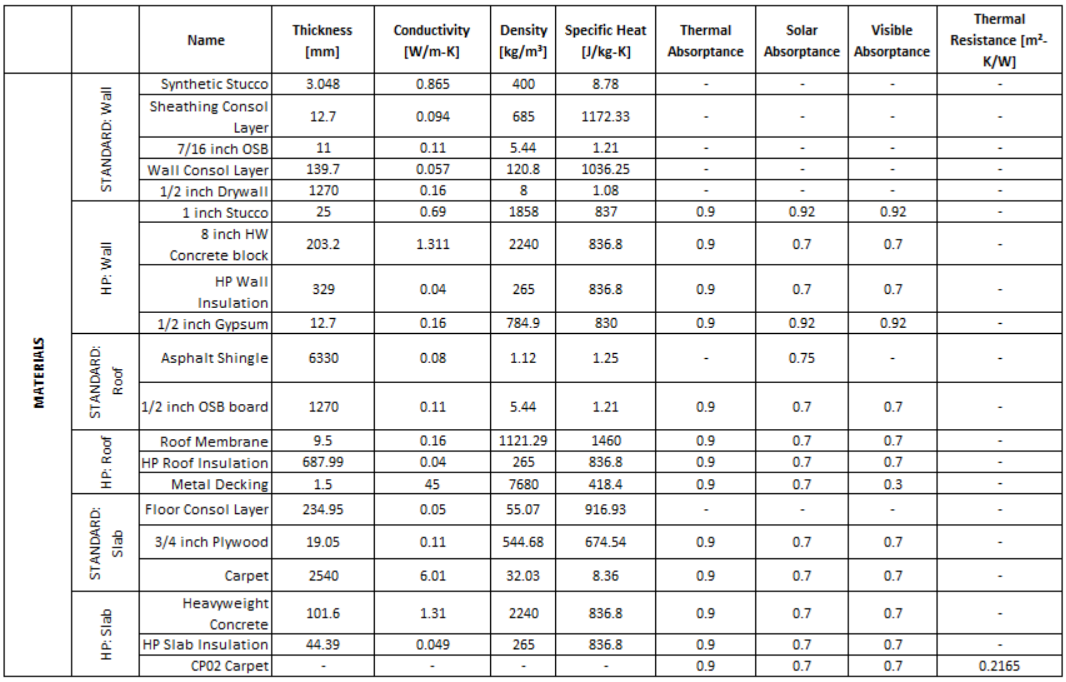
For the standard construction, commonly employed materials are considered, like insulated wood frame walls, plywood floors, asphalt shingle roof coated with OSB boards, double pane glazing, and others. When simulating a high-performance version of the neighbourhoods, materials are generally selected to reduce the energy demand and increase the efficiency of the buildings, like highly insulated walls, roofs, and windows. The table below shows the various material components applied to the buildings in the energy model simulation.

Table 1 - Glazing Materials



GLAZING MATERIALS				
Name	**Thickness**	**Solar Transmittance**	**Visible Transmittance**	**Conductivity**
6 MM Glass	6	0.775	0.881	0.9
Bleached Film Glass 12MM	12	0.814	0.847	0.9
Glass 12mm	12	0.653	0.841	0.9

