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A Framework for Integrating Zoning Regulations and Site Layout Design to Enhance Visual Comfort-A Study based on Zoning Regulation and EN 17037

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Abstract

Daylight is one of the primary sources to ensure a comfortable, healthy, and energy-efficient neighborhoods. Zoning regulations significantly influence daylight-driven site layouts by constraining design decisions, particularly at the neighborhood scale. This study therefore hypothesizes that zoning design rules should be structured to optimize visual comfort in buildings, ensuring that daylight access is not compromised by restrictive policies. In this regard, the study examines the impact of the different site-layout alternatives, compliant with the Turkish zoning regulation, on the visual comfort conditions in the residential spaces designated for a new residential development. In parallel, the study also analyzes the extent to which site layout design parameters—such as obstruction angle, light reflectance, and building type—affect daylight performance. To achieve these, various parametric daylighting simulations were conducted via Climate Studio for Grasshopper, and site-layout configurations under different legal constraints were comparatively analyzed based on EN 17037 metrics. The results show that the effects of obstruction angle and light reflectance value vary significantly with building type and orientation. Furthermore, obstruction angle can be misleading as a standalone design indicator for predicting daylight performance within a space. The findings of the study contribute to the development of visually comfortable and sustainable living spaces for newly developing residential areas and existing site layout patterns that have changed as a result of urban transformation. In addition, the study can also provide insight into the evaluation methods given in the daylight standard to assess the daylight performance of space in the context of neighborhood scale.

1. Introduction

Daylight and sunlight as a part of it, is the vital source for inhabitant's life in the cities. Access to daylight during day affects positively the people's psychological [1,2] and physiological [3,4] states in both indoor and outdoor spaces [5]. Similarly, daily sunlight exposure has an improving effect on human health [6-9]. Therefore, the design decisions that aim to create livable, healthy and comfortable spaces should enable access to sunlight for a certain period of time during the day [10], especially in the residential spaces [11]. On the other hand, visual connection with the environment thanks to the daylight openings is also pivotal in terms of supporting user well-being [12] due to the restorative effect when people look especially natural scenes [13]. In addition to the non-visual effect, providing visual comfort conditions with daylight also contributes to reducing energy consumption for lighting, which accounts for about 15% to 40% of total energy consumption in buildings [14]. Therefore, daylight should be regarded as a valuable resource that must be planned and managed [15] to maintain healthy, sustainable and energy-efficient built-environment, especially given the restrictions posed by the high urban densification in the contemporary cities.

Integrating daylight-oriented strategies into designing process of the built-environment is the fundamental to fully harness the benefits of daylight. They mostly depend on various natural and built environmental parameters, considering all scales from urban regional and urban development scale, down to neighborhood and building scale [16], affecting the quantity and quality of daylight in the spaces as well as access to sunlight. As the initial considerations in the design of an effective daylighting system [17], the parameters related to the site planning have the most significant impact on the daylight, sunlight and solar radiation

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Nomenclature

D_{TM}	*Minimum Target Daylight Factor*
D_T	*Target Daylight Factor*
E_{TM}	*Minimum Target Illuminance*
E_T	*Target Illuminance*
OA	*Obstruction Angle*
LRV	*Light Reflectance Value*
CM-1	*Calculation Method 1*
CM-2	*Calculation Method 2*

entering through windows, both in terms of visual comfort conditions [18] and, building energy consumption [19,20]. Notably, the building heights, the distance between the buildings, the position of the buildings relative to each other, and the surface properties are the critical design parameters in terms of solar and daylight availability at the neighborhood scale [16]. On the other hand, the slope and orientation of the site are crucial in determining the external illuminance levels depending on the latitude of the site area [21]. The studies revealed that the geometrical properties of the buildings and the distance between the buildings have the most impactful effect on the vertical daylight illuminance on the facades [22,23], and therefore the visual comfort levels in the spaces [18,24]. Similarly, Sun et al. showed that the obstruction angle, determined depending on the building height and road width, significantly affects the lighting and cooling energy consumption related to the daylight and solar radiation level [25]. Bocan et al. also emphasized that the sunlight access of the space should be carefully analyzed depending on the between building distance, especially when it is less than the maximum building height in any given settlement [26]. The site layout is another critical factor in terms of daylight performance [27]. Moreover, spatial arrangement can create a greater difference in daylight illuminance level than the height of buildings [28]. In that line, Lu et al. found that square and rectangular building layouts arranged in a staggered order are more effective on daylight utilization than mixed use [29]. The light reflectivity of the surfaces within the view considerably impacts the amount of solar radiation reaching the urban blocks, visual comfort and energy reduction [22,24]. In this sense, Bugeat et al. discovered that increasing the light reflectance of surrounding buildings enhances daylight availability in the first-floor spaces by 15% to 64% [30]. Additionally, the orientation of the site [22,24] and the street level of the investigated space [23] are the other design parameters impacting critically on the daylight, sunlight and view-out potential of the spaces.

On the other hand, the design of the external environment plays a major role in enabling attractive and restorative view-out. In this context, building block configurations in the neighborhood scale may result in different view-out performance such that a building block of different building heights outperforms a building block with uniform building heights in a block-ordered settlement [31]. On the other hand, the view layers including both built and natural elements that can be seen from the window depending on the site layout design have an impact on the view quality in urban environments [32,33]. Moreover, people's preferences related with the view-out are profoundly affected by the characteristics of urban building façades, such as shape, color, decorations, materials, texture, roof, openings, windows, and proportions. In line with that, Sadeghifar et al. [34] pointed out that the facade color is the most decisive one that affect people's preferences in a positive way, while the facade shape, color and proportions were determined to be the most important factors affecting people's exterior view preferences. In this sense, Oludare et al. [35] concluded that the people working in the office spaces mostly prefer the lighter shades of all colors on the building facades.

Regulations and policies play a significant role in site layout planning and the shape of urban textures, directly influencing the potential use of daylight in interior spaces [36-38]. They impact daylight and sunlight availability, as well as view potential, through various design rules that define daylight access criteria - such as the required Daylight Factor (DF) level [36-38] or minimum Window Floor Ratio (WFR) [39] - or by setting specific value ranges for design variables that shape urban texture [37,38, 40-42]. At that point, it is crucial to examine current site planning rules defined in the regulations for optimizing visual comfort conditions in the urban context, and designing new policies ensuring adequate daylight and sunlight level as well as offering sufficient view-out in buildings to meet residents' physiological needs. Otherwise, new developments in the cities that will be re/built depending on the regulations that do not promise the visual comfort conditions in the buildings may cause many social and environmental problems [43].

Reviewing the literature, some research studies have analyzed the daylight and/or sunlight compliances of the various regulations belonging to the different countries. Among those, Islam et al. suggested the limit obstruction angle according to the maximum building height and setback distances that allow sufficient daylight illumination in the residential space for Dhaka city zoning regulation [37]. On the other hand, Montes-Villalva et al. proposed maximum distances between the buildings for the different stories specified in the regulation so that the energy consumption for lighting is below 10% of the minimum income by meeting the minimum daylight provision criteria defined in EN 17037 [43]. Leder et al. also revealed that the maximum plot ratio should be carefully set in Brazilian regulations as it has a significant impact on sky visibility, sunlight duration and daylight levels on the façade and sidewalk [44]. Saratsis et al. analyzed the effect of the different building forms on spatial daylight illuminance for various floor area ratios (FAR) allowed in the national urban regulation, and revealed that tower building block type in high-density cities is the best-performing building form, if designed correctly, and the floor area ratio is limited to a maximum of 12 [45]. Similarly, Sprah et al. determined the space depths and window wall ratios that allow the minimum daylight provision class to be achieved according to EN 17037 considering different building layout and building forms in relation to various site coverage and floor area ratio limited under the Slovenian national city regulation [46].

Türkiye is one of the prominent countries in the world with its dense cities, especially when compared to European countries, therefore it is important to ensure that new or re-built urban development areas associate with the national regulation have access to sufficient daylight, sunlight and view-out to support sustainable development goals. "National Zoning Regulation" is the main regulation to outline the design rules for the new and re-design settlements to be adhered to in the design of planned areas [47]. This regulation imposes some restrictions at the neighborhood scale regarding maximum plot size, maximum floor area ratio (FAR), setback distances, maximum number of floors depending on the road width, minimum space dimensions, etc. Unlike some countries, the regulation does not include any requirement to assure daylight provision in the buildings. As a result of the adoption of the European standard EN 17037, which was issued in 2018, revised in 2021, and accepted as the Turkish standard as of 2022, the daylight standard is the only restrictive document in terms of creating a daylight-prioritized built environment [48]. This improvement has required to reconsider zoning regulations for especially the new development residential areas to ensure daylight requirements specified in EN 17037: Daylight in Buildings. Therefore, this study aims to examine the daylight compliances of the site layout planning strategies based on the design principles defined in the national zoning regulation of Türkiye in accordance with the daylight standard i.e., EN 17037. It further investigates how site layout parameters influence overall visual comfort conditions within buildings. The study also attempts to seek the suitability of obstruction angle (OA) indicator based on the building height and distance between the buildings by correlating it with the daylight metrics described in the EN 17037.

2. Methodology

The methodology of the study was established on analyzing of the visual comfort competencies of the site planning alternatives created considering the design rules defined in the zoning regulation, as depicted in Fig. 1. In the first step, the site layout parameters in relation to the zoning regulation are examined. In the second step, site layout alternatives are generated parametrically based on the considered design parameters in Rhino-Grasshopper environment. In the third step, the parametrically generated site layout scenarios are evaluated by means of visual comfort metrics defined within EN 17037 via Climate Studio for Grasshopper. In the final step of the study, different site layout scenarios are comparatively analyzed based on the visual performance to provide insights into the design rules outlined in the zoning regulations.

