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Comparative Solar Access Analysis on Building Surfaces, Determination of the Relationship Between Solar Radiation, SVF, and Sunlight Duration

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1. Introduction

Urbanization is a rapidly accelerating total phenomenon, particularly in developing countries. This trend is largely driven by factors such as rural-urban migration, natural population growth and the attraction of economic opportunities in cities. According to the latest data from the United Nations, more than half of the world's population lives in urban areas, which is 57% (Anonymous, 2022). This proportion is expected to increase to 66% by 2050. In 2045, there will be approximately 6 billion city dwellers (World Bank, 2023). Considering these statistics, it is evident that measures need to be taken for future urban development strategies across several domains. In this context, energy in the urban environment is a crucial aspect and warrants significant attention.

One of the most important challenges associated with energy consumption in urban areas is the need to balance energy demand and supply. With more people living and working in cities, there is a greater need for energy to power homes, businesses, and transportation. The energy consumption of buildings in urban areas is a significant issue that requires attention due to the high demand for energy and the resulting environmental impact. Buildings account for a significant portion of the world's energy consumption. Buildings contribute to roughly 32% of global final energy consumption, 17% of direct CO_2 emissions, and account for one-third of indirect emissions (Skillington et al., 2022). In particular, buildings in urban areas consume more energy than those in rural areas, making the urban building sector a crucial area for energy efficiency improvements. One of the primary reasons for the high energy consumption of buildings in urban areas is the need for heating and cooling systems. According to a study by the International Energy Agency, the energy used for heating and cooling buildings in urban areas accounts for approximately 60% of total building energy consumption (Anonymous, 2017).

The energy consumption of buildings in Turkey has been a major concern for the country due to its increasing population and urbanization. The construction industry in Turkey accounts for roughly 34% of the nation's total energy consumption and the energy usage in this sector is steadily rising each year (Anonymous, 2021). Consequently, endeavors aimed at boosting energy efficiency in the construction sector are becoming increasingly crucial. Heating accounts for 55% of the total energy consumption in housing in Turkey. The remaining distribution of energy consumption is as follows: 19% for hot water production, 4% for cooking, 3% for lighting, and 19% for household appliances (Anonymous, 2018). The predominant source of energy consumption in housing is derived from fossil fuels. For instance, in 2018, natural gas consumption in Turkish households accounted for 25.7% of the total consumption (Kabakçı, 2018). Turkey, under the scope of the "Climate Change Action Plan 2011-2023," aimed to ensure that at least 20% of the annual energy demand of new buildings from renewable energy sources starting from the year 2017 (Kabakçı, 2018). Despite this action plan, the objectives have not been fully achieved. The utilization of renewable energy sources, such as solar and wind energy, in the energy consumption of buildings, has not yet reached sufficient levels.

Among renewable energies, solar energy holds significant potential for utilization in buildings. The simplest method, known since antiquity, is the passive method. Utilizing solar energy passively does not necessitate advanced technology. Passive solar systems are designed to maximize the amount of solar radiation entering a building while minimizing heat loss. At the building scale, passive solar design strategies primarily aim to harness solar energy to achieve thermal comfort in buildings by minimizing the need for electrical or mechanical equipment (Stevanović, 2013). Active solar systems are another type of solar energy system that can be used in buildings. Unlike passive solar systems, active solar systems require the use of mechanical and electrical components to capture and store solar energy. In both cases, the buildings must have sufficient access to sunlight during the day. In the urban environment, the performance of building solar systems is strongly linked to urban density. In the present study, solar access in urban areas was analyzed on building façades in Konya, Turkey. The solar gain potential of a point on a façade differs according to the urban context. To compare the solar gains of different locations and draw conclusions, the selection of points was based on the characteristics of the immediate urban environment. The objectives of the study are as follows:

- To determine the total solar radiation received at the selected points on the building façades, which have different urban contexts, and to compare and understand the reasons for the differentiations between these points.
- The second objective of this study is to define a mathematical model based on the results obtained regarding solar gains. This mathematical model can precisely define the relationship between the built context and the total solar radiation received. It can be used in built-up areas with the same climatic context as Konya. Additionally, it could be valuable for acquiring fundamental knowledge about the potential for solar gain, particularly in the early stages of urban and architectural design.

2. Solar Access in Urban Environment

Solar Access can be defined as the continuous availability of direct sunlight a building has without obstruction by another property (Kettles, 2008). It refers to the amount of direct sunlight that a building receives without obstruction from surrounding structures. Solar access is an important consideration in urban planning, especially during the early stages of design when street layouts and building masses are being shaped (Czachura et al., 2022; Capeluto & Shaviv, 2001). It’s a critical factor in sustainable urban design (Mohajeri et al., 2019). This availability of sunlight is vital for many aspects of building performance, including energy efficiency, thermal comfort, and indoor air quality

In densely populated urban areas, the layout of buildings and the orientation of streets can greatly impact solar access. Buildings that are overshadowed by other buildings or surrounded by tall structures may have limited access to sunlight, which can reduce their potential for solar energy generation and natural lighting. This can lead to increased reliance on artificial lighting and HVAC systems, which consume significant amounts of energy and contribute to carbon emissions. The ability to harness sunlight has the potential to significantly reduce energy consumption and greenhouse gas emissions in buildings, which are major contributors to climate change. This not only reduces energy consumption and carbon emissions but also saves costs for building owners and occupants.

