Guidelines for Applying Quantitative Shade Indicators in Urban Planning in Israel

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Summary

This document presents a comprehensive methodology for promoting strategic plans for urban shading and providing planning bodies and planners with standards for quantitative and qualitative assessment of existing and projected levels of shading according to different planning scenarios. The document consists of a concise overview that identifies the weak points in contemporary methods for quantifying shading in urban areas in Israel and around the world, followed by a presentation of a new method for setting targets for shade planning on urban streets. This method, presented here as part of an overall process of formulating a municipal shading strategy, is based on a new quantitative index, **the Shade Availability Index**.

Promoting shading in urban streets using trees, as a key part of Israel's environmental response to global warming, lies at the centre of Government Decision 1022 of 23 January 2022. In the document entitled **The National Strategic Plan for Urban Shading and Cooling Using Trees**, which was published at the end of 2022 by the Ministry of Environmental Protection, the Israeli Green Building Council, the Ministry of Agriculture and Rural Development, and the National Economic Council, it was possible to read an implicit recognition of the methodological difficulties inherent in implementing the government decision from the beginning of that year. The program acknowledged that there is still a lack of a widely accepted scientific methodology for setting urban shading and urban forestry targets and defining the precise mapping needs resulting from these goals. Without such a methodology, all parties involved in advancing the decision will find it difficult to efficiently and effectively realise the planting of shade trees in Israel's cities, monitor the progress of actions in this area, and divert resources to places where they are specifically needed.

Shading in the urban environment depends entirely on the planning and design of the built environment. Therefore, one cannot expect to find well-shaded streets without giving shade a significant place in the planning processes at different levels. In specific geometric configurations, good shading can be achieved using the buildings next to the sidewalks. However, securing sufficient shading often requires additional three-dimensional components at the street level, such as pergolas, shading fabrics, **and mainly street trees**. For planning bodies to meet predefined, measurable shading targets and optimise the allocation of resources to achieve them, a uniform method must be adopted for accurate quantitative assessment of the cumulative effect of shading from buildings, trees, and any other landscaping elements. **The Shade Availability Index**, which emphasises shading conditions on sidewalks, was developed for this purpose.

Systematically improving the state of shading on streets requires an **urban shading strategy**. We propose distinguishing between three stages in building such a strategy: **mapping, prioritising actions, and planning intervention**. At the mapping stage, we suggest preparing a

shade map using a method we have developed in the past. This method, which was first developed for a project commissioned by the Tel Aviv-Yafo Municipality (2019), has been applied since in more than a dozen other cities in Israel. An urban shade map reveals a city's hierarchy of "shade assets": which street segments are well-shaded and in which parts of the city walking the streets during the hot season involves severe exposure to solar radiation. Based on a shade map, the municipality can identify the city's climate vulnerabilities and prioritise actions to significantly ease the heat stress experienced in their area. Prioritisation must stem from a set of municipal considerations that include, alongside the state of shading, additional considerations: economic, social, demographic, and transportation-related.

The detailed shade planning that follows the identification of weak spots and prioritising shade intensification is intended to ensure that the practical actions taken by a municipality will bring about a significant change in the shading conditions within a reasonable period. By definition, the planning process is expected to involve examining various alternatives, the comparison of which must be based, first and foremost, on meeting measurable shade threshold targets. **The Shade Availability Index** is designed to meet this need.

The Shade Availability Index is calculated for each of the walking strips or sidewalks in a street segment since we wish to prioritise the shading and cooling of urban walking spaces. The index is calculated by measuring the amount of shaded space on each sidewalk at ten hourly intervals between 08:00 and 17:00 on a typical summer day in early August (**the reference time** for calculating the index) since this is the time when the outdoor heat stress is at its peak under the prevailing climatic conditions in Israel. At each of these ten times, we examine the ratio between the shaded area of the sidewalk and the total pavement area. A point in time when the shaded pavement area exceeds 50 per cent of the total pavement area is a point in time when the sidewalk is **sufficiently shaded**.

The **Shade Availability Index** describes, on a scale from 0 to 1, the relative rate of time a sidewalk or walking strip is in **sufficient shading** during the reference time. For example, when the shaded pavement area is 50 per cent or more at four out of ten time points, the Shade Availability Index is 0.4. The index treats a point in space as a shaded point if it is not hit by direct solar radiation. To simplify, the calculation does not consider the effect of reflected radiation, which may cause slight differences in the intensity of light radiation at the shaded point. The calculation of the Shade Availability Index assumes that buildings and shading devices on the street are more or less distributed along it at regular intervals. In cases where the nature of construction or shading in a particular street segment varies substantially along its length, the Shade Availability Index must be calculated separately in each part of the street segment in which the street section is more or less uniform.

Based on the Shade Availability Index, it is also possible to set normative shading targets for shading on sidewalks. We suggest setting the following three levels of shading targets:

- **Acceptable shading** – Shade Availability Index value of 0.5 or higher
- **Very good shading** – Shade Availability Index value of 0.7 or higher
- **Excellent shading** – Shade Availability Index value of 0.9 or higher

Since the index reflects a relative length of time in which sufficient shading conditions are met (at least 50 per cent of the pavement area is shaded), it can be said that a sidewalk in which at least half of the relevant daylight hours (08:00-17:00) on a summer day is a sidewalk where acceptable shading is obtained. Excellent shading is obtained when at least 90 per cent of the time these shading conditions are met. On the other hand, a sidewalk cannot be considered as shaded if the required shading conditions are met for less than 50 per cent of the reference time.

The Shade Availability Index does not assign different weights to shading at different times, even though the intensity of solar radiation varies throughout the day. This is because, at the reference time (most daylight hours on a typical summer day), the need for shading is almost as vital every hour, even if the physical effect of radiation on the perceived heat stress is slightly different since without shade, the heat stress is expected to be extreme no matter what the time is. The index does not distinguish between continuous sidewalk shade and alternating light and shade patches along the sidewalk as long as the total shaded area exceeds half of the pavement area. The reason for this is that we believe that when half of the area of a sidewalk is in continuous shade, road users can choose equally between moving in the shade or being exposed to solar radiation. On the other hand, when at least 50 per cent of the sidewalk area is in intermittent shading, there is a continuous path of intermittent shaded walking along the entire walking path.

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As part of the work process on developing the normative rating of the Shade Availability Index, we also conducted a comprehensive parametric examination of thousands of planning scenarios to examine whether it is possible to meet the three levels of shading that we determined in planning main and side streets, assuming that the height of buildings on a street is four stories or more. The examination revealed that it is also possible to reach the upper threshold that we defined (Shade Availability Index of 0.9 or more) in most reasonable planning scenarios on main streets and in any reasonable planning scenario on side streets. However, to reach this state, it will be necessary to plant **shade trees** in many cases. This is true regardless of a street's orientation, although, in certain directions and geometric configurations, the highest shading threshold can be met through buildings alone.

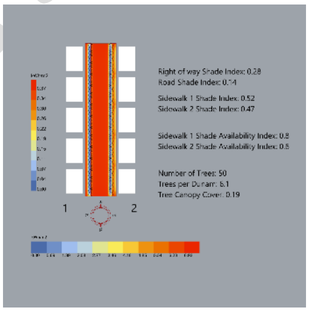
In this context, it is important to emphasise that **shade trees** are trees whose crown (all the tree branches and leaves) is wide and dense enough to cast a relatively uniform shade on the ground. Therefore, not every tree planted in built-up areas is a shade tree, even if the tree itself is of a species recommended for street planting. The design assumption should be that a tree defined as a shade tree will be a tree whose growing, pruning, and maintenance conditions allow its crown to block at least 90 per cent of the direct sunlight that hits the top layer of the tree crown and whose shade on the ground is continuous and relatively uniform. Evidently, the presence of trees in urban spaces may have positive or negative environmental impacts regardless of the shade they cast, and these effects should be considered when designing shading that is at least partially based on the use of shade trees. However, the Shade Availability Index is not intended to examine these effects quantitatively; rather, it is limited to quantifying the effect of shade trees on improving the state of shading on sidewalks.

Stages in formulating and implementing an urban shading strategy

Map the urban shade hierarchy using shade maps

Prioritise intervention sites for shade intensification or shade preservation

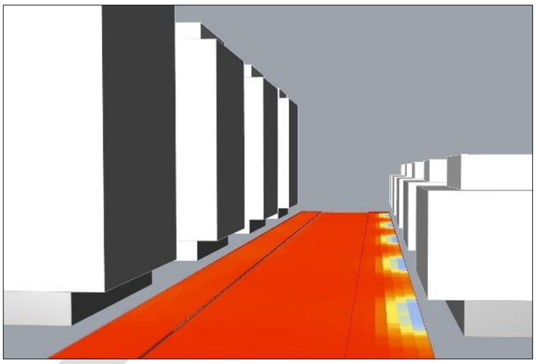
Detailed shade planning according to the Shade Availability Index



Shading levels rated according to the Shade Availability Index (SAI)

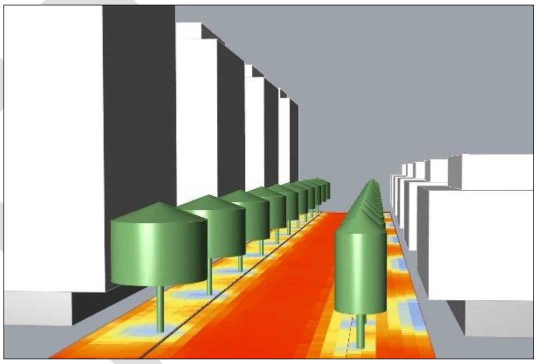
Insufficient shading

SAI < 0.5



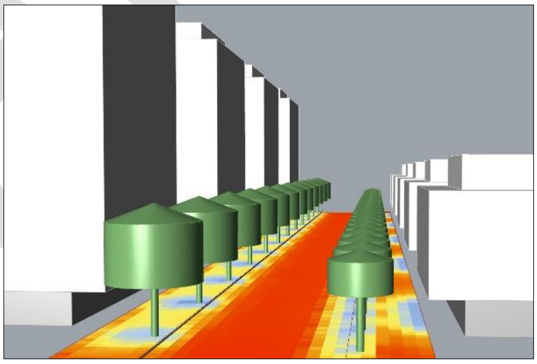
Acceptable shading

SAI ≥ 0.5



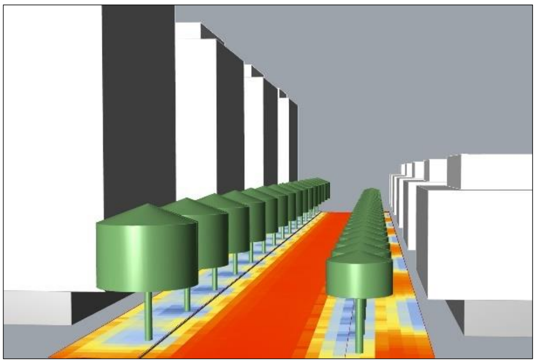
Very good shading

SAI ≥ 0.7



Excellent shading

SAI ≥ 0.9



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Introduction: The challenge of quantifying shade in urban environments

A gradual increase in air temperature during the warmer months, alongside an increase in the duration and frequency of heat waves, is expected to occur in Israel in the coming decades due to global climate change and due to the spatial distribution and densification of urban concentrations in Israel, which exacerbate the urban heat island phenomenon. These changes will lead to a significant worsening of the intensity of heat stress experienced by users in urban spaces unless preliminary actions are taken to alleviate these loads. At the same time, **already today,** in the climatic conditions prevailing in Israel over many months (and at least between May and November), direct and indirect exposure to solar radiation is the environmental factor that most affects significant daytime increase in the intensity of the felt heat stress and a sharp decline in outdoor thermal comfort.[1] In addition, exposure of outdoor spaces to direct sunlight for long hours leads to warming of the entire urban environment in the evening and early night, increasing the intensity of heat stress during these hours inside and outside buildings, and hence the energy consumption of air conditioning systems.

Planning actions can indeed cause a decline in air temperature or an increase in wind speed in the urban environment. Still, in the climatic conditions prevalent in Israel, these actions have a limited effect on improving thermal comfort. On the other hand, planning that secures significant and continuous shading along streets and in open public spaces can significantly alleviate the heat stress already felt, and even more so with the expected increase in air temperatures due to climate change. Shading in the urban environment has additional advantages, such as preventing skin cancer morbidity, moderating the urban heat island phenomenon, reducing energy consumption for cooling indoor spaces by air conditioning, and improving physical conditions that could increase walkability in urban spaces.[2]

Shading in the urban environment is closely related to the planning and design of built-up areas. In specific geometric configurations, good shading can be achieved using the buildings next to the sidewalks. However, securing sufficient shading often requires additional three-dimensional components at the street level, such as pergolas, shading fabrics, and mainly street trees. Trees have additional advantages beyond shading alone – reducing the pollution of air and surface water sources, contributing ecologically as a habitat to a variety of animals, improving the aesthetic

[1] Aleksandrowicz, O., & Pearlmutter, D. (2023). The significance of shade provision in reducing street-level summer heat stress in a hot Mediterranean climate. *Landscape and Urban Planning*, 229, 104588.

[2] Knesset – Research and Information Center (2022). Shading policy in public spaces [in Hebrew]; Ministry of Environmental Protection, Israeli Green Building Council, Ministry of Agriculture, National Economic Council (2022). A national strategic plan for shading and cooling the urban space using trees [in Hebrew].

appearance of the built-up environment and, to a certain extent, regulating surface runoff.[3] Studies from around the world also point to other possible advantages of planting trees on the streets, such as increasing business productivity[4] and real estate values.[5] However, tree shading requires financial resources to ensure significant soil volume, root growth, and constant maintenance (pruning, irrigation); without this investment, we can assume that the tree crown (all the tree branches and leaves) would not provide effective shading. Moreover, planting new trees usually does not provide an immediate solution to insufficient shade since a mature shade tree develops a significant shade-providing crown only a decade or more after planting, and even then, only if it had received proper growing conditions.[6]

Promoting shading in urban streets using trees, as a key part of Israel's environmental response to global warming, lies at the centre of Government Decision 1022 of 23 January 2022.[7] The government's decision was based on a report compiled by an inter-ministerial team led by the National Economic Council.[8] The team's conclusions were that despite recognising the immense benefit of street trees – from the environmental, health, social, and even economic perspectives – and despite their importance in climate change preparedness, the existence and prosperity of street trees in Israeli cities face many barriers, both at the planning stage and at the implementation and maintenance stages, partly due to a genuine lack of data. In the document entitled **The National Strategic Plan for Urban Shading and Cooling Using Trees**, which was published at the end of 2022 by the Ministry of Environmental Protection, the Israeli Green Building Council, the Ministry of Agriculture and Rural Development, and the National Economic Council, it was possible to read an implicit recognition of the methodological difficulties inherent in implementing the government decision from the beginning of that year.[9] The program acknowledged that there is still a lack of a widely accepted scientific methodology for setting urban shading and urban forestry targets and defining the precise mapping needs resulting from these targets. Without such a methodology, all parties involved in advancing the decision will find it difficult to efficiently and effectively realising the

[3] Tyrväinen, L., Pauleit, S., Seeland, K., & de Vries, S. (2005). Benefits and Uses of Urban Forests and Trees. In C. Konijnendijk, K. Nilsson, T. Randrup, & J. Schipperijn (Eds.), *Urban Forests and Trees* (pp. 81-114). Springer.

[4] Wolf, K. L. (2005). Business district streetscapes, trees, and consumer response. *Journal of Forestry*, *103*(8), 396-400.

[5] Song, X. P., Tan, P. Y., Edwards, P., & Richards, D. (2018). The economic benefits and costs of trees in urban forest stewardship: A systematic review. *Urban forestry & urban greening*, *29*, 162-170.

[6] Galon, I., and Heller, A. (2013). Guide to Street Trees in Israel [in Hebrew]. The Ministry of Agriculture and Rural Development and the Ministry of Environmental Protection.

[7] The Israeli Government Decision No. 1022 of 23 January 2022. Shading and cooling the urban space using street trees as part of climate change preparedness [in Hebrew].

[8] National Economic Council, Prime Minister's Office (2022). Promoting street trees in Israel's cities – shading and cooling the urban space using street trees in preparation for climate change [in Hebrew].

[9] Ministry of Environmental Protection, Israeli Green Building Council, Ministry of Agriculture and Rural Development, National Economic Council (2022).A national strategic plan for shading and cooling the urban space using trees [in Hebrew]. See also a more recent version of the plan: Yelinek, A. & Schvetz, K. (2023). A national strategic plan for shading and cooling the urban space using trees [in Hebrew].

planting of shade trees in Israel's cities, monitor the progress of actions in this area, and divert resources to places where they are specifically needed.

Determining an agreed-upon measurement method of shade in urban spaces is important for regulatory, planning, and design purposes. However, qualitative or quantitative delineation of the required shade levels raises methodological difficulties stemming first and foremost from the need to define what shade is, how to quantify it spatially, and at what times it is especially important to provide shading. Another point to consider is the basic spatial unit for which shade is measured since different shade levels can be calculated for different spatial units, such as a street segment that includes all right-of-way (namely, the entire street area dedicated to public uses), sidewalks only, effective walking area on sidewalks only, etc.

This document presents a comprehensive methodology for answering these questions to provide planning bodies and planners with standards for quantitative and qualitative assessment of existing and projected levels of shading according to different planning scenarios. The study contains a concise overview that identifies the weak points in contemporary methods for quantifying shading in urban areas in Israel and around the world, followed by a presentation of a new method for setting targets for shade planning on urban streets. This method, presented here as part of an overall process of formulating a municipal shading strategy, is based on a new quantitative index, the **Shade Availability Index**, which emphasises the shading conditions in **sidewalks** in the spirit of Government Decision 1022. In addition to a detailed description of the Index and the targets derived from it, this document also includes systematic demonstrations of the application of the index under various planning conditions and an analysis of the feasibility of meeting the normative targets we set in this work in practical planning of streets in Israel.

Existing methods for quantifying shade in urban space

Shading in urban environments receives systemic attention in certain places around the world within the framework of various types of documents: master plans, planning standards, health guidelines, guidelines for coping with heat, planning guides, and design recommendations. In general, these documents emphasise the health, social, environmental and economic benefit of shade in general and of trees in particular, such as reducing the intensity of the urban heat island, encouraging physical activity, reducing energy consumption, improving air quality, managing surface runoff, supporting biodiversity, and more. However, while some documents include binding standards, others only treat shading as a general recommendation. It is not always possible to learn from publications that present spatial shading requirements or recommendations to what extent they have binding validity, although some of them refer to external binding instructions.[10]

Policy documents dealing with shading have been published in a relatively limited number of places around the world. Many of them point to the need to give priority to shading projects so that maximum social and environmental benefit is achieved, subject to the availability of economic means, but this is often done without setting quantitative targets or a method of prioritising action based on a quantitative scale of the quality of shading in different spaces. For example, some of the documents state that shaded spots should be promoted as part of street design or an effort to secure optimal shading, but these documents do not provide an objective quantitative description that allows defining a place as a "shaded spot" or shading as being "optimally shaded".

The most detailed and extensive documents identified in this study were published in Abu Dhabi, southeastern Australia, and Arizona in the United States, and all offer a quantitative method of measuring shade. The purpose of these documents varies according to the climatic characteristics of the region and the nature of the body that initiated the publication. In Abu Dhabi, shading guidelines were included in guides for sustainable planning of public spaces. In Australia, shading first appeared in policy documents dealing with skin cancer prevention, although in recent years, it is evident that shading is increasingly presented there as an important means of dealing with heat stress. In Arizona, emphasis was placed on increasing thermal comfort through shading as a basis for encouraging non-motorized transportation, while recognising the place of shading also in reducing the intensity of the urban heat island. However, the way these documents deal with shade quantification (Table 1) is similar: shade is calculated in a simple geometric way, as the ratio between the projection area of the shading device (including trees) on a shaded horizontal surface and the

[10] A comprehensive review of the subject is presented in the preliminary report prepared as part of this project, see: Shapira, N. and Aleksandrowicz, O. (2024). Review and analysis of methods for evaluating, quantifying and promoting shade in urban spaces [in Hebrew]. BDAR Lab, Technion, and Samuel Neaman Institute.

area of reference space it is supposed to shade. This reference space can be a street segment, a public park, a square, a neighbourhood, or even an entire city.