Table 2 – Construction Materials



		Name	Thickness [mm]	Conductivity [W/m-K]	Density [kg/m³]	Specific Heat [J/kg-K]	Thermal Absorptance	Solar Absorptance	Visible Absorptance	Thermal Resistance [m²-K/W]
MATERIALS	STANDARD: Wall	Synthetic Stucco	3.048	0.865	400	8.78	-	-	-	-
		Sheathing Consol Layer	12.7	0.094	685	1172.33	-	-	-	-
		7/16 inch OSB	11	0.11	5.44	1.21	-	-	-	-
		Wall Consol Layer	139.7	0.057	120.8	1036.25	-	-	-	-
		1/2 inch Drywall	1270	0.16	8	1.08	-	-	-	-
	HP: Wall	1 inch Stucco	25	0.69	1858	837	0.9	0.92	0.92	-
		8 inch HW Concrete block	203.2	1.311	2240	836.8	0.9	0.7	0.7	-
		HP Wall Insulation	329	0.04	265	836.8	0.9	0.7	0.7	-
		1/2 inch Gypsum	12.7	0.16	784.9	830	0.9	0.92	0.92	-
	STANDARD: Roof	Asphalt Shingle	6330	0.08	1.12	1.25	-	0.75	-	-
		1/2 inch OSB board	1270	0.11	5.44	1.21	0.9	0.7	0.7	-
	HP: Roof	Roof Membrane	9.5	0.16	1121.29	1460	0.9	0.7	0.7	-
		HP Roof Insulation	687.99	0.04	265	836.8	0.9	0.7	0.7	-
		Metal Decking	1.5	45	7680	418.4	0.9	0.7	0.3	-
	STANDARD: Slab	Floor Consol Layer	234.95	0.05	55.07	916.93	-	-	-	-
		3/4 inch Plywood	19.05	0.11	544.68	674.54	0.9	0.7	0.7	-
		Carpet	2540	6.01	32.03	8.36	0.9	0.7	0.7	-
	HP: Slab	Heavyweight Concrete	101.6	1.31	2240	836.8	0.9	0.7	0.7	-
		HP Slab Insulation	44.39	0.049	265	836.8	0.9	0.7	0.7	-
		CP02 Carpet	-	-	-	-	0.9	0.7	0.7	0.2165

The simulation of the neighbourhoods is followed by a comparison of the NRCan baseline (Natural Resources Canada, 2016) and validated based on the energy consumption per area (kWh/m²/year).

2.5. Solar analysis and strategies

Energy simulations play a crucial role in the on-site distributed generation of renewable sources to assess GHG emission reduction and to compare system yields across different urban layouts. The parameters used in each simulation may vary according to the characteristics of the environment that the system is installed, but the same system configuration must be used in all the simulation for comparative purposed, if possible.

The analysis of the three neighbourhood examples allow to assess several solar strategies implementation on an urban scale and their impact on energy performance. The paper explores the integration of these strategies into different urban and buildings environments, such as car shelters, building integrated Photovoltaics, standard roof PV systems, as well as the use of different technologies, like bifacial solar panels, and others. Simulations are conducted employing PVSyst, a standard in the solar industry, for solar energy generation simulation.

Before selecting the solar strategies that are most appropriate to each case, it is important to understand the characteristics and surroundings of where the system will be implemented. A shading analysis was developed to identify possible system's hiccups due to mutual or external shading, like trees, other buildings, and rooftops.

The figure 2 illustrates a shading analysis showing the amount of time that each surface receives during certain periods of the day, and season. The shading analysis was done using a plugin for the SketchUp, called Shadow Analysis.

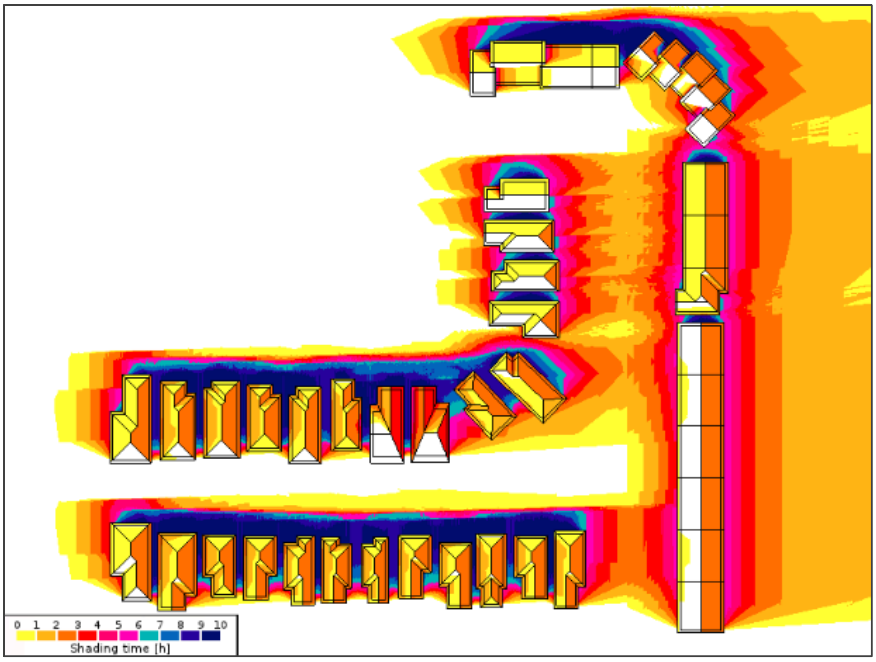


Figure *2* - Shading analysis of Saddle Ridge during Fall.

