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Sunlight as a common good. A comparative study of the overshadowing of public spaces adjacent to contemporary multifamily housing developments based on the Wrocław example

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Abstract

Sunlight plays a crucial role in everyday life. Contemporary regulations and research emphasize solar access to buildings, with more limited consideration to open spaces (OSs). This preliminary study aims to explore current overshadowing tendencies in OSs adjacent to recently built residential developments. This comparative analysis is based on simulated shadow patterns observed on March 21st on OSs adjacent to residential buildings completed between 2010 and 2024 in the centre of Wrocław. OSs were analysed in relation to density and their main characteristics, with respect to comparative benchmark based on BRE guidance. Over 150 OSs were identified. The results indicate that 75% of total analysed area received at least 2 hours of sunlight. Nevertheless, nearly 30 OSs received that amount on less than 20% of their area. They were mostly small and enclosed. The varied results indicate that further consideration should be given to overshadowing and its potential performance indicators.

Keywords: architecture, open space, sunlight, overshadowing, multifamily housing

1. Introduction

Light is a fundamental part of human existence. Sufficient contact with daylight is linked to the proper circadian rhythm regulation and good sleep quality, which provide health benefits, such as cognitive efficiency or emotional stability (Bellia et al., 2021; Boubekri et al., 2020; Mead, 2008). People's everyday interaction with the sun has significantly changed since the industrial age, which was further influenced by the technological advancements. People who once spent much of their day outdoors, with access to daylight, have turned towards more indoor-based lifestyle. According to a study conducted by Crowley et al., a typical office worker gets "~2.5 hours of bright outdoor light (>1,000 lux) on summer workdays, but only about half of this on winter workdays" (Crowley et al., 2014). Therefore, most of our access to light involves artificial lightning, which has a different influence on the human body than sunlight. A significant amount of research has been dedicated to the effect of light on the human body and vision (Sobol et.al, 2024). For those reasons, the 'Solar Access' is one of the core issues in contemporary urban planning (Islam et al., 2015) and can be considered a necessity that can lead the contemporary approach to the sustainable planning.

Numerous studies focus on sunlight's influence over buildings, including their external envelopes (roofs, facades), as well as the indoor environment (Bellia et. al., 2021). There is a notable number of research concerning potential tools and models for measuring solar access (Czachura et al., 2022; De Luca, 2019; Dogan et al., 2012).Passive solar gains influence energy consumption and performance for both heating and cooling. Contemporary research examines the influence of design decisions – such as building orientation, massing, density, materials, or internal layouts – on sustainable design strategies, particularly in relation to thermal performance and sunlight access (Kanters et al., 2021; Nasrollahi et al., 2016; Strømann-Andersen et al., 2011; Sattrup et al., 2013). Of equal importance is comfort and health of users in designed interiors, including multifamily housing developments (Sokół et al., 2017).

Significantly less common in contemporary research are considerations regarding the solar accessibility of spaces between buildings (Formolli et al., 2023). They are an integral part of the built environment, where access to sunlight is shaped as much by architectural design as it is within interior spaces. The design of architectural massing, informed by the analysis of light availability, shapes the potential of these spaces to support daily interactions within local communities, provide well-lit views, create pleasant recreational and sitting areas, or facilitate plant growth (Littlefair et al., 2022). Buildings geometry influences urban heat island effect, with urban canyons having the ability to absorb urban radiation (Yang et al., 2015). Simultaneously, overshadowing from buildings can influence bioclimate and reduce the possible activities in adjacent open spaces (Mertens, 1999). Sunlight analysis can be considered an integral part of assessing the viability of the common realm (Seruga, 2024) and a key factor for its active and diverse use (Mertens, 1999).

The possible reduction of activity within open spaces because of the overshadowing is especially important for the analysis in dense urban environments (Mertens, 1999). The contemporary process of building denser and more compact cities influences daylight availability in the common realm (Rynska et al., 2022). This approach allows to achieve the benefits of small walking distances, limiting the necessity for car use, but simultaneously requires consideration of the quantity and quality of the spaces between buildings. High densities can be achieved through diverse strategies and urban morphologies (Alexander et al., 1988; Dovey et al., 2014, Berghauser Pont et al., 2023). Nevertheless, dense and high structures mean limited sunlight provision due to long shadows influencing the surrounding (San Jose et al., 2011). This affects activity within public spaces, as well as the possibility of introducing greenery. Capeluto et al. developed the concept of 'solar volume' to recognise solar access

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for any point in space, for buildings as well as open spaces. They analysed solar access in the context of various theoretical urban densities, which enabled them to identify types of high density urban developments that preserve the required level of solar access (Capeluto et al., 2001). Achieving a balance between sunlight and shadow is essential for creating vibrant, healthy, open spaces and minimising exposure to extreme environmental conditions (Islam et al., 2015).

Crucial for the successful development of cities is the provision of a high-quality housing environment, which constitute a significant part of most cities. An integral component of these developments is the social urban interior (Schneider-Skalska, 2012), which fosters community interactions. To ensure that everyone can benefit from open spaces, it is essential to meet the diverse needs and expectations of all users (Dudzic-Gyurkovich, 2023). The 11th Sustainable Development Goal promotes development of sustainable cities and communities through inclusivity, diversity of open spaces, which includes solar access in the outdoor domain (United Nations).

Research conducted by Formolli et al. shows that solar accessibility in the outdoor domain is significantly less often investigated than solar accessibility to buildings envelopes and interiors (Formolli et al., 2023). This is also visible for studies conducted in Poland. Good open spaces are crucial for sustainable cities and communities, however 'outdoor solar access does not have the same priority as daylight indoor', which is represented by limited legislation and official guidance in that regard (Kanters et al., 2021). The issue of overshadowing in open spaces appears particularly significant in the context of urban densification. The limited contemporary research concerning the topic mainly focuses on consideration of theoretical models of buildings and urban patterns, or pertains to small samples of specific buildings or developments (Germanova et al., 2018; Johansson et al., 2018). Given the above, overshadowing of open spaces still requires further research, especially in the context of the performance of areas that are contemporarily developed.

The aim of this preliminary study was to provide an overall understanding of the overshadowing of open spaces (OSs) by contemporary multifamily residential developments in Poland, based on the example of Wrocław. The research was carried out to identify current tendencies, and main characteristics of OSs with both high and low levels of overshadowing, as recognised across entire central part of the city. Additionally, this facilitated the recognition of potential areas that could benefit from further investigation. The overshadowing was considered with regards to parameters describing density of the new built environment, as well as the basic characteristics of the differentiated types of OSs. This study was also a contribution to discussion on the current form of building regulations, in respect to further addressing overshadowing and the sunlight provision in the built environment.

Given the practical challenges architectural design faces in balancing high density with adequate sunlight and daylight provision to buildings and interiors, it was assumed that certain types of OSs may be highly overshadowed.

This paper first presents a review of existing Polish legislation and guidance concerning overshadowing of OSs. It then outlines the materials and methods employed in the study. The collected data are presented and analysed in three stages: overall levels of overshadowing; the relationship between overshadowing and density of the built environment; and the relationship between overshadowing and the main characteristics of the differentiated types of OSs. Finally, the paper discusses overall current tendencies in overshadowing, main characteristics of OSs with significant overshadowing, potential strategies for improvement, research limitations, and future research. The paper is concluded with a synthesis of findings.

