BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF CIVIL ENGINEERING
FAKULTA STAVEBNÍ

INSTITUTE OF BUILDING STRUCTURES
ÚSTAV POZEMNÍHO STAVITELSTVÍ

CHALLENGES IN EXPOSURE TO SUNLIGHT
VÝZVY U PROSLUNĚNÍ A STÍNĚNÍ BUDOV

HABILITATION THESIS
HABILITAČNÍ PRÁCE

AUTHOR — **Ing. František Vajkay, Ph.D.**
AUTOR PRÁCE

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Abstract

Light, especially daylight, is essential for life on Earth and significantly influences human behaviour. Maximizing daylight in buildings has been a priority for architects throughout history, from early cave dwellings to Roman structures with glass windows, and Greek buildings designed for sunlight capture. The industrial revolution in the 19th century transformed architectural practices, utilizing iron and steel for slender frames and expansive designs, with external structures focusing more on environmental protection than daylight enhancement. This shift allowed for bold, lightweight designs but also led to challenges like overheating and glare. The rise of fluorescent lighting allowed deeper room designs without worrying about energy costs, which diminished the emphasis on daylighting principles. However, the 1973 oil embargo prompted a resurgence in the focus on efficient daylighting strategies that had been overlooked since the industrial era. Today, architects, engineers, and scientists are exploring innovative methods to integrate daylight into building designs, considering factors such as site location, building type, and structural layout. Understanding illuminance levels in various spaces is crucial for engineering and health, impacting occupant well-being and overall building effectiveness.

Keywords

Daylight in buildings, shading, exposure to sunlight, solar altitude angle, ČSN EN 17037, photovoltaic power plants.

Author's Declaration

I declare that I have written this paper independently, under the guidance of the advisor and using exclusively the technical references and other sources of information cited in the paper and listed in the comprehensive bibliography at the end of the paper.

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Brno ....

author's signature*

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1 INTRODUCTION

1 INTRODUCTION

Light, particularly daylight and sunlight, are undeniably a critical and essential element for the sustenance and flourishing of life on Earth. The daily and seasonal variations in daylight can profoundly impact human behaviour [2], whether these changes are minor or substantial. Because of this, maximizing daylight accessibility in building design has been a fundamental concern for architects since ancient times. This emphasis on the incorporation of natural light and its benefits can be traced from early cave dwellings, where humans first sought refuge, to the grand Roman structures that featured glass windows, south-facing buildings in ancient Greece designed to capture sunlight, and the innovative Egyptian designs that incorporated metal-plated shutters to control light entry. However, the industrial revolution in the 19th century dramatically revolutionized architectural practices and methodologies [3], [4]. The advent of high-quality iron and, later, steel facilitated the construction of slender frame structures with expansive spans, where the external envelopes primarily served to withstand environmental elements rather than to enhance daylighting in a meaningful way. This significant advancement enabled architects to realize ambitious, bold designs for lightweight, resilient structures that redefined the commercial and residential landscapes. The increased spacing of supporting columns permitted larger openings and greater expanses of glazing - this led to various challenges, such as overheating, glare, and uncomfortable indoor environments that needed to be managed [4].

With the introduction of fluorescent lighting technology, rooms could be designed with considerably greater depths, allowing architects to prioritize aesthetic appeal in their projects without concerns regarding the costs of energy consumption, which were relatively low at that time. As a result, the principles of site-oriented architecture and the considerations for proper daylighting and insolation (also referred to as EXPOSURE TO SUNLIGHT) gradually became less prominent as architects embraced new technologies. However, this prevailing trend shifted dramatically in 1973 during the oil embargo, which resulted in soaring energy prices, compelling designers to rediscover and re-implement vital design principles and strategies that had been largely neglected since the onset of the industrial revolution [4] - a process that continues to evolve into the 21th century. Although, there were still some countries, in which architects did not go abroad after World War II and even earlier, like in Central European countries, where daylight and sunlight accessibility were and are still required by the BUILDING CODE[5].

Today, architects and civil engineers are actively exploring techniques to incorporate daylight effectively into building designs from the initial planning stages all the way through to the final completion. And even though property developers would like to neglect Sunlight accessibility, they are not allowed, at least for some special cases.

This thesis is focused on shading of photovoltaic power plants by new constructions, as well it verifies a modified approach for evaluation of sunlight exposure determination in new property developments.

2 DAYLIGHT IN ARCHITECTURE

Daylight in Urban Design

Importance of Daylight

Daylight in Buildings

ČSN EN 17017+A1 Daylight in Buildings

Exposure to Sunlight in Urban Settings

Effects of Shading on Photovoltaic Panels

2 DAYLIGHT IN ARCHITECTURE

Health organizations have determined that exposure to daylight, primarily to sunlight, is critical for vitamin D synthesis, because optical radiation is a globally available source of *Ultraviolet radiation* (UV radiation) and exposure for most of humanity. Adequate levels of vitamin D produced by the body are important for the health of every person regardless their age, since it has many functions and one out of those is enabling the body to absorb calcium. Calcium is a trace element ensuring stability and strength of bones. Another important function of vitamin D in the body is related to the immune system. On the other hand UV radiation exposure is also associated with several harmful effects to the human body, especially the skin, such as tanning, burning, premature skin ageing, and SKIN CANCER [6][7].

