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Impact of Urban Re-Densification on Indoor Lighting Demand and Energy Poverty on the Equator, in the City of Quito

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Abstract: Human wellbeing and their quality of life is linked to daylight. However, this is being hindered by the rapid growth of cities, promoted by regulatory frameworks and the interests of property developers that seek high-rise densification and re-densification of certain urban areas, jeopardizing access to daylight. This article proposes a methodology to evaluate the impact of urban re-densification on indoor lighting demand in high-rise buildings in Ecuador and its relationship with energy poverty. It analyzes the urban and building features of Quito, considering the location conditions of buildings and using simulation tools to explore solar irradiance reductions on the façade. It also analyzes increases in lighting demand, while determining the extreme conditions, considering an increase in energy consumption, the average salary, and the Ten Percent Rule. The results show that daylight obstructions and umbral cones generated when facing a high-rise re-densification scenario in the city reduce daylight by between 40% and 80%, generating increases of between 2% and 498% in lighting demand when compared to an unobstructed scenario. These re-densification scenarios may cause significant social problems associated with energy poverty. In conclusion, according to the Ten Percent Rule, buildings should be limited to four stories for streets under 10 m wide, between four and six stories for those between 10 and 14 m, and between six and nine stories for streets that are between 14 and 18 m wide. This research seeks to help public policy developers in making future decisions about risks that are currently not considered in urban planning and that may contradict sustainable development goals.

Keywords: solar access; urban densification; daylight obstructions; lighting consumption; energy poverty; daylight

1. Introduction

The construction sector is facing relevant issues such as energy consumption (EC), energy poverty (EP), and climate change [1], factors that are linked when vulnerable sectors are studied [2]. In the meantime, this phenomenon has caught the attention of the scientific community and society due to its political and social implications [3–5].

Buildings account for 36% of electricity consumption on a global scale [6]. From this, 30% is from the residential/commercial sector, which represents 22.7% in Latin America [7], 37% in Ecuador, and 40% in Quito in particular [8]. Solar energy has the potential to reduce this consumption in certain climates, such as the equatorial one [9], by implementing capture and generation strategies as well as passive systems [9,10].

Research on urban morphology, and its relationship with daylight and comfort, has been widely studied, leading in some cases to standards and laws that seek equality and justice regarding solar access [9,11–18]. Energy expense and climate impact variables have been added to these regulations, integrating energy efficiency (EE) and the use of renewable energies [19].

On the other hand, some research has linked solar access and urban geometry to a greater or lesser probability of EP [20]. EP has normally been connected to the inability of homes to maintain minimum temperatures, to have energy services available, or to have them at an affordable cost [2,5,21]. There is a broad consensus that EP arises as a consequence of high energy prices, low family incomes, buildings with a low EE, inefficient household appliances [22–24], and the needs, characteristics, and practices of occupants [25,26], discarding the influence of the urban context on its increase or reduction.

Along this line, some authors have introduced the concept of "Inter-building Effects", highlighting the importance of fully understanding energy problems, on considering the complex interactions that are produced by spatial proximity [12,27]. The energy performance of buildings and, therefore, family expenses, depend on climate, urban morphology, building design, efficient systems, and occupant behavior [28]. Within the urban morphology, orientation, urban density, building's height ratio, and the street's width play an important role in their performance [18,29,30] and in the greater or lesser risk of suffering from EP [20].

The densification of cities is a decisive indicator for their planning, as it is directly linked to the energy use of buildings [31]. Previous research has shown that re-densification heights of 200–240 m, in latitudes close to the Equator, reduce daylight hours during winter by between 40% and 70% within a radius of 150 m [32]. On the other hand, a densification scenario of 60%, the ratio between the built area and the total area of analysis, increases heating demand by up to 20%. Meanwhile, densification scenarios of 30% increase this by 3% [16]. Under these conditions, it has been seen that lighting demand (LD) rises by up to 42% [33]. The main problem is that urban canyons with higher aspect relations have a lower daylight potential, and possibly a higher dependence on artificial lighting, hence the higher energy demand [34,35].

In Quito, urban expansion is taking place, leading to serious mobility, service, equipment, inequality, etc., issues [36]. The issue of Quito's urban growth has always been considered in territorial regulation proposals, but it was in 1984 when these peripheral settlements were acknowledged as a problem for the city to solve [37]. Urban expansion, particularly informal expansion, with unplanned occupations or invasions so to speak, is the main urban issue in Quito [38], generating an urban segregation phenomenon and marginalization of low-income users [39], which increases inequality in the city [40], even generating labor exclusion patterns linked to residential location and mobility [41].

As a result, the re-densification of the urban center, which is very low compared to other international capitals (112 inhabitants per hectare), is being sought [42]. This process is taking place within the framework of the new Ecoefficiency Ordinance, which promotes increased constructability in areas close to stations on the city's first subway line, or close to the Bus Rapid Transit (BRT) system (See Figure 1), to create new centralities, dynamism, and real estate reinvestment, while reducing the lack of access to services, traffic, and urban expansion [43]. The effect of the BRT in Quito has already been discussed by other authors, indicating that it can cause difficulties when it comes to providing affordable housing to low-income users [44].

Although this height rise is not obligatory, it is estimated that in the future, these consolidated zones will be transformed and re-densified two-fold in terms of the current height, as has been the case in Bogota, Montevideo, Santiago, Curitiba, and Sao Paulo, among others [45–47]. This re-densification within a compact and irregular grid of narrow streets, such as Quito's, can lead to daylight obstructions that affect both the urban and housing space [19]. Currently, lighting corresponds to 28% of total energy consumption in the residential sector of the Ecuadorian Sierra [48], which will only increase if solar access is considerably reduced, most likely implying an increase in energy consumption and in turn generating an increase in energy poverty in the city [49]. However, there is a lack of research, even within the regulatory framework, linked to the impact of urban re-densification regarding the increase of lighting demand and, therefore, to EP situations on the Equator. For this reason, the purpose of this article is to evaluate how increased constructability affects solar access, considering the relationship between the number of stories, the distance between buildings, and the orientation, along with its impact on lighting demand and energy poverty in Quito's homes. It also seeks to contribute towards developing a methodology to evaluate the impact of urban densification on factors that contribute to energy poverty, looking to provide tools for decision making in urban planning. Finally, it looks to help public policy developers regarding future decision making on risks that are currently not considered in urban planning, and that may be contradictory to sustainable development goals related to reducing social inequality and energy consumption.

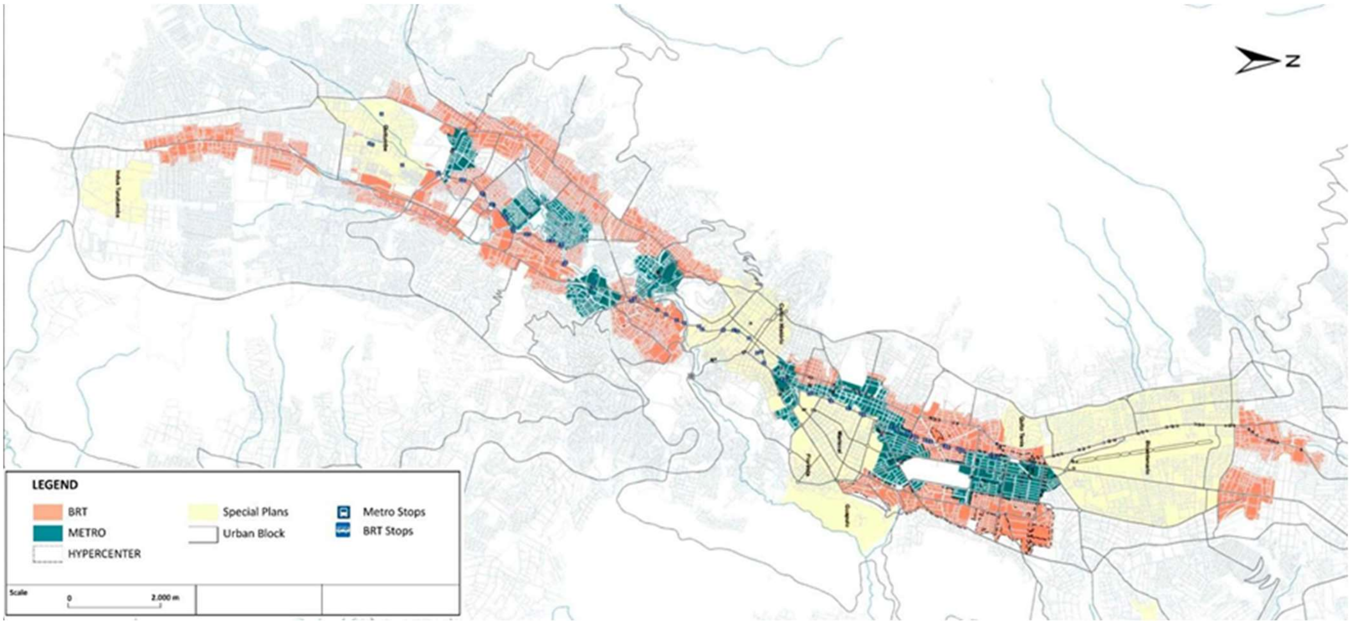

Figure 1. Area of influence of the integrated Metropolitan Transport System. STHV, 2019.

2. Methodology

The methodological framework comprises four main stages, which are described graphically in Figure 2, from up (Stage 1) to down (Stage IV). The software and the documents used in each stage are indicated on the left.

2.1. Urban Reference System

The morphological-daylight analysis is circumscribed to the concept of the urban canyon. As a result, the first stage of the research consisted of establishing the predominant urban characteristics of Quito.

For the morphological features, a survey was made of current building heights, street widths, and orientations to establish the geometry and orientation of the scenarios, using the Land Occupation and Use Plan (PUOS) and Quito's cadastre [43,50]. With the information collected, the following scenarios were defined: one without daylight obstruction, and five with the most characteristic distances of the urban grid. Said scenarios were combined with the orientations, which were collected using the ArcGIS© tool (v10.6, Environmental Systems Research Institute, Inc., Redlands, CA, USA).