On the other hand, solar access in urban environments can also significantly improve the health and well-being of urban inhabitants (Fernández, Gentili & Campo, 2022). Sunlight exposure has been shown to have a range of health benefits, including improved mood, increased productivity, and reduced stress levels. Access to natural light is, therefore, an important factor in creating healthy and livable urban environments (Kanters, Gentileand & Bernardo, 2021).

Studies on solar access in the urban environment are a topic of continued interest in scientific research. Urban areas are major contributors to total energy consumption, and the need for sustainable energy solutions in cities is increasingly recognized. In a general context, the scientific approaches carried out on solar access in urban studies can be described as follows:

1-Simulation and modeling: Studies that employ computer simulations and models to analyze the impact of various urban form factors on solar access, such as building height, density, orientation, and shading. These studies use tools such as geographic information systems (GIS) and building energy simulation software to evaluate the potential for solar energy production and assess the impact of shading on energy consumption and occupant comfort. The study of Compagnon (2004) is a good example for the simulation method to determine solar access. In this research which is one of the pioneers in the field, a method to assess the potential for active and passive solar heating, photovoltaic electricity production, and daylighting on façades and roofs of buildings in urban areas was developed in Fribourg, Switzerland (Compagnon, 2004). In another study, a methodology was developed to assess the potential for photovoltaic energy generation in an urban area using open-source solar radiation tools and a 3D city model implemented in a geographic information system (GIS) (Hofierka & Kaňuk, 2009). In 2007, the simulation software named Suntool was developed by Robinson et al. (2007) to support urban designers to optimize the environmental sustainability of their master planning proposals (Robinson et al., 2007). It is also possible to mention Townscope, and Heliodon as computer tools with which it is possible to analyze solar access (Iommi & Losco, 2016; Teller & Azar, 2001). To have exhaustive knowledge about solar simulation software, the study of Jakica (2018) can be examined. It represents a comprehensive review of solar design tools from a multidisciplinary perspective (Jakica, 2018).

2-Measurement and monitoring: Studies that use field measurements and monitoring to collect data on solar access in the urban environment, such as solar radiation levels, shading, and solar energy production (Huang, Ooka & Kato, 2005). These studies often employ sensors and data loggers to collect data on the performance of solar energy systems in urban areas. For example, measurements of total solar radiation and direct normal radiation were carried out at Universiti Teknologi Petronas (UTP), Seri Iskandar, Malaysia (Mohammad et al., 2020). In this study, the great potential for using solar energy was determined in the campus area (Mohammad et al., 2020). In another study, the solar energy gain on vertical surfaces for heating and cooling systems in big cities of Turkey has been estimated for different orientations using hourly solar radiation measurements (Şaylan et al., 2002).

3-Policy and Planning: Studies focus on the development of policy and planning strategies to promote solar access in the urban environment (Akrofi & Okitasari, 2022). These studies may examine the role of zoning regulations, building codes, and incentives in promoting solar energy systems in urban areas and may provide recommendations for urban planners and policymakers. In the early stages of the expansion of the modern movement in architecture, it is important to cite the ideas of Le Corbusier regarding the consideration of sunlight in city planning. Le Corbusier was a prominent architect and urban planner known for his innovative ideas and contributions to the field. One of his famous concepts was the heliothermal axis, which refers to the orientation of buildings to maximize sunlight exposure (Siret, 2006). This concept was a key component of his urban planning philosophy, emphasizing the importance of sunlighting in urban design. On the other hand, it is important to mention the solar envelope method developed by Knowles, which is practicable in architecture and urban planning (Knowles, 1981). The concept of the solar envelope refers to a zoning regulation that limits the height and location of buildings based on the sun's path (Topaloğlu, 2003). The solar envelope is designed to pens access to sunlight for buildings and outdoor spaces. Knowles' approach is based on the idea of solar rights, which is the principle that all individuals and communities have the right to access and benefit from solar resources. The solar envelope serves as a tool to enforce these rights and ensure that buildings and urban spaces are designed in a way that maximizes solar access and minimizes the impact on the environment (Canan & Bakır, 2008).

Several significant policy initiatives like "The Photovoltaic Power Systems Programme (IEA PVPS)" and "The POLIS2" projects have been implemented to encourage the use of solar energy in urban planning. The Photovoltaic Power Systems Programme (IEA PVPS) was among the initial endeavors to encourage the use of solar energy in urban planning. The program was initiated by the International Energy Agency (IEA) in 1997, and in 2002, the IEA reported on the efforts of Task 7, which focused on integrating PV systems in the built environment (Akrofi & Okitasari, 2022). The project ran from 1997 to 2001, and it included 21 countries, mainly from Europe, the UK, Asia, and America. The EU initiated the POLIS2 project (Identification and Mobilization of Solar Potentials via Local Strategies) in 2009 intending to identify and utilize solar potential through local strategies. This project was similar to previous projects in that it aimed to identify best practices in solar urban planning and create more organized planning and legislation practices for solar developments. Additionally, the International Energy Agency's (IEA) Solar Heating and Cooling (IEA SHC) project established a specific task force (TASK 51) in 2013 to support urban planners and architects in integrating solar PV in urban areas (Akrofi & Okitasari, 2022).

4-Design and innovation: Studies that explore innovative design strategies and technologies for maximizing solar access in the urban environment, such as building-integrated photovoltaics, solar façades, and sun-tracking systems. These studies may also examine the potential of emerging technologies such as energy storage and smart grids to improve the efficiency and effectiveness of solar energy systems in urban areas.

