The Application of Solar Envelope Zoning for the Enhancement of Solar Access in a Density Populated Neighborhood

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Abstract

The study examined the application of Solar Envelope Zoning for the enhancement of solar access in a densely populated neighborhood in Toronto. The purpose of the investigation is to find optimized envelope forms that could be integrated so that solar exposure to surfaces of adjacent buildings is maintained at least to a threshold limit of 4-6 hours daily, within limitations of existing zoning regulations.

Keywords: solar access, solar rights, solar envelope, Solar Envelope Zoning

1. Introduction

Rapid urbanization, the increasing effects of climate change, the need to reduce fossil fuels' dependency as well as to improve resiliency of the world's cities are all factors that are currently accelerating the shift toward renewable energy sources globally. In contemporary times, urban sustainability is characterized by the culmination of resilience in important sectors of the economy that includes energy, land use, water, transportation, and ecology. Moreover, it is pertinent to acknowledge that in the past few years, a number of studies worldwide have investigated the subject of energy resilience, which is evidence of its critical importance to policymakers, urban planners and researchers alike (Mola et al., 2018). It is now recognized that this form of resilience fundamentally entails focusing on the apparent nexus that now exists between a continuity in the supply of energy and a robust urban infrastructure based on optimum urban morphological characteristics, building forms and geometry. An efficient land utilization, which allows for the ready integration of passive design features and active technologies, provides the necessary context to achieving urban energy resilience. Therefore, it is necessitated that an optimum urban form is location-specific; it is designed to be in tune in its interaction with the natural environment, whilst simultaneously promoting socio-economic and environmental sustainability of the urban landscape (Sharifi & Yamagata, 2016).

2. Background

2.1. Solar access, urban density and solar rights

In light of the recent drive towards urban energy reliance, there has been renewed focus on reverting to principles of 'solar city' design in contemporary urban development (Byrne et al., 2015). Surfaces of urban buildings have been increasingly studied as potential locations for energy generation, particularly the rooftops and facades; whereby, this gradual shift in attention from traditional ground-based photovoltaic systems is noteworthy, evidently due to land usage and scarcity concerns. Therefore, in the backdrop of this Toronto-based study, it is pertinent to recognize that there exists tremendous potential for the adoption of solar centric systems for energy generation in Ontario alone, as Wiginton et al. (2010) have pointed in their study on the benefits of province wide roof-top generation, which can achieve a 30% reduction on reliance on the grid. In addition to this, if a wider application of Building Integrated Photovoltaic (BIPV) applications are also considered as a critical contributor to the energy supply, the resulting benefit can inevitably reduce this reliance further (Rosenbloom & Meadowcroft, 2014). As shown in the Compagnon (2004) study, the cities of today present great prospects for the implementation of appropriate technologies and passive features. Different urban morphological forms were analyzed, wherein based on the magnitude of insolation on the building facades, the potential for PV systems, passive solar and daylighting technologies were determined and this principally highlighted the need for meticulous planning right at the outset of any urban development. Therefore, to capitalize on such an opportunity, it is imperative that a solar ready urban neighborhood exists, and this may be somewhat lacking in today's urban centers.

There has been significant momentum on urban densification lately primarily due to the advantages this poses in terms of energy and land use. However, higher urban densities such as that due to high-rise buildings impact the availability of solar access to the vicinity, especially manifested as decreased solar exposure on adjacent buildings

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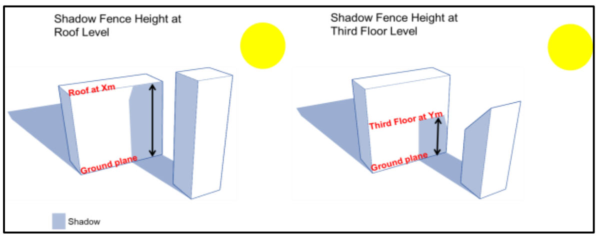
and public spaces. Energy resilience in urban quarters also hinges significantly on the benefits that accrue from solar gains, daylighting, and on-site power generation. It is therefore necessary that the risk of overshadowing is effectively tackled at the design stages of newer urban development. This process consequently leads to the optimization of building forms, thereby also accounting for the intricate relationship a development has with the its proximity (Lobaccaro & Frontini, 2014). Additionally, it has been shown that development density is correlated to environmental parameters such as Urban Heat Island (UHI) effect, outdoor solar access, and daylight penetration into indoor spaces (Chokhachian et al., 2020). Similarly, it has been shown that site orientation greatly influences the building density, whereby a higher density can be achieved as a trade-off for lower durations of solar access to spaces in the vicinity. Conversely, as the parametric study on a multi-floor apartment building in Dublin showed, lower solar exposure on adjacent buildings would inevitably augment the energy demand, evidently due to reduced daylighting, lower potential to generate electricity from onsite sources and lower solar gains (Bruce, 2008). At high urban densities, the solar irradiation was lower and hence, the performance of the passive technologies is also less. As development density increases, the rooftop solar potential also tends to decrease, thereby necessitating other building surfaces to be considered as plausible sites for an investigation (Ko et al., 2017). Moreover, the magnitude of insolation on building facades in dense urban centers is less than that of roofs; however, given the surface area involved, the total benefit that can be made from the former is significant.

