APPROACHES, METHODS AND TOOLS OF RIGHTS OF ACCESS TO SUNLIGHT AROUND THE WORLD

Jozef Hraška^{1*}

Abstract

Sunlight has always played an important role in the design of human settlements. Well-designed urban structures, especially in moderate or cold climates, should be assured of direct sunlight in indoor living spaces and also in public spaces. Direct sunlight in a built environment is an important factor for health and well-being, the effective functioning of solar systems, and sustainable construction. However, many problems involved in the exercise of rights of access to sunlight can arise when sunlight is obscured by a tall cityscape. Many states, regions, and cities regulate solar access, but solar rights and landowner rights are in a permanent conflict. The high urban density of many cities with tall skyscrapers accentuates the problem of the availability of sunlight. This paper presents a review of existing regulations and metrics for ensuring the availability of direct sunlight in buildings and of assessment methods that have been adopted in multiple countries and cities. Approaches, methods, and tools of rights of access to sunlight are critically analyzed. The paper also details experiences from former socialist countries where strict long-term strict on direct access to sunlight in flats were applied.

Address

¹ Department of Building Construction, STU Bratislava, Faculty of Civil Engineering, Radlinského 11, 813 68 Bratislava, Slovakia,

* **Corresponding author:** jozef.hraska@stuba.sk

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- Solar rights,
- Access to sunlight,
- Urban design,
- Solar envelope,
- Owershadowing.

1 INTRODUCTION

Throughout history, sun and daylight have shaped human settlements and individual buildings. Modern technologies, efficient artificial light sources, and socio-economic processes have put pressure on traditional urban structures and building dimensions. Rapid population growth and moving people into cities is causing an increase in the density of the existing urban fabric associated with the construction of tall buildings. However, adequate solar access in a built environment is generally considered to be important to people's health, well-being, and daily life (Neeman et al., 1976; Boubekri, 2008; Holick, 2008; Hodbay, 1997). The right to access and harvest sunlight is an important human right. The availability of direct sunlight in apartments not only has health and psychological effects but also has urban, architectural, social, hygienic, energy and econom-

ic consequences. Sustainable and energy-efficient construction has increased interest in the use of solar radiation. Selected criteria for solar rights greatly influence the density of development, the design of public spaces and transport, and other urban planning contexts. So, protecting solar and daylight rights in urban areas is a very complex task. In particular, dense high-rise urban areas dramatically reduce the amount of sunlight and diffuse skylight in the surrounding buildings and public spaces. High-rise buildings struggle for access to the sun and daylight with each other.

It is extremely important that solar and daylight rights are considered at an early stage of urban planning. For low and medium-density zones there are a number of procedures and tools for their design that respect solar rights and access to sunlight (Littlefair, 2011; Hraška, 2004; Darula et al., 2015; Hachem et al., 2013). In urban areas with high-rise buildings there are specific conditions for solar rights, but

there are no reliable design tools available. We do not mean various graphic tools and computer programs that can be used, but we mean rules for the layout of tall buildings within urban zones. In many cities around the world, the rules for the layout of buildings are so relaxed that buildings significantly higher than 100 meters are only a short distance apart, Fig. 1. Ensuring sufficient sunlight and natural light in buildings is illusory under such conditions. In recent years, the trends of “green” and “sustainable” buildings have brought increased interest in research on daylight and sunlight in urban planning and architecture (Chynoweth, 2009; Hraška, 2011; Cheng et al., 2006; Seong, et al., 2006; Lobaccaro and Frontini, 2014; Lopore, 2017).