In addition to these physical responses, exposure to natural light entering the visual system can regulate the production of melatonin, a hormone that helps to manage phases of sleep, mood, and sexuality. Possible mental benefits of daylight exposure include a reduction in depression and an improvement in mood. Reduced access to daylight and sunlight has significant public health implications for the population. Yet residents of densely inhabited urban environments may be particularly vulnerable to its effects, as large portions of the population may lack access to daylight even when being outside. Typical urban design strategies, such as available space in the form of recreational areas, such as parks, are one way to go against this wave. Although these efforts are well-intentioned the designed features, elements can also lead to light hazard. For example, the size and orientation of buildings, and the availability of green areas can produce disparities in who may or may not have access to daylight. Recent works have investigated a range of subjective characteristics that may predict the presence of artificial darkness in homes too, reinforcing the idea, that individuals living in cities might face potential risks of long-term daylight deprivation. Then there are also some parts of the globe where humanity is deprived of daylight because of low solar altitudes at certain times of the year resulting in polar nights, or simply due to bad atmospheric conditions, like overcast sky for an extended period [8].

However, how many people are affected by these weather conditions is subject to uneven habitation. Therefore, the benefits of daylight on human organisms should be taken into consideration already in urban design.

The human visual system is exquisitely sensitive to the wavelength distributions of daylight. It is so that out of the three photo receptors the cones are classified into[9]:

S type cones, reception of light is at its peak in the range of 420 nm to 420 nm,

M type cones with peak wavelength between 534 nm to 545 nm, and

L type cones with a peak in range of 564 nm to 580 nm.

Unfortunately, every individual has a different response to light, thus the peaks are represented by intervals.

These classes have evolved in parallel with evolutionary selection for the optimal capacity to detect ripe foliage against the sky. Although evolution to detect food may have been the selective pressure to give primates and therefore humans partial ultraviolet vision.

Humans have a basic structural similarity to primates in their luminance, color, and spatial vision. That is that the eyes of human beings do comprise of rods alongside cones. This set-up gives humans the same way as primates an increased spatial sensitivity to various wavelengths by expanding their cortical representation of the visual field. Evolution has also equipped humans with special cells in the retina, referred to as ganglion cells, which are intrinsically photosensitive and affect the internal biological circadian clock. The construction of the eye is shown in Fig. 2.1. Hence, humans have a photic entrainment pathway responsible for non-visual responses, parallel to the classic image forming pathway [8],[10].

Humans eyes therefore respond to day and night-time light intensity differently. Such response is referred to as photopic or scotopic vision. Somewhere in between there is the mesopic vision response [11]. Mesopic response ensures vision in times of transition from dark to light spaces, or vice-versa. This however does not really have a clear threshold. Its is limited solely by the individual. The photopic and scotopic response of an average observer is shown of Fig. 2.2 [12].

All of this knowledge should be applied in daylighting design of buildings.

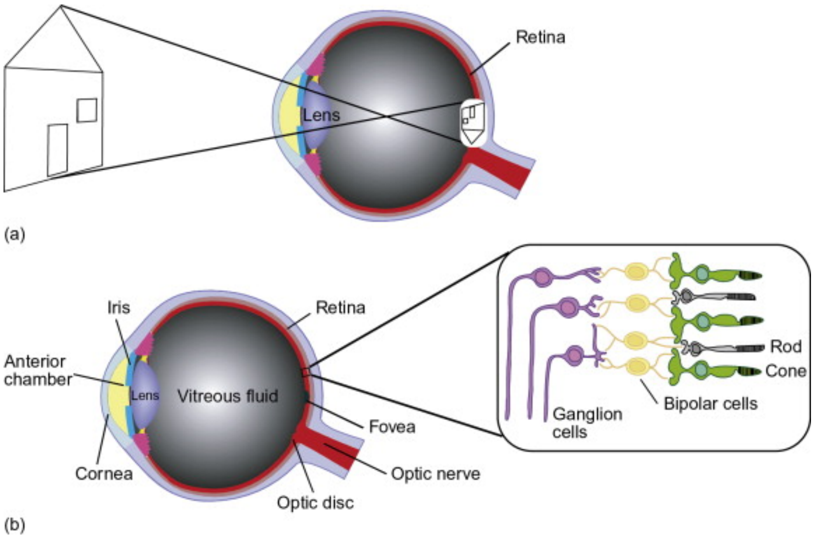


Fig. 2.1: Construction of human eye. a) How are objects visually perceived, b) cross-section of the retina and cells in it [13].