Table 1: Summary of shade indices in different countries

	Abu Dhabi[11]	Arizona[12]	Australia[13]
The purpose of shading	Improving thermal comfort (sustainable urbanism)	Creating thermal comfort for a safe and healthy future	Urban cooling alongside health aspects
Type of shading	Natural and artificial	Natural and artificial	Mainly natural
Shade calculation method	Geometric, the projection of shading devices on a horizontal surface relative to the reference area	Geometric, the projection of shading devices on a horizontal surface relative to the reference area	Geometric, the projection of shading devices on a horizontal surface relative to the reference area
Minimal shade ratio	streets 60%-75%; open public spaces 60%; seating areas 70%; cycling routes 50%; playgrounds 90%; Parking spaces 40%	For a length of 20 minutes (walking and waiting) – minimum acceptable shading is 20%; good shading is 30%, and excellent shading is 60%	30% urban tops cover; On the paths – a tree every 15 m; parking spaces 10%; and specific reference to sensitive facilities (education, health)
Accounts for tree growth time	Yes, measuring 5 years after planting and when the tree reaches its full growth potential	No	No
Reference time	13:00, 21 March and 21 June	12:00-18:00, May to October	09:00-15:00
Definition of the shaded area	1.8 m strip from the street walking zone		

However, several points remain unaddressed in these documents, as follows:

- An urban tree canopy cover, in which a single average value is supposed to represent the state of the urban forest throughout the city, is far from providing a good understanding of a possible spatial variation in the distribution of urban tree resources. For example, when the urban boundaries include "green belts" on the city's outskirts, this positively affects the urban tree canopy cover ratio but will certainly conceal the lack of canopy cover in certain inner-city neighbourhoods.

[11] Abu Dhabi Urban Planning Council (2010). The Pearl Rating System for Estidama Community Rating System; Abu Dhabi Urban Planning Council (2016). The Pearl Rating System for Estidama Public Realm Rating System.

[12] Nature's Cooling Systems Project (2019). Heat Action Planning Guide, for Neighbourhoods of Greater Phoenix. Creating Urban Heat Solutions in the Valley of the Sun.

[13] Stoneham, M., Earl, C., & Baldwin, L. (2007). Creating shade at public facilities: Policy and guidelines for local government (second edition). Australian Institute of Environmental Health (AIEH), Australia; Low Carbon Living CRC (2017). Guide to Urban Cooling Strategies; Coutts, A and Tapper. N. (2017). Trees for a Cool City: Guidelines for optimised tree placement. Melbourne Australia: Cooperative Research Centre for Water Sensitive Cities.

- Similarly, determining a target tree canopy cover ratio in a given space or a street without addressing shade continuity in that space or the changing pattern of shading during the daytime and between seasons may yield design solutions whose effectiveness is limited.
- When shade is calculated based on the projection area of the shading element on a horizontal surface (as in the tree canopy cover ratio), this representation does not express a realistic situation because, in the vast majority of cases, the sun is not located in the zenith (an angle of 90 degrees relative to the ground surface), but at lower angles. This method ignores the varying radiation intensity of the sun during the daytime and between seasons and the changing directions from which direct solar radiation comes. This, in turn, may result in the shade being often cast far from the shading device itself (for example, a tree whose crown casts a shadow on the road beside it rather than on the sidewalk where it is planted). For the same reason, this calculation method ignores buildings' contribution to street shading, although in some cases, it may be significant.
- Since the spatial coverage of shade varies from hour to hour and season to season, a broad definition of a reference time (e.g., 11:00-15:00 between April and September) does not take into account the significant differences in the sun's position in the sky and radiation intensity during these months. An overly broad definition may lead to the adoption of shading solutions that will not provide an optimal response precisely when heat stress is at its peak.
- The assumption that the various means of shading (trees, fabrics, nets, pergolas, etc.) entirely block direct solar radiation is inaccurate in most cases. The methods for calculating shade coverage usually ignore this and treat equally shading devices that are significantly different in the penetration of solar radiation through them.

In Israel, adequate shading in the public sphere is currently promoted through various policy tools. Mandatory guidelines for shading currently exist only in defined spaces, particularly in educational institutions and playgrounds, swimming pools, and beaches, to protect vulnerable populations in areas with significant sun exposure. It can be learned from discussions held on the subject that the main motivation for adopting these regulations lies in health and safety reasons (protection against skin cancer and burns), with little emphasis on thermal comfort in outdoor urban spaces.[14] However, even the most up-to-date and detailed regulations on the subject, relating to the shading of playgrounds, do not provide a clear enough response to how shading is applied even in these spaces. Although the regulations define a reference time for measuring shade and also refer to the quality of shading ("the thermal conditions obtained by a shading solution, including shade density,

[14] For example, see the Knesset's Special Committee on Children's Rights, meeting on 14 July 2015, on shading in playgrounds. Protocol No. 8.

preservation of shading conditions over time, and thermal comfort"), the regulations stipulate that shading will be planned and carried out taking into account these conditions while refraining from specifying any binding quantitative values. Likewise, the definition of what constitutes shade ("an area where the sun's rays do not reach directly") implicitly assumes that any surface used for shading fully absorbs direct sunlight, but this situation rarely exists in reality. If this is not enough, the regulations focus on shading the playground play facilities, and therefore do not relate at all to the shade of the adjacent seating and rest areas, as well as the access roads to the playgrounds and their facilities. **This means that in practice, there are currently no binding guidelines in Israel for planning shading in urban streets, and no appropriate regulatory response has been provided to secure the improvement of thermal comfort during the hot season in public spaces in Israeli cities**.

The gap between the desire to significantly improve the state of shading in urban spaces and the lack of quantitative tools for shade planning has led in recent years to initial attempts to propose a comprehensive method for quantifying shade in different types of urban spaces, emphasising urban streets. **Open Space Shade Policy Planning Guidelines** prepared by Tami Hirsh and Shachar Zur for the Tel Aviv-Yafo Municipality in 2017[15] is perhaps the first policy document published in Israel on urban shading and included comprehensive quantitative indices. The document, which is not binding, deals with the shading of different spaces in the city, including streets, open spaces, outdoor areas of educational, sports and community buildings, and parking lots, using artificial and natural shading solutions, including shading from buildings. Shading is quantified by geometric calculation of the area of a horizontal plane's shade coverage relative to that plane's total area. According to the document, the shaded area should be at least 80% of the reference area in the following locations: points of interest and gathering places (playground facilities, seating areas), passage paths and streets (where 80% continuous coverage is required, but only on one of the two sidewalks on the street). The document sets lower shade levels for school yards and underground parking lots (50%), squares or plazas (40%), and sports centres and green areas such as parks (20%). The document does not explain why the quantitative shading thresholds were set as they were set or the reason for distinguishing between the required shading thresholds in different types of open spaces. In addition, the document does not clearly refer to how the boundaries of the reference area are calculated in areas whose definition is vague (for example, how the boundaries of a certain type of "points of interest and gathering places" are determined).

The document specifies nine reference dates for which the reference space must meet the

[15] Hirsh, T., and Zur, S. (2017). Open space shade policy planning guidelines for landscaping and architectural design plans and municipal projects. City Architect's Office, Tel Aviv-Yafo Municipality.

required shading threshold: three points in time (10:00, 13:00, and 16:00) on each of three reference days (21 June, 21 August, and 21 October). The document does not explain the choice of these dates, but it can be assumed that the intention was to represent the state of shading during daylight hours in early summer, the height of summer, and autumn. The guidelines do not include a clear explanation of the tool by which the shade projection is calculated on the reference area, but it does recommend performing the calculation using 3D modelling software available on the market (such as AutoCAD, Revit, SketchUp, and Rhino).

Alongside the quantitative calculation, the guidelines document presents a method for evaluating shade quality, which includes four aspects of the impact of shading devices on the local climate in its vicinity (air temperature, humidity, heat emission, and windbreaking), two aspects of comfort and health (light transmission and protection from UV radiation), and two aspects of maintenance (lifespan and frequency of maintenance). Each shading medium (natural or artificial) is graded according to each aspect (on a three-level scale: satisfying, neutral/medium, and very good). In addition, the document presents four basic conditions for the cultivation of healthy and long-lasting shade trees in paved areas, defines recommended shade trees for inclusion in plans, and dictates guidelines for shade planning according to the type of open urban space, such as preference for natural shading solutions, selection and cultivation of trees that will ensure quality long-term shading, planning complementary shading solutions for different stages during the tree growth, and minimal tree spacing. However, the document does not provide a practical tool for comparing planning alternatives or examining the applicability of the shading thresholds it sets in different planning scenarios.

Policies and Guidelines for Shading in Public Urban Spaces were developed in 2017-2019 by a research team led by architect Naomi Angel, then the Tel Aviv District Planner at the Planning Authority, Limor Shashua-Bar, Aviva Peters, and Smadar Meir. The work, which did not receive a binding status and was not published in an official document of the Planning Authority, focused on shading streets, walking routes, and bicycle paths.[16] The study aimed to establish quantitative and qualitative criteria for planning continuous shade in public urban spaces and to formulate guidelines for optimal shading. The study determined that the purpose of shading is **to completely prevent** heat stress on the human body (complete thermal comfort), and quantitative targets were derived from this goal by using a new index called the **Open-space Shading Index** (OSI). The index was developed based on a series of sample climate measurements on urban

[16] The work was presented at plenary session 865 of the Tel Aviv District Committee on 3 September 2018. A summary of the work was published in the article: Peeters, A., Shashua-Bar, L., Meir, S., Shmulevich, R. R., Caspi, Y., Weyl, M., Motzafi-Haller, W. & Angel, N. (2020). A decision support tool for calculating effective shading in urban streets. *Urban Climate*, *34*, 100672.

streets and thermal simulations in which various daytime planning scenarios were examined in July in the Israeli Coastal Plain.

The OSI is essentially a geometric index that sets targets according to the ratio between the projection area of the shading devices on a horizontal surface and the reference area (in most cases, the right-of-way area in a street segment). The index distinguishes between the shade quality of different shading devices. It gives different weights to trees of different foliage densities and artificial shading devices, with dense foliage trees receiving the greatest weight. Thus, for example, it was determined that on a street with trees with dense foliage, canopy cover of at least 60% of the right-of-way area is required, but if shading is done using pergolas only, a higher percentage of coverage of at least 85% will be required. This study did not examine how easy it is to achieve the shading targets it sets in different urban morphologies or to what extent its targets are already being realised in urban spaces in Israel.

The index's reliance on calculating the vertical projection area of shading devices ignores the difference in shade projections on the ground in different street directions, different street canyon configurations, and at different times. These properties are indeed implicit in the index that was developed because the thermal simulations underlying it were performed for a street with an east-west orientation and for a street height-to-width ratio of 1. However, such a street represents an extreme reference scenario that is not typical of many planning situations. Hence, the work set sweeping shading targets without distinguishing between different urban morphologies in which it was perhaps possible to secure thermal comfort in summer even when design thresholds were lower. In addition, the assumption that shading can achieve thermal comfort in the Israeli summer, although backed up by several sample measurements conducted in Greater Tel Aviv, is inconsistent with the findings of a study based on measurements at hundreds of points we conducted in Tel Aviv and Kfar Saba. Our study showed that in many cases in summer, excellent shading is not a guarantee of complete thermal comfort, although it is essential for a significant reduction in daytime heat stress.[17] It follows that in formulating a quantitative index for shading, it makes sense to focus on **the relative contribution** of shade to a significant reduction in heat stress, rather than its **absolute contribution** to achieving full thermal comfort in summer.

[17] Aleksandrowicz, O., & Pearlmutter, D. (2023). The significance of shade provision in reducing street-level summer heat stress in a hot Mediterranean climate. *Landscape and Urban Planning*, 229, 104588.

Formulating a shading strategy for urban areas and its implementation: a proposed method

The method described in this document is intended to provide practical tools for quantitative assessment of existing or projected shading conditions in urban environments at various scales of urban planning. At the national level, the described evaluation method can be used to set applicable national targets for shading, to formulate binding regulations for the integration of shade in master plans, and to set targets in government-supported tenders for the actual implementation of plans for additional shading in urban spaces. At the local level, the method can be used to formulate strategic shading plans, to design basic street segments in new neighbourhoods, and to plan the inclusion of additional shading components to existing street segments.

In the method we propose, determining an urban shading strategy is based on a three-stage process (Table 2): mapping the urban shade hierarchy; prioritising intervention areas for shade intensification; and detailed shade design at the scale of a single street segment. The method we present for mapping an urban shade hierarchy was already described by the authors in a previous publication and has been applied in more than a dozen cities in Israel to date;[18] therefore, we include only a concise description of it here. Prioritising intervention zones involves local urban considerations that go beyond strict climatic considerations, and, therefore, this stage is only generally outlined here. The lion's share of this document is devoted to describing the method for setting normative quantitative shading targets and applying them to detailed plans. This method, presented here for the first time, is based on a new index, the **Shade Availability Index**, described in detail below. The method is equally suitable for redesigning existing streets and planning future streets within the framework of urban master plans.

Table 2: Applicability of the proposed work stages to different planning scenarios

	Mapping shade hierarchy	Prioritising shading actions	Detailed shading design
Setting a national policy	✓	✓	✓
Formulating an urban strategy	✓	✓	✓
Planning an urban master plan		✓	✓
Detailed design of a street segment			✓

[18] Aleksandrowicz, A., Zur, S., Lebendiger, Y., Lerman, Y. (2019). Shade maps and their application for shade conservation and intensification in Tel Aviv-Yafo: Final Report. Submitted to the Conservation Department, Tel Aviv-Yafo Municipality.

Mapping an urban shade hierarchy: the spatial Shade Index

Urban areas develop over time according to different planning concepts, resulting in significant differences in built-up density and the presence of shade trees or other means of shading in public spaces. Often, climatic issues, including the shading of public spaces, are not considered during planning and do not serve as a benchmark for examining the planning quality. As a result, many streets in Israel, including main streets that attract a wide public, do not provide minimal protection against exposure to solar radiation (direct, diffuse, and reflected) during the hot season. In light of this, the first step in determining an urban shading strategy is a detailed mapping of the urban shade hierarchy to identify the climatic vulnerabilities in the existing urban street network.

Urban shade maps are maps that visually present shading levels in urban spaces in the high resolution required to understand the specific state of shading at each point in the city from the perspective of non-motorized road users (pedestrians, cyclists, etc.). Such maps must be based on a clear and reproducible quantitative index that will allow for a simple comparison between the levels of shading prevailing in different urban public spaces. We propose to prepare urban shade maps according to the spatial **Shade Index** (SI), using a method that we have already applied in more than a dozen cities in Israel.[19] The spatial Shade Index describes on a simple scale from 0 to 1 the extent to which the cumulative direct effect of solar radiation at ground level is blocked during a typical summer day. The rate of impact blocking is derived from the position of the sun in the sky at any given hour, the intensity of the sun's radiation at that time, and the three-dimensional characteristics of the urban space (width of the right-of-way, height and density of buildings, tree density, and the height, projection area and density of tree crowns). The state of shading that a shade map reflects may change significantly due to significant changes in the built environment (for example, the demolition of buildings, the extension of existing buildings, or the erection of new structures) and the urban forest (for example, the uprooting of trees, tree pruning, planting new trees, or the rapid crown growth of young trees). Therefore, it is recommended to prepare urban shade maps at regular intervals of at least three to five years, a period of time that allows monitoring substantial changes in buildings and trees and evaluating the benefit derived from targeted projects to improve the state of shading in a city.

A shade map of streets and open public spaces facilitates the presentation of the shade hierarchy in the main walking spaces in a city. In this map, an average Shade Index is calculated for

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[19] Ibid., and also: Aleksandrowicz, O., Zur, S., Lebendiger, Y., & Lerman, Y. (2020). Shade maps for prioritizing municipal microclimatic action in hot climates: Learning from Tel Aviv-Yafo. *Sustainable Cities and Society, 53*, 101931; Aleksandrowicz, O. (2022). Mapping and management of urban shade assets: a novel approach for promoting climatic urban action. In A. Khan, H. Akbari, F. Fiorito, S. Mithun, & D. Niyogi (Eds.), *Global Urban Heat Island Mitigation* (pp. 1–27).

each street segment (a part of a street bounded between two road junctions, covering the segment's entire right-of-way) and in every open public space. For example, the shade map of the streets and open public spaces of the city of Holon (Figure 1) shows a wide range of shading levels, from a Shade Index of 0.0 (i.e., no shading at all) to 0.75 (i.e., three-quarters of the cumulative global solar radiation on a summer day is blocked before reaching the ground surface). However, a statistical analysis shows that the Shade Index in most street segments in the city ranges from 0.10 to 0.30, between very and moderately low levels of shading. Based on this map, it is, therefore, possible to easily present segments of streets and open spaces where shading conditions are extremely low, to distinguish between places where shading conditions are relatively high, and based on this hierarchy to prioritise, in combination with other planning considerations, concrete and focused actions to improve the state of shading.

The spatial Shade Index also makes it possible to calculate average shading levels in neighbourhoods or urban areas with predefined boundaries (such as districts, planning zones, and statistical zones). For example, a **zonal shade map** showing the average shading situation in urban zones defined by the city of Holon (Figure 2) reveals significant differences in shading between the city's older neighbourhoods (mainly in the north of the city) and the large industrial zone in the eastern part of the city. It can also be noticed that in an area in the heart of the city where some of the museums and main public buildings are concentrated, the general level of shading is relatively low compared to the residential neighbourhoods around it. Such an analysis, combined with additional data associated with the same zones or neighbourhoods, allows planners to focus on a defined area where shading conditions are significantly lower on average than in other areas of the city, even if it contains street segments where shading conditions are good. A combination of the two types of maps (Figure 3) also makes it possible to easily locate streets suffering from a significant lack of shading in areas with relatively good average shading and vice versa.

Shade maps also make it possible to examine the relative dependence of the level of shading in streets, public spaces, or neighbourhoods on tree shading. By comparing a shade map showing the current state of shading with a shade map showing the state of shading excluding the shade trees cast (Figure 4 and Figure 5), it is possible to locate street segments and zones where there is a particularly high dependence on shade trees to secure reasonable levels of shading and to direct conservation efforts of existing trees to these locations. A significant difference in the Shade Index between the existing conditions and in the shading condition without the effect of trees also indicates that urban morphology (the physical characteristics of the built environment, such as density and height of buildings and the width and orientation of streets) has almost no positive effect on improving shading, although proper design can secure reasonable and even good levels of shading only through buildings. **In the Israeli context, the comparison highlights the advantage of streets oriented on a north-to-south axis in shading the street area using buildings over streets with an east-west orientation, where it is difficult to achieve acceptable levels of shading without a significant and continuous layer of shade trees or other shading elements. The comparison also shows that densely built streets make it possible to reach high levels of shading resulting from the narrow proportions of the street canyon (relatively tall buildings next to a relatively narrow right-of-way).**

Figure 1: Shade map of street segments and open public spaces in Holon using the spatial Shade Index (SI), which ranges from 0 (no shade) to 1 (full shade) (mapping: Morel Weisthal and Or Aleksandrowicz). Noticeable differences in shading levels are evident.