2. Current regulations regarding sunlight provision and overshadowing in Poland

In Poland, regulations regarding overshadowing, as well as sunlight provision, are constantly developing, but are limited (Sokół et al., 2017). Local Spatial Development Plans define land use designation, as well as selected essential, maximum and minimum parameters. Regulations in those documents influence overshadowing but do not define it as a measured parameter. The fundamental regulatory document in Poland is the Regulation of Technical Conditions (Rozporządzenie, 2002), which is currently the most relevant to the analysis of the overshadowing. Most notably, the relative position of the buildings is regulated in Section II, Chapter 1, which defines:

- distances from buildings to the border of the plot,
- distances between buildings based on obscuring and the provision of natural light to rooms intended for human use (those parameters are two times smaller for the inner-city developments).

Additionally, overshadowing of the OSs is regulated in relation to playgrounds and recreational areas. Section II, Chapter 8 defines:

- minimum playground area requirements for multifamily housing, based on the number of dwellings,
- minimum 2 hours of sunlight provision for 50% of the playground on the equinox days, between 10 am and 4 pm (this is limited to 1 hour for the inner-city developments).

Furthermore, the below regulations regarding daylight and sunlight provision for the interiors are established. They do not directly relate to the public realm, however the need to allow for these parameters, influences the way buildings are oriented and located on the plot, indirectly affecting overshadowing of the OSs. Section III, Chapter 2 of the Technical Conditions states that:

- daylight has to be provided to rooms intended for human use,
- in rooms intended for human use, ratio of the window's opening area to the floor area of a given room should be 1:8 or 1:12, depending on the function of the room,
- minimum 3 hours of sunlight provision is defined for rooms intended for collective use in daycares, schools, and for habitable rooms in dwellings (this can be limited to 1,5 hour for the inner-city developments).

As mentioned above, regulations regarding overshadowing of OSs in Poland are very limited and focus on playground areas. Sunlight considerations for 21st of March, and 2 hours of sunlight provision for 50% of assessed area are the main guidance there, and benchmark value of at least 2 hours of sunlight has been established.

Another type of guidance, which is recognised and used in Poland, are certification systems. An analysis of certified buildings in Poland by PLGBC in 2025 shows that the four most commonly used assessment systems are the Building Research Establishment's Environmental Assessment Method (BREEAM), the Leadership in Energy and Environmental Design (LEED), ZIELONY DOM, and the WELL Building Standard (WELL) (Polish Green Building Council, 2025). However, the most commonly used system–accounting for over 80% of all certified buildings in Poland–is BREEAM.

Currently, no uniform international standards are available for overshadowing or sunlight provision to OSs. Aforementioned certification systems predominantly refer to indoor solar access. Nevertheless, the Building Research Establishment (BRE) provides a recommendation to overshadowing assessment for gardens and OSs, including such areas as parks, playgrounds, recreational and sitting areas. They recommend that 'at least half of the garden or open space can receive at least two hours sunlight on 21 March' (Littlefair et al., 2022). Equinoxes are often used as a standard reference for sunlight because they give comparable and averaged solar information about the site (Czachura et al., 2022). The number of hours a given area receives direct sunlight has at times been used outside of professional practice for theoretical considerations. However, the required hourly threshold, considered as a good provision of solar access, varies (Kanters et al., 2021; Formolli et al., 2023). BRE suggests that their method might help with designing areas with the biggest amount of direct sunlight for functions that can benefit from it (gardens, sitting areas), and support limiting areas of permanent shadow (Littlefair et al., 2022). The BRE guideline is a recommendation not a legislation, thus can be freely chosen by designers as a point of reference or not.

3. Materials and methods

The following study investigates the overshadowing of open spaces (OSs) adjacent to contemporary multifamily residential developments through comparative analysis of simulated shadow appearance in OSs on a selected day. A quantitative comparison was conducted across various OSs, examining differences in overshadowing in relation to the characteristics of both the surrounding built environments and the OSs themselves. The amount of area of the identified OSs receiving a predefined number of hours of direct sunlight was compared and related to the adopted comparative benchmark. This enabled the identification of general correlation between currently built urban form and overshadowing of OSs, as well as recognition of the most frequently occurring values representing sunlight provision across the central area of Wrocław. The employed method serves as a preliminary investigation for subsequent, more extensive studies to be conducted following this initial consideration.

3.1. Scope of research

The scope of this research encompassed open spaces (OSs) adjacent to contemporary multifamily residential buildings, developed between 2010 and 2024 in the central area of Wrocław, as marked in Fig. 1. Small infill buildings were omitted due to their restricted scale, and the dominant influence of the pre-existing conditions. Identification of multifamily developments created within the selected area and time frame was based on materials found on the Wrocław's Shared Information System (System Informacji Przestrzennej Wrocławia, 2025). It provided photomaps from each of the selected time frame, allowing for the identification of the emerging developments. Altogether 31 main areas with over 160 multifamily buildings were identified for this research, as marked in Fig. 1.

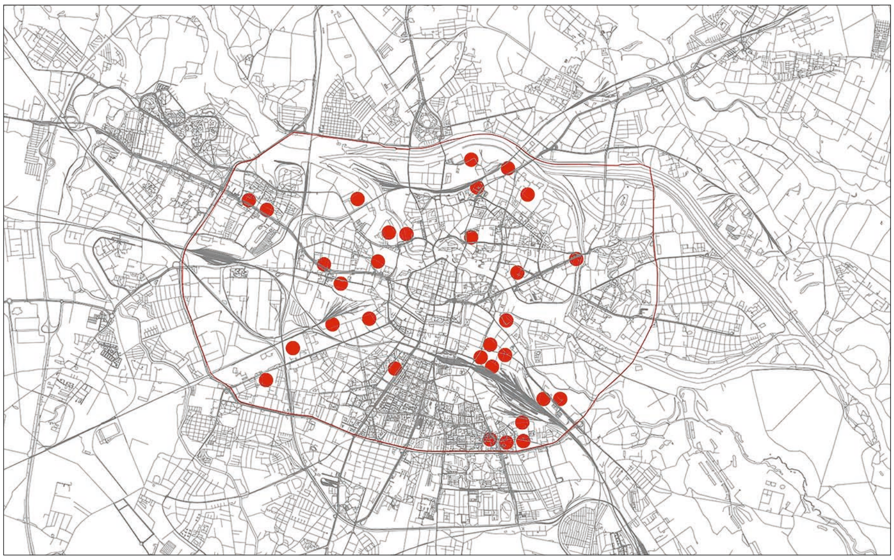

Fig. 1. Map of Wrocław with the central area outlined in red and the main areas selected for analysis marked with red dots (own elaboration)

Within each identified main area, OSs adjacent and affected by new multifamily buildings were selected for the analysis. All shared, common areas dedicated to peoples' activities were considered as OSs. Each OS was considered as a whole integral urban interior, for which the border was defined by adjacent buildings, roads, and characteristic urban elements. They were not further divided into functional zones, as these are less permanent than the established building massing.

Kinds of OSs adjacent and affected by new multifamily buildings included: newly developed OSs on building plots, pre-existing OSs on adjacent building plots, pre-existing OSs on adjacent non-building plots, as marked in Fig. 2. OSs where sunlight will be further limited by the future development were excluded from the analysis, as the overshadowing results were not complete. Thus, within the central area of Wrocław, 154 OSs were identified and selected for the following research.