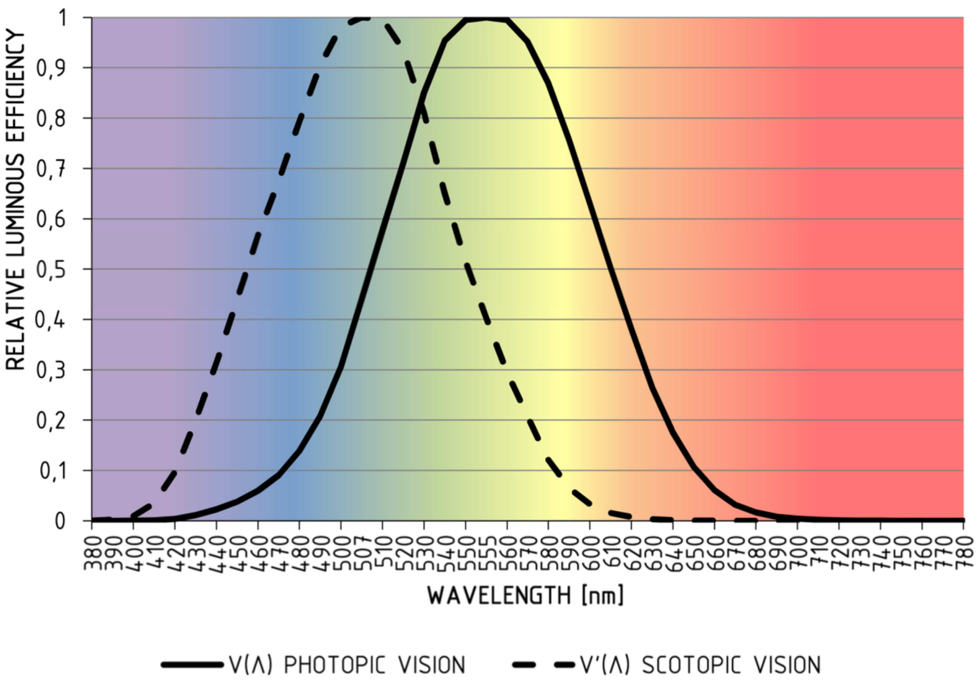


Fig. 2.2: Photopic and scotopic response of an average observers eyes [12].

2.1 Daylight in Urban Design

Daylight is a fundamental aspect of urban design. It affects the aesthetic and practical aspects of architecture and living environment like, suburban areas, cities, streets and buildings. About 50 years ago sunlight was thought to have more disadvantages than advantageous. Due to international influence glare and the possibility of glare in buildings overwhelmed its other characteristics, BENEFITS. On an international level this changed about 30, 40 years ago, when scientists, as well as lighting consultants, have begun to investigate some aspects of solar radiation, particularly the effects of blue light and ultraviolet component onto the human organism. After a variety of significant scientific studies they realised, that urban planning and buildings design should incorporate some strategies according to which inhabitants and users of a building would have guaranteed access to the daylight, and if possible sunlight as well. Some researchers and designers have even investigated the meanings of the Sun and sunlight as an essential resource for mankind's survival on Earth [14], [15], [16].

The presence of sunlight in the environment has been recognized as a primary source of energy from which human can benefit from; this aspect has become even more evident with new technological insights. Urbanisation is a factor that has led to a gradual reduction in access to sunlight. During ancient times dwellings were oriented with doorways facing south, thereby allowing the houses to be heated by the sun in the morning. Light increasingly took on a symbolic and identifying role in the creation of sacred spaces and the containment of collective identities [4].

In urban contexts, the potential offered by certain choices is not solely limited to the domain of the aesthetics, but also to bio-climatic, eco-sustainable parameters. In the latter case, some urban lighting and town planning strategies can be traced back as means to structuring and organising places to underscore light as a potential biological resource. The choice of form and space organisation is therefore bound to the use of artificial or natural light within socio-cultural, interference-free interactions, and psychological contexts. In a nutshell, natural light is seen as a BUILDING RESOURCE and the choice of whether to use more or less of it depends on the relationship between costs and benefits [17].

In a deeper historical point of view, daylight has played a significant role in architecture and town planning since early civilizations (as it was already mentioned). Although the expressions vary with social and cultural priorities. The use of daylight and sustainable practices was of utmost importance. The early buildings of civilizations, such as the Greek ones, mainly served the purpose of bringing in natural light and allowed exploration of artistic expression. In Roman architecture, more complex spatial volumes were created with natural light. The idea of atrium's evoked an expression of spatial symbolism. The Pantheon in Rome is one of most known building in history of humankind, which with its dome allowed light to enter the main aisle illuminating some special elements, locations [18], [19]. During the renaissance period architects valued another aspects of natural light, which was similar to that in ancient Egypt. That is daylight and sunlight allowed them to highlight certain elements, like stoves, or paintings for example. It allowed them to add depth in terms of *Three Dimensional* (3D) appearance. They tried to create harmonious relationships centred on the achievements of the ancient world [4], [2].

Afterwards in the 19th century urban design and architectural philosophies underwent an enormous shift in the worst direction possible because of the inventions of light bulbs. Daylight had received less emphasis than before. Buildings designed and constructed under MODERN MOVEMENT philosophy were also in conflict with daylight design. And the times following World War II topped it, when living in buildings took a shift from day to night time. However daylighting strategies are being reinvented since the 70's of 20th century when prices of energies rose rapidly and individuals and companies could not afford them. Although this in reality happened towards the west, not in Central and East Europe [20].

2.2 Importance of Daylight

According to the content of previous section, daylight does not only have a contribution to aesthetic aspects of outdoor and indoor environments, but it has an importance to the functions of interiors of buildings, as well as to health, well-being, and comfort of users of these buildings.

The environmental effects of sufficient daylight (incl. sunlight) levels increase mental health, enhance mood-behavioural choices, and improve the quality of life. It increases the physical efficiency and accelerates recovery speed of patients in hospitals, and it also has positive effects on healthcare workers [21].

In urban areas daylight gives off the feelings of an environmentally friendly and economically stable harmonious image, especially in case of cities and towns. Daylight highlights the aesthetics of buildings, streets, and public spaces. Especially when colourful materials and surfaces are used on façades of buildings and in their immediate surroundings. Daylight and sunlight can play with nature, they might help to give off varying feelings throughout the day, week, month and year. The Sun with its concept of time can be understood by everyone, without any education [22], [23].