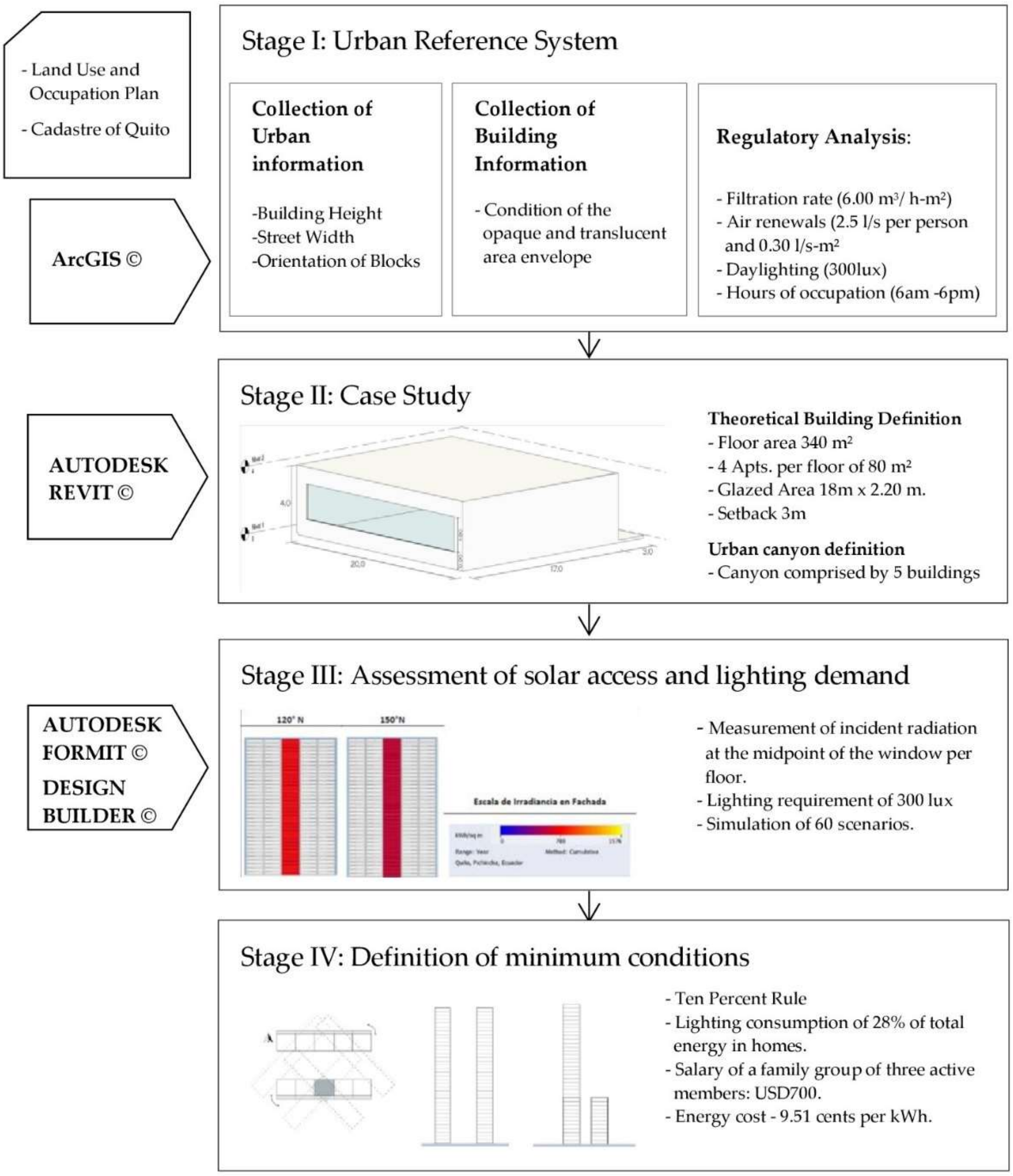

Figure 2. Methodological framework.

2.2. Case Study

The case study was implemented within a lot of at least 400 m^2, as established in Addendum 2 of Resolution N°34 on eco-efficiency, with a face of 20 m. From these minimum conditions, a floor plan area of 340 m^2 (four dwellings) was proposed, with a height between floors of 4 m, following what is stated in Metropolitan Ordinance N°210, and a window of 18 m by 2.2 m in height, along with a windowsill of 0.9 m. To characterize the urban canyon, a random sample of 14 buildings of the study area was selected, with different heights and construction features, from which the material of the façade, colors, textures, opaque, and translucent area percentage were collected to define the window-to-wall ratio (WWR), the characteristics associated with the emissivity and reflectance index of the opaque area, the solar factor, the reflectance index, and the light transmission coefficient of the translucent area. The average of these features was applied both to the theoretical buildings and to the daylight obstruction to keep the same building features in the entire canyon and to eliminate incidence bias caused by the reflection of materials. The window on the façade affected by the urban canyon was incorporated to link the results to the obstruction and to avoid distortions.

The urban canyon was formed with five buildings of the same construction and floor plan characteristics, varying the distance between the theoretical building and the obstruction for the different orientations, establishing a total of six distancing scenarios that were analyzed in the predominant orientations (See Figure 3).

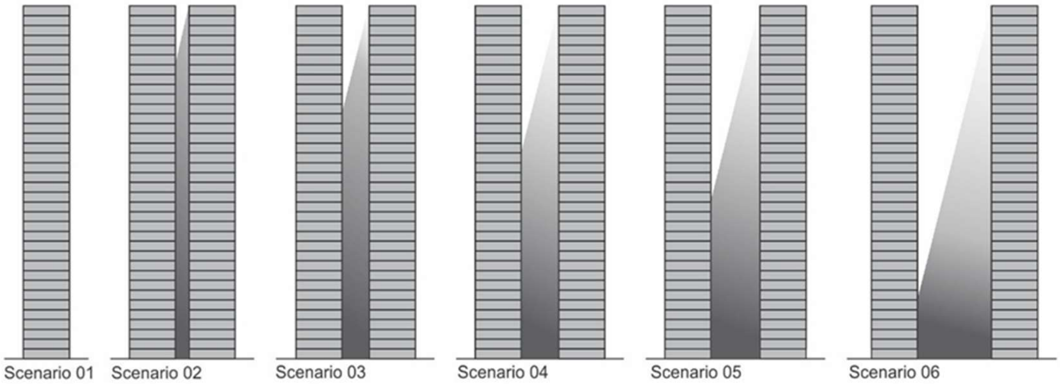

Figure 3. Analysis scenarios. Critical densification of 36 stories and distance variations.

2.3. Evaluation of Solar Access and Lighting Demand

The quantification of annual incident solar radiation (SR) (kWh/m^2) was simulated using Autodesk Formit 360®, considering the levels captured at the mid-point of the window on all the stories of the different scenarios and orientations (60 models). Dynamic LD simulations were made in an occupation timeframe from 6 a.m. to 6 p.m. [51], with an average of 300 lux on the work plane at 85 cm from the ground, following the requirements of MIDUVI [52]. At the same time, this criterion is based on the EN17037 standard, which establishes that there must be 300 lx on 50% of the bedroom's area and 100 lx on 95% of its area for at least half the daylight hours of the year (2190 h) [53,54]. Just as in other research conducted on the topic [55,56], Design Builder® (v 6.1, Design Builder Software Ltd., Stroud, UK) was used (60 models) to analyze the amount of energy required to cover lighting needs and thus quantitatively demonstrate the incidence of the canyon on the energy behavior of the consolidated surroundings.

2.4. Definition of Minimum Conditions

The last stage consisted of establishing the maximum admissible height, considering the impact of an increase in lighting demand. This analysis was made using the EP criterion established by Boardman (2010), the Ten Percent Rule (TPR), which states that a family will be in an EP situation if they use more than 10% of their income to cover energy costs. This maximum energy expense percentage corresponds to the dwelling's entire consumption (climate control, sanitary hot water, cooking, appliances, etc.). In the study location, lighting is 28% of the total consumption [48], with a minimum salary for a family group of USD 700 per month [57]; the maximum lighting expense to destine 10% or USD 70 of the income for energy expenses is USD 19.60. Additionally, a value of 9.51 cents per KWh was used to establish the energy cost [8]. With this data, the lighting consumption was determined in USD to establish the urban geometry conditions where said consumption threshold was exceeded and, therefore, could entail an energy poverty situation.

It is necessary to indicate that, with the conditions marked, the affordability criterion defined by Bhatia and Angelou (2015) is met. They defined that the cost of a standard consumption package of 365 kWh a year must be less than 5% of the home's income [58]. In this case, a 365 kWh package would cost USD 34.71 a month, entailing 4.9% of the established salary (USD 700 per month).

3. Results

The results of the research have been organized into three sections. The first is linked with the collection of urban information, which allows for making the theoretical building model and urban canyon. The second outlines variations regarding solar radiation and lighting for the different analysis scenarios. The Section 3 translates the impact of radiation and lighting variations into economic terms to propose recommendations associated with EP situations.

3.1. Characterization of the Urban and Building Context

The characterization of the urban system has been made using the heights, street width, orientations, and construction characteristics of the envelopes. In Figure 4, it can be seen that the height proposal permitted by PUOS is not standard and has great variability, with 63% of the area set aside for two and four stories, 29% for six and eight stories, 7% for buildings of between 10 and 12 stories, and the rest for buildings over 14 stories (1%), which shows that the city's current building height is medium-low. However, considering that the ecoefficiency ordinance defines four scales for the "Areas of Influence of the BRT and Subway": small scale, comprising buildings from one to six stories (4 to 24 m); medium scale, seven to twelve stories (28 to 48 m); intermediate scale, 13 to 18 stories (52 to 72 m); critical scale of 19 to 36 stories (76 to 144 m). The current zone of four stories could reach between six and eight stories (45% of the area), and the area with a current height between six and eight stories could reach between eight and sixteen stories (29% of the area), which involves a significant re-densification. Considering that the maximum height allowed by the ecoefficiency ordinance is 36 stories (144 m), this height is defined for daylight obstruction and for the case study to analyze how the distance between buildings impacts solar access.

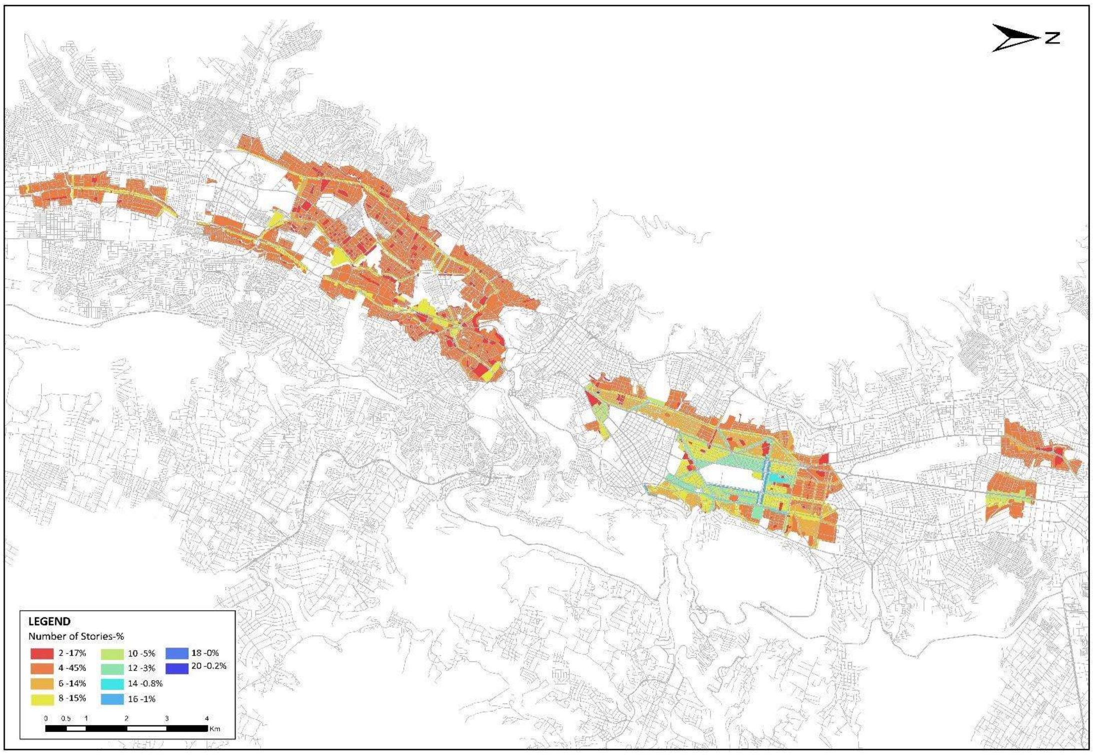

Figure 4. Heights permitted by PUOS within the studied area, BRT, and Subway.

In terms of street width, around 40% correspond to streets of between 6 to 10 m, 35% between 10 and 14 m, and 9% to a width between 14 and 18 m (See Figure 5). This is an important variety in the entire city and the reason why, for the case study, widths of 6, 12, 16, 22, and 30 m are used.