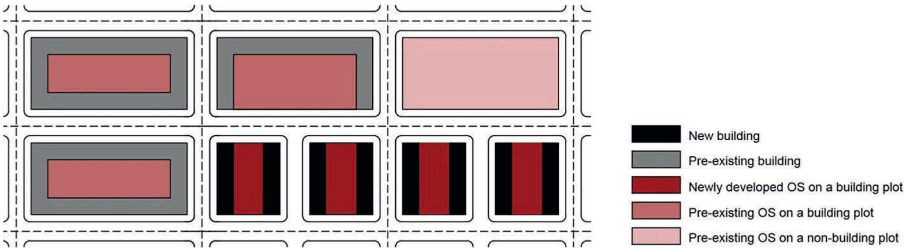

Fig. 2. An illustrative representation of various kinds of OSs influenced by the new multifamily residential development (own elaboration)

3.2. Tools and method of identification of percentage of overshadowed areas

The basic geometry of the multifamily residential buildings and their surrounding was obtained from 3D models available on cadmapper (Cadmapper, 2025), and was further verified against the data provided on the aforementioned Wrocław's Shared Information System (System Informacji Przestrzennej Wrocławia, 2025). This set of information enabled building 3D models of each of the identified areas in Revit. Facade details and cantilevered balconies were omitted for the purpose of this analysis due to the large number of analysed OSs and limited data availability in this regard.

Contemporarily, various methods and tools for analysing sun and shade provision are available (Borkowski, 2018; Czachura et al., 2022). This study used computer simulations available in Revit through Solar Studies mode. Wroclaw was set at its geographic location and sunlight provision on the ground was gathered for a single day of 21st of March between the hours of 8 am and 6 pm, measured every 30 minutes. This enabled manual measurement of the area of

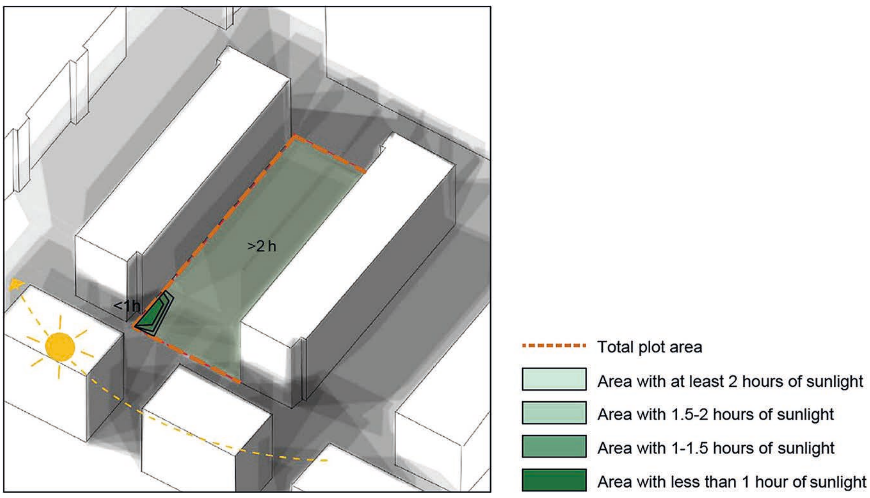

Fig. 3. Exemplary overshadowing analysis of an OS, showcasing areas achieving below 1 hour, 1–1.5 hours, 1.5–2 hours and at least 2 hours of direct sunlight to the ground level (own elaboration)

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the surface for which the shadow was not visible for below 1 hour, 1–1.5 hours, 1.5–2 hours and at least 2 hours on 21st of March, as illustratively presented in Fig. 3. Manual processing of gathered data was conducted using Excel.

3.3. The comparative benchmark

The comparative benchmark adopted for this preliminary research was based on BRE guidance and drew on Polish regulations. Due to absence of specific polish provisions addressing overshadowing to all OSs, the widely recognised and applied also for polish architecture, BRE guidance was adopted. It is comparable to the Polish regulation requiring a minimum 2 hours of sunlight provision for 50% of the playground's area on equinox days, although is not limited to play areas (Rozporządzenie, 2002). This was also considered as a straightforward point of reference supporting comparative analyses on a broader city scale and between different sets of spatial parameters. As recognised in BRE guidance, different functions can have different sunlight requirements. Hence, the goal of the BRE recommendation is to avoid the most difficult scenario, where significant area receives a very limited amount of sunlight (Littlefair et al., 2022). Similarly, the benchmark used in this research served as a reference point for identifying OSs and percentages of their areas with particularly high overshadowing. Furthermore, BRE guidance relates to and is currently used in projects built in Poland and abroad, thus providing a comparative basis of existing certified developments for future research and comparison. It was assumed that the most suitable approach for a preliminary investigation would be to examine the identified OSs by the simple method based on a guidance contemporarily optionally employed by architects in Poland, and use it as a preliminary benchmark.

3.4. Description of the study process

The comparative analysis was conducted in three main stages:

- overall overshadowing of all OSs,
- correlation between overshadowing and selected ratios of density of the built environment,
- correlation between overshadowing and the predefined types of OSs.

At the first, overall stage of the comparative analysis, all the OSs were considered collectively to identify the general trends in overshadowing. Initially, the provision of direct sunlight was considered for percentages of the total area of all OSs together, within the following time frames:

- below 1 hour,
- between 1–1.5 hours,
- between 1.5–2 hours,
- at least 2 hours.

Subsequently, the number of OSs achieving at least 2 hours of sunlight to a given percentage of their area was considered in 10% intervals. From that point onward, the overshadowing was considered in reference to the adopted comparative BRE benchmark, to establish a consistent and straightforward point of reference across a large number of analysed OSs and across selected stages of the analysis.

At the second, detailed stage of the comparative analysis, correlation between the density of the newly built environment and the percentage of area of each OS achieving at least 2 hours of sunlight was analysed across defined intervals. Initially, distribution of OSs density was presented. Subsequently, for each identified interval of density, the average percentage of area achieving at least 2 hours of sunlight was considered. Lastly, for each interval of percentage of area achieving at least 2 hours of sunlight, the average, minimum and maximum interval of density was calculated.

The calculated density varies depending on the scale and the extent under consideration, for example, fabric-scale density might differ from that at the district scale (Berghauser Pont et al., 2023). The multifamily residential developments examined in this study were predominantly individual plot initiatives, each exhibiting distinct morphological patterns. At times, the main areas under consideration were a part of the same district, yet architectural decisions and massing differed across individual plots. To ensure comparability of the results and consider consistent scale densities, a plot level density aggregation was determined for the comparative analysis, as presented in Fig. 4.

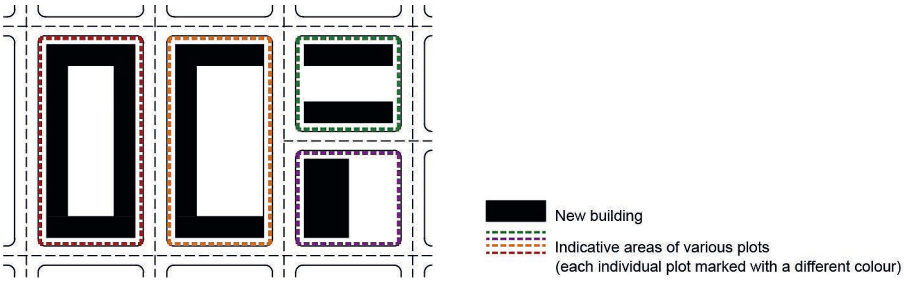

Fig. 4. An illustrative representation of various plots, with different morphological patterns, with marked individual plot areas taken under consideration for this research, each plot area marked in a different colour (own elaboration)

Pre-existing OSs on building and non-building plots were not considered for that part of the comparative analysis, because the associated density was either not of the plot level, or related to a pre-existing built environment, for which density was not developed within the time frame defined for this research. For that reason, inclusion of those OSs would not allow for comparability of the results and would not refer to currently developed residential plots. Hence, the second stage of this research referred only to the newly developed OSs created on the building plots with new-built multifamily developments, as presented in Fig. 2. Basic plot data were gathered from maps available on the geoportal website concerning geodesy and cartography (Główny Urząd Geodezji i Kartografii).