Daylight availability reduces energy demand and operational costs of buildings, which are among the factors that increase the environmental impacts related to production of electricity, whereas a prevailing number of countries are still dependent on fossil fuels. In these terms daylight contributes to the sustainability of urban and building design. The supply of efficient daylight can be achieved through appropriate urban layout planning and through preliminary studies involving the Sun's position over the sky throughout the day and year. In these studies what is evaluated is for how long can the Sun illuminate the façades of buildings, because a longer exposure to sunlight also ensures, that with big enough daylighting systems less energy will be wasted by luminaries. It can also increase the ratio of renewable energy production by photovoltaic panels compared to other forms of power generation [24], [25]. EU directives are however different, they prefer energy performance and reduction of heat losses before daylighting.

Access to sunlight and daylight respectively is important for investors to spend their money on, since it gives them the feeling of security with respect to payback times for their investments. Abroad LEED and BREEAM certifications are an important asset, albeit in the Czech Republic most of the property developers see light only as a nuisance, without which they could make more profit. Although there are some exceptions [26], [27].

2.3 Daylight in Buildings

So that in indoor spaces might meet the requirements considered in the field of daylighting, some of the available daylighting systems are to be implemented into the envelopes of buildings, already in the preliminary stages of design.

There are three major classification systems resulting in six partially overlapping categories of available daylighting elements, these might be [28], [29]:

- passive daylighting system, where daylight and sunlight are brought to the room common, fixed building elements. The building elements are thus built into the envelope of buildings,
- active daylighting systems, which require the use of technologies for daylight control. They are mostly controlled by intelligent systems most of the time controlled by a *System on Chip* (SoC) (similar to Arduino boards) or processor based units, and take into consideration various boundary conditions on a real time basis. An example of active systems are optic fibre systems Fig. 2.3. [30], [31]
- direct daylighting system, allow a visual contact between the exterior and interior. Direct daylighting system are usually passive ones, and the only active one fitting into this class would be the Heliostat, a set of mirrors, but only if the last internal mirror would be visible. Heliostats are similar to periscopes [32],
- indirect system, are the opposite of active systems. These are mostly indirect, not allowing a direct visual contact, like in case of tubular light guides [33], [34],
- primary, are actually direct system,only another name is used for them,
- and secondary. Secondary daylighting system can be seen more or less in wide and long buildings, especially shopping centres, since in these types of buildings the main aisles are illuminated through skylights, and the shop for example are daylit through the display windows.

Except of the previously mentioned elements, there is another kind of active daylighting system, although its function is more or less regulatory. The function of these systems is to limit the amount of light passing through the daylighting system, so that glare would not appear. These elements are operated through SoC's converting signals from from photo-resistors, like smart films applied to the glazing (aka Smart Glass) Fig. 2.3, or simply automatic venetian blinds.

(a) Smart privacy glass when on.

(b) Smart privacy glass when off.

Fig. 2.3: Smart glass application [35].

Regardless of the technology used, the primary goal these active regulatory systems is to reduce energy used by artificial lighting, which is feasible only if natural light is used at a higher rate. In the actual development phase, most of the controllers are in automatic mode or in mixed mode, where the user can adjust the lighting level. Several studies were carried out to verify the potential benefits of such lighting control systems, focusing mainly on energy savings, occupant comfort, and visual performance.

So in general, passive technologies are relatively simple and cost-effective to implement and include designing buildings with an appropriate orientation. Active strategies on the other side do include sensors and control devices for controlling electric lighting in response to availability of daylight [36].

Passive Daylighting Strategies and Systems

Over the years many techniques and strategies have been devised to tap the potential of daylight without using any mechanical parts. The underlying philosophy for passive strategies is that daylighting is integrated into the architectural design right from the conceptual stage. A variety of seemingly low-tech passive strategies can be successfully used to achieve the design objectives. Some of these passive daylighting techniques include the strategic placement of openings like windows, clerestories, roof windows and sky lights at appropriate locations in the peripheral structures of any building.

Light shafts are another possibility that might be used. These elements can be employed to bring light into the depths of a floor plate in multi-story buildings or terraced houses in city centres. Such features not only enhance the aesthetic appeal of a building but also provide sufficient light and ventilation, leading to lower energy use and increased convenience and comfort for occupants [37].

As a last option it might be possible to name tubular light guides consisting of a top cover referred to as a collector, then a pipe having a surface coating made of highly reflective materials, and and internal cover diffusing light into the space.

The top cover actually collects daylight and sends it into the pipelike elements inside of which it reaches the diffuser through an endless number of reflections. Since the reflectance value of the tube is around 99% some losses are still expected. With the rising number of reflections the losses are higher. However the biggest limitations of these systems are found in their diameters. So that they might be affordable companies manufacturing them do produce them up to a given diameter, and the lower the diameter the less light can be transmitted through them, with higher losses.

When taking into consideration the other classification: direct and indirect, then light guides and atria would belong into the category of the later, because from the point of observer the light source cannot be seen through them. Cross section of a light guide is visible on Fig. 2.4 [33], [34].