Solar strategies are divided into two different categories: active and passive. Passive systems are designs, building elements and everything around the building that optimizes the use of light and heat from the sun. On the other hand, active systems are devices that directly convert sunlight into usable forms of energy, like water heat and electricity.

A group of strategies are selected based on the characteristics of each neighbourhood. Several active and passive strategies are charted to clarify some of the usage of each, as well as a description of its concept. All the strategies listed were implemented in this study, but others can be considered when analysing the other case studies. BIPV were considered just as an active system in this study, but it's implementation also brings passive benefits to the building that were not considered due to the different software used to perform each simulation.

The following charts demonstrates active and passive solar strategies in the neighbourhood development.

Table 3 - Active Systems

Strategy	Technology	Description/Specification	Rationale	Application
Rooftop PV	Solar Shingles, Polycrystalline, Monocrystalline and Thin Film solar modules	Installation of solar panels to seize enough solar energy for an adequate system performance and generation.	It is the most common active solar strategy. Great cost for the performance.	Tilted rooftops with good solar orientation and free of shading.
Flat rooftops PV	Bifacial, Thin Film and Monocrystalline solar modules	Installation of solar panels to seize enough solar energy for an adequate system performance and generation.	Due to the limited area of flat rooftops, high efficiency measurements should be applied to meet	Flat rooftops with limited area for PV installation. Use of bifacial panels or East-West mount

			the energy demands of multi-family buildings.	systems for higher energy output.
Carport	Bifacial solar modules	Installation of solar panels to seize enough solar energy for an adequate system performance and generation.	If case the use of rooftops is not enough to supply the energy needed, a car shelter mounted with PV panels will help in the energy generation.	Car shelters mounted with bifacial solar panels that will be installed in parking spaces as an alternative use of solar energy.
Solar Trees	Bifacial, Thin Film and Monocrystalline solar modules	Steel structures that resemble a tree but has solar panels at the end of each branch.	Aesthetic solution for open green areas that may still have an impact on the energy generation.	Applied in green open spaces, like public parks and walkways. Good alternative for places where visuals should not be disrupted.
Building Integrated Photovoltaic	Bifacial, Thin Film and Monocrystalline solar modules	Installation of solar panels on buildings components, integrated with the building.	Used to take advantage of building sections and turn it into an area of solar generation	Applied on building façades and other building components.

Table 4 - Passive Systems

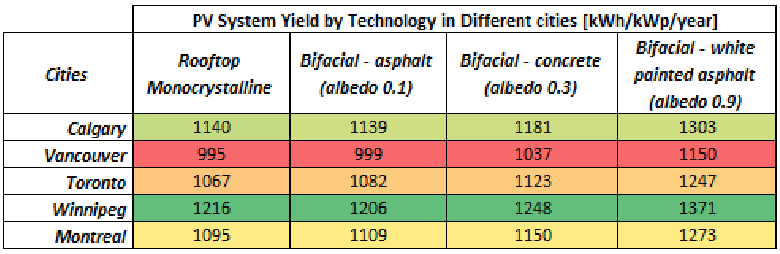
Strategy	**Technology**	**Description/Specification**	**Rationale**	**Application**
Use of vegetation	-	Placing vegetation in appropriate areas that will help to shade buildings when needed.	Vegetation helps to reduce the cooling load of buildings. In the larger picture, it helps also to reduce the heat island effect, lowering the temperature within urban sprawls.	Natural shading element that is applied where direct sunlight might not be desired.
Use of high reflective building envelope	White paint or any material with high reflectance index	Using high reflective materials, especially on rooftops will help to lower the temperature by not retaining the heat from the sun.	By not absorbing solar heat, the building will lower its cooling loads and help to prevent global warming.	Use of high reflective materials on the building envelope or green roofs.
Use of overhangs	-	Overhangs are designed to block unwanted sunlight by covering windows.	If well sized, overhangs can block the sun on summer, when it is not desired, and let the	Apply on windows and any other openings that needs sunlight control.