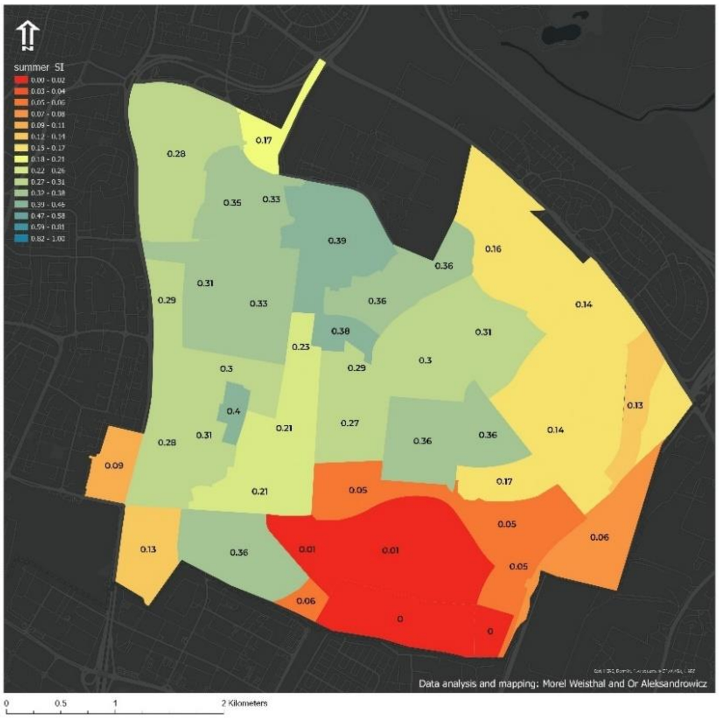


Figure 2: Zonal shade map of urban spaces in Holon (mapping: Morel Weisthal and Or Aleksandrowicz). This map makes it possible to locate entire urban environments with improved average shading conditions according to the spatial Shade Index (SI).

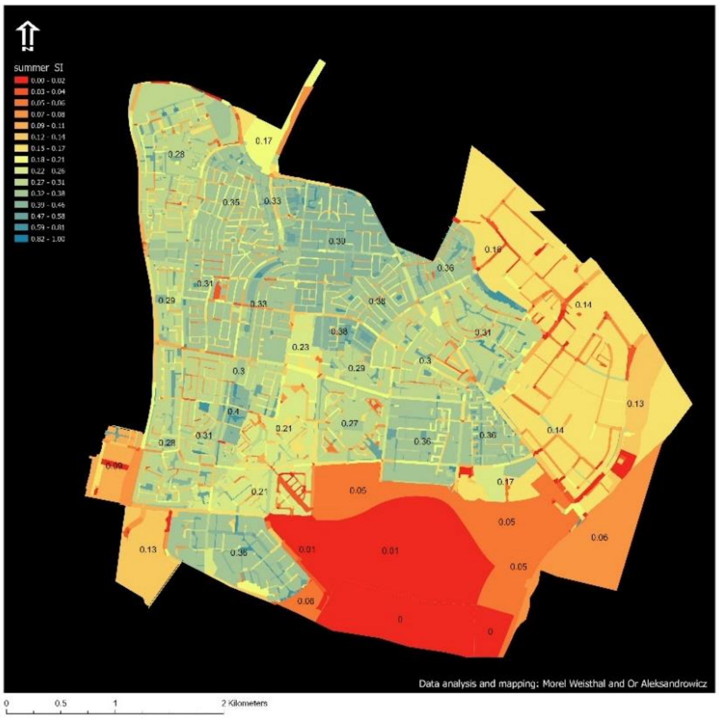


Figure 3: A combination of a shade map of streets and open public spaces and a zonal shade map in the city of Holon (mapping: Morel Weisthal and Or Aleksandrowicz). Exceptionally better or worse-shaded streets or areas relative to their surroundings can be easily located.

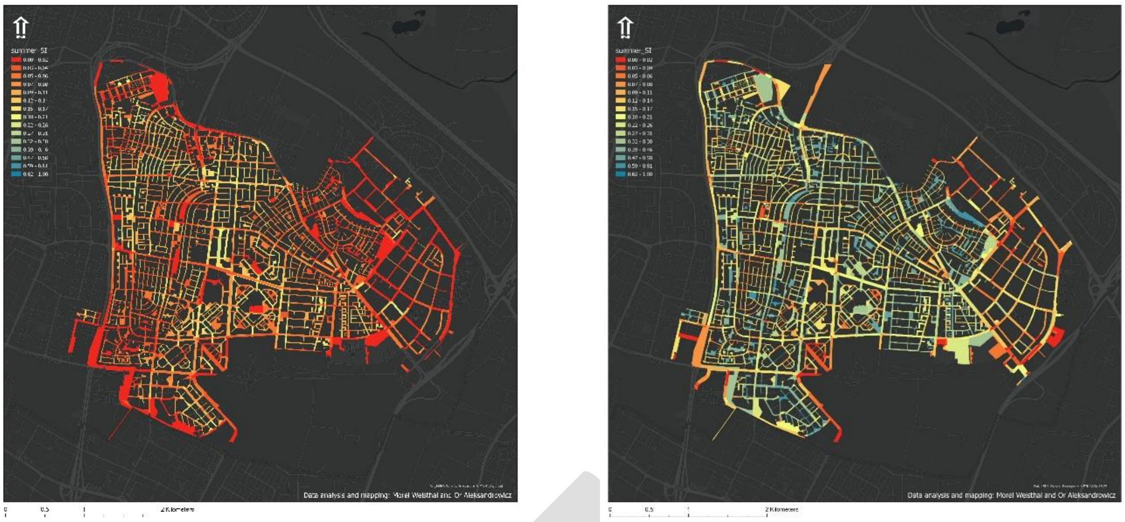


Figure 4: Shade maps of the streets and open public spaces of Holon (mapping: Morel Weisthal and Or Aleksandrowicz): a comparison between the current situation, including shading from trees (right) and a reference mode that excludes shading from trees (left).

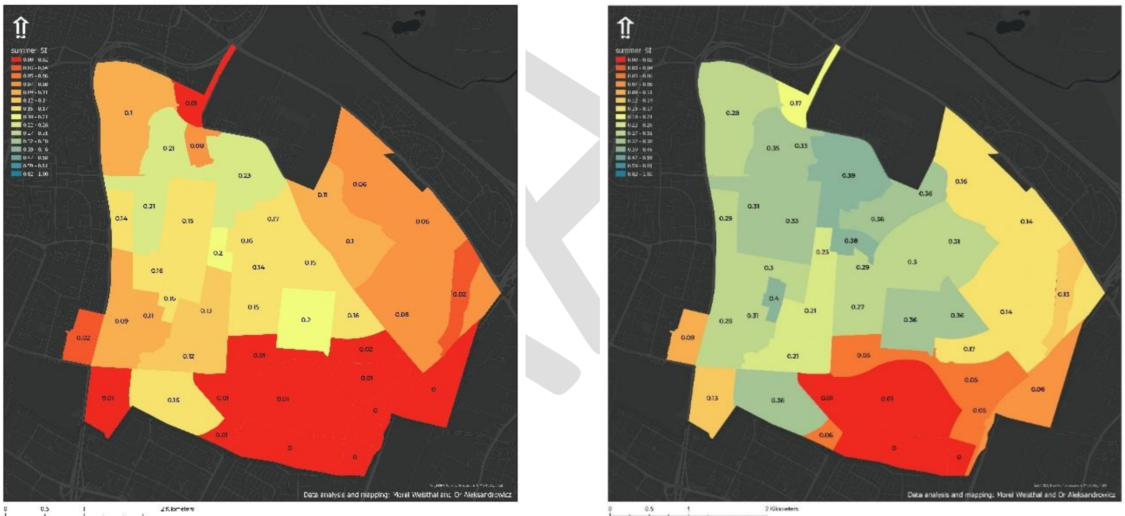


Figure 5: Shade maps of Holon's planning zones (mapping: Morel Weisthal and Or Aleksandrowicz): a comparison between the current situation, including shading from trees (right) and a reference mode that excludes shading from trees (left).

Prioritising sites for shade intensification

The second stage in determining an urban shading strategy is the stage of prioritising intervention actions. City-wide shade analysis using shade maps makes it possible to comparatively evaluate the advantages or disadvantages that certain areas have over others in terms of shading conditions and to determine sites for intervention based on this assessment. A comparative examination can help not only in determining the spatial magnitude of the lack of shade but also in locating streets or parts of the city where shading conditions are very successful. From here, it is also possible to propose two types of urban spatial intervention in terms of shading: "shade intensification" in areas with low shading levels and "shade conservation", mainly through sustainable maintenance of trees in areas where exceptional levels of shading have been located. These highly shaded areas, quickly found using shade maps, can also inspire methods for adding shade elsewhere.

In addition to defining the intervention sites, the municipality is also required to prioritise intervention activities in them and define which sites are more urgent to act on. Indeed, a municipality may rely exclusively on the spatial Shade Index and mark all streets where shading levels are below a certain threshold (for example, 0.2) as streets that are not sufficiently shaded and are, therefore, designated for high-priority shade intensification. However, setting a numerical threshold based only on the spatial Shade Index for intensifying or conserving shade may not be sufficient to prioritise municipal actions because the number of street segments designated for intervention may be very large and exceed the municipality's available resources. Lowering the threshold to reduce the number of intervention sites may result in many street segments with poor shading conditions not being considered as intended for shade intensification, even if these segments are centrally located. Therefore, the municipality must examine additional considerations in the process of prioritising actions in a manner that will enable it to determine the order of actions and the pace of execution of projects according to the resources allocated to this purpose. These additional considerations should help the municipality direct its actions to sites where their impact will be particularly noticeable (for example, a main commercial street that attracts a large number of pedestrians or a neighbourhood with an elderly population) out of all sites with similar levels of shading.

Defining the additional considerations for prioritising shading actions is a matter of values stemming from familiarity with local urban needs. Due to the great variation in local conditions and planning preferences in each city, we believe that it would not be correct to define a uniform and binding method for ranking considerations that will affect the prioritisation of shading operations. However, every city that formulates a shading strategy must establish clear and measurable criteria for prioritising shading actions that would go beyond quantifying shading levels using the spatial Shade Index (SI). These criteria can relate to social, environmental, and planning aspects that are not directly related to the existing levels of spatial shading, for example:

- **Walkability –** Urban spaces where the municipality sees potential for increased pedestrian traffic or where many pedestrians are already present may be preferred spaces for shade intensification or conservation due to the close relationship between exposure to sunlight and heat stress that negatively affects pedestrians. Therefore, considering the walkability or connectivity of streets and areas of the city may ensure that future shading actions benefit the largest number of non-motorized road users.

- **Health vulnerability** – The elderly and children, along with people suffering from various chronic diseases, are populations known to be particularly sensitive or vulnerable to heat stress. Improving shading conditions in the daily living environment of areas with a high concentration of such populations may prevent specific or ongoing health damages or prevent the exacerbation of the damage. Therefore, prioritising shading activities according to the detection of exceptional concentrations of health-vulnerable populations may bring special relief to those for whom shading is a vital need.
- **Economic vulnerability** – Populations of low socioeconomic status are populations that rely more than others on foot traffic and public transportation, which are almost always accessible by walking. In addition, these populations may be more vulnerable to hot conditions due to the lack of efficient cooling means in their places of residence. Therefore, prioritising actions to promote shading in neighbourhoods with populations with low economic means may serve more residents who have no better alternatives than walking and gathering in open spaces.
- **Urban Renewal** – The dimensions of a street canyon and the building density can significantly contribute to the shading of streets. Therefore, priority can be given to shade design in areas designated for urban renewal so that shading in these areas will be largely based on building morphology, alongside planting a sufficient number of trees. On the other hand, areas, where urban renewal is in full swing, may be areas where preference will not be given to shade intensification actions until a significant part of the construction activities is completed.

Detailed shade design: the Shade Availability Index

After locating streets designated for shade intensification, a detailed shade design should be the third step in determining an urban shading strategy. To become effective, shade design must meet quantitative objectives formulated using a uniform index describing the extent to which sufficient shading conditions exist during the daytime hours at the height of summer. The need to set shading targets according to a uniform quantitative index stems from the current difficulty of conducting a systematic assessment of shade quality, comparing the shading quality in different planning scenarios, and ensuring that municipal actions for shade intensification will simultaneously be effective and efficient. The Shade Availability Index (SAI),[20] the index that we present here for determining normative shading targets, is relatively easy to calculate while allowing the quantification

[20] Aleksandrowicz, O., & Ozery, E. (2023). A Parametric Tool for Outdoor Shade Design: Harnessing Quantitative Indices and Visual Feedback for Effective and Efficient Climatic Design of Streets. In M. Turrin, C. Andriotis, & A. Rafiee (Eds.), *Computer-Aided Architectural Design. INTERCONNECTIONS: Co-computing Beyond Boundaries* (pp. 302–316). Springer Nature Switzerland.

of the degree of shading on sidewalks or walking paths during the detailed design stage. It can be used to evaluate the relative quality of shading and examine the effect of design modifications on the state of shading. At the same time, it also overcomes the downsides of existing shade evaluation methods that we reviewed in the previous chapter.

A review of the methods currently available in Israel or other countries for evaluating shade in urban environments revealed that shading targets are set today in a small number of locations, and this, too, is almost always based on simple geometric indices (for example, the tree canopy cover ratio). Most of these methods do not consider the shading obtained from buildings, the times when shading is most necessary, and the difference in the shading pattern obtained at different hours and dates. Existing indices are problematic because they hardly present a realistic picture of the state of shading in urban spaces and ignore many physical differences that directly impact shading conditions in a space. In addition, these indices sometimes set high threshold levels for shading targets in a way that does not represent realistic planning scenarios from a physical or economic perspective. The index we propose provides a solution for these shortcomings because it takes into account the shading obtained from buildings and trees, quantifies the level of shading according to the actual shade coverage at ground level over a large number of hours in the height of summer, and is based on an extensive systematic examination of the possibilities of meeting the thresholds we set under reasonable planning scenarios.

The Shade Availability Index is based on a geometric calculation of the shaded area of a reference surface without quantifying the effect of shading on reducing the heat stress a person feels. The choice to avoid weighing thermal comfort in calculating the index stems, first and foremost, from the complexity of the precise calculation of heat stress intensity, which depends on the unique physical characteristics of each urban environment and their impact on the climatic variables included in the heat stress calculation: air temperature, relative humidity, wind speed, and radiation flux intensity on the human body. Since we do not have reliable and fast computational tools for calculating a thermal comfort index for different design tasks, a systematic assessment of heat stress in urban space for urban planning should be done by developing more efficient calculation methods, even when quantifying the heat stress is less accurate. In Israel's summer climatic conditions, the way to do this is by focusing on shade because sufficient shading can ensure, with a high degree of confidence, a significant reduction in heat stress. An extensive set of measurements we conducted in 2020 and 2021 in Tel Aviv (207 measuring points) and Kfar Saba (100 measuring points) supports this insight. The measurements revealed that during the hot season in Israel, the effect of shading on a significant reduction in heat stress is decisive. However, it is important to emphasise that the measurements also revealed that shading cannot guarantee absolute thermal comfort in the summer: **in none of the shaded points** we measured in the summer (146 points in Tel Aviv and 73 points in Kfar Saba), there was not a single time we measured complete thermal neutrality, and in the vast majority of them there was light to moderate heat stress (Figure 6 and Figure 7).[21]

Our measurements also revealed that the positive effect of shading on heat stress relief far exceeds heat stress relief caused by a slight drop in air temperature or relative humidity or an increase in wind speed.[22] Under summer conditions in Israel, improvement in these climatic variables is limited in intensity and does not come close to the intensity of heat stress relief created by shading. This was especially true when we measured two adjacent outdoor points. Three main reasons cause this: first, the air temperature in the city during summer in Israel is relatively high, and combined with high relative humidity in some areas of the country, basic conditions of heat stress are created even without the influence of solar radiation; secondly, air turbulences cause an almost completely uniform mix of air temperature between areas exposed to sunlight and adjacent shaded areas on urban streets; and third, in most cases the urban environment causes significant decrease in wind speed and thus significantly reduces the ability of wind to bring relief from heat stress.

The series of measurements that we conducted, therefore, revealed that in the climatic conditions prevailing in the summer in Israel, it is sufficient to examine whether sufficient shading exists in a particular environment to conclude that the prevailing heat stress will be significantly lower than in a similar physical environment that is not shaded. At the same time, the results of the measurements also revealed that the formulation of shading targets in Israel cannot be based on a wish to achieve total thermal neutrality in the summer, at least in the Israeli Coastal Plain, which is unrealistic in light of the results of our measurements, but must focus on optimising the impact of direct sunlight on urban walking and gathering spaces.

[21] Determining the degree of heat stress according to the PET index was made according to a scale of values adapted to climatic conditions in Israel, as defined in Cohen, P., Potchter, O., & Matzarakis, A. (2013). Human thermal perception of Coastal Mediterranean outdoor urban environments. *Applied Geography*, 37(1), 1–10.

[22] Aleksandrowicz, O., & Pearlmutter, D. (2023). The significance of shade provision in reducing street-level summer heat stress in a hot Mediterranean climate. *Landscape and Urban Planning*, 229, 104588; see also: Middel, A., AlKhaled, S., Schneider, F. A., Hagen, B., & Coseo, P. (2021). 50 Grades of Shade. *Bulletin of the American Meteorological Society*, 102(9).

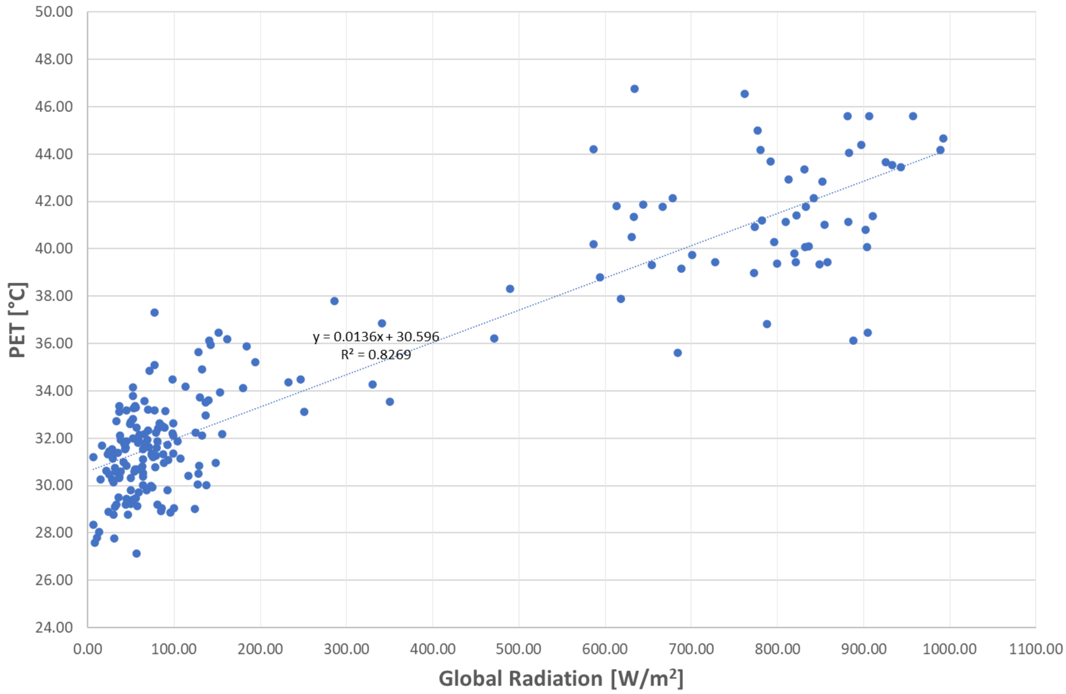


Figure 6: The relation between global radiation and thermal comfort according to the PET index, as shown in measurements we conducted in Tel Aviv between 5 July 2020 and 1 September 2020 (207 measuring points). Not a single measurement showed complete thermal neutrality (PET below 26°C). In almost every measurement in the shade, heat stress (PET above 28°C) was measured, even in cases where the shading was of high quality (global radiation of less than 100 W/m²).