For the purpose of the second stage, the two commonly used parameters identifying density were considered: Open Space Ratio (OSR), Floor Area Ratio (FAR).

OSR showed the proportion between open space and total area of the plot, showcasing coverage of the area. It was calculated as a percentage of the total open space on a given plot (O) by total area of the plot (A), as represented in Fig. 5.

$$OSR = (O/A) \times 100\%$$

FAR showed the relation between total floor area of all buildings on the plot and a total area of that plot, showcasing the intensity of land use. It was calculated by dividing total area of all floors on a given plot (F) by total plot area (A), as represented in Fig. 5.

$$FAR = (F/A) \times 100\%$$

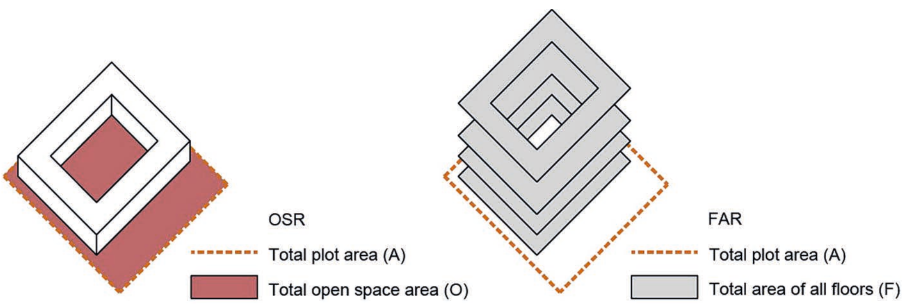

Fig. 5. An illustrative representation of OSR and FAR with marked areas considered for calculation (own elaboration)

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At the third, detailed stage of the comparative analysis, correlation between the basic spatial characteristics of OSs, within their identified types, and the percentage of area of each OS above the comparative benchmark was analysed across defined intervals. Initially, the number of OSs below and above the comparative benchmark was identified for each type of OS. Subsequently, the number of OSs within each type was analysed in relation to the average percentage of area achieving at least 2 hours of sunlight.

For the purpose of comparing results depending on OSs main characteristics, the basic spatial typology of OSs was created based on two qualities: OSs level of enclosure by the adjacent buildings, and the size of the OS. On that basis all the OSs' layouts were assigned to a type by their reduction into a basic layout type.

The level of enclosure of an area is crucial for overshadowing assessment due to the proximity of the assessed area to walls casting shadow on it. More enclosed areas are surrounded mostly by buildings while less enclosed areas may be surrounded by roads or other OSs, which do not cast a shadow. The following main types of the level of enclosure of OSs were differentiated and considered in the following research (as presented in Fig. 6):

- enclosed OSs (OSs continuously surrounded by walls of adjacent buildings, with total gap not exceeding 10% of their perimeter, e.g. courtyards, podiums),
- partly enclosed OSs (OSs surrounded from at least two sides by walls of adjacent buildings, with total gap not bigger than 50% of their perimeter, e.g. courtyards, podiums),
- open OSs (OSs surrounded from two sides or less by walls of adjacent buildings, with total gap bigger than 50% of their perimeter, e.g. squares, green passages, river banks).

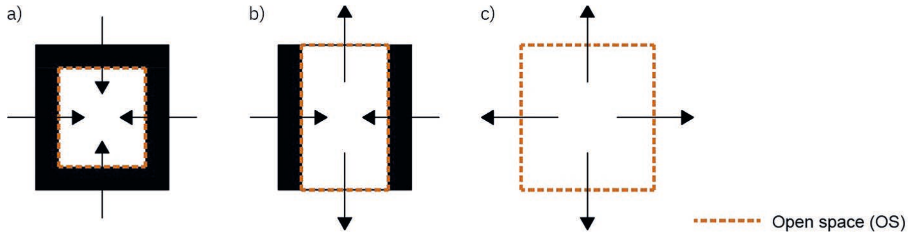

Fig. 6. An illustrative representation of the three types of OSs considered in this research a) enclosed OSs, b) partly enclosed OSs c) open OSs (own elaboration)

Overshadowing is also influenced by the spatial separation between buildings enclosing the OS. Accordingly, the size of the OS affects the potential degree of overshadowing and those identified in Wrocław varied between 200 m^2 to almost 7,000 m^2. For the purpose of this research the identified main types of OSs were divided into two groups, big and small. Big OSs achieved over 1,000 m^2, and small OSs achieved up to 1,000 m^2.

4. Results

4.1. Overall overshadowing of all open spaces

The total area of all of the identified open spaces (OSs) amounted to approximately 272,600 m^2. Three quarters of that area received at least 2 hours of sunlight. Another 4% were related to provision of 1–1.5 hours, and 1.5–2 hours. 17% of total area got less than 1 hour of sunlight (Fig. 7). This shows that while considering areas with sunlight provision below 2 hours, the majority refers to less than 1 hour. These initial results showed an overall level of provision of sunlight above BRE recommendations. Nevertheless, 25% of the analysed area, that provided less than 2 hours of sunlight, constituted over 68,000 m^2.

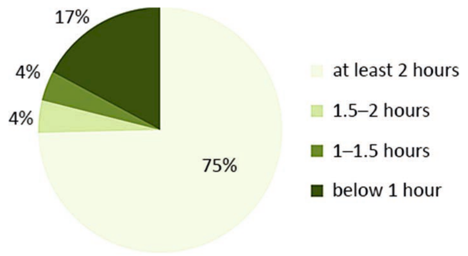

Fig. 7. Percentage of the total analysed area of OSs receiving sunlight within the defined time frames (own elaboration)

Furthermore, a significant number of OSs achieved at least 2 hours of sunlight, with around a third of all examples (57 OSs) providing this to almost a 100% of the identified area (Fig. 8). Almost equally as many examples (55 OSs) achieved the 2 hours of sunlight for less than 50% of the identified area, making it below the BRE benchmark. Simultaneously, 28 OSs achieved results falling within the two lowest ranges of below 20%, providing significantly overshadowed area.

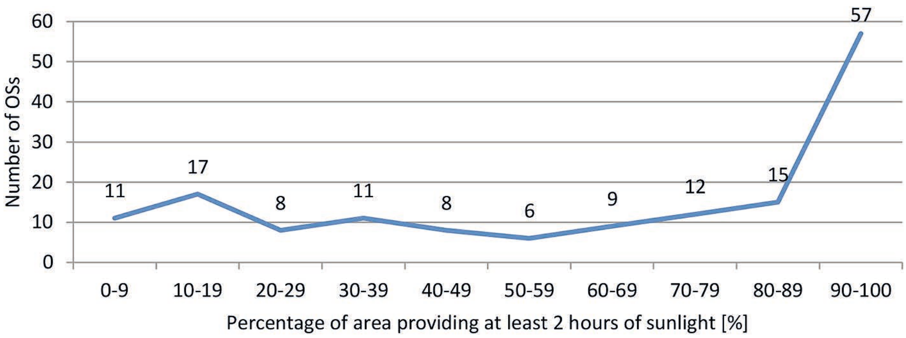

Fig. 8. The number of OSs, which provide at least 2 hours of sunlight to a given percentage of their area, considered across 10% intervals (own elaboration)

4.2. Overshadowing in relation to density of the built environment

The detailed comparative analysis of the density of the contemporarily built residential environments was conducted to enable further understanding of the way it influenced overshadowing. Density was considered for OSR and FAR parameters. A total of 138 newly developed OSs, created on building plots, were eligible for this part of the analysis, as described in Section 3.4.