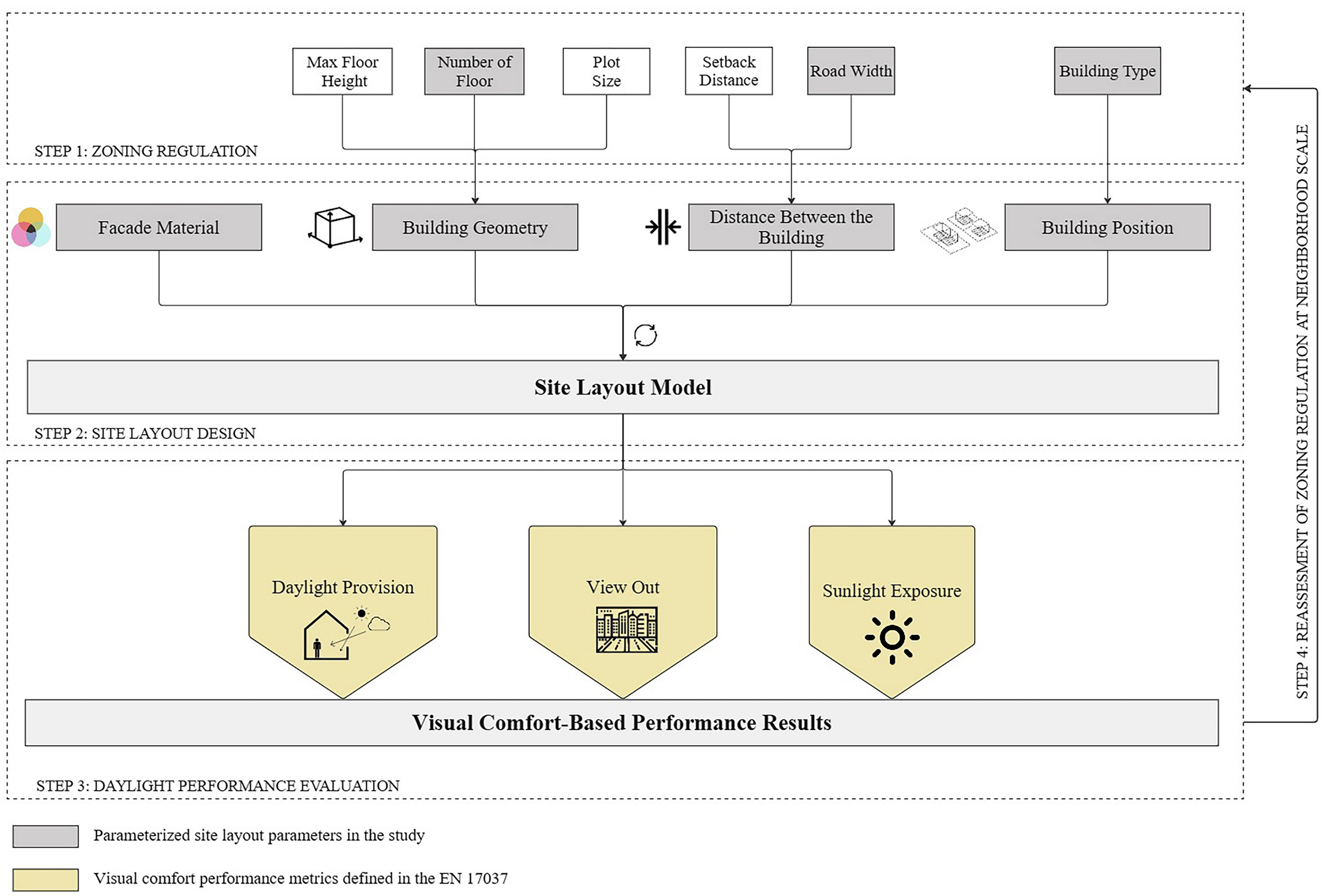


Fig. 1. The Site Layout Design Framework Integrated with National Zoning Regulation.

Table 1. The maximum number of floors allowed depending on the road width ranges in scope of the zoning regulation [47].

Road width (m)	Number of floors	Road width (m)	Number of floors
RW≤7	2	15<RW≤20	6
7<RW≤10	3	20<RW≤25	8
10<RW≤12	4	25<RW≤35	10
12<RW≤15	5	35<RW≤50	14

2.1. Determining the site layout design parameters related to national zoning regulation

The "Planned Areas Zoning Regulation" dated July 2017 [47], which encompasses regulations for new development and/or re-designing of the planned zoning areas in Türkiye, reveals various provisions about the neighborhood design parameters that affect the visual comfort conditions in the buildings. In this line, the height of the buildings in the site is confined based on the permitted number of floors, which is contingent on road widths (Table 1). The distance between buildings is defined according to minimum setback distances and various road widths specified in relation to the number of floors. Road widths correspond to the width of the road on the front facade of the parcel, excluding elements such as front gardens, green areas, refuges, squares, parking lots, railways, water channels, etc., while the setback distance for the parts of the parcel that coincide with the roadside is stipulated to be at least 5 meters [47]. The block type that are attached, detached and block is another design constraint given in the zoning regulation, which describes the continuity of the buildings in the site. The attached and detached building type refers to whether a building is adjacent to buildings on one or more adjoining parcels, while the block type represents the building mass that sits on more than one land. On the other hand, the Zoning Regulation does not impose any restrictions on the features related to the facade of buildings, which is one of the important design parameters affecting the daylight performance in the buildings at the neighborhood scale. However, it is also emphasized that municipalities are authorized to decide on the color and material of facade in order to achieve harmony between buildings according to characteristics and appearance of the urban areas [47]. In conjunction with the zoning regulation and literature studies, the study aims to evaluate the impact of the four key parameters at the neighborhood scale on visual comfort conditions in residential buildings and reveal their compliances in terms of daylight, sunlight and view performance, which are the height of the buildings, the distance between the buildings, the building type, and the light reflectance of the building surface.

2.2. Development of the parametric site-layout design scenarios

The site layout alternatives in conjunction with the zoning regulation are developed based on the 'obstruction angle' which takes into account building height and distance between the buildings, building types and the light reflectance value of the surrounding buildings located in the site. The obstruction angle (OA) is one of the prevalent urban-design metrics to establish principles for the design of site layout [49,50], and it refers to the angle with the horizontal of the line drawn from the center of a window to the vertex of the obstacle building [51]. In the study, the distance between buildings is calculated by adding 5 m setback distance and 1.5 m minimum sidewalk width [52] to the road widths specified in the zoning regulation depending on the number of floors (Fig. 2(a)). The road widths are parametrically identified with increments of 1 m, within the range specified in the regulations, with a minimum road width of 3 m. On the other side, the building height is computed by multiplying the number of floors defined depending on the road widths by the floor height, assuming the same for all buildings on site. In order to assess the worst obstruction effect, the structural floor level (SFL) is assumed as a fixed value of 3.6 m, which is the maximum SFL for residential buildings [47]. Figure 2(b) depicts the obstruction angles calculated from the ground floor (at the midpoint of the reference building above 1.40 m from the ground) as a result of the parametrization (with 1 m increments) of the permitted road widths depending on the number of floors defined in the zoning regulation. It is resulted from the graph that the obstruction angle has been ranged between 16° and 45° depending on the different configurations based on building height and the distance between the buildings. In this line, 0°, 15°, 25°, 35° and 45° are determined as the reference obstruction angles to reveal the impact of the site layout scenarios generated in accordance with the zoning regulation on the daylight performance of the building.

On the other hand, the surface properties of the surrounding buildings are also considered based on the light reflectance value to describe the lightness and darkness of the surface material color. It is generally suggested to be accepted as a constant value of 0.2 or 0.3 [48,51]. Contrary to most of the study, the surface materials having the high light reflectance value are also used to create the urban fabric in especially hotter climates to counterbalance urban overheating [53]. Therefore, considering the Mediterranean climates, the light reflectance value of the surrounding buildings is determined as 0.8, 0.5 and 0.2 in order to represent light-medium-dark colored materials respectively. Furthermore, the

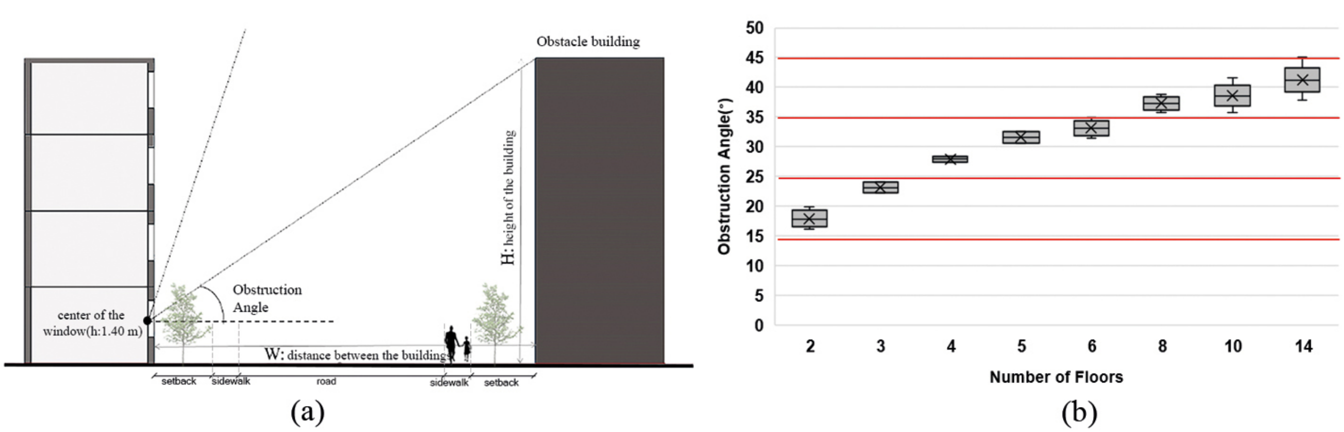


Fig. 2. The site section showing the obstruction angle (a), The obstruction angles emerged depending on the number of floors for different road width defined in the zoning regulation (b).

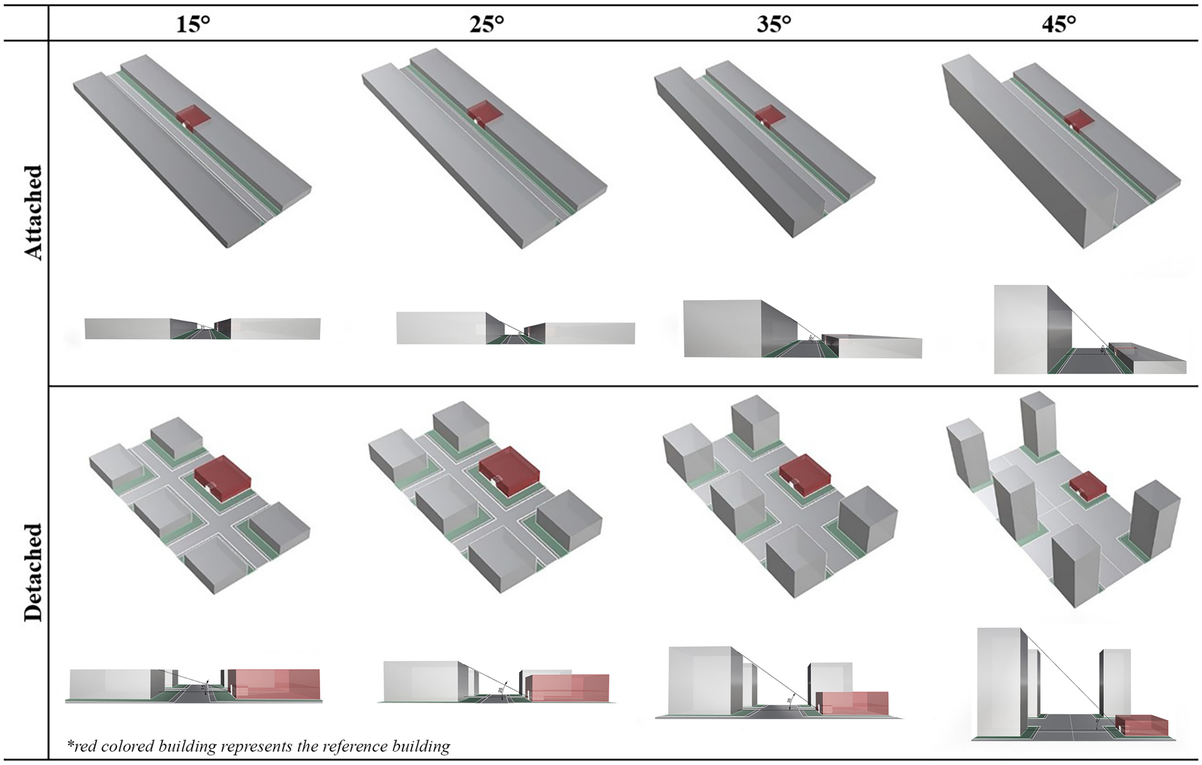


Fig. 3. The site layout configurations based on the different obstruction angle and building type.

attached and detached building types are examined in order to unveil the impact of building configuration on the visual comfort conditions in the buildings. The site consisting of 2-storey building with the minimum number of floors specified in the regulation and without any obstruction are determined as the base case to generate the parametric site layout scenarios. The site model is parametrically generated in Rhinoceros using Grasshopper, based on the base case. The total of 100 different site layout scenarios are derived with 4 different obstruction angles, 2 building types and, 3 different light reflectance values for four cardinal directions. Figure 3 represents the site layout scenario for different obstruction angles and building types.