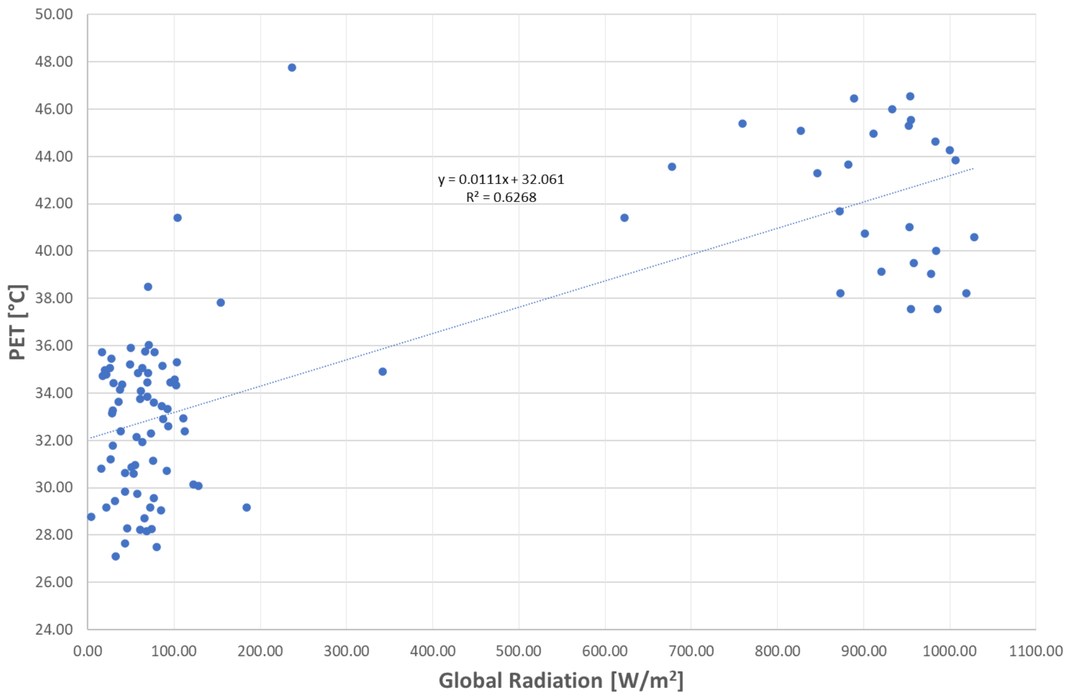


Figure 7: The relation between global radiation and thermal comfort according to the PET index, as shown in measurements conducted in Kfar Saba between 15 June 2021 and 11 August 2021 (100 measurement points). This set of measurements also yielded similar findings regarding the realistic impossibility of ensuring absolute thermal neutrality in the shade during a summer day.

In developing any shade index, it is important to provide an accurate and clear answer to three fundamental questions, the answer to which may also indicate the correlation between the index and the reduction in heat stress during the hot season caused by a decrease in solar exposure: what is the reference area for which the shading rate is calculated; what is the reference time for which the shading rate is calculated; and when it is possible to determine that a point in space is in shaded. The Shade Availability Index answers these three questions as follows:

- The primary reference area for which the Shade Availability Index is calculated is the total area of a sidewalk on a given street segment. A street segment is defined as a part of a street bounded between two road junctions. A street segment usually has two sidewalks on either side of a road (or carriageway), although there are streets (for example, pedestrian streets) where the area of the sidewalk is equal to the area of the right-of-way. The reason for choosing sidewalk space in a street segment as the spatial reference unit for which the index is calculated derived from the understanding that shading is especially essential for non-motorized road users and that it is important to maintain a shaded continuum along the entire sidewalk in a given segment to ensure a significant reduction in heat stress while walking.
- The reference time for calculating shading is most of the daylight hours on a typical summer day. In Israel, we set the reference time to 08:00 to 17:00 (daylight saving time) on 6 August, which is the middle day between the longest day of the year (21 June) and the autumnal equinox (22 September). Due to the intensity of daytime air temperature, this day also represents the peak of annual heat stress.[23] This date corresponds to 6 May in terms of the sun's position in the sky and the resulting shading pattern, thus quantifying the shading conditions in the spring, too.
- In calculating the index, a point in space is regarded as shaded when direct solar radiation does not hit it at ground level (unlike head height or the centre of gravity of the human body). The index does not consider the effect of reflected radiation since the heat load caused by reflected radiation is mostly negligible relative to the heat stress caused by direct sunlight and because of the difficulty in accurately estimating the reflection coefficients of all surfaces in the street space.

Based on these definitions, we defined a **Shade Availability Index** as describing, on a scale from 0 to 1, the relative amount of time from the entire reference period (08:00 to 17:00 on 6 August) that the reference area (sidewalk) is in a sufficient state of shading. The question of what constitutes a

[23] This is because air temperature is affected by several factors, the most important of which is the Earth's heat capacity. The Earth, warmed by the sun, emits heat into the atmosphere in the form of radiation in a slow process that usually takes between 4 and 6 weeks, which is why the hottest days in Israel are the days in early August, about a month and a half after the day when the amount of radiation hitting the surface is the highest. See Dagan, S. (2010). Why is August the hottest month of the year? Davidson Institute, the educational arm of the Weizmann Institute of Science.

"sufficient state" of shading is normative, and has no unequivocal scientific answer. Here, we have chosen to determine that the reference area (for example, a single sidewalk) will be in a sufficient state of shading at a given moment **if at least 50 per cent of its area is shaded**, assuming that the buildings and the shading elements on the street are more or less distributed along it at regular spacing. We believe that when half of the area of a sidewalk is in the shade under these conditions, road users can choose equally between moving in the shade and moving with full exposure to sunlight in the case of continuous shading (Figure 8). On the other hand, when at least 50 per cent of the pavement area is in intermittent shade (Figure 9), there is a continuous path of intermittent walking in the shade throughout the walking path. It is important to emphasise that in cases where the street section varies substantially along a single street segment, the Shade Availability Index must be calculated separately for each part of the street segment in which its morphology is uniform.

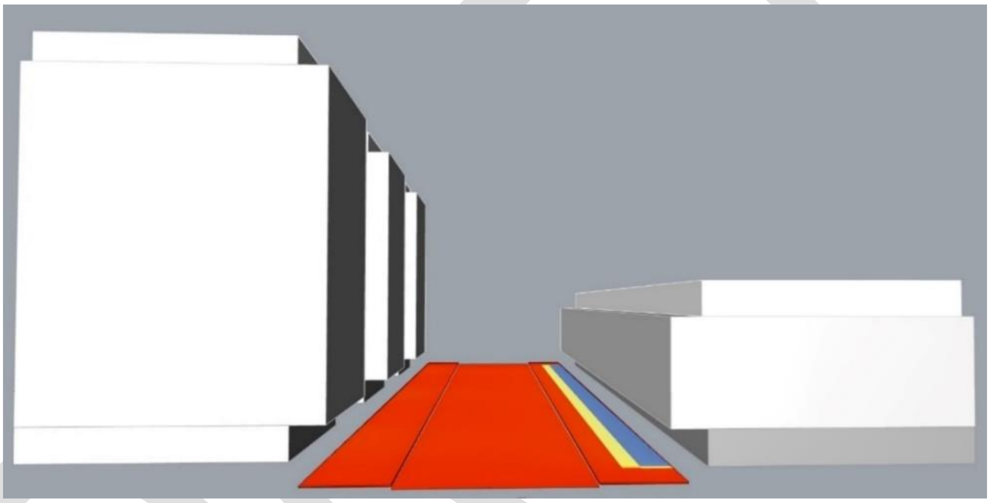


Figure 8: Example of continuous shading exceeding 50 per cent of the pavement area on the right sidewalk.

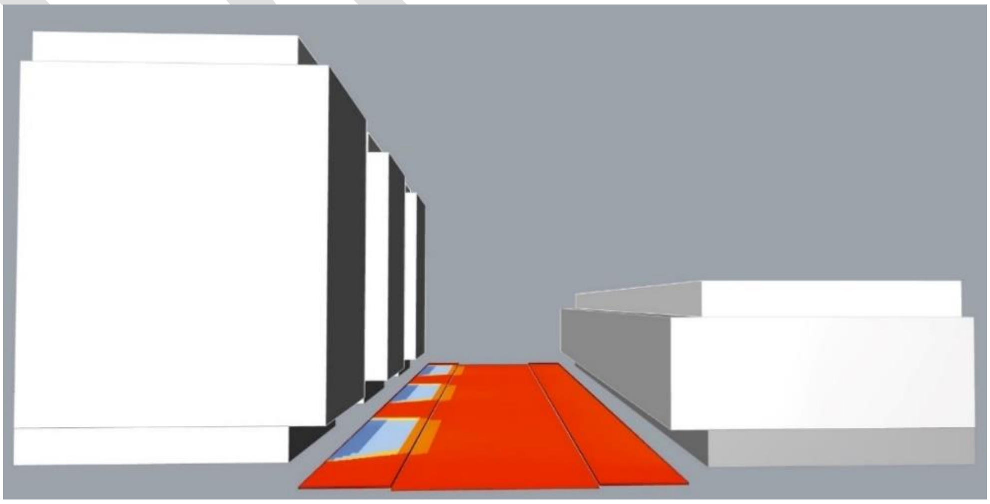


Figure 9: Example of intermittent shading exceeding 50 per cent of the pavement area on the left sidewalk.

Understandably, we could have set a more ambitious target (for example, 75 per cent of the sidewalk area or even its entire area) as a starting point for calculating the Shade Availability Index. But the question that must be asked is to what extent such an ambitious target can be realised under realistic planning conditions and to what extent it can substantially improve the reasonable possibility of walking in the shade. We believe that shading 50% of the pavement area as a "satisfactory condition" provides a balanced response to the planning challenge of shading the walking spaces because this rate ensures the existence of sufficient shaded area for continuous walking on a sidewalk that is three m wide or more.

To calculate a sidewalk's Shade Availability Index, one must check whether, at each full hour between 08:00 and 17:00 (a total of 10 time points) on 6 August, at least 50 per cent of the sidewalk area is shaded. The Shade Availability Index describes the ratio between the number of full hours during which the sidewalk is in the state of sufficient shading (50 per cent or more of the area is shaded) and the total number of full hours of the reference time (as defined above, 10 hours). The more full hours during which at least 50 per cent of the sidewalk area is shaded during the reference time, the higher the index and the closer to 1. For example, if more than 50 per cent of the sidewalk area is shaded at 6 full hours during the reference time, the sidewalk's Shade Availability Index would be 0.6.

The advantage of using the Shade Availability Index is in simplifying the calculation of shade to geometric calculation and in the ability to adopt it as a normative measure that is easy to understand because it mainly expresses the rate of time throughout a summer day in which proper shading conditions prevail, without the need for complex calculations relating to quantifying the effect of solar radiation on heat stress intensity. For example, it is relatively easy to understand that a Shade Availability Index of 0.3 does not guarantee reasonable shading conditions because it means that 70 per cent of the time the sidewalk is primarily used during daylight hours it does not have sufficient shaded space. It also follows that a normative scale of desired shade availability levels can be determined based on quantifying the amount of time during which a sidewalk is sufficiently shaded. For Israeli conditions, we propose setting three levels of shading as desirable normative targets in shading-oriented urban planning. These three levels are:

- **Acceptable shading** — Shade Availability Index value of **0.5 or higher**
- **Very good shading** – Shade Availability Index value of **0.7 or higher**
- **Excellent shading** – Shade Availability Index value of **0.9 or higher**

Setting three levels of shade availability allows you to set gradual targets for shade intensification based on current and projected resources. For example, a municipality can determine that certain streets should reach a state where **acceptable** shading will be achieved within five years, while **very**

good shading should be achieved within ten years. To meet these targets, the municipality will take ongoing actions that will also include monitoring the progress of the shading situation during the entire time frame. However, recognising the practical limitations of realising shade intensification operations, it is important that the choice of the desired level of shade availability be made in accordance with local considerations and the resources available to the planning authorities, and after an initial examination that would show what entails meeting a particular target. In the following chapters, we will expand on how design decisions may affect the level of shade availability according to the index presented here. We will also see that meeting even the highest levels of the index is almost always applicable with proper planning and a precise and efficient combination of shading from buildings, trees, and artificial shading elements (pergolas, awnings, etc.).

The Shade Availability Index is calculated for each sidewalk separately, and this calculation method allows flexibility in setting shading targets that are not identical on each sidewalk or walking strip on the street. For example, it is ostensibly possible to set as a planning goal that it is enough for one of two sidewalks on a street to meet a certain shading threshold for the entire street to be considered a shaded street. In the same way, it is ostensibly possible to determine that it is sufficient for a walking boulevard in the middle of a street with sidewalks on each of its sides to meet a certain shading threshold. However, we believe that such partial targets may miss the main purpose for which the index was created, which is to encourage non-motorized traffic through a street during the day because they force road users to change their shortest lane of movement in search of shade. Therefore, when setting shading targets, we recommend that **all walking lanes on a particular street segment meet at least the lowest shading threshold** (acceptable shading, Shade Availability Index value of 0.5 or higher).

Example of using the Shade Availability Index in design

This chapter presents an example of shade design conforming to the targets detailed above using a Grasshopper code called Kikayon developed by Or Aleksandrowicz and Ezra Ozery in a work funded by the Israel 100 Initiative (for a detailed explanation of the tool see Appendix B).[24] In this design task, the street segment is 200 m long, each of its sidewalks is 6.5 m wide, and the walking boulevard at its centre is 15 m wide. The street is precisely oriented on an east-west axis, which means that the contribution of its buildings to shading is low. On the south side of the street stands a continuous building 15 m high, and on the north side are three buildings 36 m high and 34 m wide, with a lateral

[24] Aleksandrowicz, O., & Ozery, E. (2023). A Parametric Tool for Outdoor Shade Design: Harnessing Quantitative Indices and Visual Feedback for Effective and Efficient Climatic Design of Streets. In M. Turrin, C. Andriotis, & A. Rafiee (Eds.), *Computer-Aided Architectural Design. INTERCONNECTIONS: Co-computing Beyond Boundaries* (pp. 302–316). Springer Nature Switzerland וכן ;https://israel100.org/project/1891.

32 m distance between each of them. In the original street plan, there are no trees. The calculation of the Shade Availability Index shows that shading on the sidewalks and the boulevard is very poor (Figure 10). There is no sufficient shading on the boulevard at any of the reference time hours, and each sidewalk has sufficient shading at only one hour out of 10.

The first planning action deals with the design of shading in the boulevard. For this purpose, two rows of trees with a planting spacing of 12.5 m are specified. The shade trees designated for planting are Delonix regia trees, and the shading calculation considers their condition 10 years after planting when the tree canopy diameter is expected to reach 8 m. In this situation, the Shade Availability Index in the boulevard jumps from 0 to 1 (Figure 11). As for the sidewalks, first, the scenario of planting Delonix regia trees at 20 m spacing on each sidewalk was examined. In this situation (Figure 12), the southern sidewalk receives excellent shading conditions (Shade Availability Index value of 1.0), while the northern sidewalk is reasonably shaded (Shade Availability Index value of 0.6). However, reducing the planting spacing on the northern sidewalk to 12.5 m also makes this sidewalk excellently shaded (Figure 13).

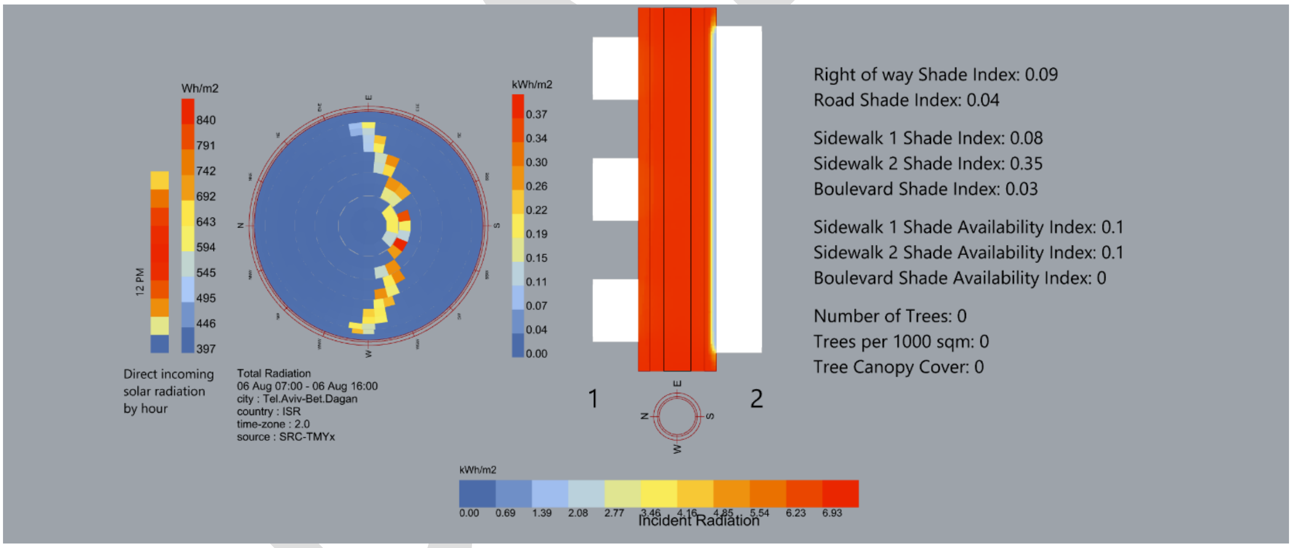


Figure 10: Shading on the street in its initial state, without adding shade trees.

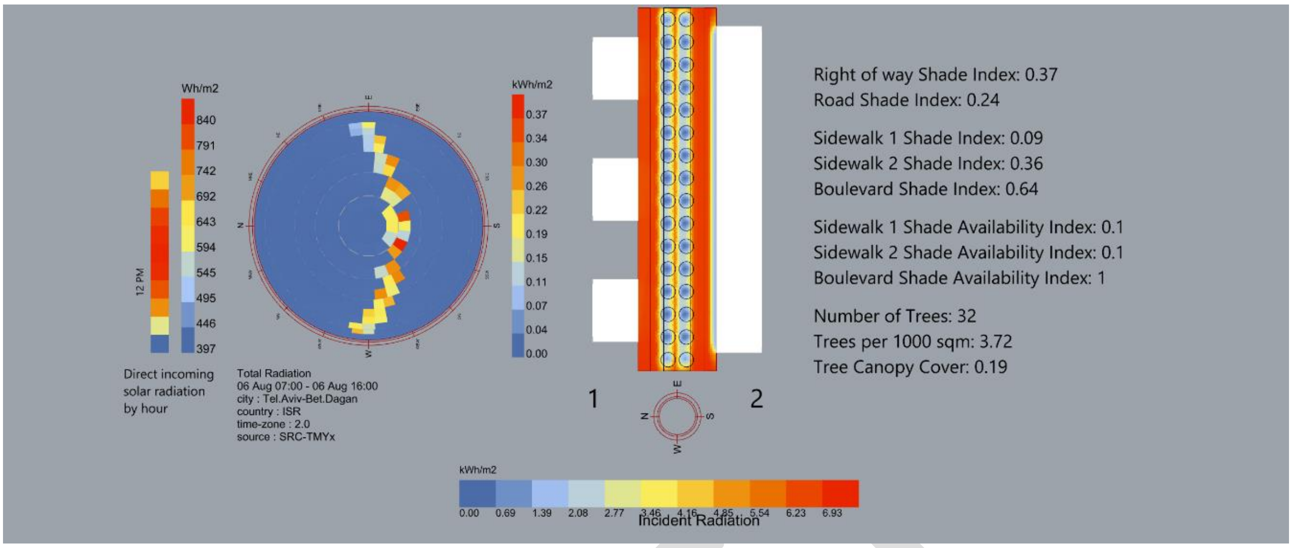


Figure 11: Shading on the boulevard after the addition of trees.