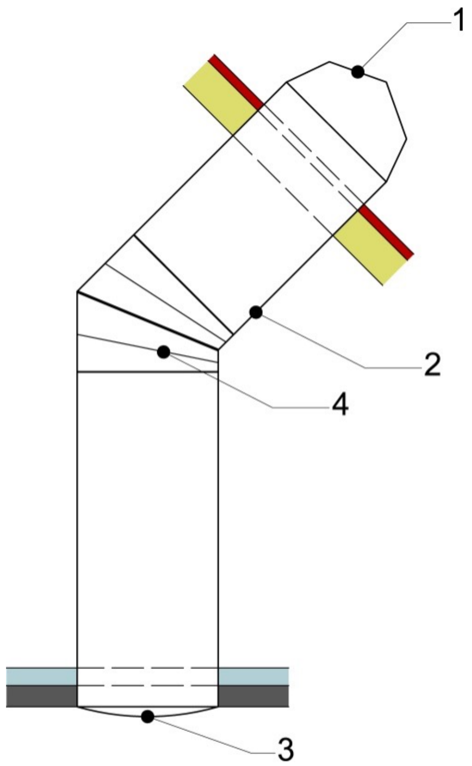


Fig. 2.4: Cross-section of a tubular light guide (1 – copula, 2 – metal pipe, 3 – diffuser, 4 – bent elements) [34].

The main advantage of passive strategies is that they are less expensive, and they might affect the aesthetic side of the building designed for the best, or the worst.

There are some drawbacks of passive systems as well, like excessive glare and heat gains. Many of the possible solutions are however location and climate specific [38].

Active Daylighting Systems

As natural light is not always available consistently, active systems are designed to respond to surrounding conditions, adjusting themselves accordingly. In the built environment, active daylighting typically refers to automated or smart systems. The technology guiding automatic responses has continued to evolve from mechanical hinges to advanced sensors and computer-based algorithms, which, together form automated controls and actuators. These automatic system might offer suitable solutions fit for contemporary building projects. With the exception of some cases on the other hand active daylighting systems are there only to supplement passive ones [39].

2.4 ČSN EN 17017+A1 Daylight in Buildings [1]

So that passive/direct and indirect systems might have proper dimensions it is necessary to design them. Over the globe most of the countries do have a BUILDING CODE [40] and standards, and throughout the integration of these documents daylighting becomes a part of good architectural design practice. It is of uttermost importance, that indoor spaces are properly illuminated by daylight, or depending on their utilisation they have access to sunlight too. Standards in which the requirements to daylight quality are set down, include a list of design methodologies as well.

The legislation and standards do not really state how far the design has to go, on the other hand they include the minimum allowed requirements, which will ensure a certain quality to the designed space.

The new European standard EN 17037+A1 for Daylight in Buildings [1] is applicable to every type of buildings may it be residential, educational, administrative, civic, ... , as well as for industrial and agricultural buildings, if there are no regional standards which would say otherwise. The standard includes requirements and recommendations in four field, out of which two to three are of outmost importance. These four requiements are:

- Daylight in buildings, just as the title of the document,
- Glare,
- View out,
- and last but not least exposure to sunlight.

Until now Czech legislation excluded glare and view out from required metrics.

Daylight in Buildings

With this topic the actual daylight availability of an indoor space is evaluated. Daylight availability can be evaluated by the means of three methods:

- With illuminance as the main quantity,
- Second possibility is to use illuminance as well, just like in the first case, with the only difference, that compared to a single and simple evaluation one is allowed to use Energy Plus data files and do a global all year long calculations. This approach can be referred to the one discussed under Useful daylight illiminance,
- The third option is one which is used by most of the professionals, since it is a continuation of metrics used before. This evaluation is based on Daylight Factor D.

The main difference between Illuminance E and Daylight Factor D is, that the later is only a representation of illuminance in percents.

$$D = \frac{E_i}{E_e} \times 100 \tag{2.1}$$

Where:

E_i is the value of illuminance determined inside in a point over the reference / working plane [lx],

E_e is the illuminance obtained outside under an unobstructed typical CIE Overcast Sky [%].

Hence it does not matter which of these approaches is used, and what software is applied to determine the results.

The working plane is essentially a set of points at a height of 850mm (for most of the buildings), 450mm (in kindergartens) and 100mm (for gyms and sporting facilities). The edge of reference plane has to be in a distance of 500mm from surrounding walls. The distance between points should create an almost square composed mesh.

As for what values are to be expected, those are related to the EN 12464-1 standard, or its Czech translation, which would be the ČSN EN 12464-1 [41]. Spaces can be looked up for in this standard by building type. On behalf of the previously mentioned standard the ČSN EN 17037+A1 [1] classifies spaces into three categories: 100lx, 300lx and 500lx. The values represent the target illuminance level E_T, which should be met in at least 50% of points making up the reference plane. In the rest a minimal target illuminance $E_{T,min}$ is required, and that has to be fulfilled in 95% of evaluated points.

In the Czech Republic only living areas in residential buildings are evaluated with a different means. Those are described in another regional standard.

Exposure to sunlight

Exposure to sunlight only verifies whether a space has access to sunrays somewhere between 1st of February and 21st of March, whereas each and every country in European Union is allowed to use a date on the basis of their own volition. The aim is that some rooms might have a sunlight exposure value exceeding

90min. Some spaces do mean: at least one room of a flat, playrooms of kindergartens and rooms of patients in hospitals.