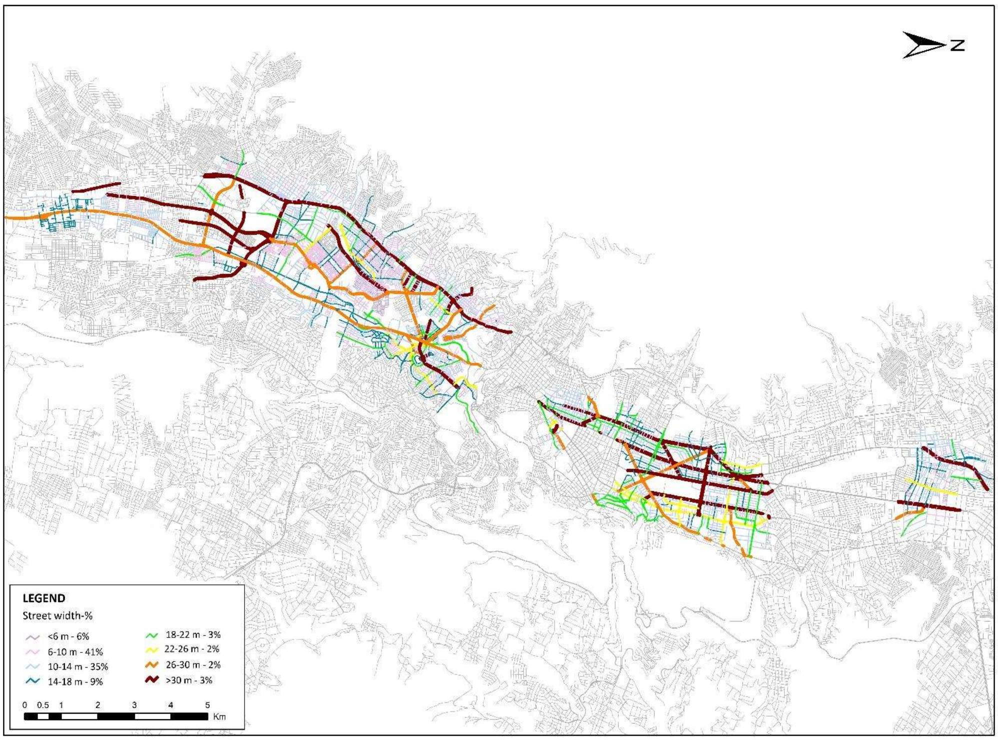

Figure 5. Street widths within the study area.

As for orientations, it is seen that the blocks have a rotation every 15° with respect to North, with the predominant orientations being 15°, 30°, 45°, 120°, 150°, and 165° and complements that already represent 71% (See Figure 6).

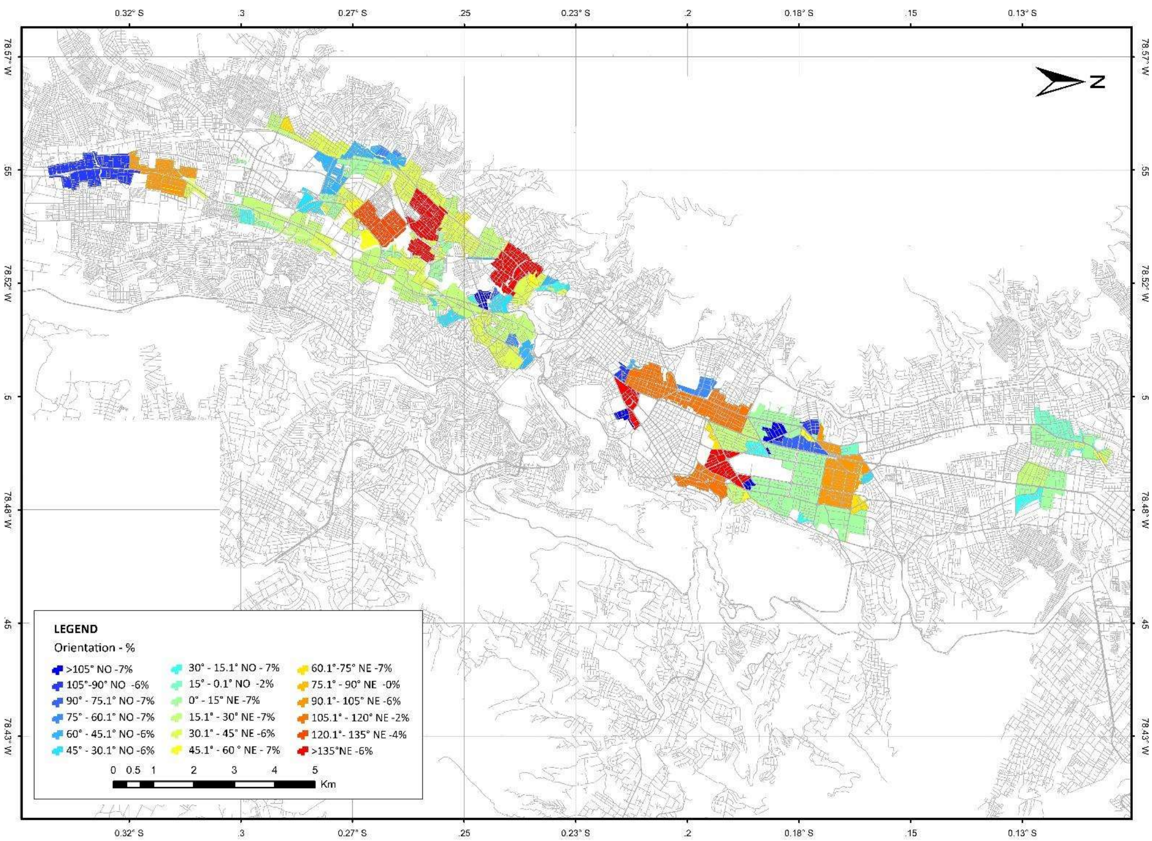

Figure 6. Predominant orientations within the study area.

Based on this, it was decided to establish six distance scenarios (6 m, 12 m, 16 m, 22 m, and 30 m) in the ten most representative orientations of the urban grid (−165°, −150°, −135°, −60°, −30°, 15°, 30°, 45°, 120°, and 150°, with respect to North) with the maximum height that the new legislation allows (36 stories) (See Table 1).

Table 1. Analysis scenarios.

Scenario	Building Height (H) m	Street Width (W) m	Ratio H/W	Orientation °N
Scenario 1	144	-	-	15°, 30°, 45°, 120°, 165°, −30°, −60°, −135°, −150°
Scenario 2		6	24	
Scenario 3		12	12	
Scenario 4		16	9	
Scenario 5		22	6.5	
Scenario 6		30	4.8	

The information collected on the facades shows that the opaque surface is between 21.43% and 79.80%, with an average of 51.27%, compared to the translucent surfaces, which are between 20.20% and 78.56%, with an average of 48.73% (See Table 2).

Regarding materials, it was seen that brick, mortar (white, brown, gray), plaster, uncovered concrete, and aluminum facades predominate (materials with emissivity levels between 0.42 and 0.95 and with reflectance indices of between 41% and 90%). On the translucent surfaces, simple glazing and airtight double glazing were seen, with their conventional features.

Hence, the building's façade was characterized by an opaque percentage of 51.27%, with white textured mortar and a reflectance index of 54%, just as had been defined in other research [59,60], while 48.73% of the façade comprises a glazed area with a 12.15% reflectance index and a luminous transmission coefficient of 39.2% for the windows.

3.2. Irradiance on Facades and Lighting Demands

3.2.1. Scenario 1: Building with No Daylight Obstruction

Scenario 1 determines the annual SR values for a 36 story building (144 m) without daylight obstruction on the different orientations. This scenario will be considered as a baseline to establish the reduction of SR received by the studied façade because of obstructions.

As can be seen in Table 3, the LD is between 7.46 and 7.75 KWh/m^2, with an average value of 7.58 kWh/m^2; the SR with a greater difference oscillates between 377 and 815 KWh/m^2, depending on the orientation, with the façade with the highest SR being the one with a 120° orientation to North and the lowest SR being the one at −165°.

Table 2. Characteristics of the study sample.

<table>
<tr><th rowspan="2">Building Scale</th><th rowspan="2">N. Stories</th><th rowspan="2">% Filled (Wall)</th><th rowspan="2">% Open (Window)</th><th colspan="5">Opaque Area</th><th colspan="3">Translucent Area</th></tr>
<tr><th>Material</th><th>Finishing</th><th>Colour</th><th>Emissivity</th><th>Reflectance Index (%)</th><th>Material</th><th>Reflectance Index (%)</th><th>Luminous Transmission Coefficient (%)</th></tr>
<tr><td rowspan="2">Low</td><td>2</td><td>73.27</td><td>26.72</td><td>Mortar</td><td>Rustic</td><td>White</td><td>0.85</td><td>60</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td>5</td><td>69.53</td><td>30.46</td><td>Brick</td><td>Even</td><td>Terracotta</td><td>0.85</td><td>57</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td rowspan="4">Medium</td><td>8</td><td>63.48</td><td>36.51</td><td>Brick</td><td>Even</td><td>Terracotta</td><td>0.85</td><td>57</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">34.31</td><td rowspan="2">65.69</td><td>Plaster</td><td>Even</td><td>White</td><td>0.42</td><td>90</td><td rowspan="2">Simple Glazing</td><td rowspan="2">7.00</td><td rowspan="2">31.00</td></tr>
<tr><td>Aluminum profile</td><td>Even</td><td>Gray</td><td>0.95</td><td>54</td></tr>
<tr><td>8</td><td>79.80</td><td>20.20</td><td>Mortar</td><td>Rustic</td><td>Brown</td><td>0.61</td><td>52</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td rowspan="4">Intermediate</td><td>13</td><td>68.34</td><td>31.65</td><td>Mortar</td><td>Rustic</td><td>Gray</td><td>0.95</td><td>41</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td>15</td><td>26.38</td><td>73.61</td><td>Plaster</td><td>Even</td><td>White</td><td>0.42</td><td>90</td><td>Double Glazing</td><td>17.00</td><td>47.30</td></tr>
<tr><td>14</td><td>33.19</td><td>66.80</td><td>Uncovered Concrete</td><td>Even</td><td>White</td><td>0.85</td><td>80</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td>18</td><td>33.17</td><td>62.82</td><td>Mortar</td><td>Rustic</td><td>White</td><td>0.85</td><td>60</td><td>Double Glazing</td><td>17.00</td><td>47.30</td></tr>
<tr><td rowspan="6">Critical</td><td>21</td><td>27.61</td><td>72.39</td><td>Plaster</td><td>Even</td><td>White</td><td>0.42</td><td>90</td><td>Simple Glazing</td><td>7.00</td><td>31.00</td></tr>
<tr><td>21</td><td>43.53</td><td>56.46</td><td>Uncovered Concrete</td><td>Even</td><td>White</td><td>0.85</td><td>80</td><td>Double Glazing</td><td>17.00</td><td>47.30</td></tr>
<tr><td rowspan="2">22</td><td rowspan="2">48.13</td><td rowspan="2">51.86</td><td>Brick</td><td>Even</td><td>Terracotta</td><td>0.85</td><td>57</td><td rowspan="2">Double Glazing</td><td rowspan="2">17.00</td><td rowspan="2">47.30</td></tr>
<tr><td>Aluminum Profile</td><td>Even</td><td>Gray</td><td>0.95</td><td>54</td></tr>
<tr><td>25</td><td>21.43</td><td>78.56</td><td>Mortar</td><td>Rustic</td><td>Gray</td><td>0.95</td><td>41</td><td>Double Glazing</td><td>17.00</td><td>47.30</td></tr>
<tr><td>32</td><td>27.37</td><td>72.63</td><td>Brick</td><td>Even</td><td>Terracotta</td><td>0.85</td><td>57</td><td>Double Glazing</td><td>17.00</td><td>47.30</td></tr>
</table>

Table 3. Solar radiation and lighting demand without daylight obstruction by orientation.