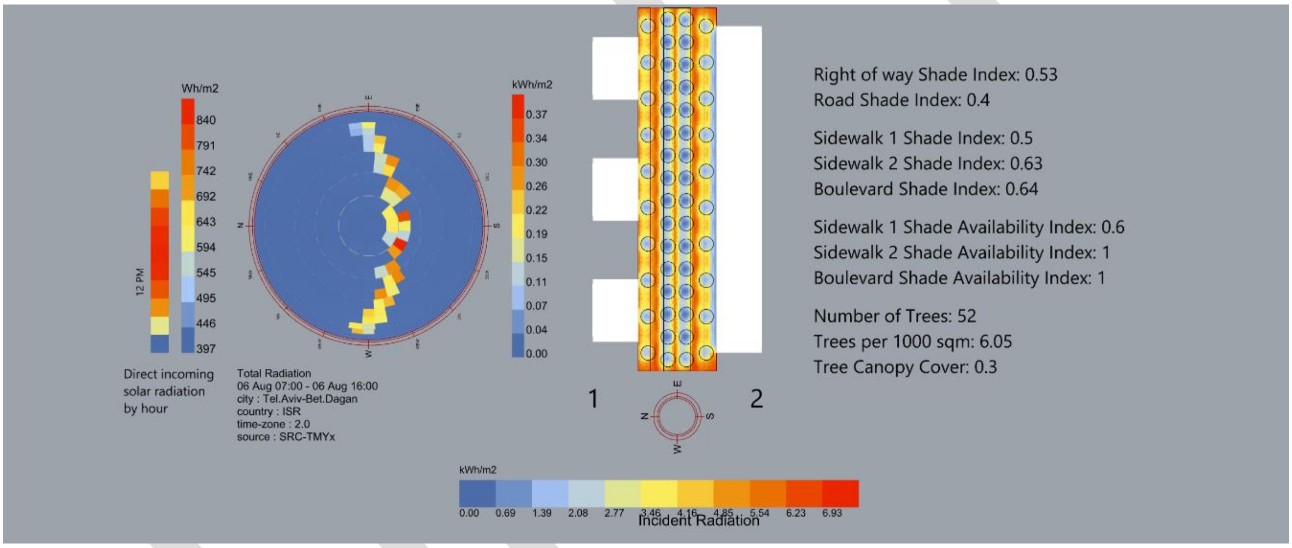


Figure 12: Shading on the sidewalks after the addition of trees.

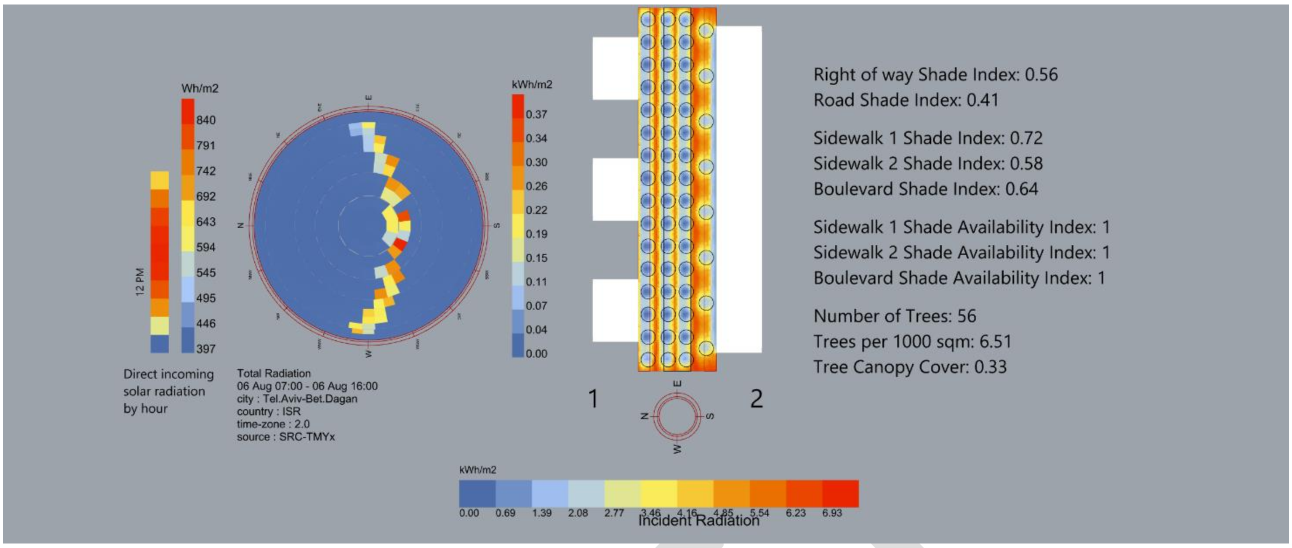


Figure 13: Improved shading on the northern sidewalk with the addition of shade trees.

Although ostensibly shade design in this manner yielded an excellent solution, in practice, it is a solution that is expected to have an effect only about a decade after its realisation due to the rate at which trees grow. Therefore, it is important to check the state of shading after five years of growth for the same tree-planting layout. During that period, the Delonix regia trees are expected to develop a tree crown diameter of only 5 m. In that situation, the Shade Availability Index will be very low on the northern sidewalk and the boulevard and will reach only an acceptable level on the southern sidewalk (Figure 14). Therefore, a much larger number of trees is necessary to ensure excellent shading on the street even after 5 years.

In the tree intensification scenario we examined, the planting spacing on the south sidewalk was 10 m and 6 m on the boulevard and north sidewalk. In this situation, on both sidewalks, the Shade Availability Index reaches the maximum threshold (1.0), while the level of shading on the boulevard manages to reach an acceptable level (Figure 15). Additional trees in the boulevard, to reach planting spacing of 5 m, bring shading in the boulevard to the maximum level (Figure 16). It is worth noting that this situation is achieved even when the **street's** tree canopy cover ratio is relatively low (30%).

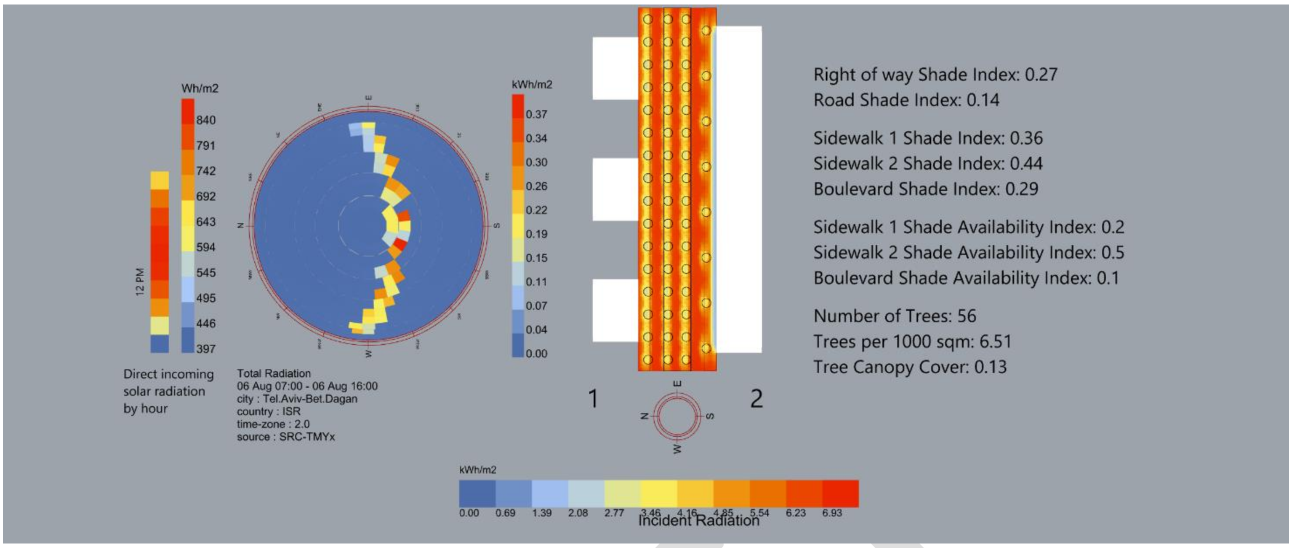


Figure 14: Shading on the sidewalks and the boulevard after 5 years of growth.

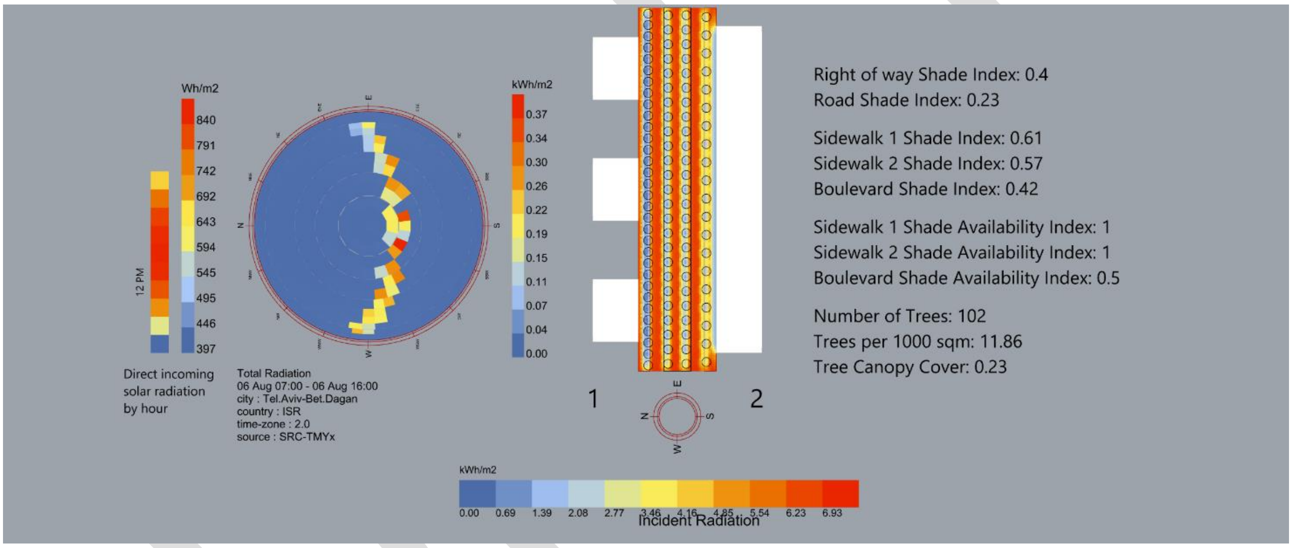


Figure 15: Shading on the sidewalks and the boulevard after 5 years of growth after significantly adding trees.

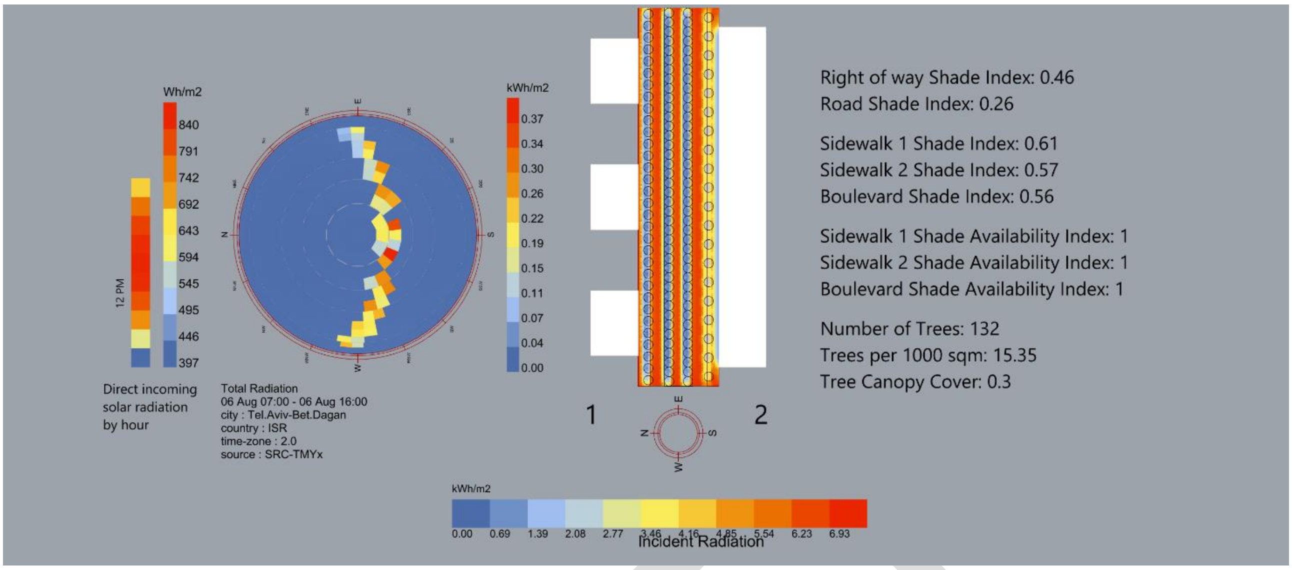


Figure 16: Shading on the sidewalks and the boulevard after 5 years of growth after adding more trees to the boulevard.

After calculating shading levels in the different planning scenarios, the planners are faced with several possible solutions for a significant improvement in shading on the street using trees. The difference between the solutions relates not only to the levels of shading that can be achieved with trees but also to when a significant change in street shading conditions is expected. Another significant difference is the number of trees required in each planning solution, ranging from 56 to 132. Although the decision on which planning scenario to choose is based on quantifying shading levels using the Shade Availability Index, it must involve additional considerations relating to the resources available for realisation and the planning goals that do not directly relate to the practical realisation possibilities of planting trees.

The effect of street design on sidewalk shade availability

The Shade Availability Index (SAI) makes it possible to comparatively examine different design scenarios while quantifying the changing effect of certain design elements on improving or worsening shading conditions. Without a quantitative index, shade design may be based on incomplete or incorrect information, leading to an overestimation or underestimation of differences between different design options. For example, shade design without a quantitative index may lead to overplanting street trees when the relative positive effect of additional trees on shading conditions is limited due to sufficient shading from existing buildings or trees. The investment in these excess trees should be directed to planting on streets where the level of shading is lower than acceptable.

When getting into detailed street shade design, we recommend beginning with calculating the Shade Availability Index obtained without trees or external shading elements such as pergolas or awnings. In this way, it is possible to understand better the basic level of shading created by the permanent physical infrastructure of the street: street orientation, sidewalk width, right-of-way height-to-width ratio, and the gaps between buildings. After calculating this, it is easy to examine different methods for increasing shade availability using trees or other elements. Using the Shade Availability Index will make it possible to achieve a reasonable balance between meeting the quantitative shading targets and reducing the public expenditure required to meet them, recognising that these components are relatively expensive to realise and that the cost of installing and maintaining them falls on the public's shoulders.

A detailed shade design process should consider the unique primary conditions of each street designated for shade intensification based on accurate documentation of the street's main elements, including its trees. This is because minor differences in street design can sometimes significantly change shade availability levels. Nonetheless, the level of shade availability will usually rely on fundamental planning decisions relating to three areas of design decisions: street orientation, street morphology (building height, location, and density, as well as the width of the right-of-way), and the dimensions of shade trees, their density, and location. The comparisons presented here between different design scenarios and the levels of shade availability resulting from them are intended to demonstrate the impact of each of these domains and, at the same time, to show that meeting the shading targets defined in these guidelines does not depend on a single "optimal" solution but can be achieved through a wide range of different design approaches.

The effect of street orientation on the Shade Availability Index

The sun's relative position in the sky varies from season to season and during the daytime. In the Israeli summer, the sun appears at a relatively low angle of 30 degrees, and its position relative to the Earth continues to change towards the south until the middle of the day. At this time, the sun's rays hit the ground surface at an angle of about 75 degrees. From here, the position of the sun gradually "decreases" westward in a mirror-like trajectory to the first half of the day (Figure 17). This means, for example, that an eastern row of buildings on a street oriented on a north-south axis will cast a long shadow on the western side of the street in the morning but will cease to cast shadows on the street's area (road and sidewalks) from noon. This situation is completely different on streets oriented on an east-west axis, because the high midday sun causes buildings on the south side of the street to cast a relatively short shadow into the street's area.

Figure 18 shows a comparison of four identical design scenarios in all their characteristics (height/width ratio 0.6, the top of tree canopies 9 m from the ground) except the street orientation, along with the results of calculating the Shade Availability Index on each sidewalk. The figure shows the street segments in a schematic view in which the outlines of the buildings (white rectangles), curb stones (black vertical lines) and tree crowns (black circles) are drawn. The right-of-way area is painted in shades ranging from blue to red to show the intensity of the cumulative exposure of the ground to solar radiation (the less intensity and the lower the shading, the closer the hue is to blue).

It can be seen that in this case, where shading is achieved by combining buildings and trees, the target of acceptable shading can be met on both sidewalks on the street oriented north-south and on one sidewalk in all other orientations. In the east-west orientation, there is a large difference in shading conditions between the two sidewalks: on the southern sidewalk, the Shade Availability Index is 0.8, compared to 0.2 on the northern sidewalk. In the other orientations, there are relatively small or no differences in the shading conditions between the two sidewalks. The comparison highlights the relative advantage of north-south streets in shading sidewalks (mainly due to the shading of buildings on the street area) over streets oriented east-west. On these streets, it is difficult to achieve acceptable levels of shading without a significant and continuous layer of shade trees, especially on the northern sidewalk, where the effect of shading from buildings is hardly felt.

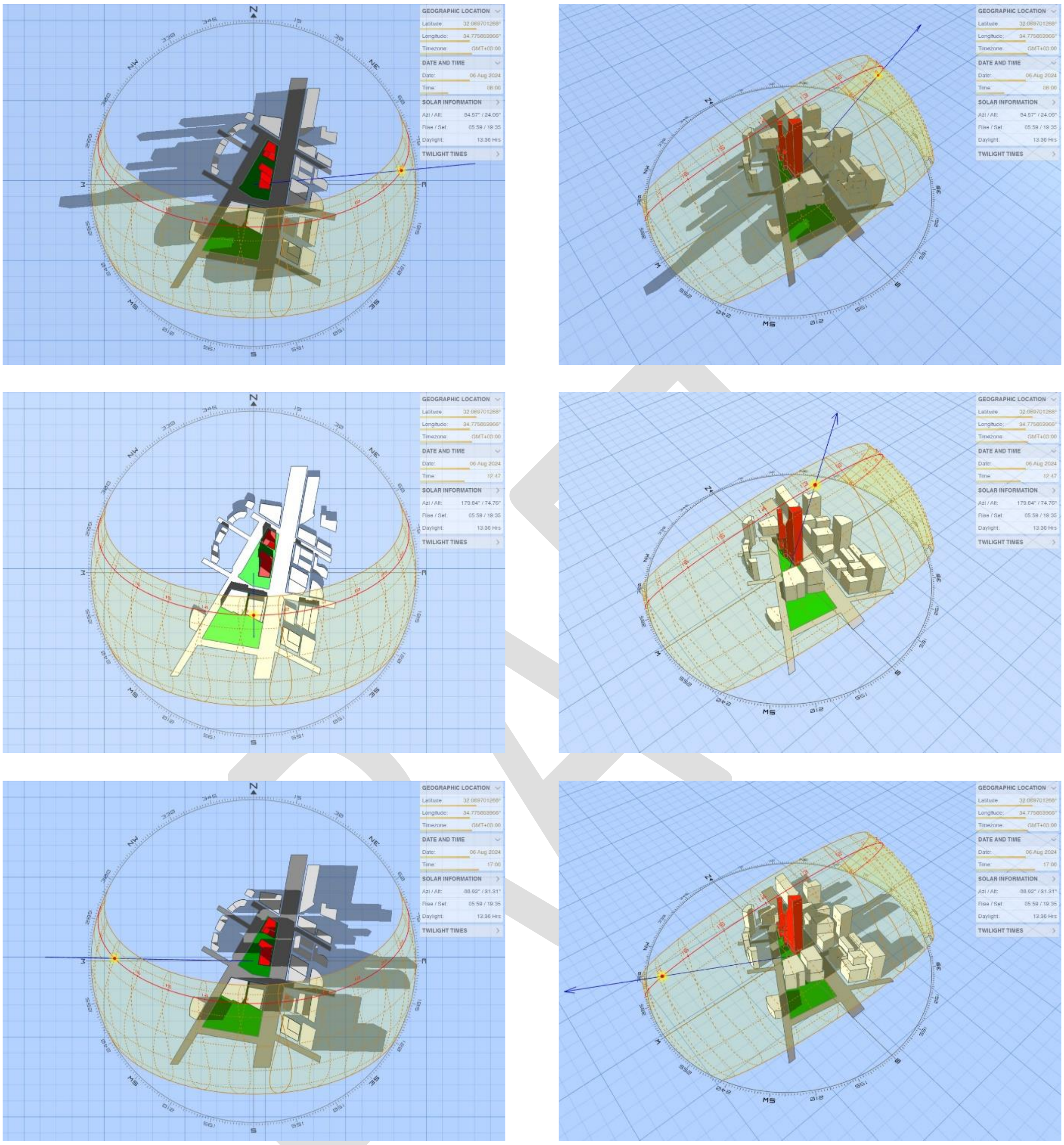


Figure 17: Schematic depiction of the Sun's orbit in the sky on 6 August in Tel Aviv (red line), showing the incidence angle of the Sun (Blue Arrow) at several times throughout the day (daylight saving time): 08:00 (top row), 12:47 PM (solar midday, middle row), and 17:00 (bottom row). Every hour shows a perspective view from the southwest (right) and a top view (left). The images were produced using [the Sunpath3d website](#)created by Dr. Andrew J. Marsh.