3. Material and Method

3.1. Study Area

The city under study is Konya (37°52′ N, 32°29′ E), situated at an elevation of 1016 m above sea level in the Konya province of southwestern Central Anatolia, Turkey (Figure 1). The population of the city is 1.3 million. The city holds significant importance as a cultural, economic, industrial, and educational center.

Figure 1. The geographical location of Konya

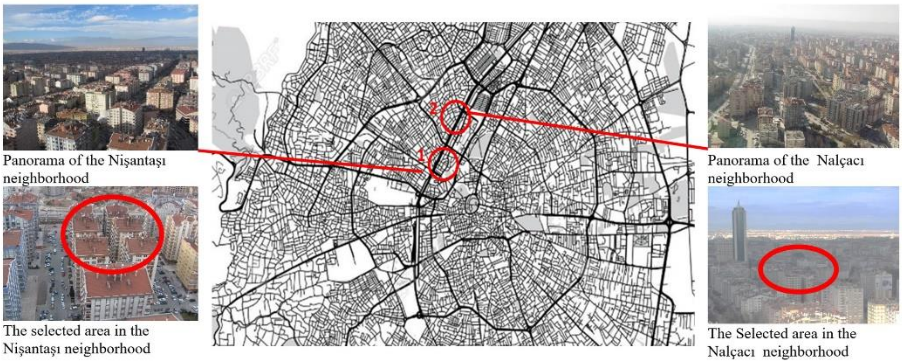


Figure 2. Selected areas in the city of Konya

Two neighborhoods were selected to carry out the solar access analyses: Nişantaşı (1) and Nalçacı (2) (Figure 2). They are both located in the new center of the city. Since the 1990s, the Nişantaşı neighborhood has experienced significant construction and densification. The Nalçacı neighborhood represents the first significant extension of the city towards the Northwest towards the end of the 1960s (1966 master plan). The first high-rise buildings constituting dense construction blocks appeared in this district. The avenue that bears the same name as the neighborhood is a very important artery of the city. Both neighborhoods have a mixed-use profile, featuring commercial, business, and residential functions. Notably, some of the most important office buildings are located here. Their urban morphology is characterized by high block density, which reflects a high level of built-up area and limited open space. Two construction blocks have been selected in these neighborhoods.

3.2. Methodology

The total solar radiation is determined by the sum of direct, diffuse, and reflective radiation. In this study, total solar radiation has been taken into consideration to quantify solar access, which refers to the availability and potential for solar gain. To assess the variation in solar gain, specific points were selected based on their immediate urban environment. The orientation and characteristics of the nearby urban environment are major factors influencing solar access on a building façade. Moreover, these two parameters (obstruction and sky opening) also vary depending on the height of the point on the façade.

In this study, the sky opening (or sky view factor) has been retained to define the effects of the close environment on the results of solar access. The Sky Opening, also known as the Sky View Factor (SVF), is a quantitative measure of the visible portion of the sky. It is expressed as the ratio of the unobstructed sky area visible from the point of interest to the total visible area of the hemisphere above it, as described by Canan (2017). The SVF ranges from 0 (no visible sky) to 1 (completely unobstructed sky) (Lyu, Buccolieri & Gao, 2019).

SVF is a crucial metric in solar access analysis in urban areas, as it affects the amount of the total solar radiation received by the location. The more unobstructed sky visible from a point, the more direct and diffuse solar radiation it can receive. On the other hand, the use of this parameter requires some attention. The SVF should not be analyzed as an isolated parameter (Krüger, 2011). The orientation of the studied point affects the result of the solar gain. Two points that are oriented differently but have the same SVF value will have unequal solar gain results. This is due to the differentiation of the solar path in the visible sky. The visible solar trajectory of a point varies according to the urban morphology (obstruction) but also according to the orientation. The visible solar path defines the duration of sunlight and therefore affects the amount of direct solar gain received by a point.

The determination of solar access, sunlight duration, and sky opening was carried out with Townscope software. Townscope calculates the total solar radiation from a point on a surface and can separately calculate direct, diffuse, and reflected radiation. The total solar radiation for each hour between 7:00 AM and 5:00 PM was obtained for representative days (December 21st, March 21st, June 21st, and September 21st) using records from the Konya provincial meteorological station. Clear sky conditions were assumed for the calculations of solar radiation. The diffuse radiation calculation assumed a perfectly isotropic sky luminance distribution. The surface reflection coefficient of the building façades was assumed to be 0.30, representing the average value for the buildings in the city of Konya. 3D urban models of the selected areas were created and imported into the Townscope software. In the initial stage of the analysis, the total solar radiation values were calculated for the predetermined points on building façades. To draw conclusions, comparisons were made between the total solar radiation values calculated for these points. The variation rates of total solar radiation values were determined based on the orientation, sky opening, and height. In the second stage, the relationships between total solar radiation values and the variables of sky opening and sunlight duration were investigated. Mathematical models were developed to estimate the total solar radiation values (dependent variable) using the sky opening and sunlight duration variables (independent variables).