			sunlight in on winters.	
Use of high-performance materials	Low-e triple pane windows, high insulated envelope, and others	Materials with high insulation that increase the air tightness of the building.	The use of high-performance materials will help to retain heat and cooling inside the building, reducing heating and cooling loads.	Materials used in the building envelope.

3. Results Analysis and Discussion

The yearly energy consumption is determined for each dwelling, including multi family buildings, and then summed to obtain the neighbourhood total energy. The simulations only consider buildings energy consumption, disregarding the energy usage of public infrastructures, such as public transportation, exterior lighting, and other services. These results are combinedwith the energy reduction of the application of high performance construction materials, and the energy generation potention using PV systems. The following figure illustrates the difference in generation by using different technologies, within different Canadian cities.

Table 5 - PV Systems Yield per city and technology



	PV System Yield by Technology in Different cities [kWh/kWp/year]			
Cities	***Rooftop Monocrystalline***	***Bifacial - asphalt (albedo 0.1)***	***Bifacial - concrete (albedo 0.3)***	***Bifacial - white painted asphalt (albedo 0.9)***
Calgary	1140	1139	1181	1303
Vancouver	995	999	1037	1150
Toronto	1067	1082	1123	1247
Winnipeg	1216	1206	1248	1371
Montreal	1095	1109	1150	1273

3.1. Energy Performance Results

3.1.1 Saddle Ridge, Calgary

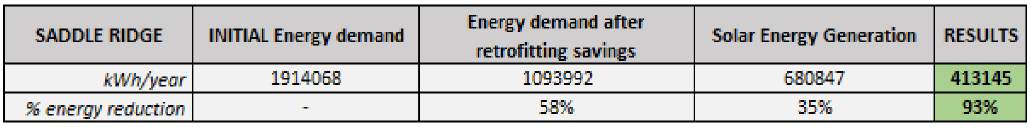
The first simulated neighbourhood is Saddle Ridge, located in Calgary. It is composed of 54 dwellings, of which 48% are classified as detached houses and 52% are classified as attached houses. The total floor area is 8895 m², the average residential population is 4.1 people per dwelling and the heating system considered was furnace (Statistics Canada, 2016).

The simulated average space heating consumption for the conventional construction 134 kWh/m²/year, achieving a performance 9% better than the baseline, which is 148 kWh/m²/year. The average yearly overall energy consumption, considering space heating, cooling, water heating, appliances and lighting is 35,446 kWh per dwelling, and 215 kWh per m². The total yearly energy consumption of the neighbourhood is 1,914,068 kWh.

After the application of high performance materials in all buildings, the total yearly energy consumption reduced by 58%, mainly through the reduction of heating loads, achieving a demand of 1,093,992 kWh. The overall energy consumption per dwelling is 15,187 kWh, and 92 kWh per m².

The selected solar strategies employed in this case study is rooftop PV systems employingmonocrystalline 375W modules, utilizing the Canadian Solar module HiKu CS3L-375MS as a reference, and solar carports located in the attached and detached houses parking space, using bifacial modules, based on the Canadian Solar module BiKu CS3U-375PB-AG, with the same 375W of power. The albedo considered in the solar generation simulations for bifacial systems is 0.3. The overall power installed is 634.13 kWp, of which 377.63 kWp is monocrystalline modules applied on rooftops and 256.5 kWp is solar carports using bifacial solar panels. The combined generation of all systems is 680,847 kWh/year, representing 35% of the initial energy demand of the neighbourhood.