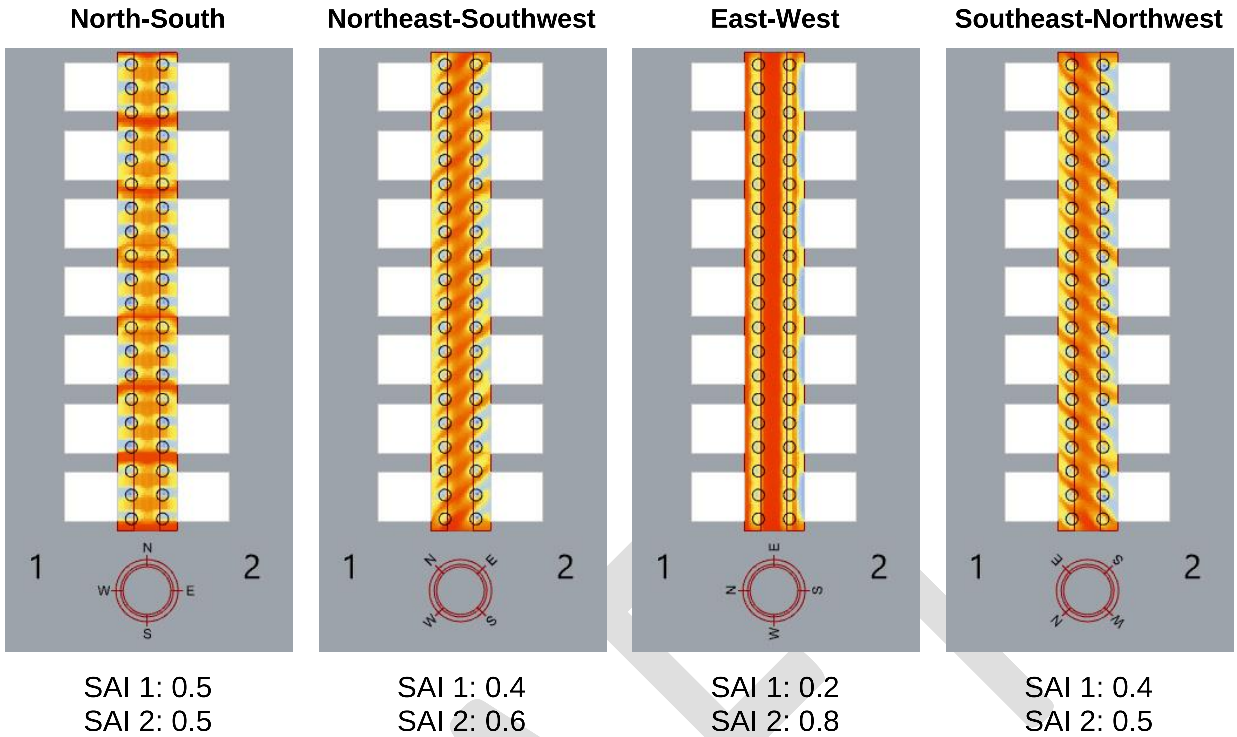


Figure 18: Comparing the Shade Availability Index (SAI) on streets of different orientations. The streets' height-to-width ratio is 0.6.

The effect of street morphology on the Shade Availability Index

The morphology of a street relates to all design decisions regarding the general dimensions of the street, the division of the right-of-way between sidewalks and traffic lanes, the number of buildings on both sides and their shape and location relative to the right-of-way. The effect of morphology on shade availability levels also depends on a street's orientation, and it will be less pronounced on east-west streets. However, it can be said, in general, that the higher the ratio between the height of buildings and the width of the right-of-way between them, the greater the chance of increasing the availability of shade on sidewalks through buildings on both sides of the street, even without the addition of trees or other means of shading in the sidewalk area.

Figure 19 shows three shading scenarios for north-south streets, each with a different right-of-way, road, and sidewalk width. The scenarios are identical in terms of the height of the buildings (13 m), their number, the setback of the front building line from the parcel line and the lateral building lines, and the lack of trees. The scenario in which shade availability is highest is also the scenario in which the road (11 m) and sidewalk (3 m each) width are the narrowest, while the scenario where the road (18 m) and sidewalks (8 m each) are the widest is also the one in which the Shade Availability Index is the lowest. This indicates that in certain orientations, acceptable levels of shading can be reached on narrow streets only by relying on shading from the buildings themselves. Examining the intermediate scenario, in which the sidewalk is relatively narrow (3 m wide), is interesting since the road is wide (18 m): although the sidewalk width and building height are identical in this scenario and the narrowest street scenario, the index is lower. The reason for the difference in this case is the additional shading obtained from the buildings on the other side of the road, the effect of which decreases as the width of the road between the sidewalks increases. This indicates that the width of the road has a negative impact on the levels of shading on sidewalks in orientations where a significant potential for shading from buildings on the other side of the street exists.

Figure 20 shows the positive effect of increasing building height on sidewalk shade availability. The four scenarios shown in this figure are of a north-south street without trees, with each sidewalk 9 m wide and the total right-of-way 36 m wide. A comparison of the Shade Availability Index values in each scenario shows that shade availability on sidewalks can be improved by significantly increasing building height on both sides of the street, even without adding trees. However, it is important to remember that such an effect is mainly characteristic of north-south streets, and its intensity will decrease as the width of the right-of-way increases.

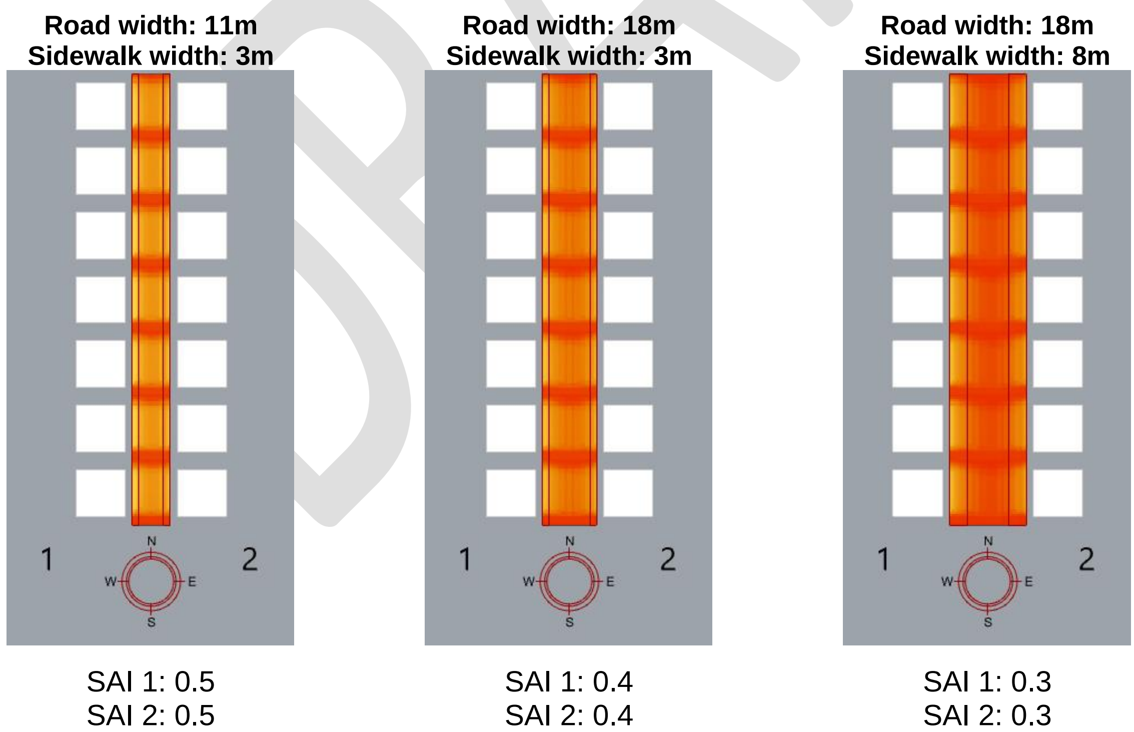


Figure 19: Comparing the Shade Availability Index (SAI) on streets with varying road and sidewalk widths. The height of the buildings is 13 m.

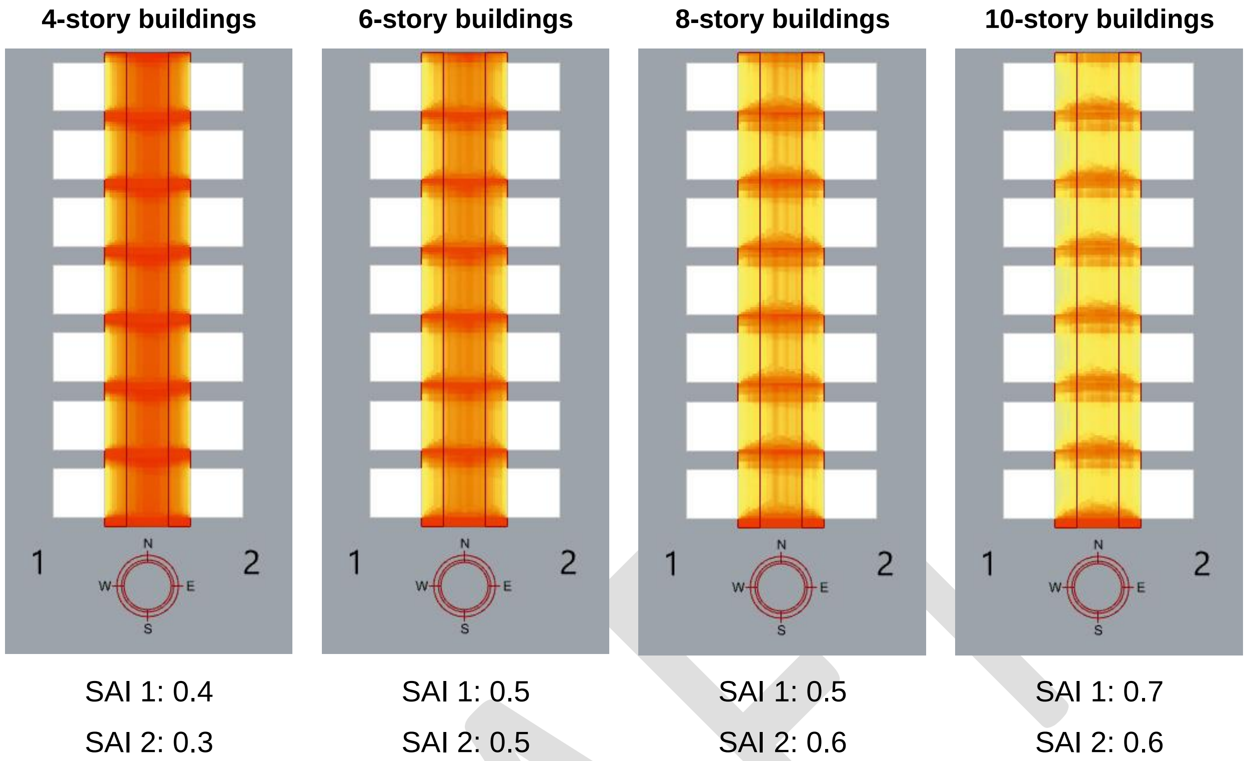


Figure 20: Comparison of the Shade Availability Index (SAI) on streets with different building heights. Right-of-way width: 36 m.

The effect of planting shade trees on the Shade Availability Index

Shade trees are trees whose crown is wide and dense enough to cast a relatively uniform shade on the ground. Therefore, not every tree planted in built-up areas is a shade tree, even if the tree itself is of a species recommended for street planting. The design assumption should be that a tree defined as a shade tree will be a tree whose growing, pruning, and maintenance conditions allow its crown to block at least 90 per cent of the direct sunlight that hits the top layer of the tree crown and whose shade on the ground is continuous and relatively uniform.[25] Evidently, the presence of trees in urban spaces may have positive or negative environmental impacts regardless of the shade they cast, and these effects should be considered when designing shading that is at least partially based on the use of shade trees. However, the Shade Availability Index is not intended to quantitatively examine

[25] In Israel, almost no systematic studies have examined the rate of solar radiation penetration through tree crowns of different tree species. An exception is the study of Limor Shashua-Bar et al. on three tree species in Tel Aviv (Ficus Retusa, Date Palm, Tipuana Tipu); Shashua-Bar, L., Potchter, O., Bitan, A., Boltansky, D., & Yaakov, Y. (2010). Microclimate modelling of street tree species effects within the varied urban morphology in the Mediterranean city of Tel Aviv, Israel. *International Journal of Climatology*, 30(1), 44–57. Much broader work has been done in the United States and may indicate the light transmittance through tree crowns of several tree species planted in Israel, considering the different growing conditions between the two countries. See McPherson, E. G., Xiao, Q., van Doorn, N. S., Johnson, N., Albers, S., &; Peper, P. J. (2018). Shade factors for 149 taxa of in-leaf urban trees in the USA. *Urban Forestry &; Urban Greening*, 31(March), 204–211.

these effects, but is rather limited to quantifying the effect of shade trees on improving the state of shading on sidewalks.

Planting shade trees is a central tool that can improve the state of shading on existing or projected streets within a period of a few years. However, similar to the effect of street morphology on shade availability on sidewalks, planting of trees may prove ineffective in improving shade conditions for two main reasons: one, due to soil volume and maintenance limitations, the trees planted do not reach their full growth potential and develop a relatively limited-size crown because their habitat could not satisfy their needs; the second is that even in a situation of full growth of the tree crown, the location of the trees or the planting spaces between them do not provide sufficient shade coverage on the sidewalks. When seeking to improve the state of street shading by planting trees, it is also important to examine the effect of different planting scenarios on the relative improvement in the level of shade availability and to take into account that the growth rate of a street's tree canopy may be slower than expected.[26] Therefore, planting shade trees should aim to plant a small number of large trees that form a continuous canopy over a larger number of small trees whose foliage is smaller but for which more resources are required (mainly irrigation, pruning, and soil management). Hence, it is possible to calculate an "optimal" planting density above which the "marginal output" of each additional tree in terms of the level of shade availability on sidewalks decreases sharply.

One accepted index for quantifying shade levels is the Tree Canopy Cover (TCC). This is a simple geometric index between 0 and 1 calculated by dividing the total area of the projection on a horizontal surface of all tree crowns in a defined space (for example, right-of-way in a street segment) by the total area of that space. This index does not take into account the direction of direct solar radiation impact and the direction and size of the resulting actual shadow projection. As a result, it can give the false impression that high levels of shading can only be realised on streets when the tree canopy cover ratio is high. As we will see in the following examples, the relationship between street tree canopy cover ratio and shade availability on sidewalks is more tenuous as the cover ratio decreases, meaning that **it should not be concluded that a low tree canopy cover ratio inevitably leads to low shading levels**. Therefore, using the tree canopy cover ratio to develop a municipal planting plan may lead to erroneous conclusions regarding the number of trees required for planting and the excess planting of trees beyond what is necessary to meet even the highest level of shading.

Figure 21 shows five **north-south** shading scenarios with shade trees at different growth times and planting spacing. The scenarios are identical in terms of building height (24 m), road width

[26] Eilon, Y. (2015). Sustainable design of street trees [in Hebrew]. Landscape Architecture, 54, 26-28.

(25 m) and sidewalk width (10 m). The left scenario shows a street without trees and to its right two scenarios at planting spacing of 10 m between trees. In the first of these two scenarios, five years after planting, the shade trees have not yet grown a significant crown and, therefore, do not lead to an improvement in the Shade Availability Index. However, ten years from planting (the central scenario), excellent shading is obtained. In both right scenarios, the planting spacing is 5 m between trees. Although this spacing achieves a significant improvement in shading levels already after five years, the level of shading after ten years is similar to the shading obtained from planting at 10 m spacing, and the benefit of doubling the number of trees on the street (from 40 to 80 trees) turns out to be only marginal. This means that in this orientation, it might have been right to make do with planting trees every 10 m because the basic level of shading of the street, even without trees, would have been acceptable.

Figure 22 shows five shading scenarios similar to those in Figure 21, but this time, the street orientation is **east-west**. In this orientation, buildings have almost no effect on the level of shading on the northern sidewalk. Still, on the southern sidewalk, already five years after planting the trees, a significant improvement in the Shade Availability Index can be achieved even at planting spacing of 10 m. In both scenarios where the planting spacing is 5 m between trees, there was no improvement in the state of shading relative to the corresponding situation at planting spacing of 10 m. This is because, in this direction, the shadows cast by the trees fall in most hours within the sidewalk area, unlike the situation on north-south streets. This comparison also shows that even a particularly dense planting of a single row of trees on the northern sidewalk cannot guarantee an acceptable level of shading after five years. In this case, planners should examine additional methods for adding shade, whether using temporary shading elements or adding another row of trees closer to the building facades.

Figure 21 and Figure 22 also show the tree canopy cover (TCC) ratio obtained in each scenario, along with the Shade Availability Index (SAI) on each sidewalk. A comparison between the TCC values and the shade availability values reveals that no direct relationship can be found between the two values, and that even a low TCC ratio (0.17 or 0.22) can yield very good and even excellent shading levels. Moreover, in this design scenario an acceptable level of shading can be ensured even when the street TCC ratio is very low (0.09). It follows that the value of TCC ratio as a successful predictor of the level of shade availability is extremely low, especially at low TCC levels. This is because the TCC ratio does not consider the contribution of buildings to the state of shading on the street and the direction of shadows cast by trees.

Figure 23 shows a comparison of streets where shading is achieved only by trees. This situation arises when there are no buildings next to the sidewalks, when buildings adjacent to sidewalks are very low, or when they are very far from the front parcel line. In each of the three scenarios, the width of the road (18 m) and sidewalks (7 m each) are the same, as well as the type of tree (a ten-year-old shade tree) and the planting spacing (10 m) between trees. The difference between the scenarios is street orientation. Although these are well-developed trees, some sidewalks do not even achieve an acceptable level of shading, and apart from the southern sidewalk of the east-west street, shading levels are not high. This comparison emphasises how important the contribution of shading from buildings is even when enough quality shade trees are planted on the street.