Orientation	Solar Radiation (KWh/m^2 Year)	Lighting Demand (KWh/m^2 Year)
15°	568	7.62
30°	660	7.68
45°	773	7.73
120°	815	7.75
150°	578	7.72
−165°	374	7.68
−150°	377	7.60
−135°	421	7.55
−60	514	7.46
−30°	458	7.47

3.2.2. Scenario 2: Urban Canyon Ratio 24

In Figure 7, a reduction of SR is shown. A product of the daylight obstruction at 6 m, being 8% and 11% on floor 36 and increasing as the number of stories drops, until reaching the maximum reduction on floor 25, where a reduction of between 60% (Orientation −150°) and 82% (Orientation 120°) is produced, with an average value of 71%. The largest differences were found on floors 33 and 34, with a difference per orientation that reaches 33% and 34%.

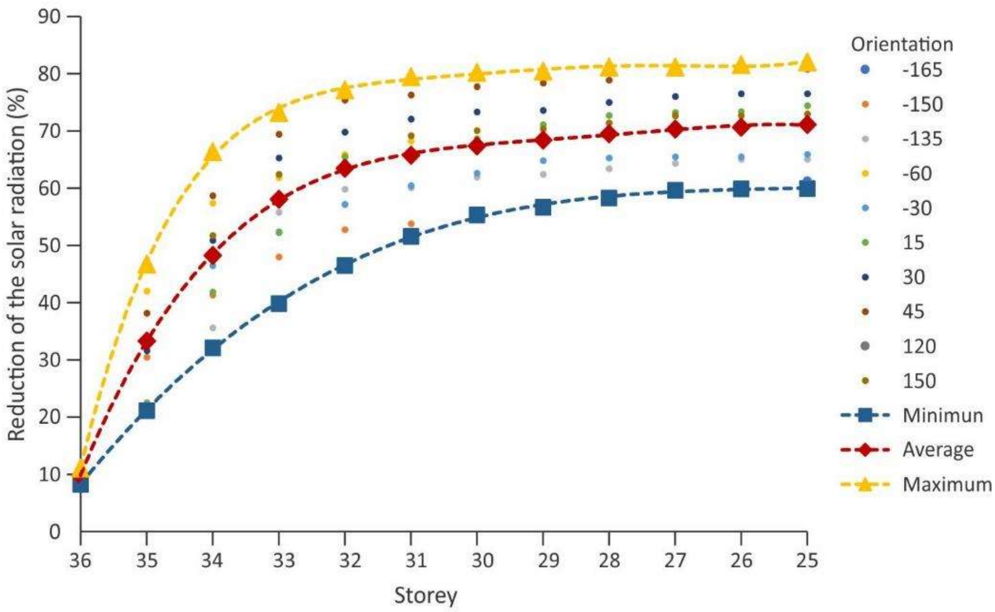

Figure 7. Percentage of radiation reduction on the façade by orientation for an obstruction of 6 m (Ratio 24).

The SR reduction implies an increase in LD compared to Scenario 1 (unobstructed) of between 5.1 KWh/m^2 (floor 36) and 37.1 KWh/m^2 (floor 25), depending on the orientation, which results in a difference by orientation on floor 36 of 4.0 KWh/m^2 as the maximum, and on floor 25 of 1.9 KWh/m^2 (See Table 4). The increase of LD on floor 25 is between 457% and 498%, with an average of 480% compared to the baseline scenario, a condition that is similar for all floors below this. On the other hand, the top floor (36) has an average LD increase of 84% (See Table 5). Scenario 2 requires an average of 42.3 KWh/m^2 to cover the LD generated by daylight obstruction, which means 504,188.5 KWh per year.

Table 4. Solar radiation on the façade for Scenario 2 (KWh/m^2) and reduction compared to Scenario 1 (%).

Orientation	Floor									
	25		31		34		35		36	
15°	145	74%	191	66%	330	42%	440	23%	521	8%
30°	155	77%	184	72%	324	51%	451	32%	599	9%
45°	148	81%	183	76%	319	59%	478	38%	689	11%
120°	150	82%	167	80%	163	80%	175	79%	196	76%
150°	156	73%	178	69%	279	52%	384	34%	526	9%
−165°	145	61%	181	52%	254	32%	295	21%	336	10%
−150°	151	60%	174	54%	221	41%	262	31%	335	11%
−135°	147	65%	168	60%	271	36%	279	34%	375	11%
−60	148	71%	163	68%	219	57%	298	42%	467	9%
−30°	156	66%	181	60%	245	47%	308	33%	419	9%

Table 5. Lighting demand for Scenario 2 (KWh/m^2) and increase compared to Scenario 1 (%).

Orientation	Floor									
	25		31		34		35		36	
15°	42.9	463%	41.4	443%	32.6	328%	24.7	224%	16.1	111%
30°	42.8	457%	41.2	437%	34.0	342%	25.8	236%	16.8	119%
45°	44.3	473%	41.9	442%	34.0	340%	24.9	222%	12.8	66%
120°	44.7	476%	42.8	452%	33.9	338%	23.3	200%	13.0	68%
150°	44.4	475%	42.4	449%	33.7	336%	23.5	204%	13.3	73%
−165°	44.5	480%	42.7	455%	33.6	338%	24.0	213%	14.0	83%
−150°	44.5	485%	42.7	461%	34.1	349%	24.0	216%	13.8	82%
−135°	44.7	492%	43.0	470%	34.1	352%	23.5	211%	13.5	79%
−60	44.6	498%	42.9	476%	34.1	358%	23.6	216%	13.5	80%
−30°	44.2	492%	42.3	466%	33.6	350%	23.5	215%	13.3	77%

3.2.3. Scenario 3: Urban Canyon Ratio 12

In the scenario with a daylight obstruction at 12 m, it is seen that the SR reduction becomes stable on floor 16, where a reduction of between 54% (orientation −165°) and 81% (orientation 120°) occurs, with an average of 69%. The greatest differences are found on floors 28 and 30, with a difference by orientation that reaches 33% and 35% (See Figure 8).

The SR reduction implies an increase of LD compared to Scenario 1 (unobstructed) of between 1.1 KWh/m^2 (Floor 36) and 39.8 KWh/m^2 (Floor 16), depending on the orientation, giving a difference by orientation on floor 36 of 0.5 KWh/m^2 as a maximum and on floor 16 of 4.8 KWh/m^2 (see Table 6). The increase in LD on floor 16 is between 417% and 487%, with an average of 436% compared to the baseline scenario, a condition that is similar for all the floors below this. On the other hand, the top floor (36) has an average LD increase of 15%, which implies a 65% difference compared to Scenario 2 (See Table 7). Scenario 3, on average, requires 33.5 KWh/m^2 to cover the lighting demand generated by daylight obstruction, which means 399,611.3 KWh per year.

3.2.4. Scenario 4: Urban Canyon Ratio 9

The results for Scenario 4 (obstruction at 16 m) showed that the reduction of SR stabilizes around floor 13, where a reduction of between 52% (orientation −165°) and 80% (orientation 120°) was seen, with an average of 67% (see Table 8 and Figure 9). The highest differences were found on floors 25 and 30, with a difference by orientation that reached 33% and 35%.

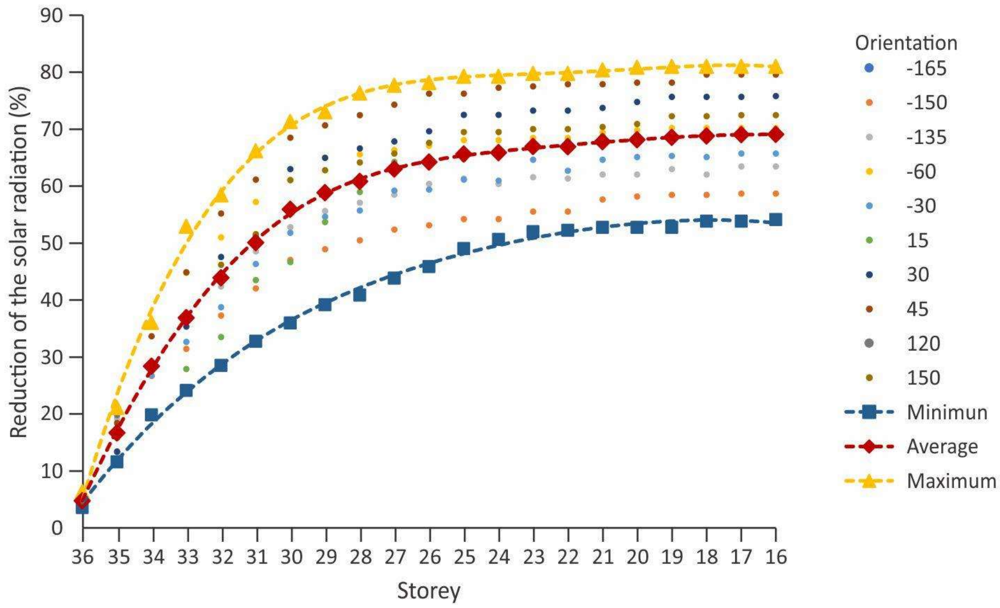

Figure 8. Radiation reduction percentage on façade by orientation for an obstruction at 12 m (Ratio 12).

Table 6. Solar radiation on façade for Scenario 3 (KWh/m^2) and reduction compared to Scenario 1 (%).

Orientation	Story									
	16		26		32		34		36	
15°	172	70%	199	65%	377	34%	455	20%	544	4%
30°	158	76%	199	70%	345	48%	471	29%	633	4%
45°	156	80%	182	76%	345	55%	512	34%	745	4%
120°	153	81%	176	78%	337	59%	525	36%	785	4%
150°	158	73%	186	68%	310	46%	415	28%	555	4%
−165°	171	54%	190	49%	267	29%	299	20%	352	6%
−150°	155	59%	176	53%	236	37%	276	27%	353	6%
−135°	153	64%	166	61%	242	43%	300	29%	396	6%
−60	152	70%	168	67%	251	51%	328	36%	486	5%
−30°	156	66%	185	60%	280	39%	335	27%	436	5%

Table 7. Lighting demand for Scenario 3 (KWh/m^2) and increase compared to Scenario 1 (%).

Orientation	Story									
	16		26		32		34		36	
15°	40.0	425%	38.7	407%	29.3	285%	22.9	201%	8.8	15%
30°	39.7	417%	38.7	404%	30.6	299%	23.5	206%	8.8	15%
45°	40.0	417%	38.7	400%	29.3	279%	22.9	197%	8.8	13%
120°	44.5	474%	42.3	445%	32.3	317%	22.4	189%	8.6	11%
150°	40.1	420%	39.0	405%	30.8	299%	23.5	205%	8.9	15%
−165°	39.8	418%	38.3	399%	29.5	284%	23.1	201%	8.9	16%
−150°	39.8	423%	38.8	410%	30.6	302%	23.7	211%	8.8	16%
−135°	44.3	487%	42.0	456%	32.5	330%	22.6	200%	8.4	11%
−60	40.8	447%	39.3	427%	30.8	313%	22.9	207%	8.8	18%
−30°	39.9	434%	38.7	419%	30.5	308%	23.5	214%	8.7	16%

Table 8. Solar radiation on façade for Scenario 4 (KWh/m^2) and the reduction compared to Scenario 1 (%).