The overall distribution of OSs indicated that multifamily developments constructed in Wrocław since 2010 typically exhibit an OSR between 50% and 74%, allocating more than half of each plots' area to OS (Fig. 9). Simultaneously, analysed OSs were most commonly a part of plots with FAR between 150% to 399%, with almost 40 OSs with FAR between 250% and 299% (Fig. 10). The highest recorded FAR, observed in association with several OSs, ranged between 600% to 650% FAR.

The relation between different density levels and the average percentage of area with at least 2 hours of sunlight revealed a tendency for low-density OSs to achieve significantly higher values than their high-density counterparts.

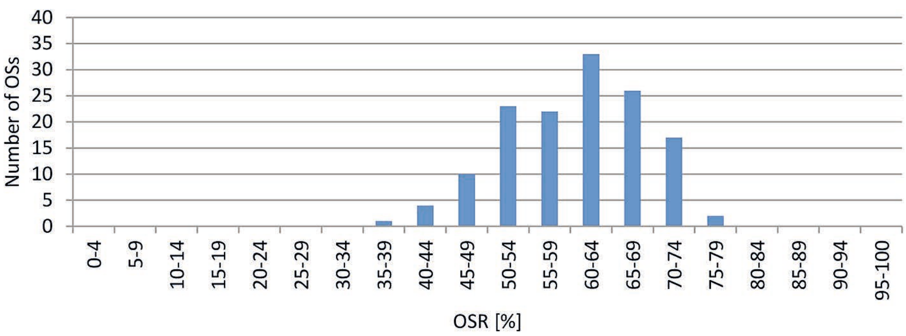

Fig. 9. The distribution of OSs achieving a given OSR, considered across defined intervals (own elaboration)

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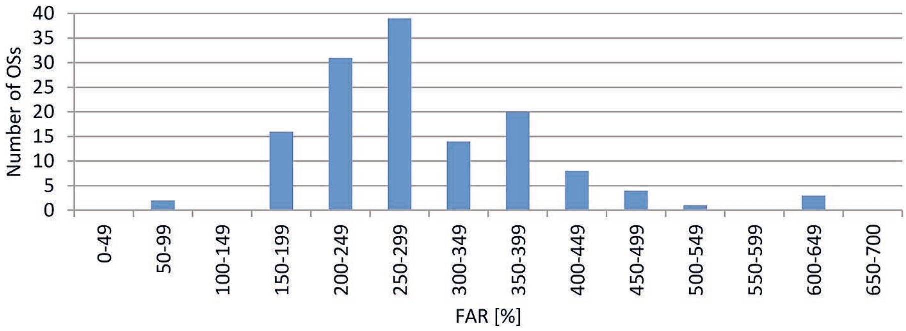

Fig. 10. The distribution of OSs achieving a given FAR, considered across defined intervals (own elaboration)

OSR increased in nearly proportional manner to the percentage of area achieving at least 2 hours of sunlight (Fig. 11). OSs with OSR between 75% and 79% achieved it for around 90% of their area, while OSs with OSR between 35% and 39% achieved it for around 20% of their area. Similar overall tendency can be noted for FAR, with deviations related to those intervals with smaller number of examples. The lower the FAR density was, the higher the average area receiving at least 2 hours of sunlight (Fig. 12). There were several intervals that stood out from the general trend, FAR of 300% to 349% and FAR of 600% to 649%, which were partly generated by the lower number of examples. The latter interval was also related to a set of high, point multifamily buildings, where those few OSs were partly enclosed, with openings to south and north, which allowed for significant level of direct sunlight provision.

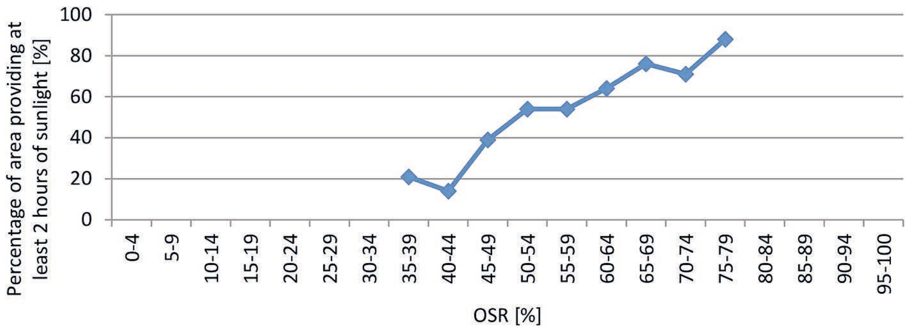

Fig. 11. The average percentage of area with at least 2 hours of sunlight achieved by OSs with a given OSR, considered across defined intervals (own elaboration)

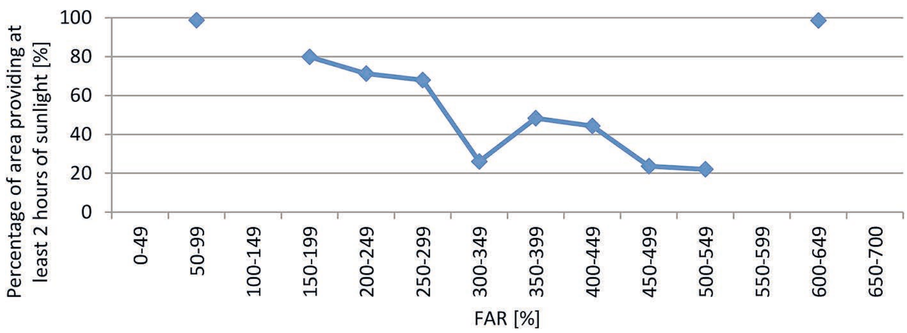

Fig. 12. The average percentage of area with at least 2 hours of sunlight achieved by OSs with a given FAR, considered across defined intervals (own elaboration)

OSs in which a smaller area received at least 2 hours of sunlight were typically associated with higher density ratios. Areas where 0% to 9% of the surface received at least 2 hours of sunlight corresponded to an average OSR of 50%, whereas areas with 90% to 100% benchmark exposure were associated with an average OSR of 60% (Fig. 13). Similarly for FAR, areas of 0% to 9% benchmark exposure corresponded to an average of 400%, whereas areas with 90% to 100% benchmark exposure were associated with an average of 300% (Fig. 14). The direct sunlight provision declined with the increase of density for both parameters, however the average density values were not significantly dispersed. Notably, the minimum and maximum values indicated that each ratio corresponded to varying percentages of area receiving at least 2 hours of sunlight. For instance, OSR of approximately 70% was observed in both 0–9% and 90–100% sun exposure intervals. The most significant variation of overshadowing was identified for FAR, where OSs with 90–100% of their area receiving at least 2 hours of sunlight were associated with FAR values ranging from 100% to over 600%.