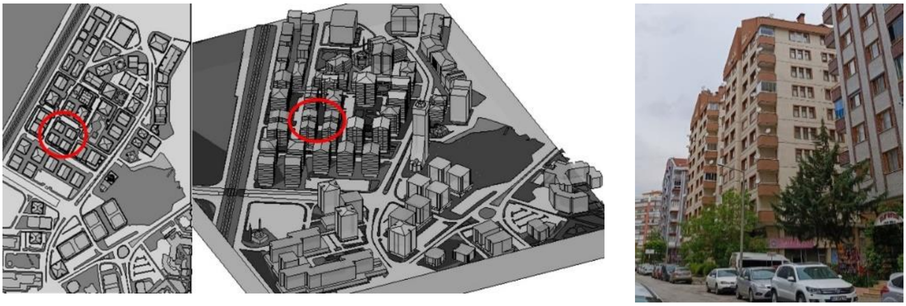
4. Findings and Discussion

4.1. Solar Access Analysis on the Building Façade

The aim is to calculate the Total Solar Radiation (TSR), Sunlight Duration (SD), and Sky View Factor (SVF) of the selected points on different façades.

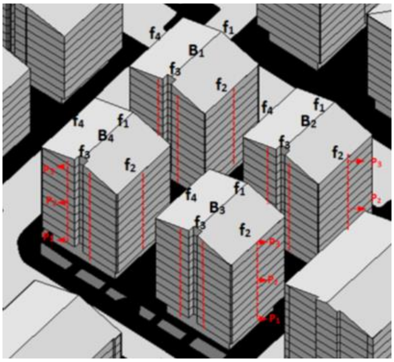
4.1.1. Analysis in the Nişantaşı Neighborhood

The 3D model and photos of the selected area and construction blocks are shown together in Figure 3. Three points at different heights were placed along an axis at the center of each façade to determine the gradual changes in solar radiation values, sunlight duration, and sky opening, as shown in Figure 4. Given a large number of possible evaluations, only typical points were selected to obtain significant conclusions, as presented in Table 1. The typical points selected on the building façades aim to demonstrate the significant differences in solar access, sunlight duration, and sky openings (SVF). They were chosen to highlight differences on the same façade by height and changes on the same height due to orientation and nearby surroundings.



a b

Figure 3. The 3d model (a) and the aspect photo (b) of the selected area (Nişantaşı)



P1 = 7.40 m (at the window level on the 1st floor)

P2 = 19.40 m (at the window level on the 5th floor)

P3 = 34.40 m (at the window level on the 10th floor)

Exemplary classification for determining a point:

B1_F1_P1: Point P1 on the façade F1 of the building B1

B3_F2_P3: Point P3 on the façade F2 of the building B3

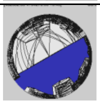
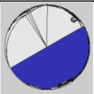
Figure 4. Determination of the points at different heights for the analyses (Nişantaşı)

Table 1. The selected points for the analysis in the Nişantaşı neighborhood

Same orientation and different heights (effect of the height).	
B1_F1_P1: North-East orientation.	B3_F3_P1: South-West orientation.
B1_F1_P2: North-East orientation.	B3_F3_P2: South-West orientation.
B1_F1_P3: North-East orientation.	B3_F3_P3: South-West orientation.
Same height, different orientation, and nearby environment (effect of orientation and nearby environment).	
B1_F1_P2: North-East orientation.	
B1_F2_P2: South-East orientation.	
B1_F3_P2: South-West orientation.	
B1_F4_P2: North-West orientation.	
Effect of orientation in 4 different buildings.	
B1_F1_P2: North-East orientation.	
B2_F2_P2: South-East orientation.	
B3_F3_P2: South-West orientation.	
B4_F4_P2: North-West orientation.	
Same orientation but different nearby environments (Height: 7.40 m, 1st floor). The effect of the nearby environment is analyzed in two different cases. All points are at the same height.	
B4_F3_P1: South-West orientation.	
B1_F3_P1: South-West orientation.	
B4_F1_P1: North-East orientation.	
B1_F1_P1: North-East orientation.	

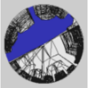
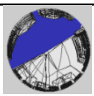
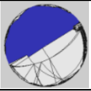
The façade 1 (F1) of building 1 (B1) has a northeast orientation. On December 21st, it was observed that the 10th floor (h=34.40m) receives 87% more TSR (total solar radiation) compared to the 1st floor (h=7.40m). Similarly, the 5th floor (h=19.40m) receives 30% more TSR compared to the 1st floor (Table 2). These gains in solar energy are diffuse and reflected as there is no direct radiation. The varying heights and neighboring buildings create obstacles, resulting in significant differences in solar energy gain along the northeast-facing façade (Table 2).

Table 2. Determination of the height effect on the total solar radiation (TSR). Same orientation, different heights. The building B1 is selected with a northeast orientation

Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
B_1_F_1_P_1 (h=7.40 m)	215	581	1108	623	0:00	1:36	2:54	1:42		%55.2
B_1_F_1_P_2 (h=19.40 m)	281	801	1583	851	0:00	2:00	3:39	2:03		%70
B_1_F_1_P_3 (h=34.40 m)	403	1376	2917	1533	0:00	2:42	5:21	2:48		%94.2

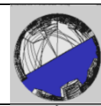
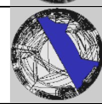
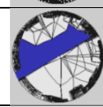
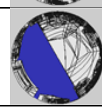
The solar access of the points on a south-facing façade is described in Table 3. The differences between the selected points are particularly pronounced for December 21st on surface 3 (F3) of building 3 (B3). There is a 280% difference in TSR between the 1st and 10th floors and a 171% difference between the 1st and 5th floors. On June 21st, the differences are minimal, with only a 95% difference between the 1st and 10th floors in this orientation, as all points receive direct radiation. In densely built areas, it is evident that points at different heights on buildings receive unequal intensities of solar radiation. The distribution of TSR on floors, even for the same orientation and façade, is strongly influenced by the nearby environment. The height and position (relative to the study points) of neighboring elements significantly affect the TSR.