Orientation	Floor									
	13		26		32		34		36	
15°	179	68%	249	56%	411	28%	490	14%	547	4%
30°	193	71%	236	64%	430	35%	531	20%	639	3%
45°	169	78%	184	76%	262	66%	327	58%	399	48%
120°	162	80%	220	73%	417	49%	588	28%	787	3%
150°	188	67%	230	60%	372	36%	458	21%	558	3%
−165°	178	52%	224	40%	282	25%	312	17%	355	5%
−150°	172	54%	199	47%	261	31%	299	21%	357	5%
−135°	161	62%	184	56%	262	38%	327	22%	399	5%
−60	157	69%	182	65%	299	42%	395	23%	488	5%
−30°	171	63%	213	53%	307	33%	371	19%	439	4%

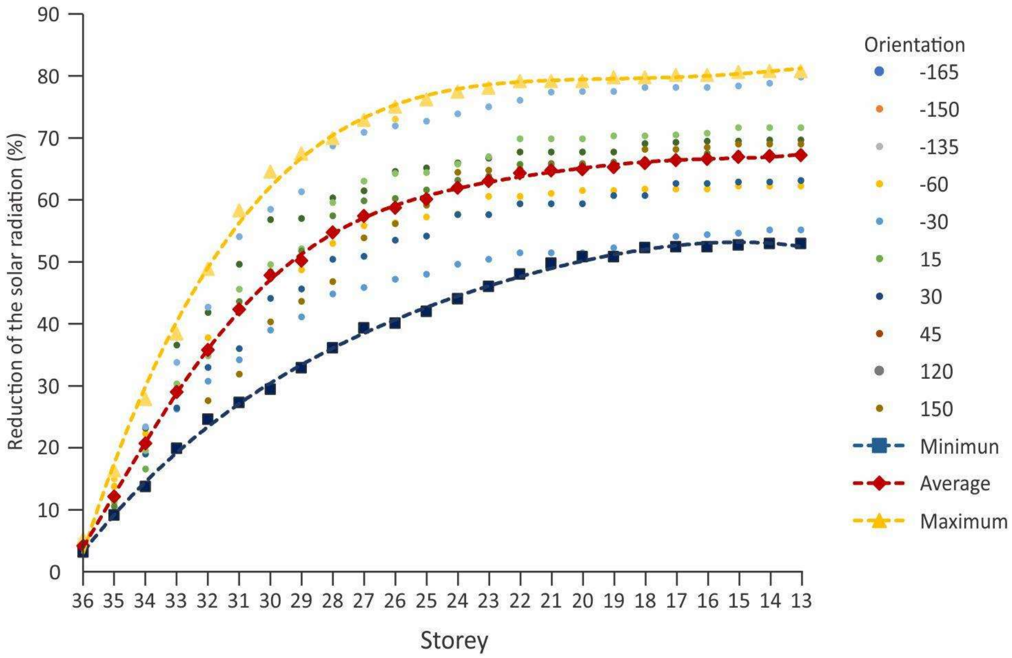

Figure 9. Radiation reduction percentage on façade by orientation for an obstruction at 16 m (Ratio 9).

The reduction of SR implies an increase in LD compared to Scenario 1 (unobstructed) of between 0.7 KWh/m^2 (floor 36) and 29.5 KWh/m^2 (floor 13) depending on the orientation, which resulted in a difference by orientation on floor 36 of 0.3 KWh/m^2 as a maximum, and on floor 13 of 4.4 KWh/m^2 (see Table 8). In this scenario, on average, the theoretical building requires 33.5 kWh/m^2 to cover the LD generated by daylight obstruction, which means 399,611.3 kWh for the whole building per year.

The increase of LD on floor 13 is between 373% and 427%, with an average of 387% compared to the baseline scenario, a condition that is similar for all the floors below. On the other hand, the top floor (36) has an average LD increase of 9%, which implies a 71% difference compared to Scenario 2 (see Table 9).

Table 9. Lighting demand for Scenario 4 (KWh/m^2) and increase compared to Scenario 1 (%).

Orientation	Floor									
	13		26		32		34		36	
15°	36.37	377%	33.36	338%	24.52	222%	18.8	147%	8.29	9%
30°	36.47	375%	34.3	347%	25.4	231%	19.32	152%	8.33	8%
45°	37.34	383%	35.35	357%	24.98	223%	18.27	136%	8.34	8%
120°	40.81	427%	37.99	390%	26.35	240%	17.68	128%	8.17	5%
150°	36.52	373%	34.35	345%	25.53	231%	19.38	151%	8.42	9%
−165°	36.54	376%	33.43	335%	24.61	220%	18.88	146%	8.36	9%
−150°	36.47	380%	34.22	350%	25.42	234%	19.36	155%	8.34	10%
−135°	36.87	388%	34.66	359%	25.06	232%	18.51	145%	8.3	10%
−60	37.47	402%	35.12	371%	25.25	238%	18.37	146%	8.25	11%
−30°	36.45	388%	34.26	359%	25.24	238%	19.16	156%	8.19	10%

3.2.5. Scenario 5: Urban Canyon Ratio 6.5

Scenario 5 (obstruction at 22 m) showed that the reduction of SR stabilized around floor 8, where a reduction of between 45% (orientation −165°) and 81% (orientation 120°) occurred, with an average of 64% (see Figure 10 and Table 10). The greatest differences were found on floors 21 and 27, with a difference by orientation that reaches 36% and 38%.

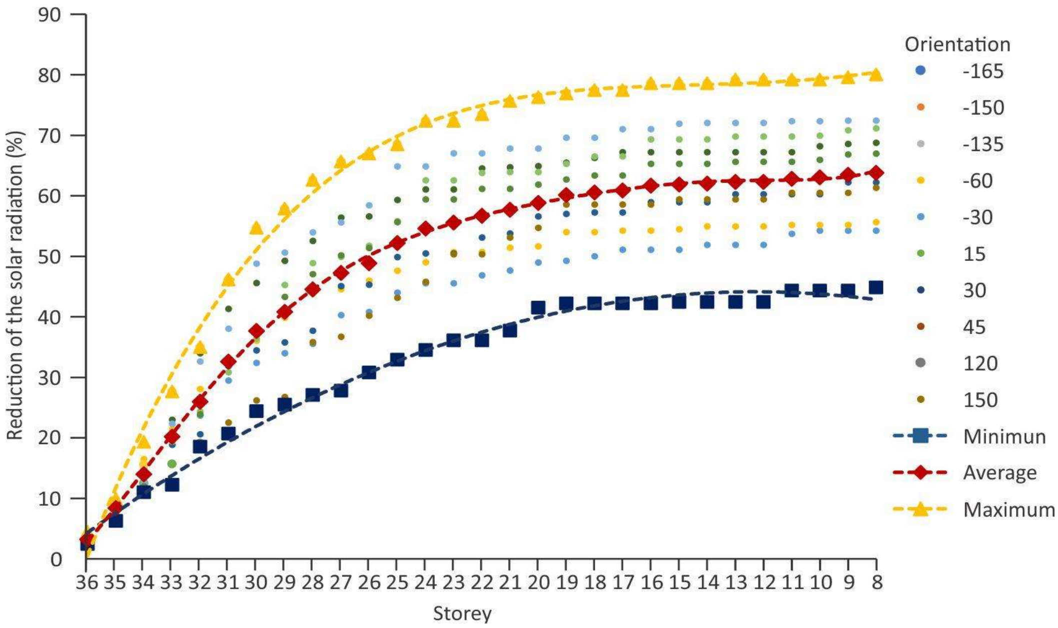

Figure 10. Radiation reduction percentage on façade by orientation for an obstruction at 22 m (Ratio 6.5).

The solar obstruction at 22 m generates an average increase in LD compared to Scenario 1 (unobstructed) of 0.6 KWh/m^2 (floor 36) and 26.6 KWh/m^2 (floor 8), resulting in a difference of orientation on floor 36 of 0.1 KWh/m^2 as a maximum, and on floor 8 of 1.8 KWh/m^2 (See Table 11). The LD increase on floor 8 was found to be between 337% and 370%, with an average of 348% compared to the baseline scenario, a condition that was similar for all the floors below this. On the other hand, the top floor (36) had an average LD increase of 8%, which implied a 76% difference compared to Scenario 2 (see Table 11). In this scenario, on average, the theoretical building required 29.5 kWh/m^2 to cover the LD generated by the daylight obstruction, which is equivalent to 352,046.6 kWh for the entire building per year. It is important to highlight that, under this scenario, the lighting continued to have relevant variations compared to the base scenario and Scenario 4.

Table 10. Solar radiation on façade for Scenario 5 (KWh/m^2) and reduction compared to Scenario 1 (%).

Orientation	Floor									
	8		13		26		32		36	
15°	217	62%	228	60%	338	40%	462	19%	554	2%
30°	187	72%	196	70%	316	52%	498	25%	642	3%
45°	209	73%	212	73%	318	59%	519	33%	751	3%
120°	158	81%	165	80%	265	67%	528	35%	794	3%
150°	188	67%	196	66%	279	52%	439	24%	562	3%
−165°	205	45%	214	43%	258	31%	302	19%	360	4%
−150°	171	55%	180	52%	222	41%	287	24%	361	4%
−135°	185	56%	188	55%	226	46%	302	28%	402	5%
−60	158	69%	166	68%	221	57%	338	34%	498	3%
−30°	171	63%	180	61%	249	46%	363	21%	442	3%

Table 11. Lighting demand for Scenario 5 (KWh/m^2) and increase compared to Scenario 1 (%).

Orientation	Floor									
	8		13		26		32		36	
15°	34.2	348%	33.9	345%	27.6	262%	19.8	160%	8.2	7%
30°	34.1	344%	33.5	336%	28.3	268%	20.4	166%	8.2	7%
45°	34.2	342%	34.0	340%	28.8	272%	19.7	155%	8.2	7%
120°	35.2	355%	35.3	355%	29.1	275%	20.2	161%	8.3	7%
150°	33.9	339%	33.3	332%	28.3	266%	20.5	165%	8.3	8%
−165°	33.5	337%	33.3	333%	27.1	253%	20.0	160%	8.3	8%
−150°	33.9	346%	33.3	339%	28.0	269%	20.4	168%	8.2	8%
−135°	33.8	348%	34.2	353%	28.8	281%	19.5	159%	8.2	8%
−60	35.1	370%	35.2	371%	28.9	288%	19.7	165%	8.1	8%
−30°	34.0	354%	33.5	348%	28.2	278%	20.3	171%	8.1	8%

3.2.6. Scenario 6: Urban Canyon Ratio 4.8

The obstruction at 30 m (Scenario 6) showed that the reduction of SR was stabilized around floor 5, where a reduction of between 38% (orientation −165°) and 76% (orientation 120°) was seen, with an average value of 57% (see Figure 11 and Table 12). The greatest differences were found on floors 13 and 25, with a difference of orientation that reaches 39% and 42%.

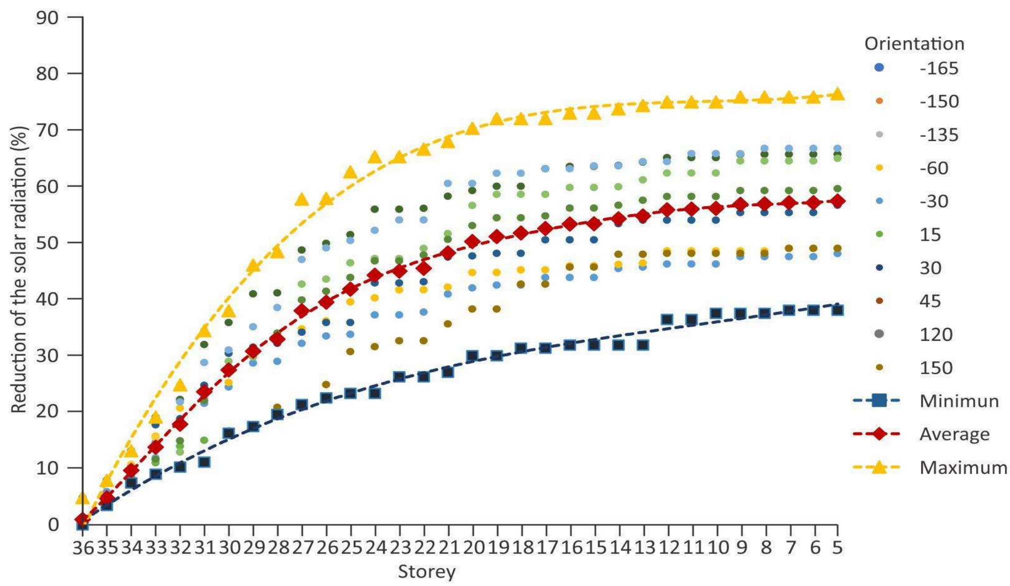

Figure 11. Radiation reduction percentage on façade by orientation for an obstruction at 30 m (Ratio 4.8).