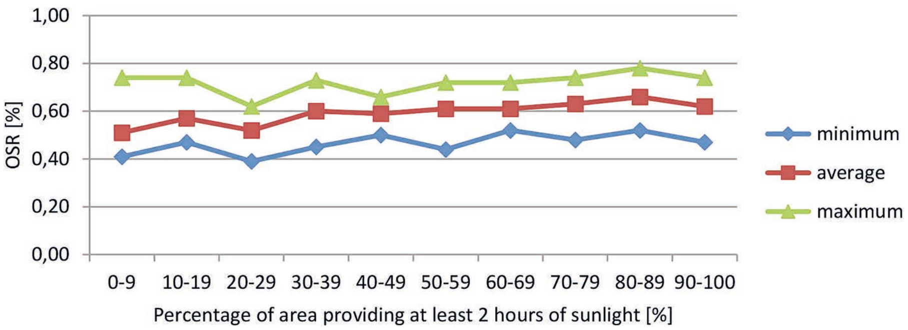

Fig. 13. The minimum, average, and maximum OSR, which provide at least 2 hours of sunlight to a given percentage of their area, considered across 10% intervals (own elaboration)

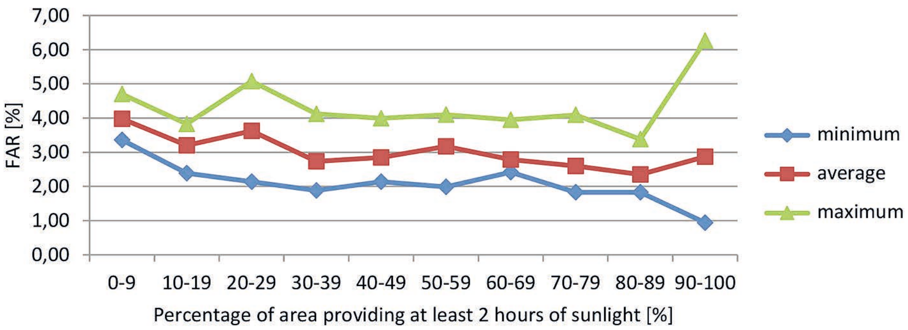

Fig. 14. The minimum, average, and maximum FAR, which provide at least 2 hours of sunlight to a given percentage of their area, considered across 10% intervals (own elaboration)

4.3. Overshadowing of the identified types of open spaces

The comparative analysis of the identified types of OSs allowed for further understanding of the way contemporary developments influence sunlight provision to the surrounding OSs. Results above the comparative benchmark were common for big, and open or partly enclosed OSs. Nevertheless, multiple of them did not achieve such results (Fig. 15). Even when a large or open OS was analysed, a significant degree of overshadowing was still noted for several OSs. Simultaneously, enclosed OSs stood out as the ones with the most limited direct sunlight provision. Only half of the big enclosed OSs provided at least 2 hours of sunlight for over 50% of their area.

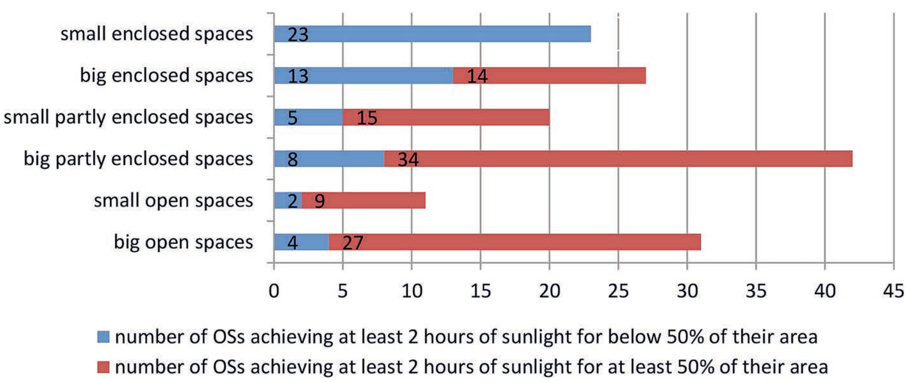

Fig. 15. The number of each of the identified OS types in which below or over 50% of their surface received at least 2 hours of sunlight (own elaboration)

The detailed analysis of open OSs showed that, regardless of the area, almost all of them achieved over 80% provision of at least 2 hours of sunlight (Fig. 16). There were however several instances, which achieved very low results. These

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were predominantly large, elongated OSs, located between the long facades to the south, and main thoroughfares to the north. Thus, main shadow area was visible on the OS, and not on the main road. The only gaps between the southern buildings were allocated for roads connecting to the main thoroughfare, which did not substantially mitigate shadows on those OSs. Lower results were also observed in OSs along the river, where areas adjacent to buildings receive limited direct sunlight, whereas areas closer to the river achieved higher values, thus improving the overall result for the OS.

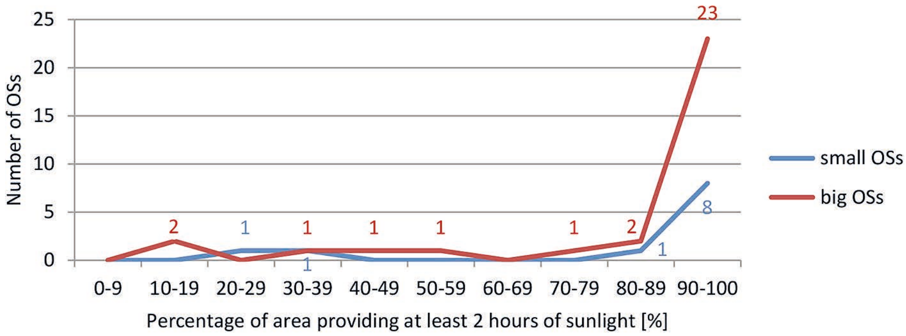

Fig. 16. The number of open OSs, which provide at least 2 hours of sunlight to a given percentage of their area, considered across 10% intervals (own elaboration)

Partly enclosed OSs showcased tendencies similar to open ones. The vast majority allowed for over 80% provision of at least 2 hours of sunlight (Fig. 17). Simultaneously, areas with lower provision appeared more often. The lowest results were connected to OSs with higher buildings to the south and openings to the north. This achieved partial openness of the perimeter, while resulting in higher levels of overshadowing. This was noted for small as well as big OSs.

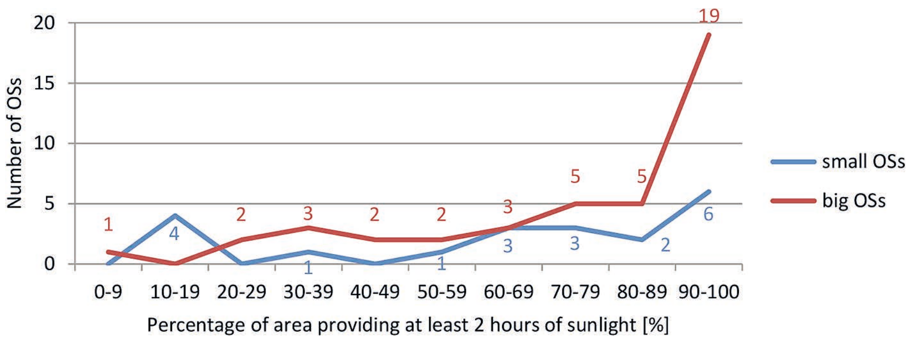

Fig. 17. The number of partly enclosed OSs, which provide at least 2 hours of sunlight to a given percentage of their area, considered across 10% intervals (own elaboration)

Enclosed OSs stood out from the other types. Especially the small ones were predominantly providing at least 2 hours of sunlight for less than 20% of the overall area (Fig. 18). Big and enclosed OSs were also more often connected to low sunlight provision, with only a few achieving over 80%. This showed that it was more difficult to provide areas with direct sunlight in spaces which are enclosed, even if larger area was provided for the OS.