Then by Czech legislation exposure to sunlight is verified also for certain outdoor areas, like playgrounds of kindergartens and areas suited for recreation of inhabitants of residential buildings.

However exposure to sunlight is to be introduced more in Chapter 4 and 5.

2.5 Exposure to Sunlight in Urban Settings

Sunlight is essential part of well-designed spaces and architectural elements. The role of sunlight in the built environment as a positive biologically effective factor is supported by a strong correlation among light exposure, mood status, physical well-being, and job or school performance. An absence of daylight has been associated with physiological disorders, such as seasonal affective disorder and rickets, as well as psychological illness, namely stress or depression and Sunlight has long been understood as means having a restorative effect. Sunlight can offer a sense of vitality, resulting in better concentration, efficiency, and fewer health complaints, indicating improved physical health. Furthermore, hypnotic effects have been shown in a hospital room facing the sunrise. Sunlight significantly influences the level of health measured by hospital stay time and the amount of analgesics [21].

However, long-term exposure should also be taken into account when analysing light exposure, since long-term exposure to sunlight combined with both noise and heat during the summer months reveals an increase in skin cancer. Therefore protection from overexposure to ultraviolet radiation is also important when designing a house or a series of buildings.

Another disadvantage of excessive sunlight exposure is that excessive infra red radiation that can penetrate the daylighting systems can result in unbearable heat, known as overheating.

Hence a range guidelines and regulations have been set up to try and benefit from sunshine [39].

There are several urban design guidelines that specify the design and planning considerations for ensuring adequate sunlight exposures. Based on the urban morphology, the guidelines suggest that for both compliance checker requirements, moving away from the determinant shadow-cast areas by a multiple of their heights provides the most significant compliance increase. To overcome the negative environmental impacts, architects, planners, and environmental specialists are required to work together. Sometime however the limitations are given by already existing buildings, in case of which nothing can be done [37].

The simplest of evaluations in urban planning phase can be achieved through SUN PATH DIAGRAMS.

2.6 Effects of Shading on Photovoltaic Panels

Shading of photovoltaic cells will decrease their efficiency. Shading can cause a loss of up to 40% of these systems efficiency, with local shades causing as much as 80% of losses. And that is when losses caused by grounding, wiring, and inverter are unaccounted for [42].

The biggest issues however do appear in when the photovoltaic panels used in the construction of photovoltaic power plants do not have built-in energy optimisers. Without optimisers under partial shading conditions some cells will and others will not generate electricity, and this effect results in back-flow.

Partial shading can be also a result of new urban development in their surrounding. Newly developed buildings might cause shade which can affect a photovoltaic panel sets output, which does not have optimisers installed. In this aspect urban design should take into consideration losses caused by the development. But how to determine the overall losses. Energy Plus files can be used the same way as in case of illuminance design. Nonetheless owners of these photovoltaic power plants do look at peek output under ideal conditions, with a meaning, that they are interested in losses of sunlight exposure time on cloudless days. To try out a set of discourse is an aim of this thesis.

3 LIGHT

Definition of Light

Natural Light Sources

3 LIGHT

3.1 Definition of Light

Light is the visible part of the electromagnetic spectrum, which includes both UV radiation and *Infra-red radiation* (IR radiation). It is composed of photons that travel in waves, exhibiting both particle and wave-like properties. This duality is fundamental to understanding various phenomena in optics, such as refraction and diffraction, emission or absorption.

MAXWELL'S theory of electromagnetic waves compared to the particle based approach characterizes lights as a radiation given by its wavelength, and amplitude. The definition of Maxwell's theory is based on two perpendicular fields, which are distributed at the same time as light is transmitted into the space (see FIg. 3.1), the electric and the magnetic field [12], [43].

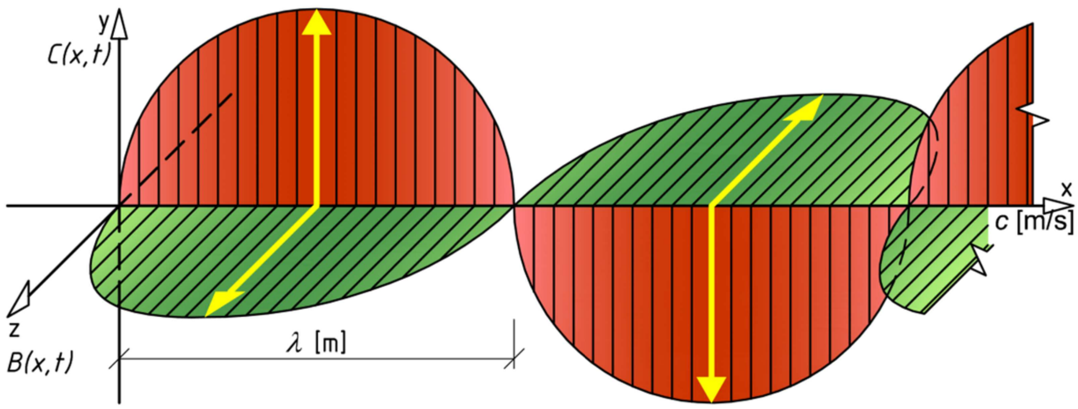


Fig. 3.1: The perpendicular magnetic and electric fields which do oscillate in harmony [43].