2.3. Determining the visual comfort criteria

The effect of site layout planning on visual comfort conditions is examined in terms of daylight availability, view-out potential, and sunlight exposure—criteria directly linked to design decisions at the neighborhood scale—while glare is excluded as it can be controlled by residents. Table 2 displays the three different level of recommendations in association with the daylight provision, view-out and sunlight duration in EN17037 [48]. In the assessment of daylight provision, the relevant standard suggests two different methods, i.e., static (daylight factor method) and dynamic (illuminance method). Calculation Method-1, which is a static method, uses the daylight factor metric corresponding to the minimum and target illuminance levels (100 lx, 300 lx, 500 lx and 750 lx) based on low, medium and high daylight provision classes for specific climates. According to the method, it is required that those daylight factor levels determined for the specific climates should be achieved at rates of 50% and 95% of the space. The compliance rates of the specialized daylight factors depending on the location are calculated based on the standard overcast sky [48]. For the case study, the minimum and target daylight factor levels for Istanbul were determined as 0.5%, 1.4%, 2.4% and 3.6%, respectively, as a result of dividing the minimum and target illuminance levels by the median diffuse horizontal illuminance level (20805.5 lx) derived from the TMY3 climate data for Istanbul. On the other hand, Calculation Method-2, which is a dynamic method, is based on the illuminance level considering the climate. This method analyzes to temporal achievement rates of the minimum and target illuminance levels (100 lx, 300 lx, 500 lx, and 750 lx) defined based on different daylight classes for interiors at 50% and 95% of the space, respectively, over half of the annual daylight hours.

Attaining the level of the view-out, one of the most important factors in daylighting design, is assessed in terms of the view access, view layer and view clarity in scope of the standard. According to the method, the view-out provided from any view-point is classified as low, medium, and high based on horizontal sight angle, distance to view from the facade, and the view layers in the field of the gaze (Table 2). The overall view-out level for each calculation point is determined according to the lowest rated criterion among those criteria. Besides the daylight provision and view-out, the sunlight exposure, which is an important criterion for user health and comfort in indoor spaces, is evaluated by determining the duration of sunlight on a specific day defined between February 1st and March 21th in scope of the standard. On this basis, the standard recommends that at least one habitable space per residential unit should receive at least 1.5 hours of sunlight per day to meet the minimum performance requirement for exposure to sunlight adequately.

2.4. Daylight simulation: model settings

The effects of the site layout scenarios on the visual comfort conditions are analyzed through a typical living space model in a typical social housing in Türkiye. The dimensions of the living space in the reference housing unit are determined as 3m x 4m x 2.6 m, which is defined as the minimum space dimensions and clear height defined for residential spaces in the zoning regulation [47]. To reveal the worst-case scenario, the single lateral window dimensions are accepted 1 m x 1.25 m (17% WWR), which is recommended in the daylight standard for providing minimum view-out in spaces with a depth of 4 m and above [48]. The parapet height of the window is determined as 0.80 m. The glazing material for the window is selected as Low-E with a light transmittance value of 79.6% in accordance with TS 825: Thermal Insulation in Buildings [52,54]. The light reflectance values of the interior surfaces are determined as 0.8, 0.5 and 0.2 for the ceiling, walls and floor respectively. The light reflectance values for the road, sidewalk and front yard are assigned in the model as a constant value of 17.7% (asphalt road), 24.8% (concrete pavement), 10.4% (greenish grass) respectively.

The evaluation of the daylight, sunlight and view-out availability in the living space is run through Climate Studio for Grasshopper, which provides highly accurate and fast daylight simulation results [55] and checks the compliance of design alternatives with the relevant standard or certification criteria [56]. To assess daylight and view-out performance in the space, two different reference planes with 0.5m wall offset from the walls were created in the space, which is at 0.85 m and 1.20 m above from the floor respectively. The distance between the calculation grid points for two reference plane was set 0.5 m. To calculate sunlight duration, an analysis point was created at the center of the window and 1.20 m above the ground. Figure 4 depicts the analysis points for daylight, sunlight and view-out evaluations in the simulation model. The radiance parameters for daylight calculations are set as accepted in CS default settings, i.e.; *ab:6; lw:0.01; samples per pass:64; max. number passes:100*. All analyses are made for the living room at the ground floor since it is the most disadvantageous situation in terms of daylight performance in dense urban settlements [15].

3. Results

In this section, two different design parameters considered at the neighborhood scale (obstacle angle and light reflectance value) were analyzed for four main orientations and two different building types (attached and detached). Each site layout scenario was evaluated in terms of their compliances in terms of daylight provision, view-out and sunlight exposure criteria as defined in daylight standard; EN17037. Findings were shown in the following sections.

3.1. Daylight provision analysis

The effect of the obstruction angle depending on the light reflectance value on the daylight provision levels in the living room according to Calculation Method-1 (CM-1) and Calculation

Table 2. Requirements of the daylight provision (specified for Istanbul), view-out and sunlight exposure criteria defined in the EN 17037.

Criteria	Metrics	Fraction of space (%)	Minimum	Medium	High
Daylight Provision	Calculation Method-1 (DF method)	95%	$D_{0.5\%}$	$D_{1.4\%}$	$D_{2.4\%}$
		50%	$D_{1.4\%}$	$D_{2.4\%}$	$D_{3.6\%}$
	Calculation Method -2 (Illuminance method)	95%	$E_{100\ lx}$	$E_{300\ lx}$	$E_{500\ lx}$
		50%	$E_{300\ lx}$	$E_{500\ lx}$	$E_{750\ lx}$
View-out	Horizontal Sight Angle	N/A	14°≤	28°≤	54°≤
	Distance	N/A	6 m≤	20 m≤	50 m≤
	Layer	75%	Landscape	Landscape+ Sky/Ground	Landcape +Sky +Ground
Sunlight Exposure	Sunlight Hour	N/A	1.5 h≤	3.0 h≤	4.0 h≤

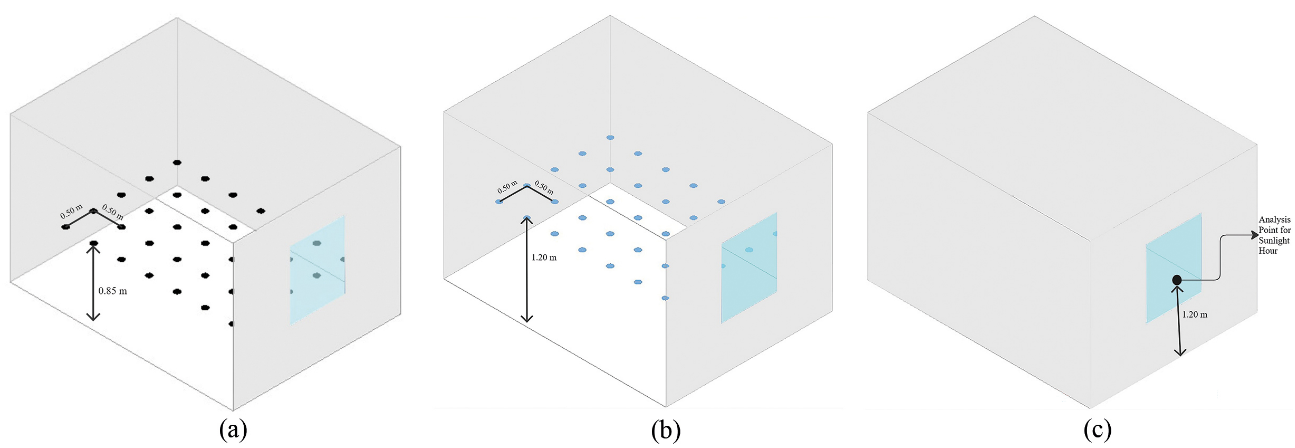


Fig. 4. The calculation points for daylight provision (a), view-out (b), sunlight hour (c).

Method-2 (CM-2) are exposed in this part of the study. The graphs given in Figs. 5 and 6 depict the daylight provision results in the sample living room, varying according to the obstruction angle (OA) and three different light reflectance values (LRV) of the surrounding buildings on the site.

According to Calculation Method-1 (CM-1), the spatial achievement rate of the minimum and target daylight factor values for Istanbul (0.5%, 1.4%, 2.4% and 3.6%) depending on the different obstruction angles are as given in Figs. 5(a) and (b) in the case of the attached and detached building type. In each graphic corresponding to the specified LRV, the X-axis represents the obstruction angles and the Y-axis refers to the spatial achievement rate of the specified daylight factor value. In the absence of obstruction (base case), the spatial achievement rates of the minimum and target daylight factor values of 0.5%, 1.4%, 2.4%, and 3.6% were determined in the living space at rates of 100.0%, 48.6%, 37.1%, and 17.1%, respectively. In case of the presence of an obstacle building, regardless of orientation and building type, the minimum daylight factor ($D_{TM,0.5\%}$, $D_{TM,1.4\%}$, $D_{TM,2.4\%}$) and target daylight factor levels ($D_{T,1.4\%}$, $D_{T,2.4\%}$, $D_{T,3.6\%}$) for all daylight classes decreased with increasing OA. The reduction level in the daylight factors was occurred dramatically when the LRV was especially low as seen from the Table 3. For the attached building type, the highest reduction rates in the $D_{TM,0.5\%}$ and $D_{T,1.4\%}$ were observed in case of that the building has 45° OA and 0.2 LRV, which is 60% and 25.7%, compared to the base case. Unlike the attached building type, the site configuration constructed by detached building type having 35° OA with 0.2 LVR led to the lowest $D_{TM,0.5\%}$ (62.9%) and $D_{T,1.4\%}$ level (37.1%) in living space compared to the unobstructed situation. This result demonstrated that there is not linear decrease in the daylight factor with the increasing obstruction angle, when the detached building type is configurated on the site. On the other hand, the lowest reduction of $D_{TM,0.5\%}$ and $D_{T,1.4\%}$ were provided by the 15° OA with 0.8 LVR for both building types. Additionally, the minimum and target daylight factors ($D_{T,2.4\%}$ and $D_{T,3.6\%}$) to provide medium and high daylight provision classes was not achieved at the desired level (more than 50% of the space occurrence) by any obstruction angle and building type. The worst spatial achievement rate for $D_{T,2.4\%}$ and $D_{T,3.6\%}$ was revealed by the 45° OA with 0.2 LRV for both building types, which were 22.9% and 8.9% for attached building type, and 22.9% and 14.3% for detached building type respectively.