Table 3. The solar access of the points for a south-facing façade

Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
B_3_F_3_P_1 (h=7.40 m)	777	1451	1678	1652	2:12	4:45	8:18	4:54		%56
B_3_F_3_P_2 (h=19.40 m)	2110	2298	1776	2429	5:39	7:09	8:24	7:09		% 70.2
B_3_F_3_P_3 (h=34.40 m)	2954	2835	2120	2863	8:09	8:42	8:12	8:42		%93

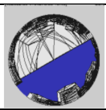
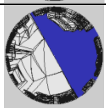
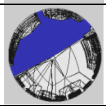
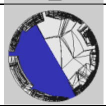
All orientations of the façades of Building 1 (B1) were analyzed at a height of 19.40 meters (5th floor) within the built environment. The effect of orientation and the nearby environment on TSR was determined (Table 4). Based on the results obtained (Table 4), the points B1_F1_P2 (Northeast) and B1_F4_P2 (Northwest) have almost identical sky openings, allowing for a direct understanding of the orientation's effect. Despite the close proximity of the eastern orientations, differences in TSR can be observed. Compared to the B1_F1_P2 point (Northeast), the B1_F4_P2 point (Northwest) receives 55% more TSR on December 21. This point is slightly more advantageous as it receives direct solar radiation, unlike the B1_F1_P2 point. The B1_F3_P2 point, despite its southwest orientation, does not receive direct solar radiation due to surrounding obstacles (in winter). Even though this orientation is considered good for the city of Konya, the surrounding buildings prevent direct solar flux penetration on a critical day. On June 21, the proportional differences are found to be less significant.

Table 4: The effect of the orientation and the nearby environment in the B1 building

Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
$B_1\_F_1\_P_2$ (h=19.40 m)	281	801	1583	851	0:00	2:00	3:39	2:03		%70
$B_1\_F_2\_P_2$ (h=19.40 m)	255	620	1497	651	1:24	2:09	3:52	2:09		%45.2
$B_1\_F_3\_P_2$: (h=19.40 m)	175	1100	1592	1199	0:00	4:12	8:39	4:18		%48.6
$B_1\_F_4\_P_2$: (h=19.40 m)	437	1051	1781	1041	1:39	2:57	4:18	3:03		%72.6

The analyses presented in Table 5 demonstrate the effect of building façade orientations on four buildings located on the outer edges of the construction block. The sky openings for all four points are almost identical (70%). On December 21st, the point B2_F2_P2 (Southeast) and the point B3_F3_P2 (Southwest) receive a significantly higher amount of TSR compared to the two other points oriented toward the northwest and northeast. The greatest difference on December 21st is observed between the point B3_F3_P2 (Southwest) and the point B1_F1_P2 (Northeast), with an approximate difference of 651%. Despite having a similar sky opening, the point B1_F1_P2 does not receive direct solar radiation, while point the B3_F3_P2 receives it for 5 hours and 39 minutes. On March 21st, the difference between these two points is 187%. In the summer, on June 21st, the largest difference occurs between the point B2_F2_P2 (Southeast) and the point B1_F1_P2 (Northeast). The point B2_F2_P2 receives 139% more TSR compared to the latter.

Table 5: Effect of the orientation in four buildings

Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
$B_1\_F_1\_P_2$ (h=19.40 m)	281	801	1583	851	0:00	2:00	3:39	2:03		%70
$B_2\_F_2\_P_2$ (h=19.40 m)	1756	2742	3791	3249	2:06	5:57	7.09	6:00		%70
$B_3\_F_3\_P_2$ (h=19.40 m)	2110	2298	1776	2429	5:39	7:09	8:24	7:09		%70.2
$B_4\_F_4\_P_2$ (h=19.40 m)	367	1311	1760	1225	0:00	4:03	4:18	4:09		%72

The analyses presented in Table 6 were conducted to demonstrate the effect of the nearby built environment. The selected points are located on the first floor (7.40m) of the building façades, all with the same orientation. The immediate surrounding environment has a significant impact on the TSR values of these points (Table 6). Factors such as the distances between neighboring construction blocks, the width of the streets, and the heights of neighboring buildings affect directly the results.

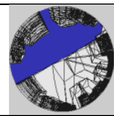
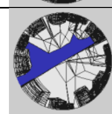
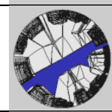
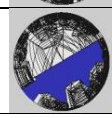
The analysis conducted on the south-west orientation (points B1_F3_P1 and B4_F3_P1):

The point B1_F3_P1 is oriented toward the southwest and faces the inside of the construction block. On December 21st, it does not receive direct solar radiation, resulting in a total solar radiation (TSR) of 118 Wh/m2 for the day. Similarly, the point B4_F3_P1 is also oriented toward the southwest but faces the outside of the block. The width of the streets, distance between construction blocks, and the location and height of neighboring buildings all influence the TSR results of these points. On December 21st, compared to point the B1_F3_P1, the point B4_F3_P1 has a TSR value that is 633% higher. The TSR difference between the two points is 103% on March 21st, 25% on June 21st, and 121% in September. Both south-west oriented points exhibit considerable percentage differences in TSR. The built environment outside the block offers greater advantages for solar access.