Table 12. Solar radiation on façade for Scenario 6 (KWh/m^2 year) and reduction compared to Scenario 1 (%).

Orientation	Floor							
	5		20		30		36	
15°	290	49%	351	38%	476	16%	566	0%
30°	232	65%	287	57%	469	29%	655	1%
45°	258	67%	306	60%	534	31%	770	0%
120°	193	76%	243	70%	506	38%	809	1%
150°	234	60%	272	53%	417	28%	574	1%
−165°	232	38%	262	30%	312	17%	374	0%
−150°	196	48%	219	42%	285	24%	376	0%
−135°	215	49%	233	45%	315	25%	420	0%
−60	177	66%	210	59%	330	36%	508	1%
−30°	199	57%	240	48%	345	25%	311	32%

This scenario generates an average increase in LD compared to Scenario 1 (unobstructed) of 0.4 KWh/m^2 (floor 36) and 20.2 KWh/m^2 (floor 5), resulting in a difference by orientation on floor 36 of 0.3 KWh/m^2 as a maximum and on floor 5 of 2 KWh/m^2 (see Table 13). An increase of LD on floor 5 of between 253% and 286% was found, with an average of 265% compared to the baseline scenario, a condition that was similar for all the floors below this. On the other hand, the top floor (36) had an average LD increase of 6%, which implies a 78% difference compared to Scenario 2 (see Table 13). In this scenario, on average the theoretical building required 23.3 kWh/m^2 to cover the lighting demand generated from the daylight obstruction, which led to 276,971.3 kWh for the whole building per year.

Table 13. Lighting demand for Scenario 6 (KWh/m^2 year) and increase compared to Scenario 1 (%).

Orientation	Floor							
	5		20		30		36	
15°	26.9	253%	24.0	215%	17.5	130%	8.1	6%
30°	27.8	261%	25.2	229%	18.1	135%	8.1	6%
45°	28.5	269%	25.7	233%	17.7	129%	7.9	2%
120°	29.1	275%	26.2	238%	18.0	133%	8.2	6%
150°	27.3	254%	25.0	223%	17.9	132%	8.2	6%
−165°	27.6	260%	24.7	221%	17.8	131%	8.1	6%
−150°	27.4	260%	24.9	228%	17.9	135%	8.1	6%
−135°	27.4	263%	24.7	228%	17.1	127%	8.0	6%
−60	28.8	286%	25.9	247%	17.7	137%	7.9	6%
−30°	27.6	270%	25.1	236%	17.9	140%	8.0	6%

3.3. Minimum Location Conditions

Bearing in mind that the increase in lighting demand associated with urban densification may imply an increase in EP situations, it was established that the maximum consumption that a family would destine monthly for lighting is USD 19.60 for TPR. Said values were used as a reference to determine the maximum number of floors, considering the distance between buildings, to guarantee access to lighting systems. Table 14 shows the monthly lighting costs for each scenario and orientation evaluated, allowing identification of cases where the established criteria were exceeded. As can be seen in the results, the difference in energy expenditure between floor 1 of Scenario 2 and the same floor of Scenario 6 is between USD 9.19 and USD 10.99, with an average value USD 10.28, with no major differences associated with orientation. In each scenario, the were important differences in the monthly energy cost, with the average difference being the one between floor 1 and 36 of Scenario 2 of USD 19.39 and for Scenario 2 of USD 12.88, which showed that daylight obstructions can generate significant energy inequalities.

Table 14. Monthly lighting cost (USD) by scenario, floor and orientation (gray: height limit whereby the expense is lower than the Ten Percent Rule).

	Floor	Orientation (°N)									
		−165	−150	−135	−60	−30	15	30	45	120	150
Scenario 2 Ratio 24	1	28.54	28.50	28.64	28.58	28.35	27.37	26.95	28.61	28.62	28.51
	25	28.24	28.19	28.31	28.26	28.05	27.21	27.10	28.06	28.31	28.13
	31	27.04	27.04	27.26	27.22	26.80	26.22	26.13	26.54	27.12	26.86
	34	21.32	21.62	21.64	21.65	21.29	20.66	21.54	21.54	21.50	21.35
	35	15.23	15.20	14.90	14.95	14.92	15.66	16.36	15.77	14.74	14.89
	36	8.89	8.75	8.55	8.53	8.40	10.18	10.67	8.11	8.26	8.45
Scenario 3 Ratio 12	1	25.45	25.61	27.98	25.94	25.59	25.58	25.63	25.58	28.11	25.82
	26	24.31	24.58	26.62	24.92	24.56	24.52	24.56	24.52	26.79	24.71
	32	18.69	19.38	20.58	19.54	19.31	18.58	19.41	18.58	20.49	19.51
	34	14.65	15.00	14.35	14.51	14.88	14.53	14.89	14.53	14.21	14.92
	35	10.60	10.73	9.59	10.13	10.57	10.35	10.55	10.35	9.31	10.37
	36	5.64	5.59	5.33	5.57	5.50	5.55	5.58	5.55	5.44	5.63
Scenario 4 Ratio 9	1	23.45	23.41	23.66	24.13	23.45	23.39	23.41	25.93	26.64	23.45
	26	21.20	21.70	21.97	22.26	21.72	21.15	21.74	22.41	24.09	21.78
	29	18.53	19.09	19.23	19.50	19.14	18.36	19.07	20.06	21.09	19.18
	32	15.60	16.11	15.89	16.01	16.00	15.55	16.11	15.84	16.70	16.19
	34	11.97	12.28	11.74	11.65	12.15	11.92	12.25	11.58	11.21	12.29
	35	9.67	9.89	9.25	9.24	9.79	9.72	9.95	8.49	8.90	9.86
	36	5.30	5.29	5.26	5.23	5.19	5.25	5.28	5.29	5.18	5.34
Scenario 5 Ratio 6.5	1	21.37	21.57	21.54	22.36	21.60	21.78	21.70	21.74	22.47	21.55
	13	21.09	21.13	21.70	22.28	21.22	21.48	21.25	21.55	22.36	21.14
	25	18.05	18.73	18.90	19.40	18.72	18.39	18.87	19.25	19.50	18.77
	26	17.20	17.77	18.23	18.33	17.88	17.49	17.92	18.24	18.44	17.92
	32	12.65	12.91	12.37	12.52	12.86	12.58	12.94	12.48	12.80	12.98
	34	9.32	9.37	8.65	8.87	9.35	9.08	9.43	8.78	8.97	9.37
	36	5.24	5.21	5.17	5.13	5.12	5.19	5.23	5.23	5.28	5.27
Scenario 6 Ratio 4.8	1	18.08	17.54	17.84	18.79	17.66	17.30	17.76	18.50	18.87	17.52
	5	17.52	17.35	17.37	18.25	17.51	17.07	17.59	18.07	18.42	17.34
	20	15.63	15.81	15.69	16.40	15.93	15.21	15.99	16.32	16.61	15.83
	30	11.27	11.32	10.86	11.21	11.36	11.12	11.44	11.22	11.44	11.35
	32	9.98	10.03	9.49	9.71	10.07	9.87	10.15	9.73	9.80	10.06
	36	5.15	5.13	5.08	5.02	5.04	5.13	5.14	5.02	5.20	5.19

Note: Gray colour identify height limit whereby the expense is lower than the Ten Percent Rule.

In Figure 12, it is possible to see that, using the Ten Percent Rule for Scenario 2 (distance of 6 m), the maximum height of the building must be 8 m to be below the maximum consumption established, i.e., two floors or a ratio of 1.33. For Scenario 3 (distance of 12 m), the maximum building height was 20 m, i.e., five floors or a ratio of 1.66. For Scenario 4 (distance of 16 m), the maximum building height was 32 m, i.e., eight floors or a ratio of 2. For Scenario 5 (distance of 22 m), the maximum building height was 48 m, i.e., 12 floors or a ratio of 2.18. Finally, for Scenario 6 (distance of 30 m) it was possible to project 36 floors (144 m) or a ratio of 4.8.

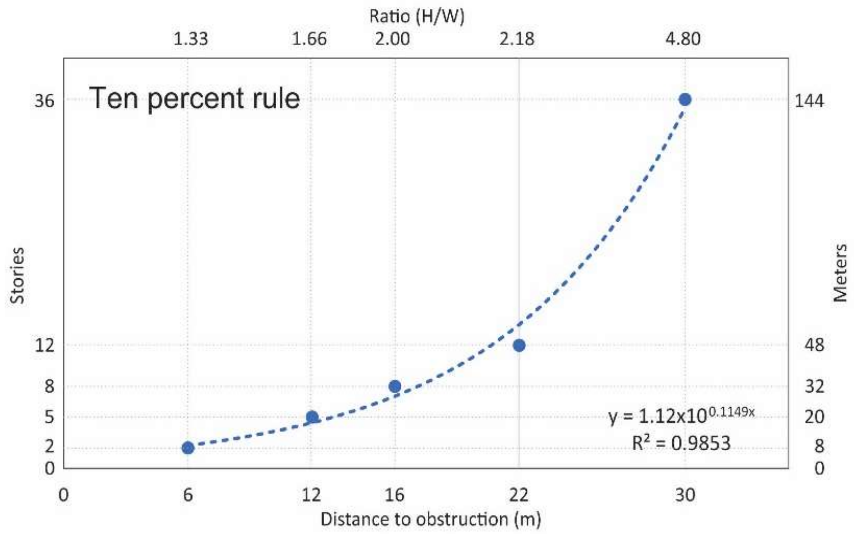

Figure 12. Maximum number of stories recommended considering the distance from the daylight obstruction.

4. Discussion

Many Latin American cities are facing urban expansion problems, generating segregation, marginalization, and exclusion issues related to residential location and mobility [37,39–41]. In this sense, re-densification policies are being generated that may affect energy consumption at an urban and a household level [49].

The characteristics of street width, orientation, and building height in Quito do not have a clear urban organization that considers urban criteria for re-densification. This is because of adapting spaces between gorges and slopes, with the result being a complex socio-spatial process and several urban development plans that, in some cases, were late in terms of controlling urban population growth [36]. It was seen that, in the BRT zone, the maximum height of four stories (72%) is predominant with the PUOS allowing an increase in constructability of 50%, reaching a total height of six stories. These have a predominant street width (50%) of between 6 and 10 m, which, if their re-densification took place, would increase their lighting demand.