If these two fields do oscillate in harmony along the direction of distribution it is said, that it handles about a monochromatic type of light. However in cases of polarization of one of these fields a complicated distribution of light occurs, nevertheless this causes, that the movement of light can be derived as a sine or cosine function of electric (eq. 3.1) or magnetic radiation.

$$C(x,t) = C_m \times \sin\left[\omega \times \left(t \pm \frac{x_E}{v}\right) + \zeta\right] \tag{3.1}$$

Where:

$C(x,t)$ is the immediate deviation of electric waves,

C_m is the amplitude of deviation,

ω is the angular frequency of motion [$\mathrm{rad\,s^{-1}}$],

t is the time [s],

x_E is the displacement of current [m],

v is the phase velocity of motion [$\mathrm{m\,s^{-1}}$],

ζ is the beginning phase angle [rad].

Howbeit, light waves can be best characterized by their wavelengths and frequencies (eq. 3.2).

$$\lambda = \frac{v}{f} \tag{3.2}$$

Where:

λ is the wavelength of motion [$\mathrm{m\,s^{-1}}$],

f is the frequency of oscillation [Hz].

At the same time phase velocity of motion depends on the characteristics of the environment the wave passes through at the moment. It is possible to express this phenomenon with the means of eq. 3.3.

$$v = \frac{1}{\sqrt{\epsilon \times \mu}} \tag{3.3}$$

Where:

ϵ is the permittivity of the environment [$\mathrm{F\,m^{-1}}$],

μ is the permeability of the environment [$\mathrm{H\,m^{-1}}$], while in special cases when the electromagnetic radiation passes through vacuum for example, it is possible to rewrite eq. 3.3 into the form of eq. 3.4, which is the velocity of light in vacuum.

$$c_0 = \frac{1}{\sqrt{\epsilon_0 \times \mu_0}} \tag{3.4}$$

That is why, the value of immediate deviation of the electric radiation can be simplified to the form of eq. 3.6:

$$\omega = 2\pi \times f \tag{3.5}$$

$$C(x,t) = C_m \times \sin 2\pi \times \left(\frac{t}{T} \mp \frac{x}{\lambda}\right) \tag{3.6}$$

Where:

T is the time [s].

The division of electromagnetic radiation based on Maxwell's theory is composed of radio and TV waves, microwaves, optical radiation, and so on. It has to be however stated that optical radiation consists of IR radiation, visible light and UV radiation [44], [45].

PHOTON THEORY (also referred to as particle theory) is applicable when an optical phenomenon cannot be directly described by Maxwell's wave based theory. For example emission of light by a black matter. That is because based on particle definition of light, light is composed of discrete small sub-atomic elements, called photons, each having its own energy (eq. 3.7), and this energy is directly connected to its oscillation frequency. So photons are also part of the electromagnetic radiation, but they transmit energy. The energy transmitted by the photons can be expressed by eq. 3.7. In Tab. 3.1 the energy transmitted by photons within the range of optic radiation is visible.

From a historical point of view, the stochastic character of light has been underlined by Newton's work on the corpuscular nature of light. The explanation of the black matter, and laws in the field of quantum physics had later led to the discovery of this particle based theory [43], [12], [46].

$$e_p = H_p \times f_p \tag{3.7}$$

Where:

e_p is the energy of a photon [eV],

H_p is Planck's constants [eV],

f_p is the frequency of oscillation of adequate electromagnetic radiation [Hz].

Tab. 3.1: Wavelengths and energies of photons within the scope of optical radiation [Author, with source lit. [12], [43].

Radiation	Division	λ [nm]			e_p [eV]		
Ultraviolet	UV-A	100	-	280	12.4	-	4.43
	UV-B	280	-	315	4.43	-	3.94
	UV-C	315	-	380	3.94	-	3.26
Visible	Violet	380	-	450	3.26	-	2.75
	Blue	450	-	485	2.75	-	2.56
	Cyan	485	-	500	2.56	-	2.48
	Green	500	-	565	2.48	-	2.19
	Yellow	565	-	590	2.19	-	2.10
	Orange	590	-	625	2.10	-	1.98
	Red	625	-	750	1.98	-	1.65
Infrared	IR-A	750	-	1400	1.65	-	0.89
	IR-B	1400	-	3000	0.89	-	0.41
	IR-C	3000	-	10000	0.41	-	0.12

Without light sources there would not be any light, and there would not energy carried by light as well. Light sources can be classified as natural or artificial light sources. But, since the topic of this thesis is related to daylighting, more specifically exposure to sunlight, only natural light sources are to be introduced.

3.2 Natural Light Sources

Natural light sources are those objects and elements, which can be commonly found in nature. The Sun and the Moon for example. There may be others as well, like volcanoes, but those are unrelated to the field of daylighting. When taking a better look at the Sun and Moon example it is possible to realise, that there is a contradiction, whereas the Moon is only a reflector. By itself it does not generate any light [47], [44], [12], [43]. Thereafter, another classification has to take place. This classification describes light sources:

- either primary,
- or secondary.

Primary light sources are those, which are able to generate and emit light all time long, like the Sun, then. These types of light sources work on the basis of incandescence, that is a process in which the objects temperature goes beyond 873K [47], and afterwards together with heat, they will emit light as well. The formulae related to incandescence were derived by M. Planck in the 19th century, and are available in many literature. Like in [43] from 1965.

Secondary light sources are those, which for example reflect light, or through various reasons block and modify the path of light, like the Raylight scattering. The most know secondary light source is the Sky, which is actually a manifestation of ever changing atmospheric conditions [47],[46].