Research on the energy and environmental aspects of solar radiation has become more complex due to the widespread use of sophisticated simulation and experimental methods (Shaviv and Yezioro, 1997; Capeluto and Shaviv, 2001; Dogan et al., 2012; Kima and Yi, 2019; Yi and Kima, 2015; Compagon, 2004; Ekici et al., 2019; Ratti and Morello, 2005; Seong et al., 2011; López et al., 2016; Teller, 2001; Mardaljevic and Rylatt, 2003; De Luca and Dogan, 2019; Perey, 2011; Lia et al., 2019; Yhang et al., 2012; Mohajerian et al., 2019). Interest in the impact of solar radiation on human health has been significantly renewed and emphasized. Research on the non-visual effects of daylight has especially brought new knowledge about the physiological and psychological well-being and performance of humans in indoor environments (Arues et al., 2015; Pauley, 2004; Rea et al., 2012). The results of these researches have no practical significance without actual daylight and direct access to sunlight in many types of buildings. In general, land-use regulations, especially in the central parts of cities, often clash with the requirements for daylight and sunlight.

The purpose of this paper is to provide an overview of regulations and standards to ensure the availability of sunlight in residential buildings in different countries and cities, as well as the calculation methods in this field. In this article we are not only concerned with the technical issues, but also with their broad context.

2 CONCEPTS OF SOLAR RIGHTS

The availability of solar energy to a property increases its value by enriching the quality of the built environment and renewable energy potential. Concepts for ensuring the availability of solar radiation vary in terms of the purpose for which they are adopted and in terms of the criteria and the way they are assessed and verified. Historically and empirically, solar and daylight laws were based on rules of obstruction angles. A 45° obstruction was considered as a suitable standard in the medium latitudes of Europe. Especially in the central parts of some larger European cities in the southern latitudes, obstructions

of 60° degrees were allowed. This practice guarantees a certain minimum access to natural light, but not enough availability of direct sunlight on the windows. A 45° obstruction did not allow access to the sun on the lower floors of buildings in traditional street canyons during the cold season of the year.

In the second half of the 20th century, concepts of access to direct sunlight (or solar rights) were adopted in various countries to guarantee its availability, especially in apartments. In the former socialist countries (the Soviet Union, Czechoslovakia, Poland, etc.) the availability of direct sunlight in each apartment and in apartment-like accommodations was considered as a hygienic standard guaranteed by law. It was understood as an actual fulfillment of constitutional rights guaranteeing healthy living conditions for all the inhabitants. The minimum number of hours of access to sunlight during critical periods of the day and the year was required not only for new apartments, but also for all the existing dwellings surrounding them, see Tab. 1. Solar and daylight rights were superior to municipal regulations, historical heritage conservation, etc. Solar rights could not be sold in these countries. One consequence of such a concept of solar rights is that new buildings had to adjust their size and shape according to the solar rights of neighboring apartments. Thus, some version of the well-known solar envelope method (Knowles, 2003) was used in the former socialist countries since the 1950s. These strictly enforced solar rights in many cases led to the deformation of new buildings, Fig. 2. Particular problems arose when the existing dwelling did not meet the standardized access to sunlight before a new building was proposed in their neighborhood. In various former socialist countries, this practice is still in place today. It was also a problem that dwellings in new buildings could obtain the required time of access to direct sunlight throughout the “critical” day if the sun’s altitude was only 5° above the horizon, for example, in what is now Slovakia. Consequently, new buildings were often disproportionately restricted in their broader surroundings.

In several Asian countries where very tall buildings were being built, public petitions were initiated against their unregulated construction. After extensive discussions, various Asian states adopted solar rights in their civil law systems, respectively in zoning regulations or building codes. These solar rights were based on health and well-being. The infringement of solar rights is dealt within the framework of laws on neighbors or easement contracts. In Japan developers must compensate residents for buildings casting shadows more than is allowed by law, for example.

In the US and some other countries, the availability of direct sunlight in apartments is not guaranteed in the civil law (Bronin, 2009;

Fig. 1 Residential buildings in Hong Kong (Ng, 2003)

Fig. 2 Solar envelope of a new building providing solar rights for flats in the central part of Bratislava, Slovakia

Rosenthal, 2013). Specifically in the US, the defense of dense and tall construction quotes from Roman law “for whoever owns the soil, it is theirs up to Heaven and down to Hell”. The well-known decision of Emperor Justinian that no neighbor can block the light “previously enjoyed for heat, light or sundial operation” is less reported.