This brings to the important subject of solar rights, which basically pivots on the need for guaranteeing solar access to the vicinity, when designing newer development. Capeluto and Shaviv (2001) investigated solar rights in the context of urban density and solar volume. They developed a simulation model to determine solar forms, which would effectively guarantee that chosen surfaces of buildings and the ground in the proximity were exposed to direct insolation. The solar rights envelope that resulted out of such a simulation was an irregularly formed mesh based on customized requirements i.e. a solar access duration and neighborhood geometry. The findings of their study showed that urban density and building height depend essentially on the street orientation and interbuilding distances. The highest urban density was calculated to be 180% or six floors, when neighborhood buildings were orientated along a North East-South West and East-West street (Capeluto & Shaviv, 2001). One of the approaches in defining the design constraints that help achieve the best solar exposure, whilst accounting for the influence of the surroundings, is the concept of 'Solar Envelope Zoning'. Solar Envelope Zoning (SEZ) is referred to "as a spatial construct which defines where, within a lot, one may build without interfering with the solar access of adjacent lots. Solar envelopes set the height limitations for a lot in accord with land configuration and seasonal positions of the sun" (Osofsky, 1983, p. 642). First defined by Knowles in 1976, the objectives of SEZ include improving the solar access of adjacent buildings; reducing the instance of overshadowing; optimizing the duration and quality of solar exposure on building surfaces and maximizing the size of the neighborhood that can be developed (Knowles, 1981). SEZ accounts for the configuration of the site being studied, whereby the influence of nearby structures and obstacles are factored in the simulations also. Being primarily a result of a specific spatial-temporal context, Knowles (2003) suggests that factors such as Shadow Fence Height, street width and orientation and solar access cut-off times all influence the generated solar envelope form. According to Knowles (2003), "the solar envelope avoids unacceptable shadows above designated boundaries", wherein the height of this boundary above the ground is referred to as the Shadow Fence Height (see Fig. 1).



(a) (b)

Fig. 1: Two scenarios showing the concept of Shadow Fence Height. In (a), the Shadow Fence Height is at roof level and denoted as Xm. In (b), the Shadow Fence Height is at third-floor level and is denoted as Ym. Note the changed building form from (a) to (b); whereby, the roof shape in (b) is inclined and the overall building height is lower than (a). Also, in both scenarios, there was no overshadowing on the roof.

The size of the generated form is essentially dictated by variations in these factors; for example, a lower Shadow Fence Height would give rise to a more limited solar envelope form. Similarly, lower solar access cut-off times may result in larger volumes of solar envelopes generated (Knowles, 2003). In a study that looked at the implementation of a building prototype (based on principles of solar envelope zoning) in Thessaloniki, Greece, it was found to have higher levels of solar access, thereby creating potential for passive solar gains (Vartholomaios, 2015).

It is noteworthy that solar rights have varying interpretations depending upon the location in question; in some cases, it would entail guaranteed solar exposure to the ground whereas at other times, it would be a more wholistic concept encapsulating solar access to buildings (Li et al., 2019). Solar rights are typically inadequately addressed in the municipal regulations of many countries. Furthermore, depending upon the type of land use i.e. whether it is a residential or commercial area, the factors for the development of the solar envelope form may vary; for example, it could be made more strict in the case of a residential zone and relaxed for commercial areas (Hraška, 2020). It is important to bridge the disconnect between legislation and research through informed decisions on solar envelope zoning. This principally hinges on studies that are specific to the spatial and temporal context of the location in consideration.

2.2. The Toronto context

The city of Toronto, in Canada, is situated at latitude 43.65°N and 79.38°W, whereby the total annual global irradiation on horizontal surface is slightly above 1385 kWh/m^2 (The World Bank, 2019). This offers considerable potential in incorporating active and passive solar strategies in the city's-built environment. As one of the fastest growing cities in North America, booming construction of residential units in high-rise and mid-rise buildings caters to the increased interest in living in the city. Moreover, a study on designing Avenues and Mid-rise Buildings (BMI/Pace, 2010), and a change in building code that allowed wood construction in buildings up to 6 stories (Ontario Building Code, 2012) presented an excellent opportunity to address the urban growth challenge by taking advantage of existing wide avenues in the city, benefitting from an abundance of solar exposure, and introducing controlled neighborhood densification through construction of mid-rise buildings.

In 1995, Bosselmann et al.'s research investigated the morphological characteristics of the Toronto downtown core, which resulted in recommendations on urban design that would substantially enhance solar access in open spaces that included sidewalks and residential/commercial streets. Though the study holistically encompassed the subjects of wind, sun, and combined elements' effects on human thermal comfort in the public realm, it set a seminal framework to the plausible adoption of solar envelope zoning for newer development in Toronto. Building on a similar concept, the Toronto Mid-rise Guidelines study stipulated requirements based on building height and ROW; sidewalks; height of ground floor; frontal, side, and rear setback; building geometry and general urban morphological provisions along Toronto's Avenues. The study recommends as-of-right zoning for buildings that fall under the "Mixed-Use Areas and Employment Areas" (BMI/Pace, 2010, p. 3). In general, a building's maximum height depends upon the ROW width; the frontal and rear setback is stipulated to be at a 45° inclination, and the rear setback occurs at a minimum height of 10.5m. The guidelines also include a provision on the right to sunlight access, particularly in the case of sidewalks where five hours is the minimum specified duration. Despite the underlying focus on solar rights, the Toronto Mid-rise Guidelines' zoning method is almost constant and does not reflect any situation specific changes. This contrasts with the process of solar envelope zoning, which is essentially an adaptation to the "natural rhythm" of the location in context (BMI/Pace, 2010; Lepore, 2017, p. 17).