Considering the effect of the light reflectance values of the surrounding buildings, the results given in the Table 3 showed that the higher light reflectance value resulted the lower reduction in the both daylight factor levels depending the obstruction angle for two building types. Moreover, LVR is more positively impactful, when the obstruction angle is high and the target daylight factor (D_T) level is low. In this sense, the highest improvement in the

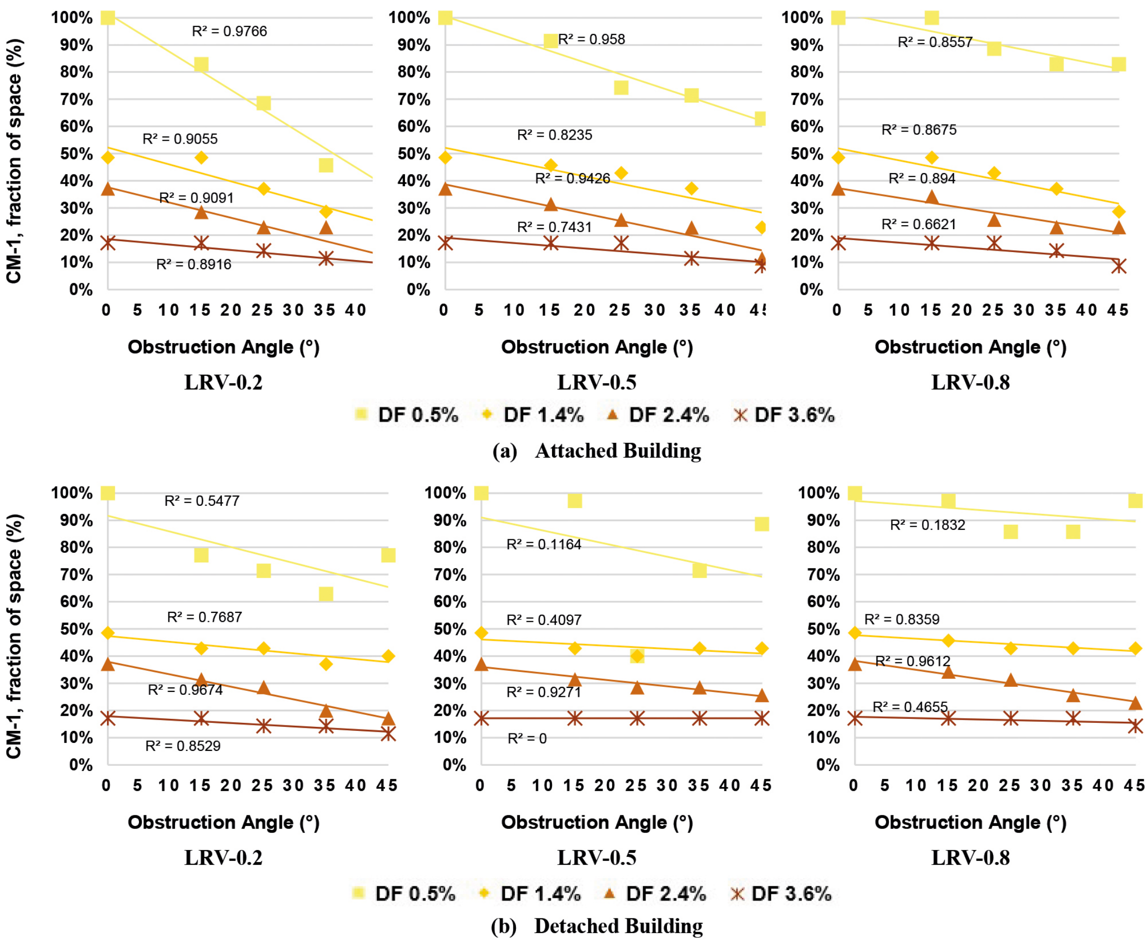


Fig. 5. The spatial achievement rates of the Daylight Factor level in the living space depending on the various obstruction angles and light reflectance values for the (a) attached and (b) detached building types.

minimum and target daylight factor levels for the minimum class was achieved by the scenario with the 45° OA and 0.8 LRV compared to the 0.2 LVR, i.e., 42.9% in $D_{TM,0.5\%}$, and 6.3% in $D_{T,1.4\%}$ for attached building type, 20.1% in $D_{TM,0.5\%}$, and 2.9% in $D_{T,1.4\%}$ for detached building type. Similarly, the highest increasing levels on the minimum ($D_{TM,2.4\%}$) and target ($D_{T,3.6\%}$) daylight factor for the high class depending on the light reflectance value was found as respectively 14.3% and 0% in the case of 45° OA with 0.8 LVR for the attached building type, and 8.6% and 5.7% in case of 45° OA with 0.5 LRV for the detached building type. The findings also confirmed that LVR has a stronger effect on the daylight factor levels for the attached building type than for detached ones.

In accordance with Calculation Method-2 (CM-2) in EN 17037, the daylight illuminance levels for minimum, medium and high daylight classes are also determined based on the obstruction angle and the light reflectance value. Figure 6 illustrates the illuminance levels provided in the living space by daylight according to three daylight provision classes for different orientations and building types. In each graphic, the X-axis represents the obstruction angles and the Y-axis shows to the temporal achievement rate of the specified illuminance level. Each colored-shaped indicators in the graphics refers to the minimum and target daylight illuminance values for different LRV. The annual temporal achievement rates of the target and minimum illuminance levels of minimum, medium and high daylight classes in the reference living space for the base case (OA:0°) according to four different directions were found as 69.3% ($E_{T\ 300lux,50\%}$), 76. 4% ($E_{TM\ 100\ lx,95\%}$), 50.9% ($E_{T\ 500\ lx,50\%}$), 39.0% ($E_{TM\ 300\ lx,95\%}$), 9.0% ($E_{T\ 750\ lx,50\%}$), 22.7% ($E_{TM\ 500\ lx,95\%}$) in South ; 66.5%, 77.0%, 26. 1%, 15.6%, 5.5%, 3.3% in East ; 55.02%, 69.27%, 1.26%, 0.00%, 0.00%, 0.00% in North ; 63.3%, 77.7%, 42.2%, 32.7%, 26.1%, 14.0% in West respectively. Table 4 presents the changes in temporal achievement rates of illuminance levels based on obstruction angle and light reflectance for the four main directions, relative to the base case.

According to the results; as the obstruction angle (OA) increases between 0° and 45° for attached and detached building type, all daylight illuminance levels in accordance with the daylight classes provided in the reference living space decreased by 1.30% to 57.80% in the South direction compared to the base case, regardless of light reflectance value of the surrounding buildings and building configuration. In the East, West and North directions, although the general inclination of the results was that the daylight illuminance levels decrease as a result of increasing obstruction angle, some site layout configurations with high obstruction angle and light reflectance value showed inversely effect, which increased the illuminance levels defined for the medium and high daylight classes in the space compared to the base case (OA:0°). As seen from the Fig. 6, as the obstruction angle increased, the $E_{T\ 500lux,50\%}$ levels in north-facing living spaces rose between 4.80% and 24.90% for attached buildings and between 2.70% and 14.50% for detached buildings with a 0.5 LRV. In the case of that the LRV of the obstacle building was 0.8, the temporal achievement rates of the $E_{T\ 300lux,50\%}$, $E_{TM\ 300lux,95\%}$, $E_{T\ 500lux,50\%}$ and, $E_{T\ 750lux,50\%}$ levels also increased in line with the obstruction angle with rates ranging from 0.07% to 37.12% (Table 4). The increase in the temporal achievement rate exceeded 10% in $E_{T\ 500lux,50\%}$ for both building types, and in $E_{T\ 750lux,50\%}$ for the attached building type. When the living space was oriented towards East and West, higher obstruction angles with 0.8 LRV for attached and detached building types resulted in a slight increase (less than 10%) in the temporal achievement rate in $E_{T\ 500lux,50\%}$ for the East direction and in $E_{T\ 300lux,50\%}$ level for the West direction, respectively. In this context, it is concluded from the results that the increase in the obstruction angle can have a positive impact on the daylight provision ($E_{T\ 300lux,50\%}$, $E_{TM\ 300lux,95\%}$, $E_{T\ 500lux,50\%}$) for both building types, primarily in the North, followed by the East and West directions, respectively.

Table 3. Percentage of reduction in minimum and target daylight factor levels depending on the obstruction angle and light reflectance value compared to base case.

Building Type	Obstruction Angle (OA)	Light Reflectance Value (LRV)	Percentage of reduction in minimum and target daylight factor (%)			
			$D_{0,5\%}$	$D_{1.4\%}$	$D_{2.4\%}$	$D_{3.6\%}$
Attached	15°	0.2	17.1	0.0	8.6	0.0
		0.5	8.6	2.9	5.7	0.0
		0.8	0.0	0.0	2.9	0.0
	25°	0.2	31.4	11.5	14.2	2.8
		0.5	25.7	5.7	11.4	0.0
		0.8	11.4	5.7	11.4	0.0
	35°	0.2	54.3	20.0	14.2	5.7
		0.5	28.6	11.4	14.3	5.7
		0.8	17.1	11.5	14.2	2.8
	45°	0.2	60.0	25.7	28.5	8.5
		0.5	37.1	25.7	25.7	8.6
		0.8	17.1	20.0	14.2	8.5
Detached	15°	0.2	22.9	5.7	5.7	0.0
		0.5	2.9	5.7	5.7	0.0
		0.8	2.9	2.9	2.9	0.0
	25°	0.2	28.6	5.7	8.5	2.8
		0.5	20.0	8.6	8.6	0.0
		0.8	14.3	5.7	5.7	0.0
	35°	0.2	37.1	11.5	17.1	2.8
		0.5	28.6	5.7	8.6	0.0
		0.8	14.3	5.7	11.4	0.0
	45°	0.2	22.9	8.6	20.0	5.7
		0.5	11.4	5.7	11.4	0.0
		0.8	2.9	5.7	14.3	2.9

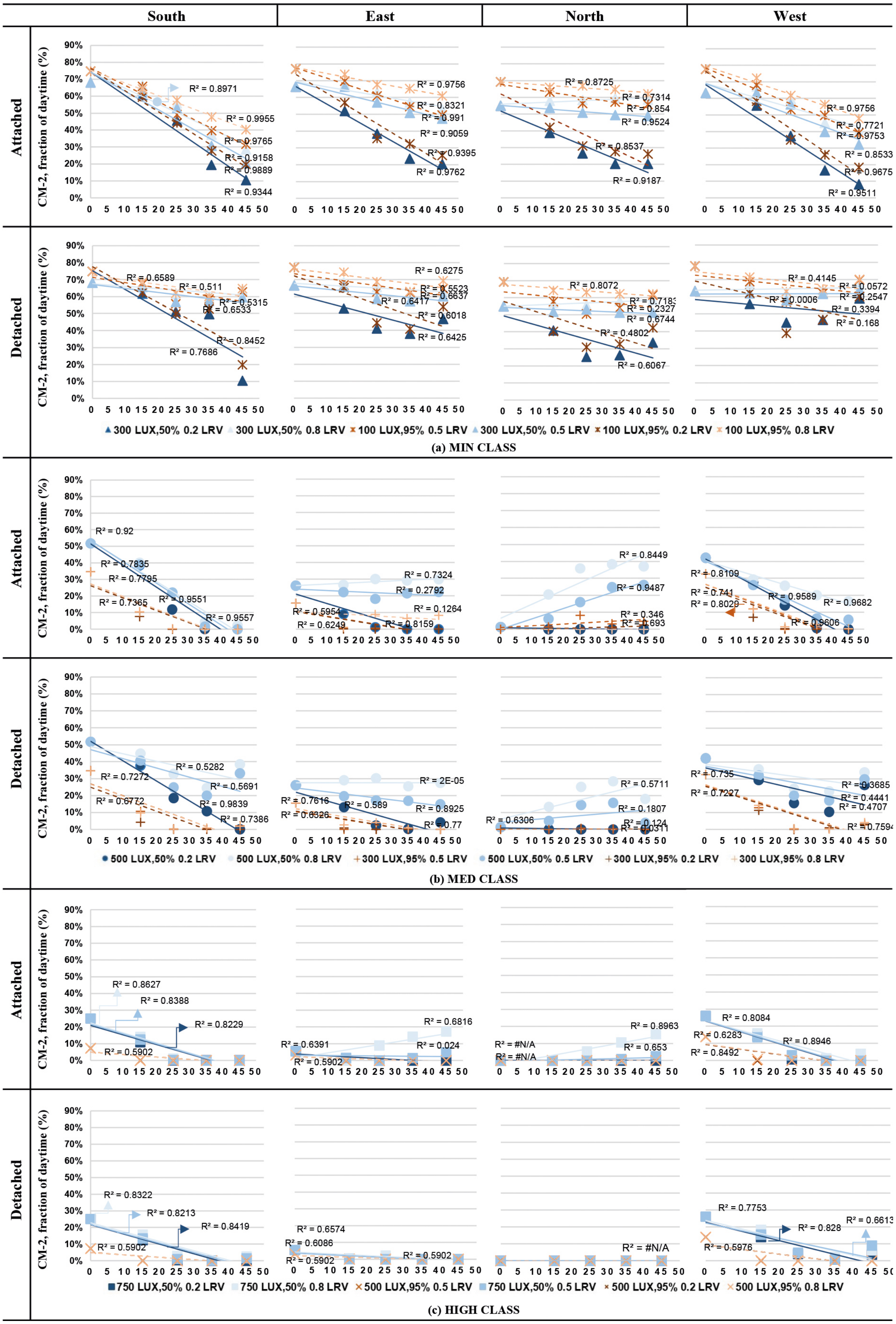


Fig. 6. The temporal achievement rates of the climate-based daylight illuminance level in the living space depending on the various obstruction angles and light reflectance values for the attached and detached building types; (a) minimum daylight class, (b) medium daylight class, (c) high daylight class.