In the US, the term “solar rights” usually refers to the right of a property owner to install a solar system. Solar rights arose in response to the energy crisis in the 1970s. A solar thermal, lighting or photovoltaic system obviously needs direct access to sunlight. Solar rights acts allow property owners some access to direct sunlight and the installation of solar collectors to protect against excessive shading. The legal protection of solar access usually requires compensation. In the US there was a problem with the legal interpretation of the right to the

availability of direct sunlight. Oil and gas laws were considered as one of the sources of inspiration in this matter. According to oil and gas law, “...the opportunity to extract oil or gas is distributed in proportion to property ownership of mineral rights under areas of land surface” (Reitze, 1976). Thus, larger owners have the right to use more solar radiation.

We can also look at the issue of solar rights through the optics of “stolen direct sunlight and solar energy”, i.e., someone uses natural resources at the expense of another. The solar envelope method is considered to be one of the protective measures to correct this problem (Knowles, 2003). It establishes the maximum volume and shape of a newly designed building that does not violate the solar rights of neighboring dwellings. Classic solar envelopes generated

Tab. 1 Direct access to sunlight according to legal regulations

State	Requirements
Russia	A minimum time of access to direct sunlight in dwellings in zones above the 58°N latitude is required for 2.5 hours in the period from April 22 to August 22, in the zones between 58° N and 48° N, 2.0 hours are required in the period from April 22 to August 22, and in zones of latitudes of less than 48° N 1.5 hours is required in the period from February 22 to October 22. If the access to sunlight is intermittent, access is required for 0.5 hours longer, but an uninterrupted period of access to sunlight of at least 1 hour must be met. For buildings located in historic city centers, access to sunlight can be reduced by 0.5 hours (San PiN 2.2.1/2.1.1.1076-01).
Czech Republic	At least 1.5 hours from March 1 or the balance of the sunlight's duration in the period from February 10 to March 21 of at least 1.5 hours is required for all new dwellings and, with minor exceptions, for all existing dwellings (Regulation No. 268/2009; ČSN 73 4301:2004).
Slovak Republic	In dwellings at least 1.5 hours from March 1 to October 13, when the solar altitude is over 5° and at least 1.0 hours in the historical central parts of cities. The same legal requirements for the availability of direct sunlight are applied to newly-built dwellings as well as to all existing dwellings. Kindergartens are required to have at least 1.5 hours of direct access to sunlight between 10 a.m. and 3 p.m.; the same requirement is applied for children's outdoor play areas (Regulation No. 532/2002; STN 73 4301:2005).
Poland	A minimum of 3 hours between 7 a.m. and 5 p.m. from March 21 in residential buildings and at least 1.5 hours if the dwelling has only one living room. In schools and child care buildings, the availability of 3 hours of direct sunlight is necessary between 8 a.m. and 4 p.m., while for children's outdoor play areas is access to sunlight required for 4 hours or at least 2 hours in the town centres (Regulation No. 620/2002).
People's Republic of China	Access to sunlight depends on the size of the city and on the climate zone in which the dwelling is located. For example, the standard for residential buildings requires at least 2 hours in metropolises and 3 hours in small to medium cities on the “Great Cold Day” (January 20) between 8 a.m. and 4 p.m. in climate regions I, II, III, and VII (People's Republic of China, Ministry of Construction, 1993).
Japan	Japanese cities are divided into several types of zones and several categories, in which heights and distances of buildings are prescribed; laws also assess the shadows cast by a proposed building on neighboring plots. Shadows are evaluated at the winter solstice from 8 a.m. to 4 p.m. at different heights above the terrain, depending on the type of zone (for example in a low-rise residential area, the height above the terrain is 1.5 m, but in a commercial or industrial zone no such evaluation is done). The distance of a shadow cast from the border of the plots is usually from 5 to 10 m. Shaded parts of the neighboring parcels can be shaded for 3 to 5 hours (Urban Land Use Planning System in Japan, 2007).
Republic of Korea	More than 2 hours in every housing unit during the winter solstice from 9 a.m. to 15 p.m. is required, in the case of accumulative access to sunlight; access to sunlight must be more than 4 hours. The distance between each block should be kept to more than 0.8 times a building's height to the south from a neighboring apartment building (Korean Legislation Research Institute, 2009).
Japan	Japanese cities are divided into several types of zones and several categories, in which heights and distances of buildings are prescribed; laws also assess the shadows cast by a proposed building on neighboring plots. Shadows are evaluated at the winter solstice from 8 a.m. to 4 p.m. at different heights above the terrain, depending on the type of zone (for example in a low-rise residential area, the height above the terrain is 1.5 m, but in a commercial or industrial zone no such evaluation is done). The distance of a shadow cast from the border of the plots is usually from 5 to 10 m. Shaded parts of the neighboring parcels can be shaded for 3 to 5 hours (Urban Land Use Planning System in Japan, 2007).
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Tab. 2 *Direct access to sunlight in state standards*