Also, as Toronto envisages a greenhouse gas (GHG) emissions target reduction by 2030, urban development guidelines such as the Toronto Green Standard (Version 3) promote the integration of renewable energy systems under certain criteria. Under the Tier 2 section, recommendations under the category of renewable energy technologies stipulate that buildings are designed to be solar ready. This essentially means that there exists an inherent flexibility to introduce renewable energy technologies such passive solar heaters, etc, in future. In a bid to achieve a minimum level of energy efficiency, developers are encouraged to attain higher tiers i.e. Tier 2 – Tier 4 status. These guidelines may be interpreted to indirectly support the inclusion of solar rights in newer development in Toronto, however currently, there exists no regulatory or legislative basis for enhanced solar access for buildings and open spaces (City of Toronto, 2018).

The purpose of this study is twofold: it entails a parametric study for a typical representative location along the Eglington Avenue West corridor and a case study based on an actual location i.e. the Eglington Avenue West/Bathurst intersection in Toronto. This location has been chosen as it is fast becoming a hub of commercial activity in Toronto due to improved transportation connectivity. Similarly, there are also plans for increased urban densification entailing mid-rise buildings via "as-of-right permissions" (City of Toronto, 2014, p. 77) along this corridor. Building forms would be generated based on three different types of zoning methods i.e. City of Toronto zoning, Toronto Mid-rise Guidelines and Solar Envelope Zoning. The developable densities (also indicated as Floor Space Index in this study) based on the Solar Envelope Zoning criteria of orientations, Shadow Fence Height, solar access cut-off times, Right of Way (ROW) width and environmental parameters would be compared to the Floor Space Index (FSI) from other zoning methods. The FSI is typically the "result of the gross floor area of a building divided by the area of the lot" (City of Toronto - Zoning By-Law, 2020, p. 23).

Additionally, it is pertinent to mention that over the past few years, a number of high-rise buildings (residential towers, with 40+ storeys) have been constructed along several main avenues in downtown and midtown Toronto, which substantially exceed the maximum height allowance as per zoning regulations. This evidently indicates that the height limitations (as seen in Tab. 1) are nearing obsoleteness and are thus not being strictly followed by developers. The developer typically applies for a location specific zoning by-law amendment, and the maximum height restriction is relaxed depending upon the development density that is desired to be achieved (City of Toronto, 2013). The implications of tall buildings constructed near low-rise residential single-family houses and other public spaces such as parks are well known. As documented by Bosselmann et al. (1995), the resulting microclimatic effects negatively impact thermal comfort levels due to the disruption of the natural sun and wind balance in the site that undergoes high-rise development. Providing analysis that would document benefits of urban densification through encouragement of midrise mixed-use buildings that could also provide adequate solar access on their own facades and avoid overshadowing surroundings is one of the main motivations of this study.

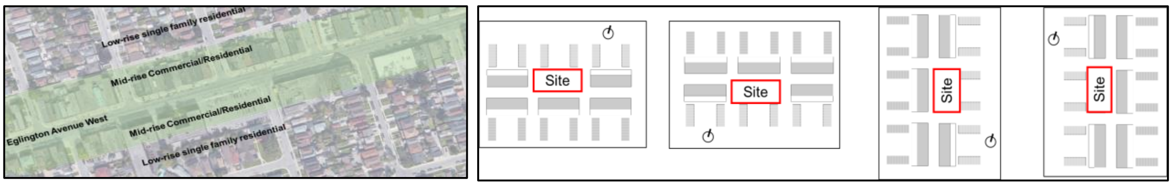
3. Methodology and Results

Building on this concept of solar rights, De Luca and Dogan (2019) recently introduced the 'subtractive method' for Solar Envelope generation, whereby this basically entailed a strategy of subtracting parts of the building form that overshadowed adjacent buildings. The results of their study showed that building forms generated through this method were larger in comparison to those based on the earlier approach of the 'additive strategy'. Similarly, the method also guaranteed that there was always direct solar access to all the adjacent buildings. Thus, this study aims to provide an insight on how solar access is guaranteed given the spatial and temporal variations of the solar irradiation.

The methodology entails identifying sun vectors incident on a given façade; selecting those that correspond to a threshold altitudinal angle and finally generating a solar envelope that meets the prescribed duration of 'solar window' i.e. four to six hours on the nearby buildings. Considering SEZ, the study also seeks to examine the impact of the street width and development density on the solar exposure on buildings located in a typical neighborhood. Finally, the solar envelope generated through this study would be compared to the conditions stipulated in the Toronto Zoning standard and the criteria for Mid-rise Buildings development. Preliminary findings of the study have highlighted the immense potential in estimating the extent of Solar Envelope Zoning that could be achieved in Toronto, wherein this may in future form the context of subsequent integration in mid-rise planning guidelines for the city.

3.1. The Process for the Parametric Study

For the parametric study, a typical location along the Eglington Avenue West corridor was chosen. The urban geometry and morphology of the area was studied, whereby the zone classifications were identified and dimensions pertaining to the ROW width, the lot depth, lot width and street orientation were determined (see Fig. 2 and Tab. 1). The roof morphology of a typical townhouse at the location of the study was emulated for the houses shown in the 3D model developed for the parametric study.