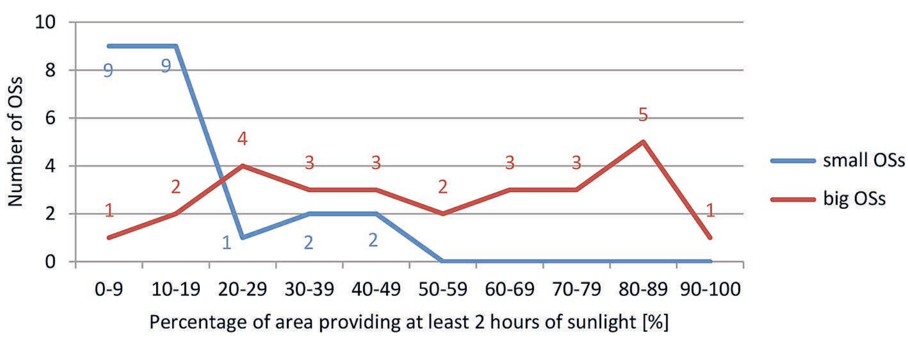

Fig. 18. The number of enclosed OSs, which provide at least 2 hours of sunlight to a given percentage of their area, considered across 10% intervals (own elaboration)

5. Discussion

The conducted study further expands on the subject of overshadowing of OSs in reference to identified tendencies observed in the currently built residential environment in Poland, considered at the scale of the whole central part of the city.

5.1. Observed tendencies in overshadowing of open spaces

A key finding of the comparative analysis of the OSs adjacent to the contemporarily constructed multifamily residential developments in Poland is the noticeable occurrence of areas experiencing significant levels of overshadowing. As shown in Section 4.1, 75% of the total area considered for OSs in the Wrocław city center received at least 2 hours of sunlight. Nevertheless, when individual OSs were compared, almost equal number received that amount of sunlight across their entire area as did across less than 50% of their area. This indicated a tendency for the contemporary residential developments to generate variety and disparity of levels of overshadowing among OSs. These results were consistent with findings that a variety of urban layouts and sunlight results are possible in contemporary urban environments (Czachura et al., 2022).

There were also noted almost 30 OSs, where at least 2 hours of sunlight were provided to less than 20% of their area. Additionally, the majority of area which received less than 2 hours of solar access was allowing for less than 1 hour of sunlight, as shown in Section 4.1. This resulted in the majority of the area within those OSs being in shadow on equinox day, with the shade extent naturally increasing during winter. The OSs with the lowest results are especially important for further research and consideration, especially in the context of developing performance indicators based on user experience.

Most common densities were related to OSR between 50% and 74%, and FAR between 150% and 399%. Higher and lower densities were rare or not present at the Wroclaw's central area. Furthermore, there was a clear tendency for denser plots to receive on average less sunlight. Nevertheless, achieving both very low and very high sunlight provision was possible for high density developments, which shows importance of local conditions and design decisions in creating well-lit public realm. This further supports the findings of Capeluto et al. that high density can provide well insolated areas (Capeluto et al., 2001). The results also indicated that in low-density environments, greater design flexibility was possible while still achieving high levels of sunlight provision. In contrast, for high density areas, considering overshadowing was particularly important, with incorporation of open OSs enabling higher provision.

The number of OSs within each differentiated type was mostly comparable, with big, partly enclosed OSs being designed more frequently, whereas small, open OSs were less commonly developed, as noted in Section 4.3. The analysis showed that the types of OSs receiving the least sunlight, and often falling below BRE benchmark, were typically small and enclosed. Given their common development, comparable to occurrence of other types, the design of such OSs appeared to be a common practice in contemporary residential developments in the city.

The large number of OSs with high overshadowing indicated that contemporary Polish regulations did not effectively translate into high sunlight provision within OSs, or a threshold that could be identified at this stage. Thus, it was not a self-regulating factor, which independently met the adopted benchmark. The limited existing regulations and presence of OSs with high overshadowing demonstrated the tendency to prioritise interior spaces and buildings over OSs. This aligns with considerations of Formolli et al., who emphasised that optimising solar accessibility in the public domain is an important facet of contemporary design, particularly as densification processes can generate significant overshadowing (Formolli et al., 2023).

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Another important factor to consider while analysing overshadowing is that new developments might influence pre-existing OSs. This might be an especially crucial factor in very dense urban environments. For such conditions, the BRE guidance states that if, following new development, an OS receives less than 0.8 times its former value, this change will be noticeable to users (Littlefair et al., 2022). Hence, such interference should be avoided. As noted in the presented research, new multifamily developments mostly influenced new, not pre-existing, OSs. This might be largely attributed to Wrocław's urban density and building heights, not necessarily individual decisions. Nevertheless, several pre-existing OSs were overshadowed by the new development, further supporting Mertens' findings regarding the potential limitations imposed by new construction on existing spaces. These influences should be carefully considered during the design process, as they may affect or diminish usability of the existing OSs (Mertens, 1999).

5.2. Main characteristics of open spaces with significant overshadowing

During the course of the study, OSs exhibiting significantly higher overshadowing than others were noted. Different activities may be comfortable within varying levels of sunlight provision, and variety of usage of OSs for the local community is something that should be preferred for the built environment (Mertens, 1999). Especially considering that the usage of OSs can vary across seasons and over the years. While solar access to the OS can be further limited by landscape design, by incorporation of e.g. canopies, trees, it cannot be further improved without interfering with the built form (Mertens, 1999). For those reasons, developing OSs without significant overshadowing is important for ensuring their good quality and multifunctionality.

It was common for enclosed OSs to achieve limited amount of sunlight. This is typical for areas with restricted access to the southern part of the sky (Littlefair et al., 2022), like analysed enclosed OSs, where perimeter was continuously bordered by the adjacent facades. Creating small, enclosed atriums is a common solution to generate better natural lighting for the interiors (Rynska et al., 2022). However, this can result in creating OSs that receive limited solar access. Courtyards or podiums used mostly by local inhabitants, are important for community building. They contribute to the active social life within multifamily complexes, and adequate sunlight is an important part of the high level of user engagement and diverse use (Mertens, 1999). Big and enclosed OSs were also at times connected to low sunlight provision, with only a few achieving over 80%, as noted in Section 4.3. This demonstrated that achieving high results was more challenging in enclosed areas, regardless of their size, due to substantial overshadowing from the sunniest, southern side. In contrast, significantly higher outcomes were observed in partly enclosed OSs, which produced results closely resembling those of open OSs. Hence, allowing for openings to the surrounding open areas can greatly benefit the sunlight provision. This was introduced through changes in heights, as well as gaps among the buildings within the block.

Another key factor contributing to lower-performing OSs was their size. A small OSR is one of the strategies supporting the design of dense urban environments, which can generate small OSs. Concepts such as pocket parks are intended to humanize and offer better quality to compact contemporary cities (Bajwoluk et al., 2023). The received results showed that contemporarily developed small OSs faced particular challenges related to limiting the overshadowing, which aligns with Mertens' analyses for various types of courtyards (Mertens, 1999). Large OSs allow for potential functional distribution, enabling better-lit areas to accommodate functions that require sunlight. For instance, play areas can be located in zones with high solar access, while parking can be located in more shaded section. Functional distribution in small OSs may not always be feasible due to their size. If a small OS is significantly overshadowed, activities like playing, sitting, resting may be uncomfortable there or require allocation to other OSs, thereby limiting OSs' capacity for community building. Placemaking strategies, such as enabling functional diversity, adapting area to the changing functional needs of a local community, or incorporating substantial greenery for pocket parks may be limited by extensive shadow. Therefore, these OSs should be subject to further analysis and may particularly benefit from the establishment of the threshold values to support their active use and broad functional potential.