State	Requirements
Germany	At least one room of a dwelling needs to receive 4 hours on March 21 st , an additional criterion is 1 hour of access to sunlight on January 17 th (DIN 5034-1:2011-07).
U.K.	A room should receive at least 25% of the annual probable sunlight hours. 5% of the required direct sunlight should be accessed from September 21 to March 21 (BS 8206-2:2008).
Estonia	3 hours of sunlight from April 22 to August 22 (RT I 2002).
Slovenia	At least 2 hours on December 21 st , 4 hours on March 21 st , and 6 hours on June 21 st (TSG-1-004:2010).
European Union	Minimum exposure to sunlight should be provided in patient rooms in hospitals, play rooms in nurseries, and at least one habitable space in dwellings. The selected date for assessments of exposure to sunlight should be between February 1 and March 21. The standard sets a minimum exposure to sunlight of 1.5 hours from the minimum altitude of the sun, which varies from one EU country to another. The standard recommends achieving longer times of sunlight exposure, i.e., 3 or 4 hours (EN 17037:2018).

Table 3 *Direct access to sunlight according to the ordinance of the municipality*

City	Requirements
Sydney (Australia)	Living rooms and private open spaces of at least 70% of apartments in a building should receive a minimum of 2 hours of direct sunlight between 9 a.m. and 3 p.m. on December 21 st in specified areas with a dense development; a minimum of 3 hours of direct sunlight is required in other areas. A maximum of 15% of apartments in a building can receive no direct sunlight on the above specified date and time (SEPP 65).
Auckland (New Zealand)	At least 70% of living rooms and private open spaces in a development should receive a minimum of 3 hours of direct sunlight between 9 a.m. and 3 p.m. in mid-winter. Single aspect apartments oriented towards cardinal points with no direct sunlight in mid-winter should account for a maximum of 10% of the total units proposed. Developments that do not meet this minimum should be able to demonstrate how the site constraints and orientation prohibit these standards from being achieved, and how issues of energy efficiency will be addressed (Auckland design manual, 2018).
Boulder, Colorado (USA)	New buildings cannot cast shadows on surrounding facades where heights are different, depending on the Solar Access Area (Area I 3.66 m, Area II 7.62, Area III no shadow line) between 10 a.m. and 2 p.m. on December 21 (Solar Access Guide, 1981).
Ashland, Oregon (USA)	A new building cannot cast a shadow taller than 1.83 m on the most northern point of its own property line on December 21 at 12 a.m. (Solar Access, 2011).
Vienna (Austria)	Residents in Vienna do not have the right to complain that their flat or other part of a property does not have enough access to sunlight, as defined by the municipal regulations. The urban planning of Vienna clearly defines the conditions of development, which are controlled by the competent authorities (Stadt Wien, 2009).
Zurich (Switzerland)	Zurich restricts the length of time of sunlight for a high-rise addition to residential areas. A tall building can cast shadows on a horizontal surface of a plot, but is limited to less than 3 hours on November 3 or February 8 between 8 a.m. and 4 p.m. (Kanton Zürich, Baudirektion, Allgemeine Bauverordnung).

pyramid-shaped buildings that resembled a parody of urbanism. The wide and deep lower floors of such buildings did not use daylight and required mechanical ventilation, which cannot be considered as an environmentally and energy-efficient approach to building design.