(a) (b) (c) (d) (e)

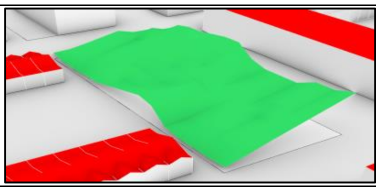
Fig. 2: (a) The typical representative location along the Eglington Avenue West corridor showing the different zoning classifications. The typical representative site layout (along the Eglington Avenue West corridor) under the indicating the view from different orientations (a) North-facing (b) South-facing (c) East-facing (d) West-facing

Tab. 1: The dimensions pertaining to the site in the parametric study

ROW width	Lot depth	Lot width	Street orientation	Maximum height of adjacent commercial buildings
27m	30m	75m	Tilted at an angle of 16.75º south of East	13.5m (with City of Toronto zoning specified FSI = 2.5)

The combination of Grasshopper and Rhino programs enable the development of solar envelope, which can used to make informed decisions on urban zoning and achieving a level of developable density (Niemasz et al., 2013). They facilitate the evaluation of the hourly- magnitude of solar potential, which is an integral component to the development of a customized solar map of any dense urban locality. Therefore, solar analysis simulations have been performed in Ladybug Version 0.0.69, which is an environmental analysis tool. This works with an interface in Grasshopper™, which is also now a plug-in integral to Rhino® Version 6. The input parameters for the solar envelope component in Ladybug Version 0.0.69 were of temporal and spatial nature (see Tab. 2).

Tab. 2: Details on the input parameters of the Ladybug Version 0.0.69 'SunPath' and 'SolarEnvelope' component

Input parameter	Description
_location	This would essentially connect to the location output of Ladybug Version 0.0.69's 'importEPW' component. The input to the 'importEPW' component is the 'Open Weather file', where the Toronto epw file 'CAN_ON_Toronto.716240_CWEC.epw' has been uploaded.
hour _day_ _month_	The '_hour_', '_day_' and '_month_' correspond to the analysis period. For this parametric study, the initial analysis period has been set for every 21st of the month from January to December. The time and hours of analysis has been adjusted based on the sensitivity factor investigated.
_baseSrf	The site limits (the dimensions are indicated in Tab. 1).
_obstacleCrvs	The surrounding context
maxHeight_	This is the maximum height that a building can have.
_sunVectors	This is an output of the Ladybug Version 0.0.69 'SunPath' component. The sun vectors are defined by the analysis period, location, and site orientation.
Ground floor height	4.5m
First floor and above height	3
Site area	$2250m^2$
The generated solar envelope form, which is a result of specific input parameters.	

Similarly, information pertaining to the Toronto Mid-rise Guidelines and City of Toronto zoning was extracted for the respective FSI determination (see Tab. 3).

Tab. 3: The prescribed FSI, building height and setbacks as the three zoning methods: City of Toronto zoning, Toronto Mid-rise Guidelines and Solar Envelope Zoning

	City of Toronto zoning	Toronto Mid-rise Guidelines	Solar Envelope Zoning
Maximum building height	24m	ROW width	None
Maximum building FSI	2.5	None	
Setbacks	Varies depending on the building face considered. Typically, frontal setback is at a 45° inclination plane at a height equivalent to 80% ROW width.		

3.2. The Results for the Parametric Study

The sensitivity analysis for the parametric study initially involved setting a baseline combination of variables, and this essentially constituted as the baseline analysis (see Tab. 4). The categories of factors tested in the sensitivity analysis of the parametric study included orientation, Shadow Fence Height, solar access cut-off time and ROW width. Depending upon the variables examined, the number of sun-vectors[1] used to generate the solar envelope can reduce, thereby serving to enhance the development density. For example, reducing the solar access time or increasing the Shadow Fence Height would result in fewer sun vectors. It is noteworthy that the higher the sun-vectors generated, the more the restrictive are the conditions to generate the building form through Solar Envelope Zoning.

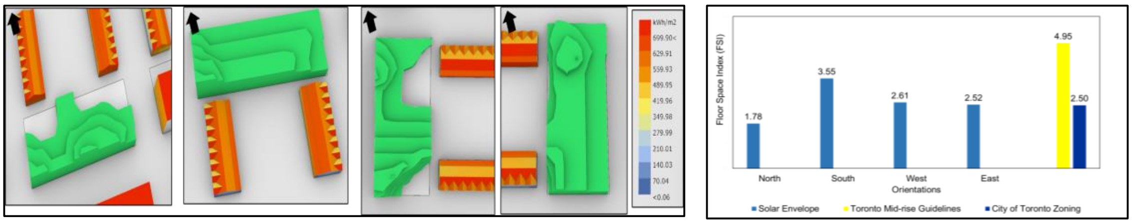
[1] Sun vectors are representations of hourly incident solar radiation from the sun to a point in space.

Tab. 4: Variables in the baseline analysis

Variable type	Description
Orientation	North The site is at the north side of the street
Shadow Fence Height	0m This is essentially the at the ground plane of the adjacent buildings in the context. This basically means that all the facades and roof surfaces of adjacent buildings will not be overshadowed during the solar access cut-off time.
Solar access cut-off time	10:00am – 4:00pm (6 hours)
ROW width	27m

1) Street Orientation

The baseline form was investigated vis a vis four different orientations i.e. the north facing side of the east-west street; the south-facing site for the east-west street; the east side of the north-south street and the west side of the north-south street. It is noteworthy that the building forms resulting from Toronto Mid-rise Guidelines and City of Toronto zoning are effectively independent of the orientations and are uniform irrespective to site changes. The shape and form of the building generated as per the Solar Envelope Zoning method varied greatly from the north, south, east to west orientations. It is observed that the building forms at the north-facing and east-facing orientations took up less proportion of the total site area, in comparison to the forms at the other orientations, which encompassed greater coverage of the area. As seen in Fig. 3, the building form generated at the south-facing (FSI = 3.56), west-facing (FSI = 2.61) and east-facing (FSI = 2.52) orientations have a higher Floor Space Index (FSI) compared to that of the City of Toronto zoning method. This essentially means that compared to the building form due to City of Toronto zoning method, the former has a higher gross floor area and essentially more floors in the same site area. The highest FSI of 3.55 was achieved when the building was south facing; this is characterized by a building height of 22.5m (corresponding to 7 floors) and a total gross floor area 7995 m^2. The lowest FSI of 1.78 was in the baseline case which was when the building was north facing; the building has a total height of 16.5m (corresponding to 5 floors) and a total gross floor area of 4000m^2. It is noteworthy that the gross floor achieved in former is about twice than that of the north facing building. From a development perspective, these results show that an appropriate site orientation (such as a site that is south-facing or west-facing) are critical for maximizing building gross floor area.