The results showed that the umbral cones generated when facing a high-rise re-densification scenario reduced SR by between 40% and 80%, findings that differ from the study made in Bogota, where there was a reduction of between 30% and 50% [32]. Said variation in SR leads to an LD associated with daylight obstructions that oscillates between 7.90 kWh/m^2 to 44.70 kWh/m^2, depending on the depth of the urban canyon, implying an increase compared to the unobstructed scenario of between 2% and 498% for the most unfavorable case. This increase was reduced as the distance from the daylight obstruction increased, with the average difference between Scenario 2 (obstruction at 6 m) and Scenario 6 (obstruction at 30 m) for the most unfavorable floor being 214%. The research made by Strømann-Andersen et al. (2011) in Copenhagen indicated that an urban canyon with a ratio of 3.0, regarding an unobstructed environment, could multiply energy consumption sixfold [61]. However, it can be indicated that findings regarding the increase or decrease in the use of energy in buildings are quite diverse [31]. Some authors indicate that an increase in urban density may imply a reduction in energy consumption associated with a reduction of energy gains and losses [62–64]. However, others consider that there is an offset between the reduction of heat losses, solar radiation, and daylighting that implies an increase in energy consumption [65–67]. In the case of Quito, where the consumption associated with air-conditioning is very low, without a doubt the latter occurs.

On one hand, regarding the relationship between orientation and solar access, some authors indicate that urban East-West orientation is more favorable in terms of solar access [13], decreasing as they move further away from the Equator [68]. However, the results of Scenario 1 showed that the greatest solar radiation takes place on the South-East orientation (120 °N). It was also seen that a reduction of incident solar radiation on the building is mainly related to the distance from the daylight obstruction and its height, with orientation passing to a second plane. This was already indicated by Bournas et al. (2019) in Sweden, where they evaluated 54 buildings and indicated that the performance of each typology was shown to depend significantly on surrounding obstructions [69]. Nonetheless, for the set of orientations evaluated, the average incident radiation oscillated between 145 kWh/m^2 and 809 kWh/m^2, with between 145 kWh/m^2 and 336 kWh/m^2 for the most unfavorable orientation (−165 °N). Thus, the East-West orientation was not the most favourable for all urban grids, despite being on the Equator. It was also seen that the East orientation had a 10% reduction compared to the West, information that must be considered when implementing solar capture systems on the facades.

On the other hand, the increase in lighting demand implied an increase of up to USD 30 per month per dwelling, exceeding the admissible maximum of 10% of the monthly salary, USD 19.60, with 28% destined to lighting. According to other authors, an urban planning strategy to reduce this impact consists of that lower floors with less favorable conditions for solar access are destined to uses other than housing (for example, storage, parking, service areas, and other uses that require less daily lighting daylight) [11], or according to the results obtained, the building heights are limited depending on lighting consumption, in order to reduce energy poverty.

The relationship of urban re-densification with EP generation lacks study, although Poruschi et al. (2018) indicate that, for low-income households, greater density is related to a greater likelihood of experiencing energy poverty, which is statistically significant at the 5% level [49]. Other research has linked both variables in other climates but mainly associated with air-conditioning control [20]. This research also adds to the debate, with the need of establishing energy poverty criteria using the context studied. As the results showed, the indicator used would be a determining factor to establish re-densification scenarios, with maximum heights considering the existing street widths. From the results, it can be said that with TPR, the heights should establish four stories for 50% of the streets whose width is under 10 m, between four and six stories for 33% that have a width of between 10 and 14 m, and six to nine stories for 9% of the streets whose width is between 14 and 18 m (see Figure 12).

By extending the analysis of the impact of urban planning on the effect of the environment on the energy demand of dwellings, it is worth mentioning that recent research highlights other aspects that may affect indoor lighting levels, such as the floor area ratio and site coverage, highlighting the incompatibilities of building and urban scale regulations to guarantee the lighting levels required inside dwellings [70]. The need for additional research regarding solar access planning is significant, and the literature available is limited, which implies a knowledge gap, just as Kanters et al. (2021) mentioned [71].

The methodology used has contributed towards evaluating the minimum distance between buildings with aligned facades. These findings must be cautiously evaluated due to methodological limitations that may compromise their external validity. The first from the case study is a generic theoretical case created from the main characteristics of the studied setting. The second corresponds to the material characteristics of the urban canyon, both in terms of reflectance and envelope material, as these variables greatly impact the results. The third limitation is the fact that, in this study, the effects of the urban canyon on the air-conditioning control demands were not analyzed, so it would be interesting to research the set of building variables that affect EP, as well as the relationship of different ways of occupying the land, such as detected, semi-detached, or terraced. Finally, it is important to indicate that the results are closely tied to the EP indicator used; therefore, it is essential to define the percentage that would best fit Ecuador.

It is suggested that future lines of research must be associated with the variability of parameters linked to lighting requirements, hours of use employed, criteria to establish

EP situations, use type, lighting types, shading devices, and other factors such as climate change, as well as data collection onsite that allows validating the results.

5. Conclusions

Solar energy has the potential to reduce energy demands for indoor comfort in certain climates, helping to face problems associated with energy consumption and poverty. Research on urban morphology and its relationship with daylight has been studied at length, generating laws and regulations in some cases. However, in Quito, the urban growth projected by current urban planning may cause daylight obstructions that affect both urban and indoor space.

This research focused on evaluating how the increase of constructability affects solar access, and its consequences on indoor lighting consumption in high-rise buildings in Quito, to develop a methodology that allows establishing maximum heights considering the distance between buildings that reduces energy poverty situations associated with lighting.

Re-densification scenarios studied have allowed seeing that a reduction in average solar radiation of between 71% (Scenario 2) and 57% (Scenario 6) can be found, with the orientation and the story the dwelling is on influencing decisively. Said reductions can imply an average increase in lighting consumption of between 480% (Scenario 2) and 265%, ranging from a lighting consumption of 7.58 kWh/m^2, when unobstructed, to an average of 42.3 kWh/m^2 in the most unfavorable case.

The proposed methodology allowed determining for the case study that, to avoid an increase of EP in Quito, heights should be limited. However, the results had a significant variability depending on the indicator used. As a result, it is necessary to look closer at which energy poverty indicator is suitable to limit building height. Although, there is evidence that a greater increase of constructability reduces solar access and can generate increases in lighting demand to cover daylight shortfalls, which causes an increase in energy costs and may increase energy poverty.

Re-densification is an opportunity to stop damaging the natural landscape and to stop reducing productive areas or agricultural land. Currently, planning policies are being developed that seek that city centers with their services, amenities, transport, etc., provide for the highest number of people, promoting an increase in housing density. These processes greatly affect the solar access of buildings, just as has been shown in the results, and therefore, urban development plans on the Equator must consider the proportionality of building height and the distance from the environment and, to a lesser extent, the orientations of their location.

Ultimately, this research seeks to help public policy developers in making future decisions about risks that are currently not considered in urban planning. A methodology has been generated that may apply to other contexts and situations to study urban re-densification associated with energy poverty, showing that growth in height can lead to an increase in energy poverty, or a lower light comfort for families, something that without a doubt may be contradictory to sustainable development goals related to the reduction of social inequality. Thus, these aspects should be included in urban planning updates in the near future.

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References

1. Santamouris, M. Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change. *Sol. Energy* **2016**, *128*, 61–94. [CrossRef]
2. Pérez-Fargallo, A.; Rubio-Bellido, C.; Pulido-Arcas, J.A.; Javier Guevara-García, F. Fuel Poverty Potential Risk Index in the context of climate change in Chile. *Energy Policy* **2018**, *113*, 157–170. [CrossRef]
3. Shonali Pachauri, D.S. Energy Use and Energy Access in Relation to Poverty. *Econ. Polit. Wkly.* **2004**, *39*, 271–278.
4. González-Eguino, M. Energy poverty: An overview. *Renew. Sustain. Energy Rev.* **2015**, *47*, 377–385. [CrossRef]
5. Bouzarovski, S.; Petrova, S. A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. *Energy Res. Soc. Sci.* **2015**, *10*, 31–40. [CrossRef]
6. IEA; UNEP. International Energy Agency and the United Nations Environment Programme—Global Status Report 2018: Towards a zero-emission, efficient and resilient buildings and construction sector. *Glob. Status Rep.* **2018**, *73*. Available online: https://www.iea.org/reports/2018-global-status-report (accessed on 2 March 2022).
7. REPSOL. Anuario Estadístico-Energético. *Dir. Estud.* **2019**, *169*. Available online: https://www.repsol.com/content/dam/repsol-corporate/es/energia-e-innovacion/documentos-energia-e-innovacion/anuario-estadistico-energetico-2019.pdf (accessed on 2 March 2022).
8. ARCONEL. *Estadisticas Anuales Y Multianual Del Sector Eléctrico Ecuatoriano 2018*; ARCONEL: Quito, Ecuador, 2019.
9. Cárdenas–Jirón, L.A.; Uribe Araya, P. Acceso solar a las edificaciones. El eslabón pendiente en la norma urbanística chilena sobre la actividad proyectual. *Rev. Urban.* **2012**, *2*, 21–42.
10. Lobaccaro, G.; Frontini, F. Solar energy in urban environment: How urban densification affects existing buildings. *Energy Procedia* **2014**, *48*, 1559–1569. [CrossRef]
11. Capeluto, I.G.; Yezioro, A.; Bleiberg, T.; Shaviv, E. Solar rights in the design of urban spaces. In Proceedings of the PLEA 2006—23rd International Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6–8 September 2006; pp. 6–8.
12. Curreli, A. El Acceso Solar a la Escala del Tejido Urbano. El Enfoque Morfológico y el Método de Análisis Comparativo Aplicados al Caso de Barcelona. Ph.D. Thesis, Universitat Politècnica de Catalunya, Departament de Tecnologia de l'Arquitectura, Barcelona, Spain, 2016; p. 335.
13. Knowles, R.L. The solar envelope: Its meaning for energy and buildings. *Energy Build.* **2003**, *35*, 15–25. [CrossRef]
14. Mccann, C.; Solar, K.; Meeting, A.S. A Comprehensive Review of Solar Access Law in the United States Suggested Standards for a Model Statute and Ordinance. 2008. Available online: http://www.solarabcs.org/about/publications/reports/solar-access/ (accessed on 2 March 2022).
15. Derby, G.S. Ligation of the Common Carotid Artery for Malignant Recurrent Hemorrhage of the Vitreous. *JAMA J. Am. Med. Assoc.* **1907**, *XLIX*, 107–110. [CrossRef]
16. Tereci, A.; Ozkan, S.T.E.; Eicker, U. Energy benchmarking for residential buildings. *Energy Build.* **2013**, *60*, 92–99. [CrossRef]
17. Van Esch, M.M.E.; Looman, R.H.J.; De Bruin-Hordijk, G.J. The effects of urban and building design parameters on solar access to the urban canyon and the potential for direct passive solar heating strategies. *Energy Build.* **2012**, *47*, 189–200. [CrossRef]
18. O'Brien, W.T.; Kennedy, C.A.; Athienitis, A.K.; Kesik, T.J. The relationship between net energy use and the urban density of solar buildings. *Environ. Plan. B Plan. Des.* **2010**, *37*, 1002–1021. [CrossRef]
19. Alicia, L.; Jirón, C.; Pablo, J.; Zamorano, J.C.; Acevedo, C. Explorando luz solar en modelos de desarrollo inmobiliario. Aplicaciones en cinco ciudades chilenas. *Rev. Urban.* **2016**, *34*, 158–173.
20. Pérez-Fargallo, A.; Rubio-Bellido, C.; Pulido-Arcas, J.A.; Trebilcock, M. Development policy in social housing allocation: Fuel poverty potential risk index. *Indoor Built Environ.* **2017**, *26*, 980–998. [CrossRef]
21. Thomson, H.; Bouzarovski, S.; Snell, C. Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. *Indoor Built Environ.* **2017**, *26*, 879–901. [CrossRef]
22. Boardman, B. *Fixing Fuel Poverty: Challenges and Solutions*; Earthscan: London, UK, 2010.
23. Rosenow, J.; Platt, R.; Flanagan, B. Fuel poverty and energy efficiency obligations—A critical assessment of the supplier obligation in the UK. *Energy Policy* **2013**, *62*, 1194–1203. [CrossRef]
24. Ambrose, A.R. Improving energy efficiency in private rented housing: Why don't landlords act? *Indoor Built Environ.* **2015**, *24*, 913–924. [CrossRef]
25. Love, J.; Cooper, A.C. From social and technical to socio-technical: Designing integrated research on domestic energy use. *Indoor Built Environ.* **2015**, *24*, 986–998. [CrossRef]