The analysis conducted on the north-east orientation (points B1_F1_P1 and B4_F1_P1):

The Point B1_F1_P1 is oriented towards the northeast and faces the outside of the construction block. Conversely, the point B4_F1_P1 is also oriented towards the northeast but faces the inside of the construction block. Sky openings are larger for the points facing the outside of the construction block, while the environment within the block reduces the sky opening for building facades. On December 21st, the point B1_F1_P1, benefiting from a larger sky opening, receives 65% more TSR throughout the day compared to the point B4_F1_P1, which is oriented towards the inside of the construction block. This difference is 42% on March 21st, 62% on June 21st, and 38% on September 21st.

Table 6. Same Orientation but different close nnvironment (Nalçacı)

Points	Received Total Solar Radiation (TSR, wh/m²)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
$B_4\_F_3\_P_1$ (h=7.40 m)	866	1603	1651	1826	2:09	5:03	8:33	5:15		%59.2
$B_1\_F_3\_P_1$ (h=7.40 m)	118	789	1318	825	0:00	3:03	6:39	3:00		%33.6
$B_4\_F_1\_P_1$ (h=7.40 m)	130	408	683	450	0:00	0:48	1:39	1:00		%32
$B_1\_F_1\_P_1$ (h=7.40 m)	215	581	1108	623	0:00	1:36	2:54	1:42		%55

4.1.1. Analysis in Nalçacı neighborhood

At the urban scale, the "Nalçacı" zone presents a variety of obstructions, with urban spatial voids largely obstructed by building alignments (Figure 5). The distribution of densities is quite unequal, with certain dwellings benefiting from good sky exposure and orientation, while others do not.

The Selection of the buildings and the points for the analyses in the Nalçacı neighborhood is shown in Figure 6 and Table 7. Table 8 shows the effect of the height on TSR and SD.

a b

Figure 5. The 3d model (a) and the aspect photo (b) of the selected area (Nalçacı)

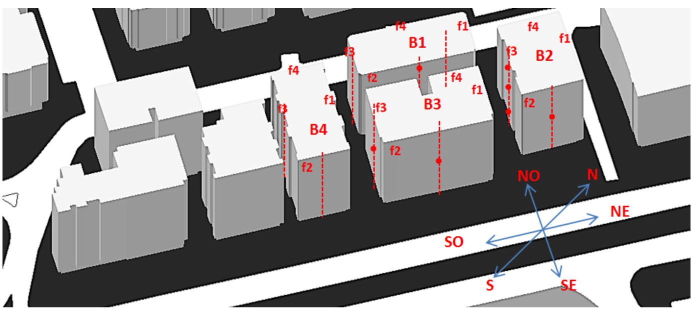


Figure 6. Determination of the points at different heights for the analyses (Nalçacı)

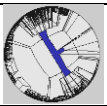
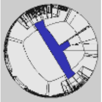
The results obtained at the points B1_F2_P1 and B1_F2_P2 (Table 8): The TSR values are higher in December, March, and September at the point B1_F2_P1, which is at a lower height (5.20m), compared to the point B1_F2_P2 (17.20m). The results are influenced by the higher reflection value at the point B1_F2_P1. The diffuse radiation, which is

109 Wh/m2 at the point B1_F2_P2 (17.40m), is significantly higher than the point B1_F2_P1 (5.40m), which is 7 Wh/m2.

Table 7. Selection of the buildings and the points in the Nalçacı neighborhood

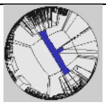
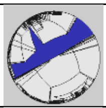
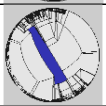
B1_F2_P1 B1_F2_P2 B1_F2_P3	(h=5.40 m) (h=17.40 m) (h=35.40 m)	South-East South-East South-East	Significant masking effect on the SE façade of building B1, façade: (B1_F2). The analysis was carried out to determine the solar access according to the heights.
B1_F2_P2 B2_F3_P2 B3_F4_P2 B4_F1_P2	(h=17.40 m) (h=17.40 m) (h=17.40 m) (h=17.40 m)	South-East South-West North-West North-East	Determination of solar accesses at the same height according to different orientations in a very dense urban context.
B3_F2_P1 B3_F2_P2 B3_F2_P3 B3_F4_P1 B3_F4_P2 B3_F4_P3	(h=5.40 m) (h=17.40 m) (h=35.40 m) (h=5.40 m) (h=17.40 m) (h=35.40 m)	South-East South-East South-East North-West North-West North-West	Determination of solar access on opposite façades: very limited sky view factor and unobstructed sky view factor. Solar access was studied on the façades facing the avenue and the obstructed side, taking into account the difference between the obstructed and unobstructed areas, as well as the orientation.

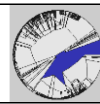
Table 8. The effect of the height on TSR and SD (B1, F2)

Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
B1_F2_P1 (h=5.40 m)	146	301	437	332	0	0:48	0:48	0:48		9.4 %
B1_F2_P2 (h=17.40 m)	116	263	547	173	0	00:42	02:18	00:57		19 %
B1_F2_P3 (h=35.40 m)	2440	2935	3386	3714	5:42	6:18	7:09	6:36		86 %

The analysis conducted in Table 9 aimed to determine the variations in TSR values among the points located at the same height in the dense urban texture, where the obstacle effect is high and SVF values are low, based on different directions. The largest difference in TSR values on December 21st was observed between the point B2_F3_P2 (southwest direction) and the point B3_F4_P2 (northwest direction). Due to the higher SVF value and appropriate direction, the point B2_F3_P2 had a significantly higher TSR value compared to the point B3_F4_P2, with a difference of 1948%. Similarly, comparing the TSR values of the point B3_F4_P2 (northwest direction) and the point B1_F2_P2 (southeast direction), which had similar SVF values, highlighted the impact of direction more accurately. On December 21st, the TSR value of the point B1_F2_P2 in the southeast direction was 213% higher than the point B3_F4_P2 in the northwest direction. The values for other seasons are provided in Table 9. The Points with low SVF values and unfavorable directions do not receive direct solar radiation. This can be observed by examining the "sunlight duration" values. The Points with a sunlight duration of zero can still benefit from solar energy gain through reflection and diffuse radiation, although these values are quite low.