Table 6 - Saddle Ridge Energy Performance



SADDLE RIDGE	INITIAL Energy demand	Energy demand after retrofitting savings	Solar Energy Generation	RESULTS
kWh/year	1914068	1093992	680847	413145
% energy reduction	-	58%	35%	93%

The total reduction in energy consumption after implementing solar strategies combined with retroffiting is around 93%, reducing the energy demand to 413,145 kWh per year. The addition of solar carports to the design helped to nearly achieve net-zero energy. However, these type of structures are usually much more expensive and might compromise the aesthetic looks of the residences, thus having a hard implementation proccess. The figure 3 shows the solar systems distribution and how it was employed according to the solar analysis study.

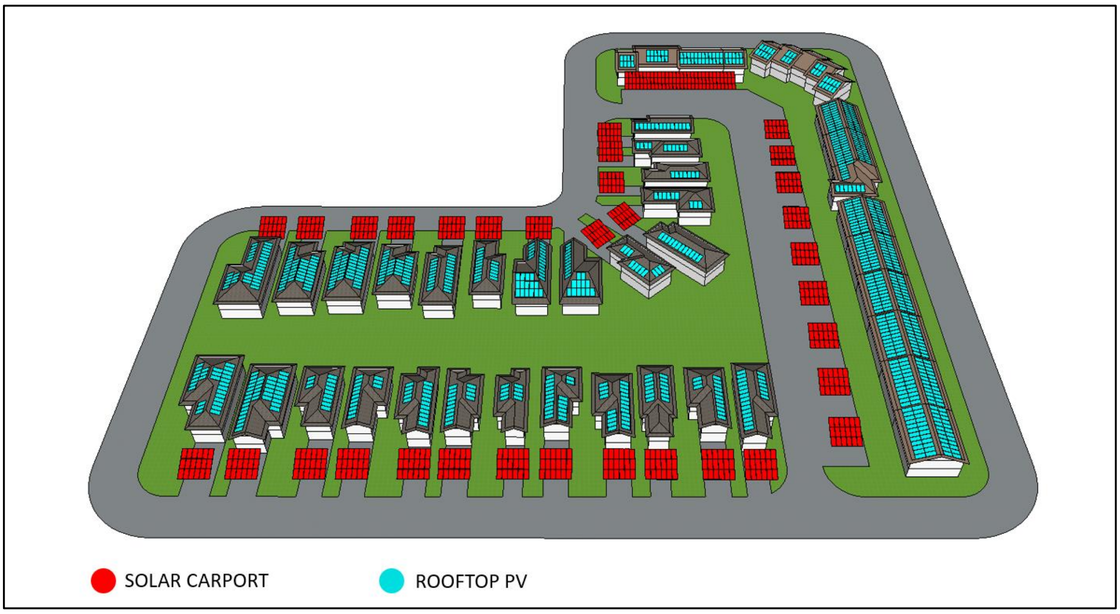


Figure 3 - Saddle Ridge Solar Systems Distribution

3.1.2 Mount Pleasant, Vancouver

The second neighbourhood analyzed is Mount Pleasant, located in Vancouver. It is composed by 133 dwellings, of which 23% are detached houses and the other 77% are apartments in low-rise buildings. The floor area has a total of 16615 m², combining the houses and apartment area. The predominant heating system is also furnace and the population per dwelling is 2.6.

The average space heating consumption per area (kWh/m²/year) is 79.5 for the detached houses, and achieving a performance 13.32% better than the baseline, which is 91.71. As for the apartments, the space heating consumption is 27.7 kWh/m²/year, a performance almost 39% better than the average apartment in the province of British Columbia. It is important to point out that the average size of the apartments in this neighbourhood is considered a little bit over 22% smaller than the average apartment in the baseline, impacting in the energy performance.

The average yearly overall energy consumption, considering space heating, cooling, water heating, appliances and lighting is 16,910 kWh per dwelling, and 135 kWh per m². The total yearly energy consumption is 2,249,052 kWh.

After applying high energy performance materials in all buildings, the total yearly energy consumption reduced by 33%, achieving a demand of 1,508,688 kWh. The overall energy consumption per dwelling is 16,910 kWh, and 91 kWh per m^2.