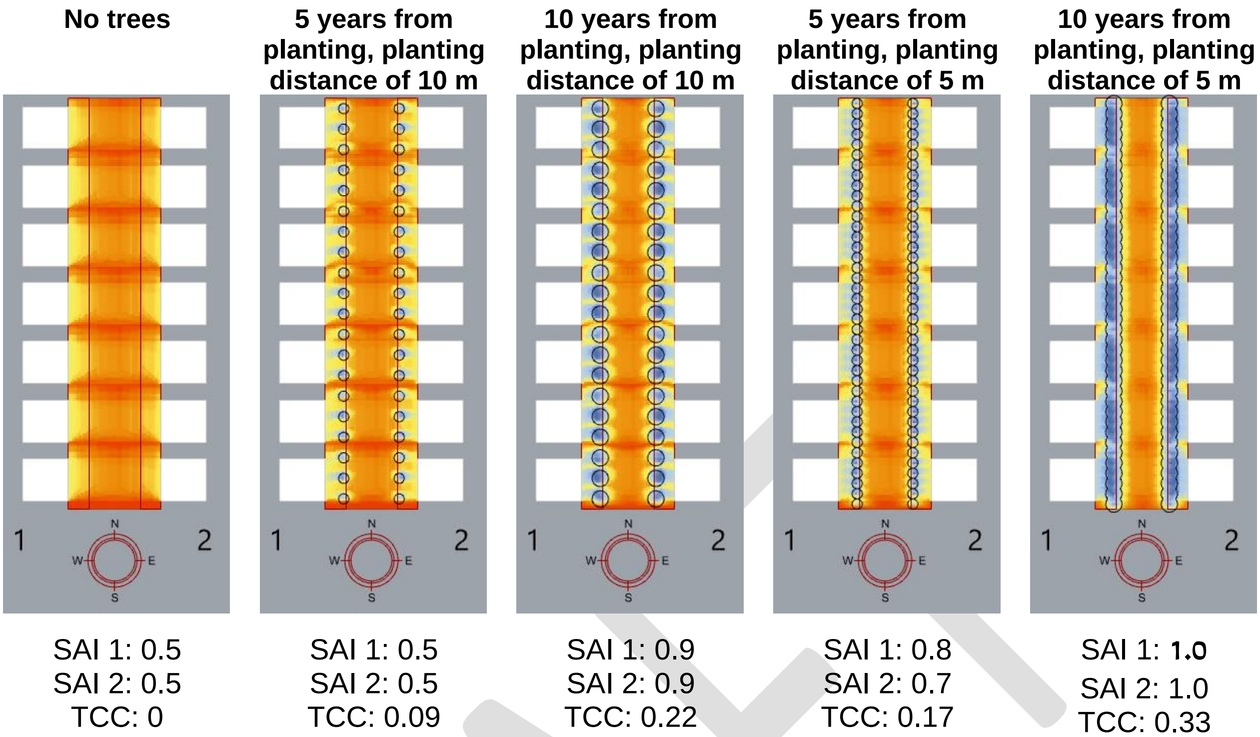


Figure 21: Comparison of Shade Availability Index (SAI) on north-south streets without trees and with trees at different planting spacing and growth times.

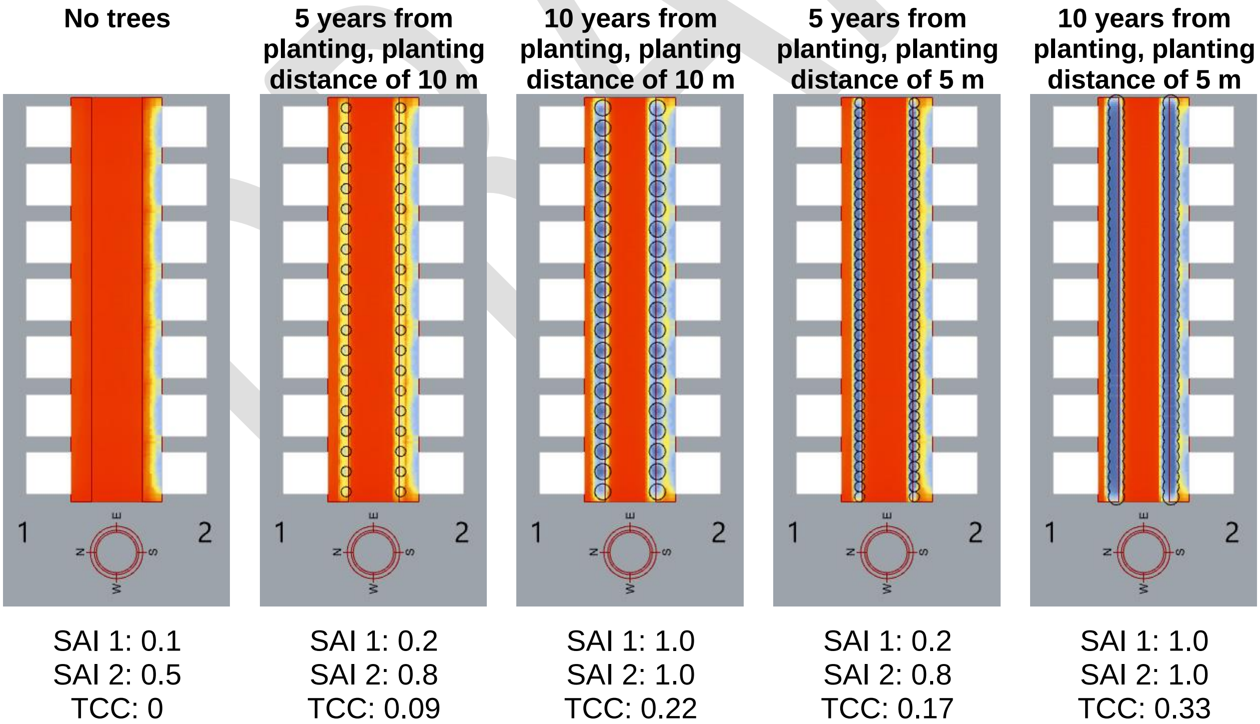
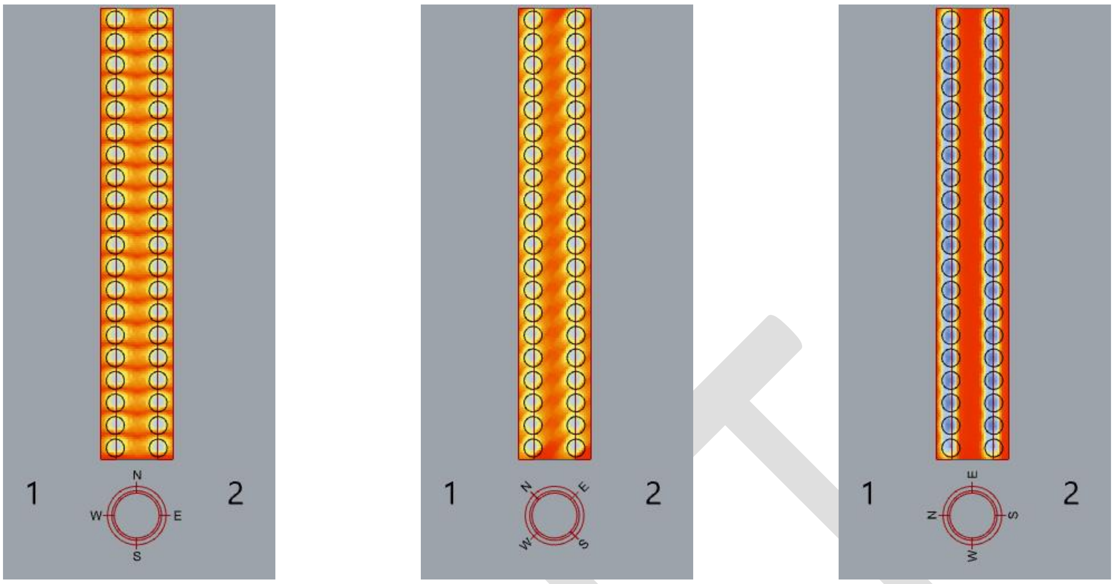


Figure 22: Comparison of Shade Availability Index (SAI) on east-west streets without trees and with trees at different planting spacing and growth times.

North-South	North East-South West	East-West



SAI 1: 0.4	SAI 1: 0.6	SAI 1: 1.0
SAI 2: 0.4	SAI 2: 0.3	SAI 2: 0.4

Figure 23: Comparison of Shade Availability Index (SAI) on streets with no buildings in different orientations.

Feasibility of meeting shading targets under different planning scenarios

Setting measurable quantitative targets may prove ineffective if these targets cannot be met under reasonable, realistic conditions. Therefore, during the formulation of the normative degrees of shade availability, we examined how difficult it is to meet the targets we set in a wide range of reasonable planning scenarios. The test was done by modelling about 20,000 design scenarios using the parametric code we developed in a previous project (see Appendix B) and calculating the Shade Availability Index on each sidewalk in each design scenario. This dataset made it possible to statistically examine the compliance rate to the shade availability targets at the various SAI index levels (0.5, 0.7 and 0.9) out of all the scenarios examined. The results showed that reaching the top shading target is possible in almost any planning situation typical of Israeli urban areas. However, reaching this target often depends on planting shade trees on the streets.

The scenario modelling was done using the Kikayon code (see above). The scenarios were designed to cover a wide range of street designs, separating main and side streets. In each scenario, the shade availability levels without adding trees were examined alongside different tree planting scenarios. The basic model consisted of a 200 m long straight street (without turns) with one sidewalk on each side of the street and a road in its centre. All street elements, including the buildings, were modelled in several possible situations, assuming they are identical on each side of the street, as follows (Figure 24):

- **Street orientation:** We modelled three street orientations: north-south, northeast-southwest, and east-west. Due to the symmetrical sun path in the sky and the calculation of the Shade Availability Index to represent the cumulative state for most of the daylight hours, the results in the northeast-southwest direction are essentially identical to the results in the southeast-northwest direction, and these scenarios did not need to be modelled too.
- **Sidewalk width:** On main streets, the sidewalk width was 7, 8, 9, or 10 m, assuming the sidewalk includes a bicycle lane and a continuous planting strip. On side streets, the sidewalk width was 2, 3, 4, or 5 m, with no bike lane or wide planting strip.
- **Road width:** The premise in each scenario was a 2 m-wide parking strip on each side of the road. On main streets, 2, 4, or 6-lane roads were considered, and on side streets, one- or two-lane roads were examined. Each lane was set to 3.5 m width. The total road width on main streets was, therefore, 11, 18, or 25 m, and on side streets 7.5 or 11 m.
- **Number of buildings along the street:** We modelled scenarios where 3, 5, or 7 buildings are on either side of the street.

- **Lateral building line:** We modelled two scenarios: a lateral building line of 4 or 8 m from the parcel line, which translates to a lateral gap of 8 or 16 m between buildings.
- **Front building Line:** We modelled two scenarios: a front building line of 0 or 3 m.
- **Building height:** We modelled four building heights: 3, 5, 7, or 9 floors above the ground floor. The ground floor height was 4 m, and the height of a typical floor was 3 m. Therefore, the total height of the buildings we modelled was 13, 19, 25, or 31 m, respectively.

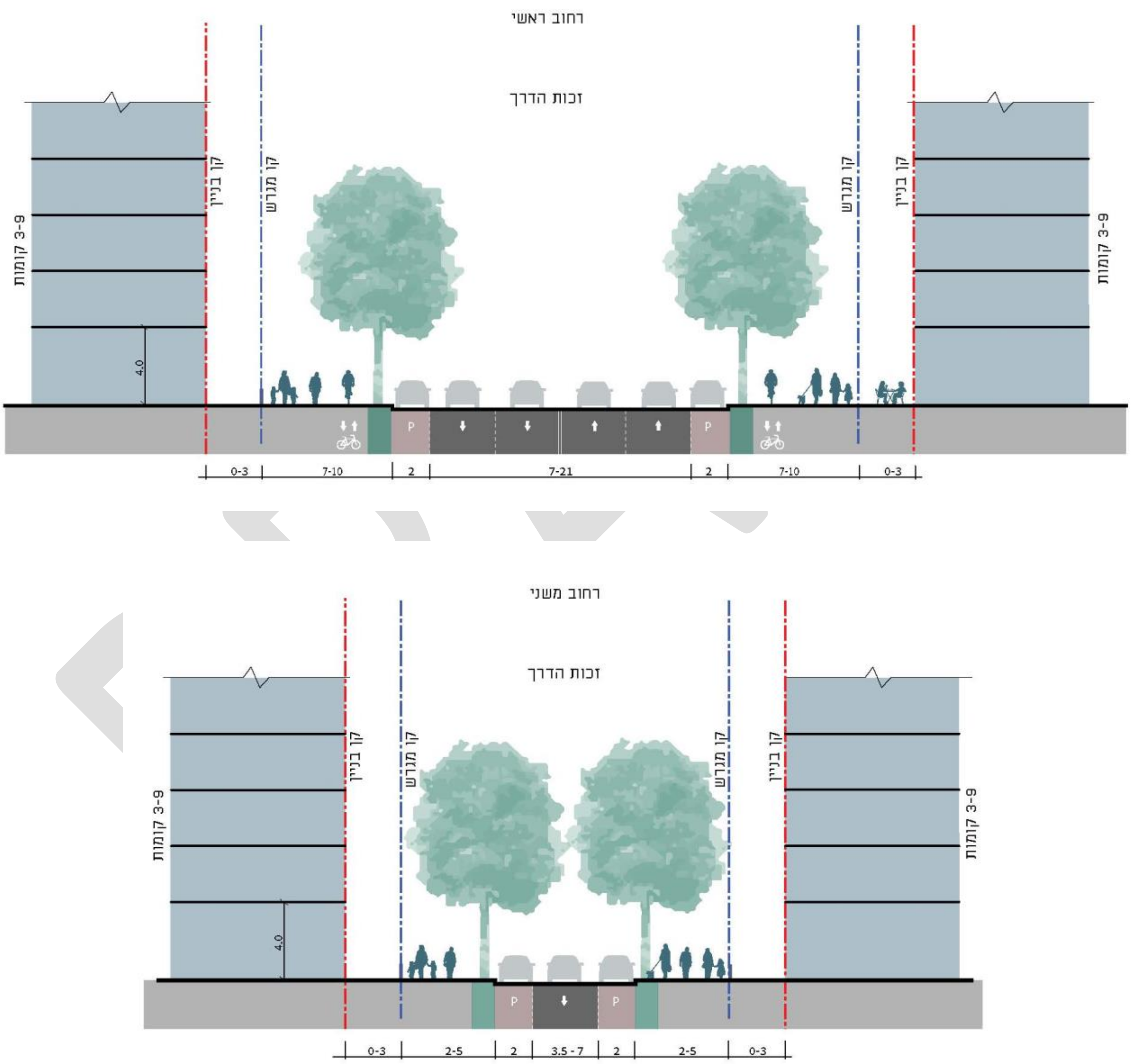


Figure 24: Schematic street section showing the fixed and variable components in the models examined for a main street (top) and a side street (bottom).

The tree planting scenarios in each model consisted of shade trees only, at planting spacing of 5 and 10 m. A shade tree is a large tree, usually from the broadleaf botanical group, planted to provide significant shade in its vicinity. In shade trees, the natural morphology creates a wide canopy combined with dense foliage, allowing optimal blocking of solar radiation that hits the tree crown. However, the urban environment is a hostile and challenging living space for trees whose natural habitat is forests and woodlands. The urban street is saturated with engineering infrastructure. Concrete and asphalt flooring seal the soil and significantly reduce gas exchange, surface runoff seepage, and water evaporation between the local soil and the atmosphere. Moreover, in many cases, the urban soil under the pavement has been exposed for years to industrialisation, construction, and pollution processes from road waste. Above all, the most limiting factor in the growth of an urban street tree is the lack of sufficient soil volume for its roots. The basic assumption in modelling the trees was that they were given conditions that supported proper growth: sufficient soil volume for rooting, irrigation, ventilation and drainage in accordance with high standards of tree habitats within a hard-paved environment.[27]

We modelled the trees at two points in time, five and ten years after planting, during which the tree may have already grown a significant shading crown even before reaching its maximum size. The planting scenarios were based on the growth scales of two common shade trees in Israel, Celtis bungeana and Delonix regia.[28] The Celtis bungeana is a tree native to China and Korea, with a deciduous character and rapid growth rate, a rounded crown about 15 m high and 10 m in diameter as a mature tree. The Delonix regia is a tree native to Madagascar, with a conditionally deciduous character and a very fast growth rate, its umbrella-like crown is about 12 m high and about 20 m in diameter as a mature tree. At the time points modelled (5 and 10 years), the tree crown of the Celtis Bungeana is 4 and 8 m in diameter and 7 and 9 m high, respectively; The Delonix regia crown is 5 and 8 m in diameter and 7 and 9 m high. Therefore, the results obtained after ten years of growth were essentially identical in both trees, but different in their condition five years after planting.

A summary of the statistical analysis of the modelling results appears in Tables 3-8. The tables show the percentage of scenarios that met one of the three levels of shade availability out of all scenarios of the same type. Scenarios in which the shading target is achieved in more than 90 per cent of cases are highlighted in green, and scenarios in which the shading target is achieved in 75-90 per cent of cases are highlighted in yellow. For example, in a table showing all the planning scenarios for north-south main streets, it can be seen that through buildings alone (in all types of building and street dimensions examined) the target of acceptable shade availability (0.5) can be met in 56 per cent of the scenarios examined on the east sidewalk and 55 per cent on the western

[27] Zur, S. (2018). Guidelines for planting details and living space for street trees in Tel Aviv [in Hebrew]. Tel Aviv-Yafo Municipality.
[28] The growth scales used in this work are based on the work of landscape architect Yaakov Eilon and his many years of personal experience.

sidewalk. The analysis of the results also raises several general conclusions regarding the feasibility of meeting the shading targets, as follows:

- **Street orientation:** Street orientation significantly impacts meeting shade availability thresholds. It is easier to achieve high levels of shading even without using trees or with little use of trees on north-south streets or in streets of a diagonal orientation (northeast-southwest or southeast-northwest). The most difficult streets to shade without trees are east-west streets, but it is important to remember that even on these streets, buildings can have some positive effect on shading at certain times.
- **Shade trees:** It is difficult, and in many cases impossible, to reach the highest level of shade availability (0.9) without planting street trees that have developed an optimal crown within ten years of planting. To achieve this target, it is important to ensure significant underground habitats for root growth and constant maintenance (deliberate pruning, irrigation) over the years.
- **Planning flexibility:** There are countless ways to meet each of the three levels of shade availability with the right combination of shading from buildings and trees. Therefore, the obligation to meet the shading levels is not expected to limit planning flexibility or realise planning goals that go beyond sheer shading.
- **Setting high targets:** The lowest shading threshold (acceptable shading) is designed to create a low common denominator as a starting point for improvement and is not an end target. The top shading targets can be met using trees in almost any morphology and orientation (assuming urban buildings above four stories high, even on relatively wide streets). Hence, an ambitious shading policy can be achieved in most cases.