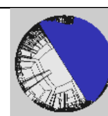
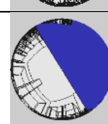
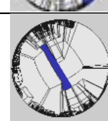
Table 9. TSR values of the points located at the same height in the dense urban texture

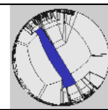
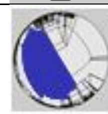
Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
B1_F2_P2 (h=17.40 m)	116	263	547	173	0:00	00:42	02:18	00:57		19 %
B2_F3_P2 (h=17.40 m)	758	1044	1532	1161	2:45	3:00	5:42	3:00		42.6 %
B3_F4_P2 (h=17.40 m)	37	141	297	145	0:00	0:48	1:12	0:48		17.4 %

B4_F1_P2 (h=17.40 m)	248	303	453	343	0:00	2 02	1 :45	2:01		27.4%

In Table 10, the TSR values of all points on the two opposing surface orientations (F2 and F4) of Building B3 were analyzed. The significant differences in TSR values between the two façades at various heights can be observed. There are significant differences between all points on the two opposite façades: an unobstructed view with a southeast orientation (F2) and a northwestern façade with significant obstruction (F4). At the first-floor level (5.20 meters), there is a difference of 4617 Wh/m2 in solar access between the point B3_F2_P1 (unobstructed view, good orientation) and the point B3_F4_P1 (poor orientation, significant obstruction).

Table 10. TSR analyze in all points of the two opposite surface orientations (F2 and F4) of the B3 building

Points	Received Total Solar Radiation (TSR, wh/m^2)				Sunlight Duration (SD, in hours and minutes)				Sky Opening (SVF, %)	
	21/12	21/03	21/06	21/09	21/12	21/03	21/06	21/09		
B3_F2_P1 (h=5.40 m) SE	4691	4813	4405	5761	6:48	7:21	7:21	7:21		93.6 %
B3_F2_P2 (h=17.40 m) SE	4643	4768	4686	5699	6:51	7:21	7:48	7:21		97.2%
B3_F2_P3 (h=35.40 m) SE	4684	4851	4930	5775	6:51	7:21	7:51	7:21		%99
B3_F4_P1 (h=5.40 m) NW	74	160	313	183	0:00	0.00	0:54	0:36		%8.8

B3_F4_P2 (h=17.40 m) NW	37	141	297	145	0:00	0:48	1:12	0:48		% 17.4
B3_F4_P3 (h=35.40 m) NW	395	1232	2081	1139	2:09	3:51	5:30	3:51		%90

4.2. Relationships Between Variables and Model Generation

In the present study, data on total solar radiation, sunlight duration, and sky openings were collected from 25 different points on building façades in two neighborhood of the city. Sunlight duration and sky openings have a significant impact on the total solar radiation received. A wide range of total solar radiation values was obtained, enabling the establishment of correlations between the dependent variable (total solar radiation, TSR) and the independent variables (sunlight duration, SD, and sky openings, SVF).

The relationships between the dependent variable (TSR) and the two independent variables (SD and SVF) were separately analyzed using regression for all seasons. Firstly, the relationship between total solar radiation (TSR) and sunlight duration (SD) was examined. Secondly, the relationship between total solar radiation (TSR) and sky opening (SVF) was investigated (Figure 7).

The distribution of points in a set can influence the type of relationship and the choice of the appropriate regression model. In both categories of analysis, the distribution of points on the graphs allowed for the creation of exponential and linear regressions. Both types of regression are shown on all graphs (Figure 7). The linear regression model is presented in Equation 1, while the exponential regression model is presented in Equation 2 (Figure 7). For all seasons, the relationship between TSR and SVF variables could be more robustly explained by exponential regression models than linear regression models. Regarding the relationship between TSR and SD variables, apart from the winter seasons, exponential regression models provided the best explanation for the relationships in all other seasons. The obtained exponential regression models can establish the relationship between the variables with some precision. Based on the results, exponential models can provide more appropriate predictions.

It was determined that the predictive power of the models produced to determine the relationships between TSV-SVF and TSR-SD varied according to the seasons. The explanatory power of the models can be classified based on the R^2 values (coefficient of determination). By considering the R^2 values, the predictive power of the models produced for each season can be classified. A higher R^2 value indicates a better fit, suggesting that a larger proportion of the variability in the dependent variable is explained by the independent variables. In other words, the independent variables have a greater impact on the variation in the dependent variable. Conversely, a lower R^2 suggests that the model does not capture much of the variation in the dependent variable.

The strongest relationship between TSR (dependent variable) and SVF (independent variables) was observed during the summer season, while the weakest relationship was identified during the winter season.

$R^2_{(Summer)} > R^2_{(Spring)} > R^2_{(Autumn)} > R^2_{(Winter)}$

The strongest relationship between TSR (total solar radiation; dependent variable) and SD (solar duration; independent variables) was observed during the spring and summer seasons, while the weakest relationship was identified during the summer season.