There are a large number of variations and modifications to the solar envelope method (Hraška, 2004; Capeluto and Shaviv, 2001; Morello, 2009; Capeluto, 2001; Vartholomaios, 2015; Cotton, 1996). Most publications on this topic address the technical side of the problem. More recent scientific work in this field deals with solar radiation simulations that analyze regular urban structures, an array of buildings, urban canyons, and regular urban blocks that rarely occur in real life (Cheng et al., 2006; Panão et al., 2008; Stasinopoulos, 2018; etc.). Year-round simulations of the irradiance of building surfaces in complex urban structures in which winter and summer are mixed are not suitable for the initial design stages of an urban structure or a building. They are not particularly suitable where there is a civil law guaranteeing access to sunlight in all dwellings or other interior and exterior spaces. However, the technical details of the solar envelope method are not of primary importance, but the philosophy behind the issue and the accepted criteria are essential.

Solar rights are closely linked to concepts such as “social equity”, “public health”, a “post-carbon society”, “green buildings”, a “solar city”, morals, general welfare, etc. The application of such concepts has a number of legal and political implications. To what extent can these concepts be filled with real content at a time when tall buildings are densely built in cities around the world? Can access to sunlight be based on rights that contradict urban planning? Conversely, can a “healthy” and “sustainable” city be planned without reasonably applied solar rights? The philosophical bases of the rights to sunlight are of a humane and anthropocentric nature.

The minimum criteria for the availability of direct sunlight should be unambiguous, taking into account the expectations of people and the actual possibilities for their fulfillment. The criteria should also be clearly and easily verifiable. It is apparent from Tabs. 1 to 3 that the criteria for direct access to sunlight that are applied in practice have a simple space-time character. Clear criteria and methods for their verification are needed for agreements between property owners, zoning ordinances, and court litigation. It is true that possible and probable sunlight hours vary from region to region. The availability of sunlight in the morning and the afternoon is different and also varies from

Fig. 3 Annual possible/probable direct access to sunlight on windows facing towards different cardinal points in Bratislava, Slovakia (Hraška, 2004)

month to month, while the availability of sunlight at a given location affects the vegetation, self-shading, surface reflectance, and other specifics. According to (Hraška, 2004), there are relatively small differences in the evaluation results of possible or probable direct access to sunlight on a year-round basis in a specific location, see Fig. 3. Taking into account these and other specifics in the early stages of designing is counterproductive and relativizes the substance of the issue. Determining the date and time of direct access to sunlight requires a cautious approach in order to achieve an acceptable balance between the benefits of solar access and urban development needs. There is no fundamental difference in whether we assess solar rights by the time of direct access to sunlight or by the time of the shading of the evaluated site. However, when assessing the availability of direct sunlight in specific apartments, unexpected complications may arise. As mentioned above, situations where direct access to sunlight in existing apartments does not meet current criteria are problematic.

3 TOOLS OF RIGHT OF ACCESS TO SUNLIGHT

For effective policy implementation, the simplest and most transparent methods with graphic interpretations are appropriate for assessing the right of availability of direct sunlight. Classical assessment methods of direct access to sunlight are based on many types of sun-path dia-

Fig. 4 Cylindrical sun-path diagram generated by the computer program INS (Hraška and Štjuber, 2000)

grams or on shadow diagrams. The access to sunlight can be manually calculated using solar charts by applying simple descriptive procedures. Working with solar charts does not require special knowledge, and their advantage is that the results of the assessment have a graphic form that is easily verifiable. The well-known transparent sun-on-reference-point indicator has been used in Slovakia for decades, see Fig. 5a (STN 73 4301:2005). With the help of this indicator, an architect can evaluate the access to sunlight even in complex external shading ratios in several minutes. At present, digitalized versions of the sun-path diagrams are mostly used; these are generally cylindrical and stereographic diagrams. A cylindrical sun-path diagram generated by the INS computer program is on Fig. 4 (Hraška and Štjuber, 2000). Methods for assessing shadows cast are usually based on evaluating the length of shadows at a certain time or at the time of shading a particular plot.