Table 4. Percentage fluctuation in temporal achievement rates for various minimum and target illuminance levels in the living space based on obstruction angle and light reflection coefficient relative to the base case.

			Attached Building				Detached Building			
			15°	**25°**	**35°**	**45°**	**15°**	**25°**	**35°**	**45°**
South	**0.2**	$E_{TM\ 100lux,95\%}$	-15.20%	-30.60%	-47.00%	-55.00%	-12.50%	-25.00%	-22.20%	-55.00%
		$E_{T\ 300lux,50\%}$	-7.40%	-22.70%	-48.70%	-57.80%	-6.50%	-17.00%	-18.60%	-57.80%
		$E_{TM\ 300lux,95\%}$	-27.10%	-34.60%	-34.70%	-34.70%	-30.40%	-34.60%	-34.70%	-34.70%
		$E_{T\ 500lux,50\%}$	-13.30%	-39.90%	-51.70%	-51.80%	-14.30%	-33.30%	-41.00%	-51.80%
		$E_{TM\ 500lux,95\%}$	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%
		$E_{T\ 750lux,50\%}$	-14.20%	-25.00%	-25.10%	-25.10%	-12.70%	-24.60%	-25.10%	-25.10%
	0.5	$E_{TM\ 100lux,95\%}$	-8.90%	-25.60%	-35.10%	-43.10%	-7.40%	-19.10%	-16.30%	-12.10%
		$E_{T\ 300lux,50\%}$	-5.10%	-15.20%	-37.50%	-47.80%	-2.70%	-11.50%	-10.90%	-8.70%
		$E_{TM\ 300lux,95\%}$	-24.30%	-34.40%	-34.70%	-34.70%	-24.10%	-34.40%	-34.50%	-32.50%
		$E_{T\ 500lux,50\%}$	-12.70%	-29.70%	-50.10%	-51.70%	-11.20%	-27.00%	-31.90%	-18.70%
		$E_{TM\ 500lux,95\%}$	-7.30%	-7.30%	-7.30%	-7.30%	-7.20%	-7.30%	-7.30%	-7.30%
		$E_{T\ 750lux,50\%}$	-12.70%	-24.80%	-25.10%	-25.10%	-11.70%	-24.00%	-24.80%	-23.60%
	0.8	$E_{TM\ 100lux,95\%}$	-10.60%	-17.20%	-27.00%	-34.40%	-6.30%	-12.80%	-14.70%	-10.20%
		$E_{T\ 300lux,50\%}$	-1.70%	-12.40%	-30.80%	-39.50%	-1.30%	-6.70%	-8.50%	-4.30%
		$E_{TM\ 300lux,95\%}$	-24.00%	-34.40%	-34.70%	-34.70%	-24.90%	-34.60%	-33.80%	-32.80%
		$E_{T\ 500lux,50\%}$	-11.60%	-29.60%	-47.40%	-49.40%	-7.00%	-19.00%	-27.30%	-13.30%
		$E_{TM\ 500lux,95\%}$	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%	-7.30%
		$E_{T\ 750lux,50\%}$	-11.00%	-23.90%	-25.10%	-25.10%	-9.40%	-22.20%	-25.00%	-22.40%
East	**0.2**	$E_{TM\ 100lux,95\%}$	-20.10%	-41.30%	-44.60%	-51.40%	-11.90%	-32.60%	-36.20%	-23.20%
		$E_{T\ 300lux,50\%}$	-14.50%	-28.00%	-42.90%	-46.00%	-13.60%	-25.30%	-28.50%	-19.80%
		$E_{TM\ 300lux,95\%}$	-15.50%	-15.60%	-15.60%	-15.60%	-14.70%	-15.60%	-15.60%	-15.60%
		$E_{T\ 500lux,50\%}$	-17.10%	-24.90%	-26.10%	-26.10%	-12.90%	-23.70%	-25.80%	-21.90%
		$E_{TM\ 500lux,95\%}$	-3.26%	-3.26%	-3.26%	-3.26%	-3.30%	-3.30%	-3.30%	-3.30%
		$E_{T\ 750lux,50\%}$	-5.10%	-5.50%	-5.50%	-5.50%	-5.30%	-5.50%	-5.50%	-5.40%
	0.5	$E_{TM\ 100lux,95\%}$	-7.40%	-16.10%	-22.40%	-27.50%	-10.30%	-14.30%	-14.70%	-12.40%
		$E_{T\ 300lux,50\%}$	-0.10%	-9.40%	-15.60%	-19.10%	-0.80%	-7.90%	-9.40%	-6.40%
		$E_{TM\ 300lux,95\%}$	-15.00%	-15.00%	-15.60%	-15.50%	-15.60%	-15.60%	-15.60%	-15.60%
		$E_{T\ 500lux,50\%}$	-3.80%	-7.90%	-4.70%	-3.80%	-6.50%	-9.00%	-9.10%	-11.20%
		$E_{TM\ 500lux,95\%}$	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%
		$E_{T\ 750lux,50\%}$	-3.90%	-5.50%	-4.00%	-0.60%	-5.50%	-5.50%	-5.50%	-5.50%
	0.8	$E_{TM\ 100lux,95\%}$	-3.20%	-9.40%	-11.70%	-16.10%	-2.70%	-8.50%	-14.10%	-7.80%
		$E_{T\ 300lux,50\%}$	**+1.30%**	-3.30%	-9.40%	-13.40%	**+1.90%**	-0.80%	-4.70%	-3.10%
		$E_{TM\ 300lux,95\%}$	-14.50%	-6.80%	-9.10%	-7.20%	-12.90%	-11.60%	-14.80%	-15.60%
		$E_{T\ 500lux,50\%}$	**+0.50%**	**+4.10%**	**+3.20%**	**+3.80%**	**+3.00%**	**+4.20%**	-0.60%	**+1.40%**
		$E_{TM\ 500lux,95\%}$	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%	-3.30%
		$E_{T\ 750lux,50\%}$	-5.50%	**+3.40%**	**+8.70%**	**+11.80%**	-5.00%	-3.30%	-5.20%	-5.40%
North	**0.2**	$E_{TM\ 100lux,95\%}$	-27.19%	-38.20%	-41.62%	-42.99%	-28.97%	-38.27%	-36.44%	-26.94%
		$E_{T\ 300lux,50\%}$	-16.16%	-28.51%	-34.84%	-34.68%	-14.27%	-29.72%	-28.76%	-21.34%
		$E_{TM\ 300lux,95\%}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		$E_{T\ 500lux,50\%}$	-1.26%	-1.26%	-1.26%	-1.26%	-1.19%	-1.26%	-1.26%	-1.26%
		$E_{TM\ 500lux,95\%}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		$E_{T\ 750lux,50\%}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	0.5	$E_{TM\ 100lux,95\%}$	-6.10%	-13.00%	-12.10%	-13.60%	-11.50%	-18.80%	-15.10%	-7.70%
		$E_{T\ 300lux,50\%}$	-1.30%	-4.20%	-5.60%	-6.20%	-3.40%	-1.80%	-3.90%	-3.90%
		$E_{TM\ 300lux,95\%}$	0.00%	**+0.20%**	**+0.90%**	**+2.60%**	0.00%	0.00%	**+0.10%**	0.00%
		$E_{T\ 500lux,50\%}$	**+4.80%**	**+14.80%**	**+23.60%**	**+24.90%**	**+3.80%**	**+13.20%**	**+14.50%**	**+2.70%**
		$E_{TM\ 500lux,95\%}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		$E_{T\ 750lux,50\%}$	0.00%	0.00%	0.80%	2.50%	0.00%	0.00%	0.00%	0.00%
	0.8	$E_{TM\ 100lux,95\%}$	-3.33%	-2.40%	-4.50%	-7.17%	-5.07%	-6.12%	-7.10%	-6.92%
		$E_{T\ 300lux,50\%}$	**+2.97%**	**+3.38%**	**+4.41%**	**+3.61%**	**+2.06%**	**+0.57%**	**+2.99%**	**+3.75%**
		$E_{TM\ 300lux,95\%}$	**+1.42%**	**+8.17%**	**+3.20%**	**+4.73%**	**+0.02%**	**+0.64%**	**+0.27%**	0.00%
		$E_{T\ 500lux,50\%}$	**+19.22%**	**+34.63%**	**+37.12%**	**+35.86%**	**+12.00%**	**+23.85%**	**+27.10%**	**+16.69%**
		$E_{TM\ 500lux,95\%}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		$E_{T\ 750lux,50\%}$	**+0.07%**	**+5.34%**	**+10.64%**	**+15.53%**	0.00%	0.00%	**+0.11%**	**+0.23%**
West	**0.2**	$E_{TM\ 100lux,95\%}$	-19.25%	-42.70%	-51.81%	-59.32%	-15.64%	-38.98%	-31.05%	-17.72%
		$E_{T\ 300lux,50\%}$	-7.58%	-25.93%	-46.75%	-55.06%	-7.62%	-18.37%	-16.84%	-4.40%
		$E_{TM\ 300lux,95\%}$	-25.55%	-32.26%	-32.67%	-32.67%	-21.35%	-32.65%	-31.71%	-29.54%
		$E_{T\ 500lux,50\%}$	-14.52%	-28.17%	-41.50%	-42.21%	-12.92%	-26.53%	-31.78%	-15.93%
		$E_{TM\ 500lux,95\%}$	-13.95%	-13.95%	-13.95%	-13.95%	-13.93%	-13.95%	-13.95%	-13.95%
		$E_{T\ 750lux,50\%}$	-11.69%	-25.43%	-26.05%	-26.05%	-12.12%	-22.01%	-25.21%	-22.42%
	0.5	$E_{TM\ 100lux,95\%}$	-9.60%	-24.50%	-27.90%	-38.50%	-9.00%	-20.90%	-15.80%	-8.00%
		$E_{T\ 300lux,50\%}$	0.00%	-6.90%	-23.50%	-31.10%	-1.50%	-5.40%	-1.70%	**+0.70%**
		$E_{TM\ 300lux,95\%}$	-20.70%	-32.70%	-32.60%	-32.70%	-19.70%	-32.20%	-32.30%	-30.00%
		$E_{T\ 500lux,50\%}$	-16.10%	-24.70%	-35.90%	-36.60%	-10.20%	-22.10%	-25.00%	-12.40%
		$E_{TM\ 500lux,95\%}$	-14.00%	-14.00%	-14.00%	-14.00%	-13.90%	-14.00%	-14.00%	-14.00%
		$E_{T\ 750lux,50\%}$	-12.40%	-23.00%	-26.10%	-26.10%	-10.60%	-21.10%	-25.20%	-17.10%
	0.8	$E_{TM\ 100lux,95\%}$	-5.46%	-15.96%	-21.33%	-29.89%	-6.35%	-14.73%	-13.66%	-7.67%
		$E_{T\ 300lux,50\%}$	**+3.89%**	-3.69%	-18.05%	-22.64%	**+4.00%**	-1.73%	**+0.35%**	**+3.57%**
		$E_{TM\ 300lux,95\%}$	-20.84%	-31.16%	-30.00%	-32.42%	-18.40%	-32.35%	-32.33%	-28.54%
		$E_{T\ 500lux,50\%}$	-12.80%	-16.50%	-22.12%	-25.68%	-6.57%	-18.10%	-19.56%	-8.31%
		$E_{TM\ 500lux,95\%}$	-13.22%	-13.95%	-13.95%	-13.95%	-13.81%	-13.95%	-13.95%	-13.95%
		$E_{T\ 750lux,50\%}$	-10.16%	-22.92%	-24.79%	-22.08%	-7.74%	-21.53%	-23.81%	-19.86%