Table 3: Rate of compliance with the levels of shade availability **on main streets** oriented north-south from all the modelled scenarios

Design scenario (main street)	Planting distances between trees	Percentage of cases in which acceptable shading is achieved (shade availability: 0.5)		Percentage of cases in which very good shading is achieved (shade availability: 0.7)		Percentage of cases in which excellent shading is achieved (shade availability: 0.9)	
		Western sidewalk	Eastern sidewalk	Western sidewalk	Eastern sidewalk	Western sidewalk	Eastern sidewalk
Buildings only		55	56	7	7	0	0
Buildings and Celtis Bungeana trees after 5 years of growth	10 m	66	65	14	13	0	0
Buildings and Delonix Regia trees after 5 years of growth		70	68	19	18	0	0
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth		100	99	98	97	69	72
Buildings and Celtis Bungeana trees after 5 years of growth	5 m	78	83	44	53	9	7
Buildings and Delonix Regia trees after 5 years of growth		100	97	89	84	33	32
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth		100	100	100	100	99	95

Table 4: Rate of compliance with the levels of shade availability **on main streets** oriented northeast-southwest from all the modelled scenarios

Design scenario (main street)	Planting distances between trees	Percentage of cases in which acceptable shading is achieved (shade availability: 0.5)		Percentage of cases in which very good shading is achieved (shade availability: 0.7)		Percentage of cases in which excellent shading is achieved (shade availability: 0.9)	
		South-western sidewalk	North-eastern sidewalk	South-western sidewalk	North-eastern sidewalk	South-western sidewalk	North-eastern sidewalk
Buildings only		10	59	0	7	0	0
Buildings and Celtis Bungeana trees after 5 years of growth	10 m	25	69	2	15	0	0
Buildings and Delonix Regia trees after 5 years of growth	10 m	34	73	3	19	0	0
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth	10 m	100	100	100	97	82	84
Buildings and Celtis Bungeana trees after 5 years of growth	5 m	82	92	28	71	0	22
Buildings and Delonix Regia trees after 5 years of growth	5 m	100	96	76	80	40	43
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth	5 m	100	100	100	95	99	96

Table 5: Rate of compliance with the levels of shade availability **on main streets** oriented east-west from all the modelled scenarios

Design scenario (main street)	**Planting distances between trees**	**Percentage of cases in which acceptable shading is achieved (shade availability: 0.5)**		**Percentage of cases in which very good shading is achieved (shade availability: 0.7)**		**Percentage of cases in which excellent shading is achieved (shade availability: 0.9)**	
		Northern sidewalk	Southern sidewalk	Northern sidewalk	Southern sidewalk	Northern sidewalk	Southern sidewalk
Buildings only		0	31	0	7	0	0
Buildings and Celtis Bungeana trees after 5 years of growth	10 m	0	44	0	32	0	4
Buildings and Delonix Regia trees after 5 years of growth	10 m	0	51	0	41	0	16
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth	10 m	100	86	100	82	97	79
Buildings and Celtis Bungeana trees after 5 years of growth	5 m	22	60	19	52	0	28
Buildings and Delonix Regia trees after 5 years of growth	5 m	51	70	46	64	25	44
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth	5 m	100	94	100	93	97	88

Table 6: Rate of compliance with the levels of shade availability **on side streets** oriented north-south from all the modelled scenarios

Design scenario (side street)	**Planting distances between trees**	**Percentage of cases in which acceptable shading is achieved (shade availability: 0.5)**		**Percentage of cases in which very good shading is achieved (shade availability: 0.7)**		**Percentage of cases in which excellent shading is achieved (shade availability: 0.9)**	
		Western sidewalk	Eastern sidewalk	Western sidewalk	Eastern sidewalk	Eastern sidewalk	Western sidewalk
Buildings only		89	92	53	59	0	10
Buildings and Celtis Bungeana trees after 5 years of growth	10 m	98	94	70	77	16	25
Buildings and Delonix Regia trees after 5 years of growth		99	95	73	82	19	41
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth		100	100	100	100	100	100
Buildings and Celtis Bungeana trees after 5 years of growth	5 m	100	100	99	98	80	85
Buildings and Delonix Regia trees after 5 years of growth		100	100	100	100	98	96
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth		100	100	100	100	100	100

Table 7: Rate of compliance with the levels of shade availability **on side streets** oriented northeast-southwest from all the modelled scenarios

Design scenario (side street)	Planting distances between trees	Percentage of cases in which acceptable shading is achieved (shade availability: 0.5)		Percentage of cases in which very good shading is achieved (shade availability: 0.7)		Percentage of cases in which excellent shading is achieved (shade availability: 0.9)	
		South-western sidewalk	North-eastern sidewalk	South-western sidewalk	North-eastern sidewalk	South-western sidewalk	North-eastern sidewalk
Buildings only		70	93	30	65	0	9
Buildings and Celtis Bungeana trees after 5 years of growth	10 m	81	96	47	77	0	24
Buildings and Delonix Regia trees after 5 years of growth	10 m	89	100	66	95	23	73
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth	10 m	100	100	100	100	100	100
Buildings and Celtis Bungeana trees after 5 years of growth	5 m	100	100	100	100	84	93
Buildings and Delonix Regia trees after 5 years of growth	5 m	100	100	100	100	98	99
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth	5 m	100	100	100	100	100	100

Table 8: Rate of compliance with the levels of shade availability **on side streets** oriented east-west from all the modelled scenarios

Design scenario (side street)	Planting distances between trees	Percentage of cases in which acceptable shading is achieved (shade availability: 0.5)		Percentage of cases in which very good shading is achieved (shade availability: 0.7)		Percentage of cases in which excellent shading is achieved (shade availability: 0.9)	
		Northern sidewalk	Southern sidewalk	Northern sidewalk	Southern sidewalk	Northern sidewalk	Southern sidewalk
Buildings only		0	71	0	46	0	0
Buildings and Celtis Bungeana trees after 5 years of growth	10 m	71	86	5	84	0	75
Buildings and Delonix Regia trees after 5 years of growth		96	90	75	88	2	80
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth		100	100	100	100	100	99
Buildings and Celtis Bungeana trees after 5 years of growth	5 m	100	93	100	92	100	84
Buildings and Delonix Regia trees after 5 years of growth		100	98	100	96	100	94
Buildings and shade trees (Celtis Bungeana/Delonix Regia) trees after 10 years of growth		100	100	100	100	100	100

Conclusions

This document presents a practical method for formulating an urban shading strategy based on uniform quantitative indices. The method is intended to be applied at different scales of urban planning, from formulating a national policy on shading to directing interventions in urban spaces. At the municipal level, the method is based on a three-stage process that includes mapping the urban shade hierarchy, prioritising intervention areas for additional shading, and detailed shade design on the scale of a single street segment. The method of mapping the urban shade hierarchy that appears in this document is based on a computational method developed by the authors in previous works and has been applied to more than a dozen cities in Israel to date. With regard to the method of prioritising intervention areas, it should combine the results of shade mapping with data on other issues relating to the urban environment, such as walking, health and economic vulnerability of residents, as well as city-wide planning processes, including urban renewal. The main innovation in this work is the presentation of a uniform index for quantifying shading on sidewalks, the **Shade Availability Index**, which enables not only quantitative comparisons between the level of shading on different streets but also sets measurable normative shading targets for realising interventions to improve the state of shading and to monitor their success.

The Shade Availability Index is a measure that considers the shaded area available for walking throughout most of the daylight hours on a typical summer day. It expresses the quality of shading according to the relative number of hours in which sufficient spatial shading is achieved on the sidewalk. Its advantage lies in the realistic representation of the combined effect of shading from buildings, trees, and other shading elements on the state of shading on sidewalks while maintaining a relatively simple and essentially geometric calculation method. This simplicity facilitates the use of this index to determine normative thresholds that can be intuitively understood even without deep knowledge of the influence of different climatic factors on a person's perceived thermal comfort. For Israeli conditions, we propose setting three levels of shading as desirable normative targets in shading-oriented urban planning, as follows:

- **Acceptable shading –** Shade Availability Index value of **0.5 or higher**
- **Very good shading –** Shade Availability Index value of **0.7 or higher**
- **Excellent shading –** Shade Availability Index value of **0.9 or higher**

We propose formulating minimum targets for designing new streets nationwide based on these thresholds. Regarding intervention in existing streets, recognising the practical limitations of realising shade intensification operations and out of familiarity with the problematic shading situation in countless streets and urban spaces in Israel, our recommendation is to allow each municipal authority flexibility in choosing the level of shading it wishes to reach at the intervention sites it determines in light of its current and projected capabilities, and at the same time mandating achieving at least the lowest level of shading availability (acceptable shading on each sidewalk) as a target below which a street cannot be considered a shaded street.

We know that to promote a significant change in the state of street shading in many cities in Israel, general urban targets must be set, such as the percentage of streets that need to meet a certain shading threshold. However, we believe that setting such targets is possible only on the basis of a systematic analysis of the current situation and the scope of economic investment required to realise urban goals. The Shade Availability Index makes it possible to make such informed evaluations. Still, before such evaluations are made, we recommend avoiding setting sweeping quantitative targets that may prove unfeasible in the short or long term.

Setting quantitative targets related to shading also depends on the development of uniform calculation tools that are open to use by all planning entities that may be involved in promoting the state of shading in urban spaces, from government and public bodies to planners operating in the private market. The indices we present in this work were developed with their simple application in digital computing tools in mind. Without the development of such tools, it will be difficult to effectively monitor the implementation of shade plans that are being promoted today or will be promoted in the future. It will also be difficult to ensure that the adoption of the indices presented in this work is correct or accurate, even though the method of calculating the indicators is clearly presented. Moreover, without the adoption of uniform quantitative indices and uniform calculation tools, it will be difficult to examine the promotion of shading in urban spaces at a comparative level between different cities in Israel and to update national shading targets based on such an examination. The adoption of a uniform measurement method for shading in urban spaces is a necessity, without which the state will find it difficult to efficiently and effectively promote of the issue despite decisions made at the national or municipal level to date.

Finally, it should be emphasised that the index presented in this guide is intended for the design of sidewalk shading only to secure shading for pedestrian or non-motorized traffic in urban spaces. Although it is possible to develop the concept further and extend it to other urban land uses where shading is required, such as squares, public gardens and parks, playgrounds, central street intersections, and entrance plazas to public buildings, a complementary work is required to examine the shading needs in each of these uses and the quantitative indices derived from them in relation to their shading.

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Appendix A: the spatial Shade Index

The spatial **Shade Index** provides a relative quantification of the amount of global radiation blocked before reaching ground level on a typical summer day. It is calculated based on high-resolution three-dimensional mapping of the built-up space, distinguishing between buildings and trees. Computationally, this distinction is necessary because a tree's crown extends beyond its trunk, thus having a shading effect in the space directly below it. The index considers the variation in solar radiation intensity throughout the day and compares the cumulative blocked insolation at a certain location and the maximal cumulative insolation of an unobstructed surface at the same time and location. The formula used to calculate the index is:

$$SI_p = 1 - \left(\frac{Insolation_p}{Insolation_r}\right)$$

where SI_p is the Shade Index at a certain point, $Insolation_p$ is the insolation at that point, and $Insolation_r$ is the insolation at the unobstructed reference point. It follows that the higher the level of shading, the closer the value of the Shade Index is to 1.

The calculation resolution of the Shade Index depends on the mapping quality on which it is based. However, to reflect significant differences in the insolation intensity of the human body, it is recommended to calculate the index in spatial intervals not exceeding 50 cm. The index is calculated as **an average** shading value per a defined unit of area, usually a street segment or a neighbourhood, based on calculating the individual Shade Index values at each sampling point included in the area unit. In principle, it is possible to calculate a spatial Shade Index not only for the entire right-of-way but also for each sidewalk separately, but in the absence of precise mapping of sidewalks in most cities in Israel, it is currently impractical to produce shade maps of sidewalks only excluding the shading on the road next to them.

To reflect the average level of shading over a typical summer day, shade maps show a spatial Shade Index that takes into account the intensity **of cumulative** exposure of the ground surface between 08:00 and 17:00 (daylight saving time) on 6 August, which is the middle day between the longest day of the year (21 June) and the autumnal equinox (22 September), and also represents in Israel the peak annual heat stress resulting from peak daytime air temperatures. However, the spatial Shade Index can be calculated for other periods (for other hours or dates) but these may yield different results due to differences in the direction and intensity of the impact of solar radiation at different times of the year.

Shade maps based on the spatial Shade Index are produced using spatial analyses and calculations in a GIS environment. The input data required to produce urban shade maps are:

- Digital Surface Model (DSM) with a resolution of 0.5 m per pixel.

- Digital Terrain Model (DTM) with a resolution of 0.5 m per pixel.
- A vector file of the city's tree canopy contours.
- A vector file of the land use boundaries in the city.
- A vector file of all building footprints in the city (not mandatory but highly recommended).

As much as possible, it is also advisable to provide the following layers:

- Orthophoto (preferably one that includes a NIR channel) with a resolution of 0.2 m per pixel, corresponding to the input DSM. The orthophoto can help detect errors in the other mapping layers.
- To calculate shade levels in neighbourhood-level spatial units that differ from a city's statistical zones, a vector file of the city's neighbourhood boundaries.
- To calculate sidewalk shade levels, a vector file of the contours of all sidewalks in the city is required.
- To calculate the density of tree planting in a city and its effect on shading conditions on streets and open public spaces, a vector file containing precise locations of all tree trunks in the city.

It is important to note that shade maps document a situation that may change substantially due to changes in the urban space (urban renewal, cutting down trees, or planting trees). Therefore, **we recommend producing shade maps at intervals of at least once every three to five years**, depending on the intensity of development activities in the city. Therefore, it is also important to ensure at the national level that the basic data necessary to produce shade maps are produced at least as frequently. By processing and analysing the raw mapping data listed above, one can generate the following shade maps:

- Map showing spatial Shade Index in street segments and open spaces.
- Map showing a spatial Shade Index in street segments and open spaces, excluding the effect of trees on this index.
- Spatial Shade Index in statistical zones, according to the current spatial definitions published by the Central Bureau of Statistics, or in any other spatial units used by a municipality (districts, neighbourhoods, planning zones).
- Spatial Shade Index in areas excluding the effect of trees on this index.

Appendix B: Kikayon, a parametric code for calculating shade in streets

The Kikayon code is a Grasshopper code developed by Or Aleksandrowicz and Ezra Ozery in a work funded by the Israel 100 Initiative.[29] The code allows to make a parametric examination of the effect of street design on its shading conditions, to compare different shading scenarios and to evaluate, based on quantitative indices, the effect of different designs on improving shading conditions on the street. The code receives a three-dimensional design of a street segment and calculates the values of two different shading indices:

- Shade Index: As detailed in Appendix A of this document.
- Shade Availability Index: As detailed in the main text of this document.

The spatial Shade Index is calculated for several parts of the street as follows:

- Right-of-way as a whole: The entire area of the street segment, including the two sidewalks, the road, and a central walking boulevard (when existing).
- Road: The total area allocated for the passage of cars and vehicles. If a walking boulevard is planned in the centre of the street, the area of the road includes the two carriageways that flank the boulevard on either side.
- Left sidewalk (Sidewalk 1): This area does not include private open space between the front parcel line and the front building line.
- Right sidewalk (Sidewalk 2): This area does not include a private open space between the front parcel line and the front building line.
- A central walking boulevard, when existing.

The Shade Availability Index is calculated only for the sidewalks and the central walking boulevard. In addition, the code calculates three quantitative measures relating to trees if these are incorporated into the design:

- **Number of Trees:** The total number of trees planned on the street, without distinction between tree types.
- **Tree density per unit area (Trees per Dunam):** The number of trees per 1000 sqm of right-of-way area. The recommended value is 10 trees per dunam, as far as the physical layout of the street allows.
- **Tree Canopy Cover:** The ratio of the total area of vertical projections of tree crowns within

[29] Aleksandrowicz, O., & Ozery, E. (2023). A Parametric Tool for Outdoor Shade Design: Harnessing Quantitative Indices and Visual Feedback for Effective and Efficient Climatic Design of Streets. In M. Turrin, C. Andriotis, & A. Rafiee (Eds.), *Computer-Aided Architectural Design. INTERCONNECTIONS: Co-computing Beyond Boundaries* (pp. 302–316). Springer Nature Switzerland.

the street to the total area of the street (the entire right-of-way).

For the calculation, users must first build a 3D model of a street segment by entering the dimensions or quantities of many physical components that make up the street model, as follows:

- Street segment length
- Street orientation
- Traffic strip width
- Parking strip width, on one side of the street or both sides
- Walking boulevard width at the centre of the street, if there is one
- Walking strip width
- Street furniture strip
- Bike lane width
- Planting strip width
- Number of buildings on each side of the street
- Depth of each building on each side of the street
- Front building line and the lateral building lines of the ground floor on each side of the street
- Ground floor height on each side of the street
- Number of typical floors above ground floor on each side of the street
- Typical floor height on each side of the street
- Front building line and lateral building lines of a typical floor on each side of the street
- Number of roof floors on each side of the street
- Roof floor height on each side of the street
- Front building line and the lateral building lines of the roof floors on each side of the street
- Number of rows of trees on each sidewalk or a central walking boulevard
- The position of each row of trees relative to the curb stone
- The type of tree in each row of trees (from a predefined list)
- Planting spacing between trees in each row of trees
- Depth of a shading awning above the ground floor on each side of the street

The code can be downloaded via the following GitHub repository:
https://github.com/oraleks/Kikayon

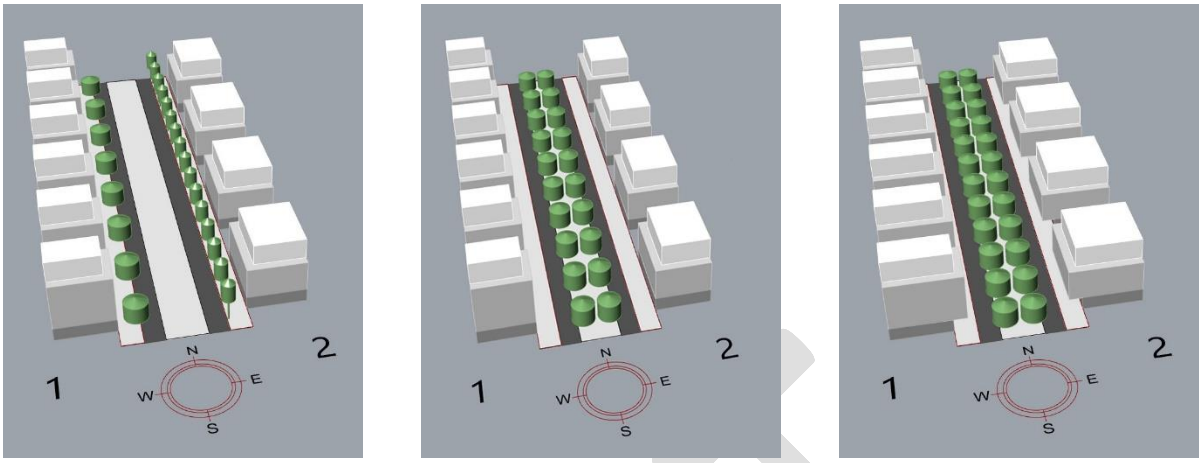

Figure 25: Modelling different design scenarios using the Kikayon parametric code.

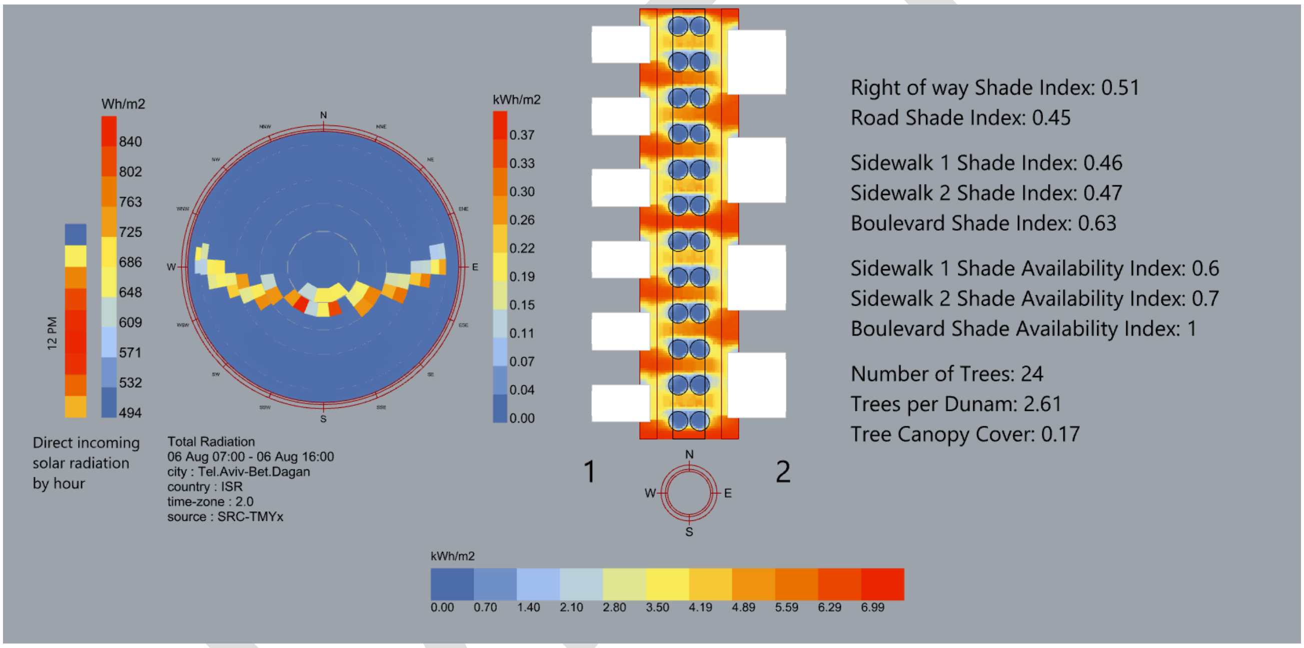

Figure 26Kikayon's results screen shows an overview of the modelled street, the cumulative shade layout on the ground, and numerical values calculated for each quantitative indicator.

About the authors

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