26. Snell, C.; Bevan, M.; Thomson, H. Justice, fuel poverty and disabled people in England. *Energy Res. Soc. Sci.* **2015**, *10*, 123–132. [CrossRef]
27. Wang, P.; Liu, Z.; Zhang, L. Sustainability of compact cities: A review of Inter-Building Effect on building energy and solar energy use. *Sustain. Cities Soc.* **2021**, *72*, 103035. [CrossRef]
28. Baker, N.; Steemers, K. Energy and Environment in Architecture: A Technical Design Guide. Available online: https://books.google.com.ec/books?hl=es&lr=&id=FJp5AgAAQBAJ&oi=fnd&pg=PP1&ots=6jxEryx_7L&sig=EMIGJUAlwL8QlisH1fG4eq38d58&redir_esc=y#v=onepage&q&f=false (accessed on 4 June 2021).
29. Sanaieian, H.; Tenpierik, M.; Van Den Linden, K.; Mehdizadeh Seraj, F.; Mofidi Shemrani, S.M. Review of the impact of urban block form on thermal performance, solar access and ventilation. *Renew. Sustain. Energy Rev.* **2014**, *38*, 551–560. [CrossRef]
30. Hachem, C.; Athienitis, A.; Fazio, P. Evaluation of energy supply and demand in solar neighborhood. *Energy Build.* **2012**, *49*, 335–347. [CrossRef]
31. Quan, S.J.; Li, C. Urban form and building energy use: A systematic review of measures, mechanisms, and methodologies. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110662. [CrossRef]
32. Franco Medina, R.; Bright, P.; Benitez, J.; Beckers, B. A study of solar access in Bogotá: The Las Nieves neighborhood. In Proceedings of the First International Conference on Urban Physics, Quito, Ecuador, 25 September–2 October 2016; pp. 96–121.
33. Han, Y.; Taylor, J.E.; Pisello, A.L. Exploring mutual shading and mutual reflection inter-building effects on building energy performance. *Appl. Energy* **2017**, *185*, 1556–1564. [CrossRef]
34. Mangan, S.D.; Koclar Oral, G.; Erdemir Kocagil, I.; Sozen, I. The impact of urban form on building energy and cost efficiency in temperate-humid zones. *J. Build. Eng.* **2021**, *33*, 101626. [CrossRef]
35. Krüger, E.; Suga, M. Recommendations of height restrictions for urban Canyons in Curitiba, Brazil. *J. Asian Archit. Build. Eng.* **2009**, *8*, 447–452. [CrossRef]
36. Carrión, F.; Erazo Espinosa, J. La forma urbana de Quito: Una historia de centros y periferias. *Bull. L'institut Français D'études Andin.* **2012**, *41*, 503–522. [CrossRef]
37. Peralta Arias, J.; Higueras García, E. Sustainable urban evaluation of Quito's Master Plans. Period 1942–2012. *Estoa* **2016**, *5*, 21–34. [CrossRef]
38. Cuvi, N. Un análisis de la resiliencia en Quito, 1980–2015. *Bitácora Urbano Territorial.* **2016**, *25*, 35. [CrossRef]
39. Durán, G.; Martí, M.; Mérida, J. Crecimiento, segregación y mecanismos de desplazamiento en el periurbano de Quito. *Íconos-Rev Cienc. Soc.* **2016**, *56*, 123–146. [CrossRef]
40. Carrión, F.; Pinto, J.P. Producción y organización espacial de viejas y 'nuevas' desigualdades en Quito. *Andamios Rev. Investig. Soc.* **2019**, *16*, 101. [CrossRef]
41. Herrero Olarte, S. Identifying Patterns of Labor Exclusion by Residencial Causes in South America: The Case of Quito. *J. Urban Reg. Anal.* **2021**, *13*. [CrossRef]
42. CAMICON. Quito, el Cantón más Poblado del Ecuador en el 2020. Available online: https://www.camicon.ec/la-camara-quito-el-canton-mas-poblado-del-ecuador-en-el-2020/ (accessed on 13 December 2020).
43. Secretaría de Territorio. *Hábitat y Vivienda Anexo 2. Instructivo de Aplicación de los Parámetros de Eco-Eficiencia*; Secretaría de Territorio, Hábitat y Vivienda: Quito, Ecuador, 2020; pp. 1–61.
44. Rodriguez, D.A.; Vergel-Tovar, E.; Camargo, W.F. Land development impacts of BRT in a sample of stops in Quito and Bogotá. *Transp. Policy* **2016**, *51*, 4–14. [CrossRef]
45. Bocarejo, J.P.; Portilla, I.; Pérez, M.A. Impact of Transmilenio on density, land use, and land value in Bogotá. *Res. Transp. Econ.* **2013**, *40*, 78–86. [CrossRef]
46. López-Morales, E.; Sanhueza, C.; Espinoza, S.; Órdenes, F. Verticalización inmobiliaria y valorización de renta de suelo por infraestructura pública: Un análisis econométrico del gran santiago, 2008–2011. *Eure* **2019**, *45*, 113–134. [CrossRef]
47. Sandroni, P. Recent Experience with Land Value Capture in São Paulo, Brazil. Available online: https://www.lincolninst.edu/publications/articles/recent-experience-land-value-capture-sao-paulo-brazil (accessed on 13 December 2020).
48. Baquero, M.; Quesada, F. Eficiencia energética en el sector residencial de la Ciudad de Cuenca, Ecuador. *Maskana* **2016**, *7*, 147–165. [CrossRef]
49. Poruschi, L.; Ambrey, C.L. Densification, what does it mean for fuel poverty and energy justice? An empirical analysis. *Energy Policy* **2018**, *117*, 208–217. [CrossRef]
50. Municipio del Distrito Metropolitano de Quito. *Ordenanza Metropolitana 210. PUOS*; Secretaría de Territorio Hábitat y Vivienda: Quito, Ecuador, 2018. Available online: https://gobiernoabierto.quito.gob.ec/wp-content/uploads/documentos/ordenanzas/ordenanzas_sancionadasview.php?showdetail=&ORD=210 (accessed on 2 March 2022).
51. Jhohnson, B. *Patterns of Residential Occupancy*; National Research Council Of Canada Report No. 464; National Research Council of Canada: Ottawa, ON, Canada, 1981. Available online: http://web.mit.edu/parmstr/Public/NRCan/ir464.pdf (accessed on 2 March 2022).
52. Ministerior De Desarrollo Urbano Y Vivienda (MIDUVI). *Eficiencia Energética en Edificaciones Residenciales NEC-HS-EE*; Ministerior De Desarrollo Urbano Y Vivienda (MIDUVI): Quito, Ecuador, 2018; p. 40. Available online: https://www.habitatyvivienda.gob.ec/wp-content/uploads/downloads/2019/03/NEC-HS-EE-Final.pdf (accessed on 2 March 2022).
53. *CEN European Standard EN 17037*; 2018 Daylight in Buildings. European Committee for Standardization: Brussels, Belgium, 2018.

54. Bournas, I. Daylight compliance of residential spaces: Comparison of different performance criteria and association with room geometry and urban density. *Build. Environ.* **2020**, *185*, 107276. [CrossRef]
55. He, Q.; Ng, S.T. Energy-Efficient Window Retrofit for Existing High-Rise Residential Buildings with the Consideration of Mutual Shading. In Proceedings of the 33rd Annual ARCOM Conference, Cambridge, UK, 4–6 September 2017; pp. 755–764.
56. Taleghani, M.; Tenpierik, M.; Van Den Dobbelsteen, A.; De Dear, R. Energy use impact of and thermal comfort in different urban block types in the Netherlands. *Energy Build.* **2013**, *67*, 166–175. [CrossRef]
57. El Comercio INEC: El Ingreso de la Familia Típica en Ecuador es USD 700 Mensuales, en Promedio | El Comercio. Available online: https://www.elcomercio.com/actualidad/inec-ingreso-familia-ecuador-sueldo.html (accessed on 2 January 2021).
58. Bhatia, M.; Angelou, N. *Beyond Connections Energy Access Redefined. World Bank. Energy Sector Management Assistance Program (ESMAP)*; World Bank: Washington, DC, USA, 2015; pp. 1–224.
59. Alchapar, N.; Correa, E. Reflectancia solar de las envolventes opacas de la ciudad y su efecto sobre las temperaturas urbanas. *Inf. La Constr.* **2015**, *67*, e112. [CrossRef]
60. Venegas Quintulén, S.A.; Piderit Moreno, M.B. Reflectancia de las envolventes verticales y su influencia sobre disponibilidad de luz natural en el cañón urbano de la ciudad de Concepcion. *Rev. Hábitat Sustentable* **2018**, *8*, 6–15. [CrossRef]
61. Strømann-Andersen, J.; Sattrup, P.A. The urban canyon and building energy use: Urban density versus daylight and passive solar gains. *Energy Build.* **2011**, *43*, 2011–2020. [CrossRef]
62. Kontokosta, C.E. Predicting Building Energy Efficiency Using New York City Benchmarking Data. *ACEEE Summer Study Energy Effic. Build.* **2012**, 163–174.
63. Ko, Y.; Radke, J.D. The Effect of Urban Form and Residential Cooling Energy Use in Sacramento, California. *Environ. Plan. B Plan. Des.* **2014**, *41*, 573–593. [CrossRef]
64. Rodríguez-Álvarez, J. Urban Energy Index for Buildings (UEIB): A new method to evaluate the effect of urban form on buildings' energy demand. *Landsc. Urban Plan.* **2016**, *148*, 170–187. [CrossRef]
65. Quan, J. Density and Energy Performance of Solar Powered Buildings in the Urban Context. Ph.D. Thesis, Georgia Institute of Technology, Atlanta, GA, USA, 2016.
66. Quan, S.J.; Economou, A.; Grasl, T.; Yang, P.P.-J. Computing Energy Performance of Building Density, Shape and Typology in Urban Context. *Energy Procedia* **2014**, *61*, 1602–1605. [CrossRef]
67. Vartholomaios, A. A parametric sensitivity analysis of the influence of urban form on domestic energy consumption for heating and cooling in a Mediterranean city. *Sustain. Cities Soc.* **2017**, *28*, 135–145. [CrossRef]
68. De Decker, K. The Solar Envelope: How to Heat and Cool Cities without Fossil Fuels. Low-Tech Magazine. Available online: http://www.lowtechmagazine.com/2012/03/solar-oriented-cities-1-the-solar-envelope.html (accessed on 2 March 2022).
69. Bournas, I.; Dubois, M.C. Daylight regulation compliance of existing multi-family apartment blocks in Sweden. *Build. Environ.* **2019**, *150*, 254–265. [CrossRef]
70. Šprah, N.; Košir, M. Daylight provision requirements according to EN 17037 as a restriction for sustainable urban planning of residential developments. *Sustainability* **2020**, *12*, 315. [CrossRef]
71. Kanters, J.; Gentile, N.; Bernardo, R. Planning for solar access in Sweden: Routines, metrics, and tools. *Urban Plan. Transp. Res.* **2021**, *9*, 348–368. [CrossRef]