Table 7 – Mount Pleasant Energy Performance

MOUNT PLEASANT	INITIAL Energy demand	Energy demand after retrofitting savings	Solar Energy Generation	RESULTS
kWh/year	2249052	1508688	791979	**716709**
% energy reduction	-	33%	35%	**68%**

The solar strategies applied for this neighbourhood are the same as the previous case study for detached houses: rooftop PV systems using the same 375W monocrystalline modules. Those systems account for 359.25 kWp. Since the multi-family buildings has a limited rooftop area, an east-west mount strategy is designed to elevate the occupancy rate of the solar panels. This strategy allows to employ 378 kWp on two buildings. Two other smaller multi-family buildings employ bifacial modules arrays, totalling 55.88 kWp. Building Integrated Photovoltaic (BIPV),are employed as overhangs for the south facing windows. This strategy adds 65.25 kWp to the solar design. Lastly, solar trees are employed in public landscapes where there are minimal shading. Each solar tree has 8 solar panels, and by distribuiting 21 of these structures, it addsmore 63 kWp to the project. The total solar power installed on this neighbourhood is 870.38 kWp and the total generation is 791,979 kWh/year, covering almost 35% of the total energy demand of the buildings.

The total reduction in energy consumption after implementing solar strategies combined with retroffiting is around 68%, reducing the energy demand to 716,709 kWh per year. This design presents multiple solar strategies allowing the implementation of maximum amount of solar panels. However, due to a combination of lower solar radiation in Vancouver and non-ideal condiitons of some solar systemsleading to reduced performance, the neighbourhood is still 32% away from achieving net-zero status. Figure 4 illustrates the systems distribution and its solar analysis study.

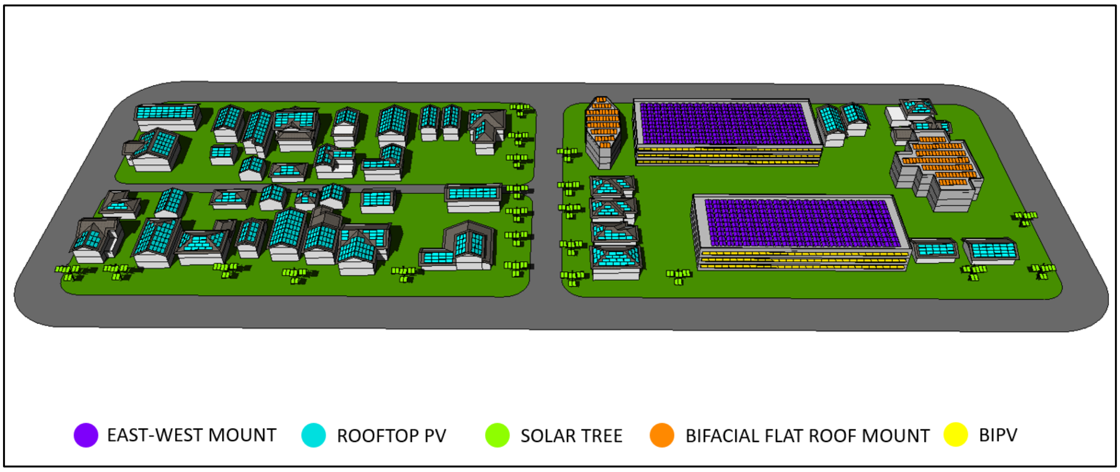


Figure 4 - Mount Pleasant Solar Systems Distribution

3.1.3 East York, Toronto

The last neighbourhood analyzed is East York, situated in Toronto. The selected area presents 44 households, being all of them detached houses. Total floor area accounts for 5059 m^2 and the residential population per dwelling is 2.2.

The average space heating demand per area is 124.5 kWh/m^2/year, having a better performance than the Ontario's baseline of just over 12%. The average overall energy consumption considering all the end-uses is 23,742 kWh per household, and 197 kWh per m^2. The total yearly energy demand is 997,176 kWh.

After the application of high performance materials in all buildings, the total yearly energy consumption reduced by 55%, achieving a demand of 445,896 kWh. The overall energy consumption per dwelling is 10,134 kWh, and 84 kWh per m^2.