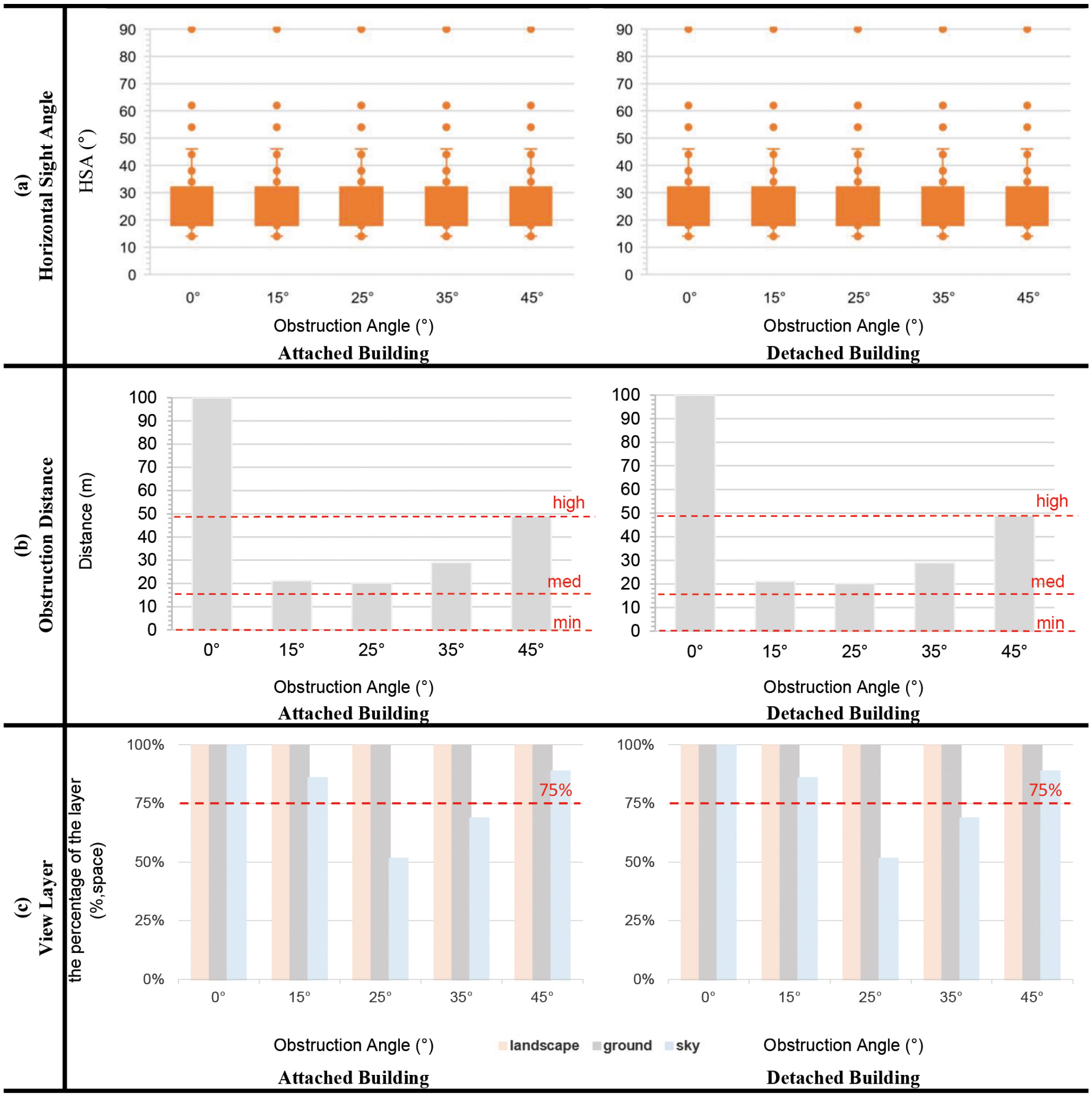


Fig. 7. The effect of the obstruction angle on the view access and quality in scope of the EN 17037 considering horizontal sight angle (a), distance to obstruction (b), view layer (c).

The effect of the exterior surface materials of the surrounding buildings on climate-based daylight illuminance levels was also analyzed with CM-2 method. Figure 6 illustrated that increasing the light reflectance value enhanced the daylight availability in the living space, across the all-defined daylight illuminance levels based on the minimum, medium and high daylight classes. Compared to the base case, the increase in light reflectance value led to significant rises in $E_{TM\ 100lux,95\%}$, $E_{T\ 300lux,50\%}$ and $E_{T\ 500lux,50\%}$ levels, while the increases in temporal achievement rates for $E_{T\ 750lux,50\%}$, $E_{TM\ 300lux,95\%}$ and $E_{TM\ 500lux,95\%}$ remained minimal due to insufficient illuminance levels in the living space. Similar with the daylight factor results via CM-1, the temporal achievement rate in daylight illuminance level depending on the light reflectance value occurred at high levels as the obstruction angle increased, especially for attached building type compared to detached building type. In both building configurations, the increase in the achievement rates of daylight illuminance as a result of raising the light reflectance value from 0.2 to 0.5 (avg. 32.5%) was averagely %18.5 higher than the raising it from 0.5 to 0.8 (avg. 14%). Moreover, the highest rates of increase in daylight provision in the space due to the light reflectance value were observed in North (avg.30.70%), East (avg. 26.96%), West (avg. 17.70%), and South (avg. 15.73%), respectively, for both attached and detached building types. Therefore, especially on the North façade, the surface materials having the higher reflectance value provided more effective daylight strategy. In addition to the obstruction angle and light reflectance value, the orientation of the building significantly affected how the obstruction angle influenced daylight provision within the living space [57]. As presented in Fig. 6, the reduction in the temporal achievement rate at $E_{TM\ 100lux,95\%}$ and $E_{T\ 300lux,50\%}$ levels due to an increase in obstruction angle was most pronounced in the South (avg. 22.5%), followed by the West (avg. 20%), East (avg. 10.4%), and North (avg. 1.9%), respectively. Furthermore, the decline in the illuminance level within the living space was significantly less in the detached building type compared to the attached building type across all orientations, with the most substantial differences occurring in the Southern and Western directions.

3.2. View-Out analysis

The view-out level of the living space depending on the change in obstruction angle for two different building configuration was quantitatively evaluated according to the horizontal sight angle, obstruction distance and number of layers in the view criteria as described in the EN 17037 (Table 2). Figure 7 illustrates the provided levels in the living space by each criterion for different obstacle angles. The effect of light reflectance value on view-out quality was not analyzed due to methodological limitations, although the color of the buildings on the site plays a crucial role in people's view-out assessments [34,35]. According to the results given in Fig. 7(a), the horizontal sight angle (HSA) for each calculation points in the living space varied between 14° and 90°, which was the same for the all-obstruction angles (OA) due to the same window dimension. The results based on distance criteria showed that the view-out improved with an increase in obstruction angle for the both building types. This occurs because zoning regulation mandate wider road widths for taller buildings (Fig. 7(b)). Considering the spatial visibility of the view layers, the ground and landscape layer were seen from the space in 100% for both attached and detached buildings. On the other hand, the proportion of visible sky layer decreased from 85.7% to 11.4%, when the obstacle angle increased from 15° to 45° for the attached building type, and the adequate spatial sky visibility rate was not to be achieved above the 15° OA. For the detached building type, the spatial achievement rate of the visible sky layer firstly decreased with the increasing obstruction angle to 15° (85.7%) and 25° (51.4%), then increased in case of that obstruction angle are 35° (68.6%) and 45° (88.6%). As can be seen Fig. 7(c), the sky layer visibility was achieved by the scenarios having 0°, 15° and 45° OA with the detached building type.

The overall view-out level of the reference living space for each obstruction angle was determined according to the view-out class, which was the lowest level among the three criteria (EN 17037). Figure 8 shows the spatial achievement rate of the minimum, medium, high view-out level in the space for each site layout scenario created according to obstruction angle and building type. As a result of increasing the obstruction angle, the high level of view-out decreased in a different rate, while the medium level of view-out increased for the both building types. The low level of view-out did not alter as a result of increasing the obstacle angle between 0°-45° for both building types. Unlike the other obstruction angle, 45° OA led to increase the rate of the high view-out level, as the distance to obstruction building was greater than in other scenarios. Additionally, the 45° OA in the detached building type allowed for visibility of the sky, further enhancing the high view-out level compared to the attached building type.

3.3. Sunlight exposure analysis

The level of sunlight exposure of the living space for different directions was determined for the point at a height 1.2 m above from the ground on March 15, which is the representative day of the month [58]. Figure 9 illustrates the sunlight hours for three directions in relation to attached and detached building configurations, depending on the obstruction angle. The results revealed that the sunlight durations at the analysis point in South, East and West directions were 9, 5 and 4 hours for the unobstructed case, respectively. As a result of increasing the obstruction angle from 0° to 15°, 25°, 35° and 45°, the sunlight hour for the site layout scenarios with the attached building type was calculated as 9, 9, 9, 8 hours for the South; 4, 3, 3, 2 hours for the East, and 5, 4, 3, 3 hours for the West, respectively. In case of the detached building type, the sunlight hours reaching at the analyze point were 9, 9, 9, 9 h for the South; 4, 3, 3, 4 h for the East; and 5, 4, 4, 5 h for the West orientation when the OA was 15°, 25°, 35° and 45° respectively. The results indicate that the 15° OA in all directions has no impact on access to sunlight. On the south, sunlight hours in the living space were only reduced with a 45° obstruction angle in the case of the attached building type. On both the east and west, increasing the obstruction angle from 15° to 25° resulted in a reduction of only one hour of sunlight duration for both the attached and detached building types. However, further increasing the obstruction angle from 25° to 35° did not lead to any additional changes in sunlight hours. On the other hand,