5.3. Potential strategies for improvement

Potential strategies for limiting overshadowing, as based on the presented research, can be considered in two aspects:

- regulatory measures or guidance,
- design strategies.

As aforementioned, current regulations in Poland regarding overshadowing are limited and focus on solar access to buildings. Further consideration of what constitutes an appropriate benchmark for solar access in OSs could support efforts to limit overshadowing in such areas.

Furthermore, urban strategies in Poland regarding density and building heights are mostly regulated by Local Spatial Development Plans. Based on them, minimum and maximum building parameters are provided, main functions, directions and thoroughfares are planned. These aspects are further shaped within plots through regulations set by the Technical Conditions. However, the primary parameters established by Local Plans exert a notable influence on the built environment. As identified in this research, parameters such as density influenced average levels of overshadowing. Therefore, to effectively mitigate high levels of overshadowing, such issues could be also initially considered at the urban planning stage, where strategic decisions regarding building massing and spatial configuration are made. In this regard, this research further supports the perspective that 'indicators for solar performance evaluations at the urban planning level are still lacking' (Czachura et al., 2022) and are needed for cities development (Kanters et al., 2021; Czachura et al., 2022).

Potential architectural strategies to limit overshadowing may be informed by the typologies that achieved better outcomes in the course of this study. This includes bigger and less dense OSs, which is not always feasible. but also refers to partly enclosed OSs, which demonstrated higher overall sunlight provision, comparable to those of fully open OSs. This type of OSs was generated by introducing gaps between buildings or incorporating height variations––measures that reduce building mass and the number of dwellings, but in return may enhance access to direct sunlight to the OS. These further complements comparisons of various buildings orientations and densities, and the way they shape solar access (Formolli, 2021; Germanova, 2018; Mertens, 1999; Sattrup, 2013), by considering strategies such as diversified building massing.

5.4. Research limitations

Limitations of the conducted research can be considered in the following aspects:

- the comparative benchmark,
- the limitation of the study to Wrocław.

As noted in Section 2., polish regulations make limited reference to the overshadowing of OSs. Therefore, BRE guidance was selected as a currently used comparative benchmark for this research. The main difference between the Technical Conditions and BRE guidance is that the latter does not specify predefined hours for the analysis, and the OSs it considers are not limited to play areas. It enabled a comprehensive comparative analysis of large dataset

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of OSs, as well as current tendencies in contemporary residential developments, taking into account various parameters characterising both the built forms and the OSs themselves. Nevertheless, the development of performance indicators enabling more comprehensive assessment of satisfactory sunlight levels in OSs could benefit from further discussion.

Architects make buildings massing decisions, which influence the overshadowing of OSs, as early as the conceptual design stage. Because of that, simple and uniform means of assessment might be crucial for architects to be able to incorporate guidance related to solar access (Nault et al., 2015). This is further supported by the comparison of various solar analyses conducted by Kanters et al., which also suggested that simple metrics are preferred by urban planners, as they are easy to understand and implement. However, as commented by Kanters et al., single factor metrics impede understanding of changes in solar access during the day, and range or scale parameter seemed to be more representative of the OS quality than a single value (Kanters et al., 2021).

The universal number of hours or percentage of area that should receive the solar access is difficult to objectively define. There is no quantification for sunlight provision that encourages people to use the OS, like the level of solar access that produces specific amount of solar energy (Kanters et al., 2021). 30 minutes of exposure to daylight is required to provide sufficient vitamin D (Volf et al., 2024), but it does not translate into usability of a single OS. Different age groups and activities are associated with varying times and amounts of solar access that benefit them. Certain OSs may be designated for specific functions and intended for use only in particular times, thereby defining solar provision requirements unique to their purpose is important (Littlefair et al., 2022). However, further considering general minimum standards for sunlight provision could support the diverse and changing functionality of OS, as discussed in Section 5.2. Therefore, future research could be undertaken to determine appropriate levels of solar access within the public realm, in order to define values that ensure comfort in OSs.

Nevertheless, the comparative benchmark adopted as a reference point for this research facilitated the comparability of the large and diverse datasets examined. Although the selected method does not provide an in-depth analysis of individual OSs, it enabled the identification of key tendencies in contemporarily built residential developments and allowed to achieve the objective of this analysis.

The scope of the preliminary research presented here was limited to Wrocław. This was primarily due to the preliminary nature of the study, which aimed to enable an initial evaluation and highlight key tendencies and areas requiring further investigation. Although only one city was examined, over 150 various OSs were identified, providing a substantial data sample. The current scope was deemed sufficient for the purposes of this research. However, a larger dataset should be considered for future, more detailed analyses, as discussed in Section 5.5.

5.5. Future research

In relation to observed limitations regarding the adopted benchmark, as described in Section 5.4, future research will be carried out to support development of adequate performance indicators for solar access to OSs. It will aim to further discuss and compare existing overshadowing measures, as well as investigate users' needs, comfort, and spatial performance of different types of OSs.

Primarily, the obtained preliminary results will serve as a basis for future more extensive research regarding overshadowing of OSs in the context of densification of the built environment in Poland. Firstly, larger data sample will be considered to allow comparison between different cities, central and peripheral developments, as well as changes in tendencies throughout the recent years.

Secondly, sunlight provision should be further analysed, not only in reference to overall quantity of space achieving at least 2 hours of sunlight, but also in the context of hourly changes in percentages of overshadowed area. This will be further supported by the functional differentiation of OSs, showcasing the uses as well as the contemporarily provided solar access.

6. Conclusion

This preliminary research contributed to a better understanding of the extent of overshadowing of open spaces (OSs) generated by the contemporarily built multifamily residential developments adjacent to them. The Technical Conditions, which constitute a fundamental regulatory framework currently applied in Poland, do not directly address overshadowing of all OSs, focusing on solar access to buildings and their interiors. The adopted method enabled the identification of prevailing tendencies and overall characteristics of both the built environment and OSs that are currently being designed, in relation to the extent of overshadowing.

It was found that the overall amount of area providing at least 2 hours of sunlight was high and constituted 75% of total area considered. Furthermore, the majority of analysed OSs achieved that result to over 50% of their area. Simultaneously, 1/3 of all OSs achieved results below the adopted benchmark. Almost 30 OSs provided the lowest solar access of at least 2 hours of sunlight provided to less than 20% of their area. This revealed significant variation and disparities in the extent of overshadowing among the identified OSs.

The further detailed comparison of relation between density and overshadowing showed that on average denser areas achieved lower solar access. Nevertheless, within each density ratio a variety of results was noted, which showed that high solar access can be achieved in high density environment and was generated within contemporarily built multifamily developments. Particularly high overshadowing was noted for enclosed or small OSs, however open or big OSs also achieved lower results when access to southern part of the sky was obstructed. The number of small OSs with high levels of overshadowing suggested that they were commonly incorporated into contemporary architectural design.

This study offers an initial insight into the tendencies of overshadowing generated by currently built environment. The provided information made it possible to note typical results for the centre of the city, as well as key areas, which could benefit from further research. This demonstrated that, in order to support the development of sustainable cities with healthy local communities and good places for diverse and shared activities, broader research should be undertaken and further consideration should be given to developing appropriate performance indicators for overshadowing.

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