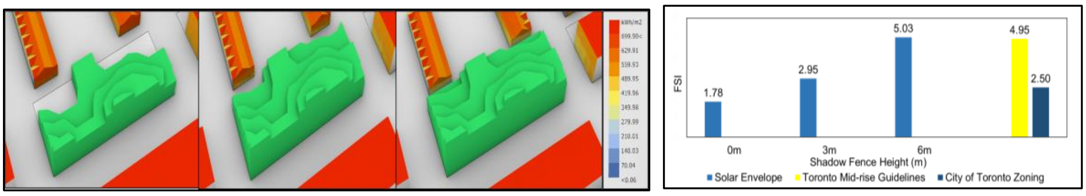


(a) (b) (c) (d) (e)

Fig. 3: Building forms through Solar Envelope Zoning (SEZ) (a) Baseline case: North-facing (b) South-facing (c) East-facing (d) West-facing. (e) Comparisons of Floor Space Index (FSI) between different SEZ building forms, Toronto Mid-rise Guidelines and City of Toronto Zoning

2) Shadow Fence Height

The analysis for Shadow Fence Height accounted for the vertical surfaces of adjacent residential buildings present at the north side of the site, which have a typical height of 10m: the total wall height is 6m while the depth of the roof is 4m. Thus, the baseline envelope (Shadow Fence Height at 0m) was compared to Shadow Fence Heights when it is at 3m and 6m corresponding to the second floor and roof level, respectively. These cut-off heights refer to solar access above the second-floor level and at the roof. In contrast to the case when the Shadow Fence Height is at 0m, these cut-offs can also be construed as there being a lower magnitude of solar radiation intensity on the facades, apparently due to the instance of overshadowing. With increasing Shadow Fence Height, the building volume due to Solar Envelope Zoning is observed to become larger, whereby this represents greater gross floor area and a higher development density. When the Shadow Fence is at 6m, the building FSI is 5.03; the building has a height of 22.5m (corresponding to 7 floors) and a gross floor area of 11,319m^2. The gross floor area in this case is about 2.8 times higher than that when the baseline case. Furthermore, the FSI achieved when the Shadow Fence Height is at roof level is higher than the FSI of the building form based on Toronto Mid-rise guidelines (4.95) and City of Toronto zoning (2.5). This indicates that easing the Shadow Fence Height restrictions can greatly augment the development density (see Fig. 4).

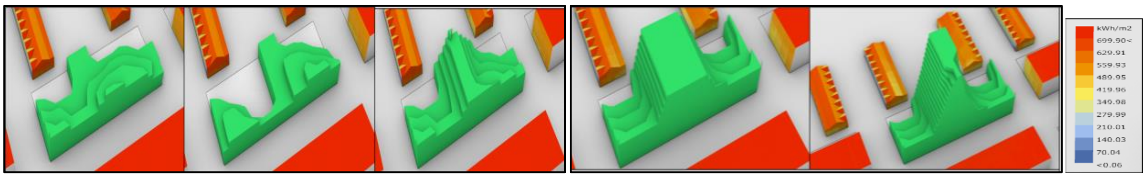


(a) (b) (c) (d)

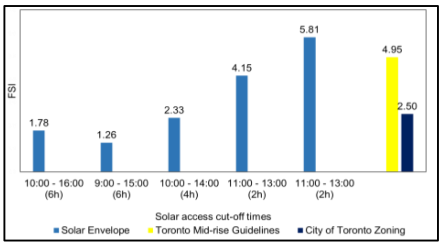
Fig. 4: Building forms obtained by varying the Shadow Fence Height (a) 0m (b) 3m (c) 6m (d) FSI comparisons for different Shadow Fence Heights (m).

3) Solar access cut-off times

The solar access cut-off time is the duration during which solar access is guaranteed to adjacent surfaces. Several studies have looked at solar access cut-off time with the intent to examine the associated impact on health, work productivity and passive solar design. It is important to note that the recommended solar access cut-off time is 6 hours as per Knowles (2003). In this analysis, five solar access cut-off times were considered characterized by varying times and hours of analysis i.e. 9:00am to 3:00 pm (6 hours); 10:00am to 4:00pm (6 hours); 10:00am to 2:00pm (4 hours) and 11:00am to 1:00pm (2 hours) when the height of the building for generating the solar envelope was limited to 27m and 50m. As seen in Fig. 5, the shapes and forms of the buildings generated greatly varied; for example, the one for the cut-off time from 9:00am – 3:00pm is observed to have the most asymmetry in the form; covering the least proportion of the site area and having the lowest FSI of 1.26 (or a gross floor area of 2840m^2). The highest FSI of 5.81 was achieved when the solar access cut-off time was set as two hours and the maximum building height to generate the solar envelope at 50m. In this case, the building form has a height of 49.5m corresponding to 16 floors and a gross floor area of 13,083m^2. In both cases when the solar access cut-off time was 2 hours, the development density attained was higher than that through the City of Toronto Zoning method. This analysis showed that as the solar access cut-off times were reduced, the development density (constituting gross floor area and height of the building) greatly rose. However, it is also apparent that this occurred at the cost of solar radiation intensity on the adjacent facades, which decreased with iterations involving lower solar access durations.