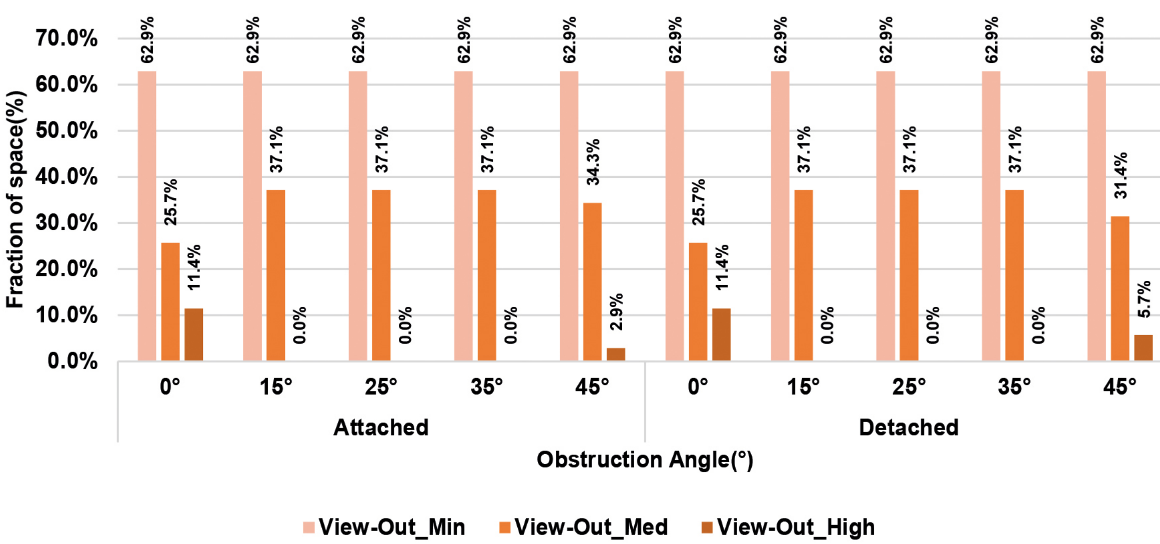


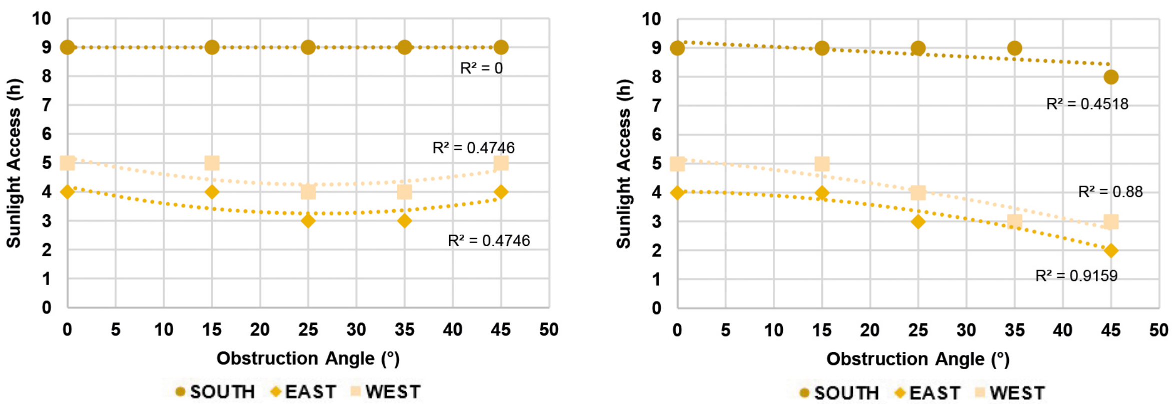
Fig. 8. The spatial achievement rates of the view-out level for three class in the living room according to EN 17037.

with a 45°OA, sunlight hour decreased by one hour for the attached building type in both the east and west orientations, resulting in 2 and 3 hours of sunlight, respectively. In contrast, for the detached building type, sunlight hours increased by one hour, reaching 4 hours in the east and 5 hours in the west. This increase is attributed to the wider spacing between the buildings on the site, which allowed for greater sunlight exposure due to the more sky view compared to the 25° and 35° obstruction angles (Fig. 7(c)).

3.4. Visual comfort level classification

The daylight provision classes occurring in the living space for different settlement scenarios are as presented in Table 5 according to the Calculation Method-1 (CM-1) and Calculation Method-2 (CM-2). It is expected that all of the scenarios generated based on the zoning regulation should enable the minimum daylight provision class in the living space in order to provide visual comfort conditions with daylight. According to CM-1, the minimum daylight provision class, which is the lowest level that requires the provision of $D_{TM,0.5\%}$ and $D_{T,1.4\%}$ in 95% and 50% of the space respectively, was not to be achieved in the living space for any site layout scenario including the base case (OA:0°). Contrary to CM-1, the minimum daylight provision classes determined by CM-2 were achieved in the living space with some site-layout scenarios differing by building type and orientation.

Given the daylight provision classes determined by CM-2 according to the site layout scenarios, the findings showed that the south-oriented settlements enabled to obtain the minimum daylight provision class in the living space with the lower obstruction angle and the higher light reflectance value for both building types, while the minimum daylight class for the highest obstruction angles was provided only by the detached building type. If the settlements configurated with the attached building type were oriented east direction, they were more likely to meet the minimum daylight provision in living rooms compared to a south orientation. In the case of detached buildings, when the light reflectance value of the surrounding buildings was 0.5 or 0.8, the minimum daylight requirement for the living space was achieved across all obstruction angles. Compared to east orientated settlements with adjacent building types, west orientated settlements could achieve the minimum daylight requirement in



(a) Attached Building (b) Detached Building

Fig. 9. The provided sunlight hours at the analysis point depending on the obstruction angle and orientation.

Table 5. Daylight provision classes provided in the living room depending on the site layout scenarios via CM-1 and CM-2.

		0.2				0.5				0.8			
		Attached		Detached		Attached		Detached		Attached		Detached	
		CM-1	CM-2	CM-1	CM-2	CM-1	CM-2	CM-1	CM-2	CM-1	CM-2	CM-1	CM-2
South	0°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	15°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	25°	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	35°	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	FAIL	FAIL	MIN
	45°	FAIL	FAIL	FAIL	MIN	FAIL	FAIL	FAIL	MIN	FAIL	FAIL	FAIL	MIN
East	0°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	15°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	25°	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	35°	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	45°	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN
North	0°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	15°	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	25°	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	35°	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN
	45°	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN
West	0°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	15°	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	25°	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	MIN	FAIL	MIN	FAIL	MIN
	35°	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	MIN	FAIL	FAIL	FAIL	MIN
	45°	FAIL	FAIL	FAIL	MIN	FAIL	FAIL	FAIL	MIN	FAIL	FAIL	FAIL	MIN

the living space at lower obstruction angles. However, west-oriented settlements with detached building types, having a light reflection coefficient of 0.2, are more advantageous than east-facing ones in meeting the minimum daylight requirements at higher obstruction angles in the living space. On the other hand, in North-oriented settlements, the minimum daylight provision class was achieved only for the site layout scenarios occurring at obstruction angles of 0°-15°-25° and 0°-15°-25°-35°-45° with the attached building type, when the light reflectance value was 0.5 and 0.8 respectively. In the case of the detached building type, the minimum daylight provision class in the living room was obtained with the light reflection value of 0.5 and 0.8 for all scenarios, in contrast to 0.2, which does not allow achieving the minimum daylight class with any obstruction angle.

In addition to the daylight provision classes, the view-out and sunlight exposure classes provided in the living space with the different site layout scenarios created within the scope of the study are as given in Table 6. According to the results, the view-out class of the living space was minimum for all scenarios generated based on obstruction angle, light reflectance value, and building type. Depending on the site layout design, the sunlight exposure class obtained in the living space was high for all options in the South direction, regardless of the building type. In the East direction, the sunlight exposure class was medium for 15° OA and 25°; minimum for 35° OA; fail for the 45° in case of the attached building type. The all-obstruction angles except 45° for the detached building type ensured the high sunlight exposure class in the East direction.

The settlement scenarios that allow minimum visual comfort level in the living space having the minimum room and window dimensions are given in Table 7, corresponding to the number of floors specified in the zoning regulation depending on the road widths. Considering the overall performance of the living space in terms of daylight provision, view-out and sunlight exposure, it was seen that the settlement scenarios oriented North direction did not guarantee the adequate level of performance due to the lack of access to sunlight. For South, East and West directions, the obstruction angles (OA) that allow to ensure minimum visual comfort class in the space, based on the light reflectance value (LRV) of the obstruction, were determined as follows for two different building type;

When the building type was attached:

- 0° and 15° OA for 0.2 LRV; 0°, 15° and 25° OA for 0.5 and 0.8 LRV in South.
- 0° and 15° OA for 0.2 LRV; 0°, 15°, 25° and 35° OA for 0.5 and 0.8 LRV in East.
- 0° and 15° OA for 0.2 LRV; 0°, 15° and 25° OA for 0.5 and 0.8 LRV in West.

When the building type was detached:

- 0°, 15° and 45° OA for 0.2 LRV; 0°, 15° and 25° OA for 0.5 LRV; 0°, 15°, 25°, 35° and 45° OA for 0.8 LRV in South.
- 0° and 15° OA for 0.2 LRV; 0°, 15°, 25° and 35° OA for 0.5 and 0.8 LRV in East.
- 0°, 15° and 45° OA for 0.2 LRV; 0°, 15°, 25°, 35° and 45° OA for 0.5 LRV; 0°, 15°, 25° and 35° OA for 0.8 LRV in West.

4. Discussion

In this section, the visual comfort performance and daylight compliances of the site layout design alternatives are discussed based on the results for daylight provision, view-out and sunlight exposure presented in Section 3. In addition, the relationship between the evaluation methods and the site layout design parameters is examined by using linear regression model.

Table 6. View out and sunlight exposure classes of the living room depending on the site layout scenarios.

		View-out						Sunlight Exposure					
		0.2		0.5		0.8		0.2		0.5		0.8	
		Attached	Detached	Attached	Detached	Attached	Detached	Attached	Detached	Attached	Detached	Attached	Detached
South	0°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	15°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	25°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	35°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	45°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
East	0°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	15°	MIN	MIN	MIN	MIN	MIN	MIN	MED	MED	MED	MED	MED	MED
	25°	MIN	MIN	MIN	MIN	MIN	MIN	MED	MED	MED	MED	MED	MED
	35°	MIN	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	MIN	HIGH	MIN	HIGH
	45°	MIN	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
North	0°	MIN	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
	15°	MIN	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
	25°	MIN	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
	35°	MIN	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
	45°	MIN	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
West	0°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	15°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	25°	MIN	MIN	MIN	MIN	MIN	MIN	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
	35°	MIN	MIN	MIN	MIN	MIN	MIN	MED	HIGH	MED	HIGH	MED	HIGH
	45°	MIN	MIN	MIN	MIN	MIN	MIN	MED	HIGH	MED	HIGH	MED	HIGH

Table 7. Visual comfort classes of the living space having the minimum window dimension according to the number of floors of the obstruction specified in the zoning regulations.

			Number of Floor							
			2	**3**	**4**	**5**	**6**	**8**	**10**	**14**
	Road Width(m)		RW≤7	7<RW≤10	10<RW≤12	12<RW≤15	15<RW≤20	20<RW≤25	25<RW≤35	35<RW≤50
			15°≤OA≤25°			**25°<OA≤35°**			**35°<OA≤45°**	
South	**Attached**	**0.2**	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.5	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.8	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
	Detached	**0.2**	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.5	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.8	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN
East	**Attached**	**0.2**	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.5	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL
		0.8	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL
	Detached	**0.2**	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.5	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL
		0.8	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL
West	**Attached**	**0.2**	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.5	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.8	MIN	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
	Detached	**0.2**	MIN	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
		0.5	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN
		0.8	MIN	MIN	MIN	MIN	MIN	FAIL	FAIL	FAIL

4.1. The impact of the site layout design parameters on the visual comfort

The obstruction angle—encompassing building height and distance between the buildings—along with the light reflectance value of the surrounding buildings and building type affects indoor daylight efficiency differently when evaluated by using the static (CM-1) and dynamic (CM-2) methods defined in the EN 17037. According to the Calculation Method-1 (CM-1), which assumes overcast sky conditions, an increase in obstruction angle results in reduced daylight availability in the reference living space for both building typologies as a general consequence (Fig. 5). However, this reduction diminishes as the light reflectance coefficient of the obstructing building increases, therefore providing the higher daylight provision in the living space due to the higher light reflectance values of the exterior surface [59].