Table 8 – East York Energy Performance

EAST YORK	INITIAL Energy demand	Energy demand after retrofitting savings	Solar Energy Generation	RESULTS
kWh/year	997176	445896	505056	-59160
% energy reduction	-	55%	50%	105%

Since this neighbourhood is composed basically of detached single family houses, the main strategy implemented was the same as all the previous neighbourhoods for single family dwellings, which is filling the rooftops with the same monocrystalline panels and adding a solar carport on the parking space in front of each house.The rooftop PVs total an amount of 181.13 kWp, while the carports are responsible for 270 kWp. The multi-family building includes a 9.38 kWp system composed of bifacial modules installed on the flat rooftop, in addition to a BIPV of 6 modules, 2.25 kWp, that serve as overhangs for the south façade of the building. The total generation of the systems is 505,056 kWh/year, saving around 50% of the initial energy demand predicted.

The total reduction in energy consumption after implementing solar strategies combined with retroffiting is around 105%, generating 59,160 kWh/year more than what is consumed, reaching net-zero status. Following similar strategies to Saddle Ridge, East York benefits from a lower energy demand due to small-size houses and the implementation of solar carports as well. Figure 5 illustrates the systems distribution and its solar analysis study.

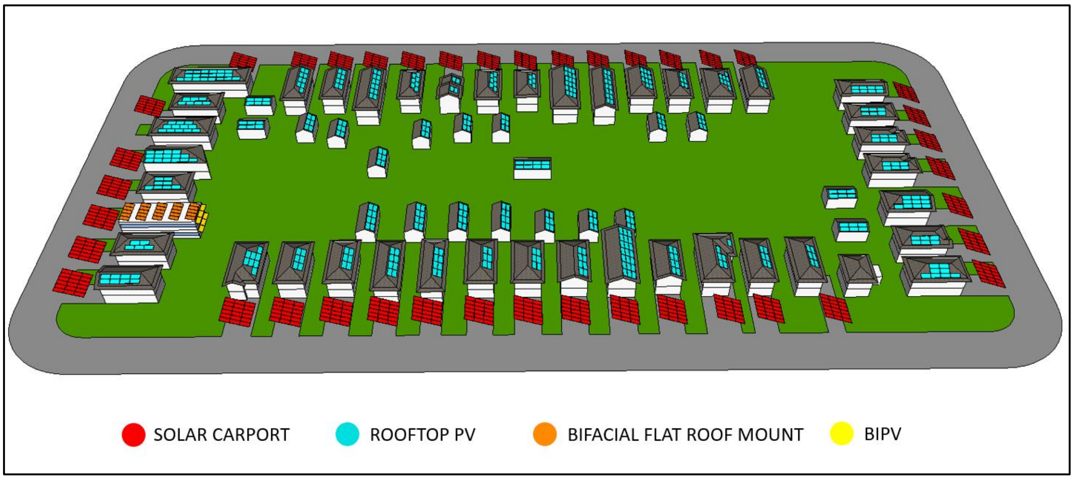


Figure 5 - East York Solar Systems Distribution

4. CONCLUDING REMARKS

The current study presents a new methodology to develop an energy performance analysis in a larger scale environment, considering the primary energy end-use of Canadian households, taking into account the implementation of retrofitting strategies combined with on-site solar generation.

The parameters included in this study are energy performance of a group of buildings, urban design, density, climate, and building type and use. The resulted energy performance is a balance between the initial energy demand, reducing the savings from the proposed retroffiting envelope and the employing of different solar energy systems. The achieve results points to East York achieving net-zero energy status, while Saddle Ridgeachieves near net zero energy status. Mount Pleasant is the neighbourhood that implements the most diverse solar strategies but still was far behind when trying to achieve net-zero status. The most effective strategy is the combination of solar carports utilizing bifacial modules, which is not implemented in the last mentioned neighbourhood, Mount Pleasant, because most of the housing garages are sheltered and located in the back alley, which was already used to install rooftop PV systems.

Although this methodology is applied to Canadian neighbourhoods, it can be replcated to different environments, serving as a guideline for possible future energy performance assessments on a larger residential and commercial areas. Some other locations might present different aspects that should be also considered, for instance a different street layout, archetypes, different ways of consuming energy or even other sources of energy renewable application that might have a better performance and implementation in parts of the world.

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