(a) (b) (c) (d) (e)

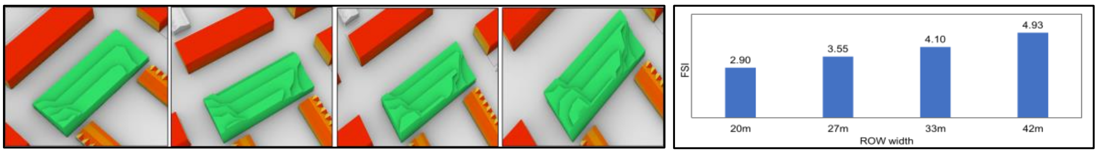


(f)

Fig. 5: Building forms for different solar access cut-off times (a) 10:00am – 4:00pm (6 hours) (b) 9:00am – 5:00pm (6 hours) (c) 10:00am – 2:00pm (4 hours) (d) 11:00am – 1:00pm (2 hours) – height = 27m (e) 11:00am to 1:00pm (2 hours) – height = 50m. (f) Comparisons of FSI between building forms corresponding to different solar access cut-off times

4) ROW width

The baseline was compared to three other ROW widths i.e. 20m, 33m and 42m. In this case, a south facing site was considered as the building form that would be impacted by changes in the ROW widths. As seen in Fig. 6, the building volume/FSI rises with increasing ROW width. The highest building FSI of 4.93 is inevitably reached when the ROW width is 42m; whereby, this corresponds to a building height of 49.5m characterized by 16 floors and a gross floor area of 11,088m^2. The lowest FSI of 2.90 corresponds to a ROW width of 20m, whereby the building height is 6 floors and a gross floor area of 6542m^2. The development density when ROW is 42m is 1.7 times greater than that when the ROW width is 20m. The results show that increasing the ROW width enhances the height/gross floor area of the building form generated.



(a) (b) (c) (d) (e)

Fig. 6: Building forms for different Right of Way (ROW) (a) 20m (b) 27m (c) 33m (d) 42m (e) Building FSI pertaining to different Rights of Way (ROW)

3.3. The Process for the Case Study on Eglington Avenue West

The site in consideration for the Case Study was situated at the Eglington Avenue West/Bathurst intersection. The buildings in the vicinity have been zoned under either the commercial or residential categories, whereas the maximum height of buildings in this area vary between 16m to 24m (City of Toronto, 2013). A site map was imported in the Rhino® format from CADMapper, which is an online tool used to extract property maps (see Fig. 7). The site is situated at the south of the east-west street and is inclined at an angle of 16.75º south of the east orientation, whereby the ROW width is 27m. The analysis period has been set from 10:00am to 2:00pm (4 hours) at every 21st day of all the twelve months. The building form generated is hence referred to as the 'Baseline' in the subsequent section.

Fig. 7: The site layout at the Eglington Avenue West/Bathurst intersection

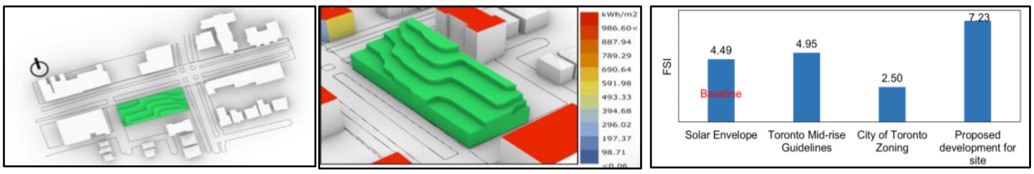
The site is located on the south side of the Eglington Avenue West street. Like the sensitivity analysis in the parametric study, the process of analysis for the case study involved establishing a baseline based on a combination of variables (see Tab. 5). There categories of factors tested in the sensitivity analysis of the parametric study included Shadow Fence Height, solar access cut-off time and environmental parameters.

Tab. 5: Variables in the baseline analysis

Variable type	Description
Orientation	South The site is at the south side of the street
Shadow Fence Height	0m This is essentially the at the ground plane of the adjacent buildings in the context. This basically means that all the facades and roof surfaces of adjacent buildings will not be overshadowed during the solar access cut-off time.
Solar access cut-off time	10:00am – 2:00pm (4 hours)
ROW width	27m

3.4. Results for the Case Study of the site at Eglington Avenue West/Bathurst

The south-facing baseline building form has an FSI of 4.49, whereby this is characterized by a building height of 22.5m (corresponding to 7 floors) and a gross floor area of 9912m^2. The baseline density is lower than that proposed for the site (FSI = 7.23) but higher than that due to City of Toronto Zoning (2.5) and only slightly lower than that due to Toronto Mid-rise Guidelines (4.95) (see Fig. 8). It is pertinent to mention that the differences in density are in effect due to the gross floor area, as the site area remains same irrespective of the zoning method. In the backdrop of the abovementioned sensitivity factors, the relationship between development density and solar access to adjacent sites will be subsequently investigated.