$R^2_{(Spring)} > R^2_{(Autumn)} > R^2_{(Winter)} > R^2_{(Summer)}$

Except for the summer season, it is observed that predicting TSR (total solar radiation) using SD (sunlight duration) is more suitable for all seasons. In other words, for the winter, spring, and autumn seasons, the use of TSR-SD models would be more appropriate for estimating TSR. In TSR-SD models, TSR results are influenced by environmental obstacles as well as the daily sun path and orientation. When the SVF values are taken into account, orientation and the sun's path are ignored. However, the obtained TSR-SVF models do not have very low predictive power and can still be used. In this sense, the best result was determined for the summer season.

Multiple regression models were attempted to predict TSR for each season. In other words, the predictability of TSR using two independent variables (SVF and SD) was investigated. Good R-squared values were found for each model. The R-squared values for the winter, spring, summer, and autumn seasons were determined as 0.83, 0.79, 0.70, and 0.74, respectively. However, the P value of one of the independent variables in each season was not significant (P > 0.05), which means the results were considered statistically insignificant. Therefore, the equations corresponding to these models were not included in the study.

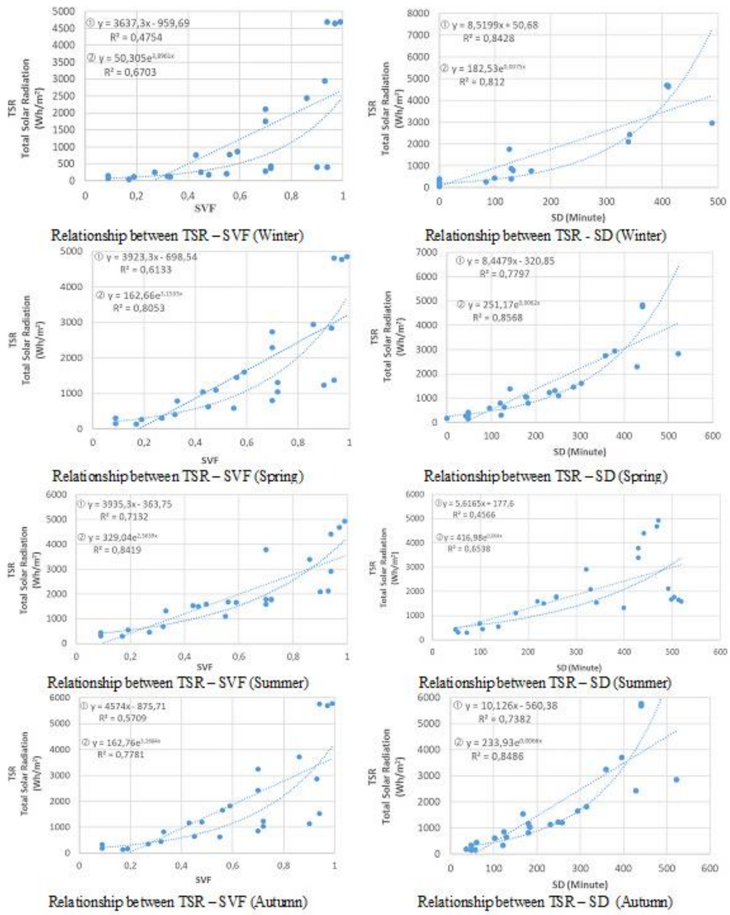


Figure 7. Relationship between TSR-SVF and TSR-SD in all seasons

4. Conclusion and Suggestions

Among renewable energies, solar energy has great potential for use in cities. Firstly, urban surfaces can be utilized to obtain solar energy. The utilization of solar energy in urban areas is only possible if sufficient solar access is ensured. To demonstrate the impact of the urban context on solar gain potential, various points on the façades of buildings in the city of Konya, Turkey, were selected. The obtained results significantly demonstrate the effects of obstacles, height, sunshine duration, and orientation on the TSR (total solar radiation) of a point on the façade. On the same façade, the TSR obtained at different points is closely correlated with their respective heights. In summer, on the façade of building B1 (Nişantaşı), the TSR at the highest point (34.40m) was 2.63 times higher than at the lowest point (7.40m). Conversely, during the analyses in the Nişantaşı neighborhood, on December 21st, with nearly identical sky openings of two buildings, the effect of orientation was significant. The difference between the point B3_F3_P2 (southwest) and the point B1_F1_P2 (northeast) was approximately 651%. The obtained results also demonstrated that good orientation alone is not sufficient. The sky view factor (SVF) is an important parameter that highlights the effects of obstacles on solar gains. Additionally, it is crucial to consider sunlight duration (SD) simultaneously. This is because the duration of sunshine varies based on the orientation of the studied façade.

It was found that Total Solar Radiation (TSR) varies as a function of Sky View Factor (SVF) (sky opening) and Sunlight Duration (SD). The prediction models for TSR were obtained using linear and exponential regression. The relationship between TSR and SVF variables could be more robustly explained by exponential regression models in all seasons. Apart from the winter season, in all other seasons, the relationships between TSR and SD were also best explained by exponential regression models. Predicting TSR (total solar radiation) using SD (sunlight duration) is more suitable for the winter, spring, and autumn seasons. On the other hand, for the summer season, predicting TSR using SVF is much more convenient.

From the perspective of sustainable development, it is necessary to establish common strategies between the architectural and urban scales if energy-efficient buildings, districts, and cities are to be planned. This subject concerns architects, town planners, landscape architects, and, above all, municipal authorities.

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Author Contribution and Conflict of Interest Declaration Information

The book section has a single author and there is no conflict of interest with any individual or entity.

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