Conversely, when evaluating indoor daylight performance using the Calculation Method-2 (CM-2), which considers the sunlight based on the climate, the decrease in target illumination levels does not exhibit a linear relationship with increasing obstruction angles for either attached or detached building configurations. In fact, under specific conditions—particularly when the reference living space is oriented to North—indoor daylight provision may improve with a larger obstruction angle. This improvement is more significant when the light reflectance of the obstructing building is higher. This anomaly in the results is associated with two main reasons: the increase in reflected light from the obstacle surface, which is directly proportional to the number of building floors, thus obstruction angle, and the greater distance between buildings as the obstruction angle increases, in accordance with zoning regulations. The first inference aligns closely with the study's findings, namely that the opposite facade of high-rise buildings can function as a passive daylighting device, thus increase indoor daylight illuminance in the high-luminous climates, especially on the sunny façade directions (Azimuth Angle≥ 90°) under the clear sky conditions [60]. This is also evidence by the result of the study conducted by Sun et al [25], where the western settlement zone causing the high obstruction angle reached the maximum daylight hour level in the space compared to the southern and eastern perimeter zones. Similarly, Lu et.al [29] indicated that the obstruction can enhance daylight availability especially on the north façade. Furthermore, the higher light reflectance value of the obstacle building increased the positive impact of the obstruction angle by allowing more rays to bounce off, thereby enhancing light penetration into the space [61]. On the other hand, the results indicated that the higher obstruction angle having the larger openness between the buildings, as seen from the reference space within the site layout context, had a substantially impact on the increasing of daylight provision in the space, when the detached building type was considered. In this sense, Islam et al pointed out that the required daylight factor level can be achieved in case of the high obstruction angles due to having the high ratio of void portion of canyon walls against the solid portion [37]. The view-out analysis results in Fig. 7 also demonstrated that the percentage of the sky view seen from the living space firstly decreased up to 25° OA, then increased as obstruction angle was increased with widening the road width. This finding proved that effective daylighting can still be achieved with a tall obstruction, as long as it is not continuous and remains narrow enough to permit sky view and sufficient daylight to pass around its sides [11]. It also emphasized that an increase in obstruction angle may not necessarily mean a poor view-out. Similar to the daylighting results, the duration of sunlight exposure on the window surface exhibits unusual behavior, increasing as the obstruction angle exceeds 25° due to greater sky visibility resulting from the wider spacing between buildings. As a results of the findings, the obstruction angle might be deceptive as a standalone indicator in evaluating the daylight performance of the site layout design alternatives.

4.2. Visual comfort compliance of the national zoning regulation—policy insight

The findings given in the Section 3.4 show that the maximum obstruction angle for both building types to ensure minimum class for three visual comfort criteria, based on the minimum room size allowed in the zoning regulation and the smallest window size specified in EN 17037, is 15° (Table 7). Increasing the light reflectance of the surrounding buildings allows to meet the minimum class with the higher obstruction angles on the site if the sufficient distance between the buildings is existing. Additionally, the detached building type more readily achieves minimum and higher daylight classes, as the voids in the urban canyon allow for greater sky exposure and daylight access. In the wording of the Turkish zoning regulation, the buildings with two or three floors can achieve the minimum visual comfort class across all orientations with nearly all light reflectance values. If the light reflectance value is 0.2, the distance between buildings may need to be greater than the sum of the existing road widths and setback distances recommended in zoning regulations. To ensure the minimum visual comfort in living spaces facing south and west, based on site layout scenarios created with the road widths specified for four, five, and six-story buildings, the surrounding buildings must have a high light reflectance value (LRV ≥ 0.5) and feature a detached building design. When the number of floors exceeds eight, achieving the minimum visual comfort level is only possible with site layout designs for buildings of 14 or more floors, where the LRV is at least 0.5 and the detached building type is employed. These implications are applicable for the climate-based daylight results determined by the Calculation Method-2 (CM-2). Evaluation using the DF method (CM-1) reveals that none of the scenarios achieve an adequate comfort class regarding daylight provision and overall visual comfort levels. This situation is related to the fact that the CM-1 method is more conservative assessment compared to the CM-2 method, which is similar to the results of the study [39] that daylight compliances are barely achieved using DF method than climate-based illuminance method. This would also necessitate larger window areas than those specified by the CM-2 method to achieve the minimum daylight class for the same site layout planning scenario when using the CM-1 method [62,63]. Furthermore, the results obtained by the CM-2 method also proved that the site layout scenarios developed in accordance with zoning regulations can only achieve improved daylight classes with larger window sizes. At that point, it is crucial to account for the overheating risk, thus increasing cooling loads when determining the window sizes that will provide higher daylight class in the considered site layout scenarios [20]. The implementation of the higher light and solar reflective materials on the urban surfaces and passive shading strategies in scope of the regulations can optimize the daylight performance in the buildings while reducing the urban heat island effect [64].

4.3. Relationship between site layout design parameters and evaluation methods

The relationship between the daylight metrics described in EN17037 and site layout design parameters is interpreted by the coefficient of determination (R^2) in scope of the study. The coefficient of determination (R^2) represents the goodness of fit for a linear regression mode [65]. According to the Fig. 5, The results indicated a strong correlation between the daylight factor (DF), especially for the minimum daylight class ($R^2 \geq 0.90$), and the obstruction angle in contrast to the urban density parameter [38]. However, it was seen that this correlation was weaker for the detached building type ($R^2 \geq 0.55$) compared to the attached building type. Given the linear correlation coefficient (R^2) between the achievement rate of the daylight illuminance level determined by the CM-2 method and the obstruction angle depending on the orientation, the strongest relationship between CM-2 method and obstruction angle was found for the south, west, east and north orientation, respectively, considering all target illuminance levels for the attached building type. On the other hand, the results for the detached building type demonstrated that the relationship between the obstruction angle and the CM-2 method was weaker with the detached building type configuration compared to those with attached building type. Additionally, the correlation between the obstruction angle and the CM-2 method produced more consistent results for South and East orientations, compared to the West and North orientations in case of the detached building type.

Given the view-out evaluations, the results demonstrated that the obstacle angle has no effect on the horizontal sight angle, which aims to evaluate the access to the exterior view regardless of the building layout, thus there is no relationship between the obstacle angle and the horizontal sight angle metric. On the other hand, no correlation was found between the distance to the main obstruction and the obstruction angle, since the obstruction angle was not directly proportional to the distance between buildings. This implies that an increase in the obstruction angle does not directly result in a decrease in the window view. Similarly with the distance to obstruction criteria, the spatial achievement rate of the view layer, specifically sky view layer, determined by EN 17037 did not give strongly correlated results with the obstruction angle (OA). In this context, it was determined that the visible sky percentage in the living space for the detached building type did not decrease linearly with the increase in obstruction angle, i.e., firstly decreased up to 25° OA compared to the unobstructed case, and increased at 35° and 45° OA compared to 25° OA. Conversely, the rate of the sky layer that can be seen from the living space for the attached building type decreased inversely with the increase of the obstruction angle. Considering the overall view-out evaluation of the living space, it was seen that the obstruction effect, which differed depending on the building type on the basis of the view-out criteria, did not cause any change in the overall view-out class provided in the reference space. In addition, given the weak correlation between people's assessments of view-out and the compliance class of the view-out of the space according to EN 17037 [66,67], the method requires to be analyzed in more detail to reveal the differences in the overall assessment of view-out by the site layout design parameters such as obstruction angle, building type and the light reflectance value of the surrounding buildings.

The sunlight hour provided in the living space according to the attached and detached building types showed a parabolic change depending on the obstruction angle, as given in Fig. 9. For the attached building type, the sunlight hour and the obstruction angle exhibited a strong relationship depending on the coefficient of determination, especially for the east (R^2:0.92) and west (R^2:0.88) directions, while a weaker relationship emerged in the south orientation (R^2:0.45) compared to other directions. In the building configuration having the detached buildings, there was not found any relationship between the obstruction angle and sunlight hour in the south orientation. On the other hand, the coefficient of determination (R^2) between the obstruction angle and sunlight hour was calculated as 0.47 in the east and west orientations. In this regard, it was inferred that the obstruction angle and the sunlight hour have a weak correlation for the detached building type compared to attached building type.

5. Conclusion

The effective use of the daylight as a design tool is essential for creating comfortable, healthy, and energy-efficient buildings and settlements. Therefore, the site layout design compliant with zoning regulation must be developed to meet the minimum level of visual comfort criteria defined within the scope of EN 17037: Daylight in Buildings Standard. Within this context, this study examines how the site layout scenarios, which are generated parametrically taking into consideration the design parameters at neighborhood scale, affect the daylight availability, view-out potential, and sunlight access of a theoretical residential space oriented to four main orientations. Considering the design parameters, it is evident that light reflectance value and obstruction angle, therefore building height and distance between the buildings, significantly affect daylight and sunlight availability in the spaces. However, they do not serve as influential design parameters regarding view quality. Furthermore, building configuration and orientation significantly modify the impact of the design parameters on indoor daylight provision and sunlight exposure. This underscores that urban indicators, such as obstruction angle, alone are insufficient for accurate daylighting assessments; thus, multiple design indicators should be considered collectively to achieve a daylight-efficient site layout.

In context of the Turkish zoning regulation, the results indicate that the zoning regulation for designing new developments or re-designing settlements fall short of meeting the minimum daylight requirements in the residential space representing the permissible minimum dimensional condition. In contrast, some site layout scenarios lead to levels of sunlight exposure well above what should be provided in the living space, which can cause to thermal discomfort due to the overheating. Therefore, it is obviously understood that the road widths and number of floors defined within the scope of the zoning regulation should be reconsidered in order to optimize the design parameters that affect visual comfort performance at the neighborhood scale. In line with this, describing the minimum allowable distance between buildings and maximum building heights may provide more accurate results for developing of the optimized site layout designs. Furthermore, proposing minimum light reflectance value for the surrounding buildings depending on the orientation, especially in sites with attached building type can be crucial to enable comfortable and energy efficient site layouts by providing sufficient daylight levels in the buildings. On the other hand, the study reveals that the methods that will be used for evaluating daylight, sunlight and view-out performance in buildings are crucial to identify the visually efficient site layout solution.

5.1. Limitations and directions for the future research

Although the provided workflows and many findings represented in the study can be generalized for the similar climate conditions, the study also consists of some limitations. First, the daylight compliance of the site layout scenarios is specific to Istanbul; however, the view-out results may be applicable to other cities. Second, the results apply to the living space, which has the minimum permissible room and window dimensions defined in the zoning regulation, and EN 17037. Therefore, the visual comfort results depending on the site layout design may differ for different room sizes and window sizes. Third, building heights across the site are assumed to be uniform, thus variations in building height could alter the results. Future studies could enhance understanding by examining binary combinations of building height and spacing, incorporating different window sizes to optimize daylighting in site layout design. Additionally, evaluating facade materials based on their light reflectance, color, and hue properties may provide new insights into designing more sustainable and comfortable settlements. In addition, it would be important to re-consider the overall assessment of view out at the spatial scale defined in the standard in order to more accurately determine the view quality, and to provide a more detailed description of the impact of the parameters considered at the neighborhood scale on view-out performance.

Contributions

Zehra Aybike Kılıç: Conceptualization, Data Curation, Methodology, Formal Analysis, Validation, Writing-original draft, Visualization. Alpin Köknel Yener: Conceptualization, Methodology, Validation, Writing-Reviewing & Editing, Project administration, Funding acquisition.

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Declaration of competing interest

The authors declare no conflict of interest.

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