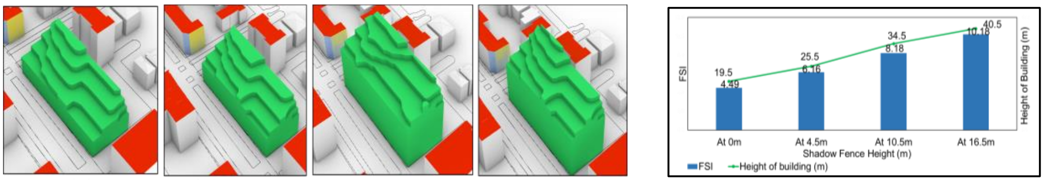


(a) (b) (c)

Fig. 8: (a) A plan view of the building form at the case study site (b) the side view of the building form based on Solar Envelope Zoning (SEZ) (c) Comparisons of FSI between different building forms SEZ building forms, Toronto Mid-rise Guidelines and City of Toronto Zoning

1) Shadow Fence Height

The buildings on the north side of the site are classified as commercial/residential, whereby the building heights range from 16m to 24m (corresponding to 4 to 6 floors). In the baseline analysis, the Shadow Fence Height was initially set at 0m (or the ground plane). The variables tested in the analysis for the category of Shadow Fence Height were 4.5m, 10.5m and 16.5m. As discussed in the parametric study, this essentially means that all the adjacent facades and roofs are not expected to be overshadowed above these cut-off heights. The volume of the building form generated is seen to steadily rise with an increasing Shadow Fence Height (0m to 16.5m). At a Shadow Fence Height of 4.5m, the FSI is 6.16 and the building height is 25.5m (corresponding to 8 floors) and a gross floor area of 13,642m^2 (see Fig. 9). This essentially means that in this building form, overshadowing will not occur at floors above the ground floor. Moreover, at 16.5m, which is roof level of a lot of the buildings in the area, solar access would only be on the roof. The resulting building has an FSI of 10.18; the total building height is 40.5m (corresponding to 13 floors) and a gross floor area of 22,472m^2, which is almost 2.27 times baseline case (9912m^2). The results show that increasing the Shadow Fence Height increases the development density, however solar access is compromised on the surfaces of the buildings in the vicinity.

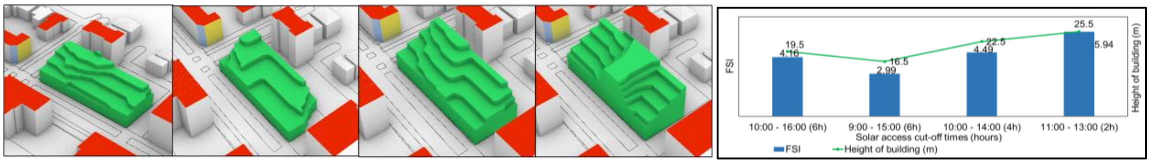


(a) (b) (c) (d) (e)

Fig. 9: Building forms obtained by varying the Shadow Fence Height (a) 0m (b) 4.5m (c) 10.5m (d) 16.5m Building forms obtained by varying the Shadow Fence Height (0m, 4.5m, 10.5m and 16.5m)

2) Solar access cut-off time

The solar access cut-off times studied were 10:00am to 4:00pm (6-hours); 9:00am to 3:00pm (6 hours); 10:00am to 2:00pm (4-hours) and 11:00am to 1:00pm (2 hours). The baseline building was based on a solar access cut-off time of 4-hours. For passive solar design, longer solar access windows are generally recommended. The volumes and FSIs of generated building forms increased with a decrease in the solar access cut-off time (6 hours to 2 hours). The highest FSI of 5.94 corresponding to a building height of 25.5m and gross floor area of 13,116m^2 occurred when the solar access cut-off time was from 11:00am to 1:00pm (2 hours). Moreover, the lowest development density occurred when the solar access cut-off time was from 9:00am to 3:00pm (6 hours), whereby the gross floor area in this case was about 6606m^2, which is about 2 times less than the case when the cut-off duration was 2 hours (see Fig. 10). With a decreasing duration of solar access, the roofs, facades, and other spaces in the vicinity are exposed to the sun for a shorter period. As seen in Fig. 10, solar access cut-off time and development density are inversely related, and this trade-off can be considered for achieving higher densities.

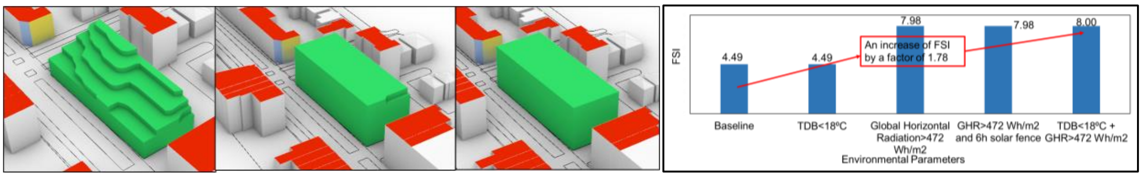


(a) (b) (c) (d) (e)

Fig. 10: Building forms obtained by varying the solar access cut-off times (a) 10:00am – 4:00pm (6 hours) (b) 9:00am – 3:00pm (6 hours) (c) 10:00am – 2:00pm (4 hours) (d) 11:00am – 1:00pm (2 hours). Maximum height = 27m (e) Comparisons of FSI of buildings based on different solar access cut-off times

3) Environmental parameters

The epw. file for Toronto presents a total of 8760 sun vectors corresponding to the total number of hours in the year. As the Capeluto and Plotnikov (2017) study showed, the number of sun vectors used in the analysis for solar envelope generation can be adjusted based on specified external conditions such as limitations on the global horizontal radiation and the dry bulb temperature. In this study, the environmental parameters tested pertaining to the sun vectors when (a) the dry bulb temperature is less than 18ºC; (b) Global Horizontal Radiation is more than 472 Wh/m^2; (c) (b) and 6-hours solar access time and (d) a combination of the parameters (a) and (b). Therefore, in the analysis, only sun vectors pertaining to these conditions are applicable. As seen in Fig. 11, the highest FSI of 8.00 is reached when the building form generated is characterized by sun-vectors in parameter (d). This is almost a uniform cuboid, which has a height of 25.5m (corresponding to 8 floors) and a gross floor area of 17,663 m^2. This building form also has a gross floor area about 1.78 times higher than the baseline case (9912m^2). This presents tremendous opportunity to achieve higher densities and concurrently maintain solar access within specified parameters, rather an all year-round approach as investigated in the parametric study earlier.