The visible sky factor method is also often used to determine the availability of direct sunlight (Johnson and Watson, 1987; Grimmond et al., 2001; Chatzipoulka et al., 2018). On physical models of urban structures, the shadows and the availability of direct sunlight can be clearly monitored using heliodons. Novel computational techniques (Seong et al., 2006; Lobaccaro and Frontini, 2014; Kima and Yin, 2019; Ekici et al., 2019; Ratti and Morello, 2005; Seong et al., 2011; López et al., 2016; De Luca and Dogan, 2019; Lia et al., 2019; Cotton, 1996) and software tools for exploring solar irradiance or the direct access to sunlight on a city scale (for example, HELIOS (Seon et al.,

Fig. 5 Simple sun-on-reference-point P indicator (a) (STN 73 4301:2005) and irradiation map of a complex urban environment (b) (Mardaljevic and Rylatt, 2003; Mardaljevic, 2004)

2006), QuVue (Kima and Yi, 2015) SunScapes (Ratti and Morello)), TOWNSCAPE (Teller and Ayar, 2001), SOLVELOPE (Schiler and Uen-Fang, 1993), and CalcSolar (Noble and Kensek, 1998)) are very sophisticated. However, despite their complexity, not all of them are suitable for evaluating direct access to sunlight rights. The currently published the novel solar envelope method based on solar ordinances for urban planning (De Luca and Dogan, 2019) seems to be very beneficial for the issue analyzed. The evaluation tools based on the total incidence of annual/monthly solar irradiation on building facades in complex urban environments are poorly suited for assessing the rights to direct sunlight. A graphic output of one method of this type is shown in Fig. 5b (Mardaljevic and Rylatt, 2003; Mardaljevic, 2004). The disadvantage of these tools is that they do not provide unambiguous assessment criteria that require direct access to sunlight rights.

They even have a hidden feature to relativize the distribution of solar energy in very dense urban settings, for example, by pointing out that the addition of another very tall building will expand the facade areas capable of the intensive use of solar radiation. Proper use of these tools with actual input data can provide a useful holistic view of the potential solar renewable energy in complex urban environments and more accurate information about solar accessibility, which can be used in many ways in urban planning.

CONCLUSIONS

Urban design has an extremely broad multidisciplinary nature. The consideration of solar energy in the urban planning process is only one of environmental, social, cultural, economic and other

subjects that are associated with dynamic urban creation processes. Environmental issues, “green construction”, and social awareness put solar rights at the forefront of urban planning. Direct access to sunlight in dwellings and in some kinds of public spaces should neither be overestimated nor underestimated. Practical use of rights of access to sunlight needs to be balanced with other objectives of integrated planning. Only a few countries in the world have incorporated the right to direct sunlight in their Civil Code. The principle of a “minimum access to direct sunlight for all” should be ensured in a differentiated and sufficiently flexible manner. The solar envelope method alone has no potential for creating a well-functioning city. This method of generating the maximum volumes and shapes of buildings that do not violate the solar/sunlight rights of the surrounding buildings has, in many cases, a distorting effect on both the buildings and urbanism. Solar rights are to be applied differently in different urban zones, consistently in residential areas and, to a reasonably limited extent, in industrial, commercial, or high-rise city areas. The differentiated approach will increase the freedom to create urban developments and help design functional, healthy and comfortable cities for future generations. Such an approach must have a clear legal basis.

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