(a) (b) (c) (d)

Fig. 11: Buildings forms based on different environmental parameters (a) TDB<18°C (b) Global Horizontal Radiation>472 Wh/m^2 (c) TDB<18°C + Global Horizontal Radiation>472 Wh/m^2 (d) Comparisons of FSI of buildings based on different environmental parameters

4. Discussion

The study looked at a parametric analysis on a typical representative site along the Eglington Avenue West corridor and a case study based on an actual location at the Eglington Avenue West/Bathurst intersection. For the parametric study, a sensitivity analysis was carried out for four factors i.e. street orientation, Shadow Fence Height, solar access cut-off times and ROW width. Similarly, for the case study, three parameters i.e. Shadow Fence Height, solar access cut-off times and environmental parameters involving ambient temperature and threshold limits for Global Horizontal Radiation were investigated.

Whilst examining trends manifested in the results for the parametric and case study, important inferences regarding solar access and urban morphology were made. With regards to the FSI achieved, for majority of the factors tested, it was observed to be higher than that specified by City of Toronto Zoning (FSI = 2.5). The relationship between ROW width and Shadow Fence Height are directly proportional, whereby as they increase, the building FSI concurrently increases. In contrast, as the duration of solar access reduces, the FSI increases, hence this may be a relevant parameter for boosting building density. With regards to street orientation, clear deductions could not be made except that it is important to recognize that the street orientation can cause building FSI to greatly vary. In this case, the highest FSI of 3.55 was achieved when the building was south facing, followed by an FSI of 2.52 when it was east facing. Another important parameter to recognize is that a high Shadow Fence Height (at the roof level) brought about a building FSI of 5.03, which was higher than that of the Toronto Mid-rise Guidelines (FSI = 4.95). Similarly, a Shadow Fence Height of 3m, resulted in a building FSI of 2.95, which was substantially higher than the specified City of Toronto Zoning limit. For the case study, a Shadow Fence Height of 4.5m led to a building FSI of 6.15, which is substantially higher than that specified by the other zoning methods. It is however important to note that there is evidently a trade-off between attaining an all-encompassing solar access, which includes all the relevant façade surfaces and the roof and building density. An optimum approach of urban design may be characterized by compromise on Shadow Fence Height (designing for a higher height) to enhance the building FSI, however also acknowledging that solar access should be guaranteed beyond a threshold floor level or building surface area.

Although the findings showed that solar access can be shortened to augment building volume/FSI, it is necessary to appreciate the benefits solar exposure in terms of its temporal context (time and duration); these benefits may include improved human health and productivity, enhanced daylighting, passive solar gains during the Winter months and energy self-sufficiency through active technologies. Therefore, given both solar access and achieving higher building FSI is necessitated, the duration of solar access can be kept at a threshold limit. As the De Luca and Voll (2017) study showed, solar access cut-off requirements could be assigned to specific times of the year, such as between 11:00am to 3:00pm during the Winter months, rather than the whole year as performed in the analysis in this study. This method of solar envelope zoning would thus maintain the sensitive equilibrium between density and solar access. Moreover, it also important to identify the extent of solar access on nearby buildings. As this study has shown, a context-specific analysis can help generate a more optimum building form. For example, commercial buildings can be a greater beneficiary of implementing photovoltaic technologies, which can be installed on the facades. Therefore, there needs to be important considerations on the Shadow Fence Height and solar access cut-off times. Similarly, passive solar gains are important for residential buildings, which can be warmed up by the sun in the morning and noon and release the heat indoors at night. Thus, in this case too it is important to generate sun-vectors (used in the analysis) more attuned to local conditions.

In regards the environmental parameters studied, the combination of a dry bulb temperature less than 18ºC and a minimum Global Horizontal Radiation of 472 W/m2, resulted in a high building FSI of 8. This showed that specifying constraints such as a minimum ambient temperature and radiation intensity, a fewer number of sun-vectors would be involved in generating the building form through solar envelope zoning. This would be an effective strategy in optimizing building forms, based on say a season-based need for prolonged solar access on building surfaces. Similarly, through the application of relevant environmental parameters and solar access cut-off times, potential issues arising due to seasonal overheating and glare can be avoided.

5. Conclusion

The goal of this study was to investigate the impact of parameters pertaining to solar access on building density/FSI. The findings have hence highlighted that orientation, shadow fence height, solar access cut-off times, ROW width and environmental parameters had varying impact on the FSI of the building forms generated. A higher FSI can be achieved when limits pertaining to relevant factors are eased. For example, a lower solar access time, a greater shadow fence height, greater ROW width, setting limits on maximum outdoor temperature and radiation intensity reduce the number of sun-vectors needed to generate the building form, therefore potentially augmenting the resulting FSI. It is probable that a higher FSI may reduce the solar radiation on surfaces of buildings in the vicinity, whilst depending on the case, not significantly impact the roofs. A holistic approach needs to be adopted for the promotion of solar envelope zoning as a robust method for enhancing building FSI and guaranteeing solar access to the vicinity. This balance in strategy needs to focus on the nitty gritty pertaining to the vicinity; wherein, it accounts for the seasonal needs, functional use of buildings and key building surfaces that need to be guaranteed solar access.

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