The Sun

The Sun is the primary natural energy source. It is working on the basis of incandescence, and it is a star located at the centre of the solar system around which planets, including the Earth, are orbiting. It radiates energy in the whole scope of electromagnetic radiation, i.e. waves from 10^{-11}m to 1m, because of the thermonuclear chain reactions undergoing in its core. The core of the Sun has temperature around 15.7×10^6K. Part of this heat is then transferred to the outermost layers of the star by the radiative and convective zones, although it handles only about a portion of it because these zones do have other functions as well, like to hold back part of the heat radiated by the core.

What can be seen from the Earth is only a manifestation of Suns photosphere, chromosphere and corona (layers and zones of the Sun visible in Fig. 3.2). From the point of daylighting the most important characteristic of the Sun might be the solar light constant, which is equal to 133800lx. Albeit with respect to exposure of sunlight it an unused quantity. [45]

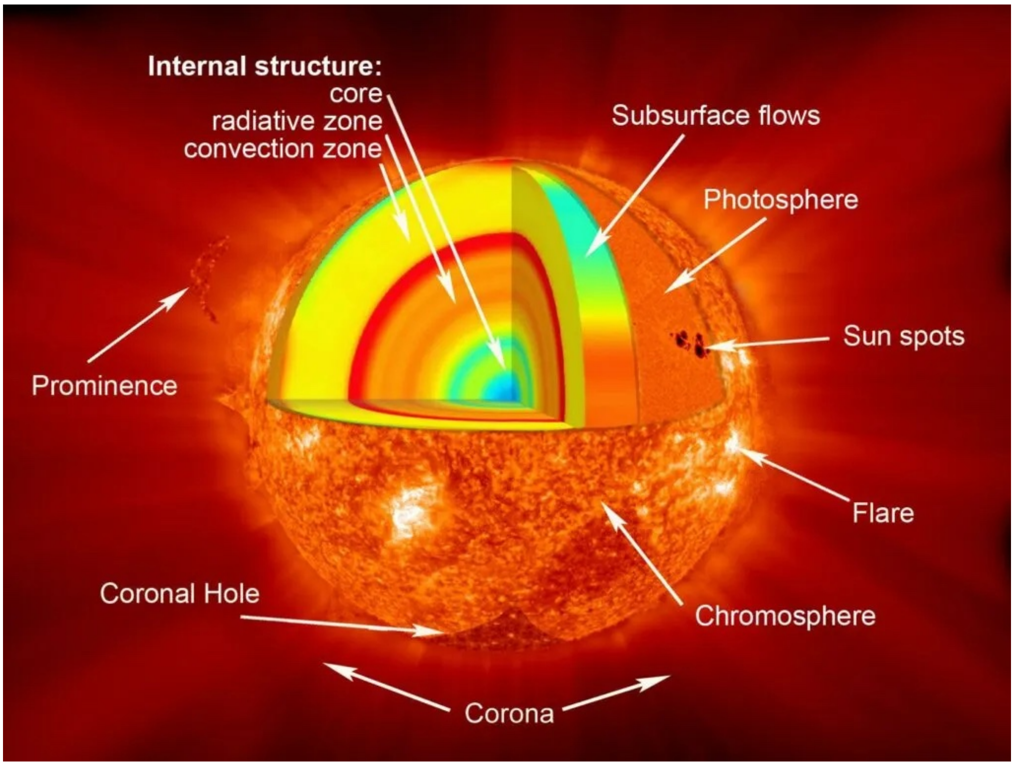


Fig. 3.2: Layers of the Sun [48].

Exposure to sunlight only works with position of Sun on the Sky using solar altitude γ_s and azimuth α_s angles, the rest is insignificant [49].

The Atmosphere and the Sky

The atmosphere and the sky are two side of the same coin. The atmosphere is often mistaken with the Sky, although what humanity refers to as sky is actually only the manifestation of interaction of optical radiation with particles in the various layers of the atmosphere. . This is referred to as scattering, and altogether three forms of scattering might take place: Raylight, Mie and Non-Selective [50].

The type of scattering depends on the sizes of the particles and molecules light might come into contact with, and also occurs in different layers of the atmosphere. In case of Raylight scattering the visible radiation is scattered by molecules of oxygen, nitrogen and other gaseous substances. The result of scattering is a visible clear blue sky. The one used in exposure to sunlight analysis. Mie scattering takes place when visible radiation get into contact with pollution caused by water, dust, pollen and other particles. It usually manifests in cloudy conditions. Non-selective scattering takes place closest to the Earth's surface and results in fog and white clouds.

At the end of the 20th century 15 sky types were defined in as a set by R. Kittler and S. Darula [45], [49]. These sky types are internationally recognized and used since then in the field of building physics.

4 AIMS OF HABILITATION

Position of Sun on the Sky

Shading of Photovoltaic Power Plants

Insolation of Indoor Spaces

4 AIMS OF HABILITATION

The aims of the presented habilitation, or simply said objectives, are focused around issues related to EXPOSURE TO SUNLIGHT[1]., which is a relatively simple, but wide topic at the same time. The roots of this particular topic can be found in both interiors and exteriors of buildings, and in determination of *Photovoltaic panel* (PV Panel) efficiency. Altogether there are two major objectives, whereas one consist of two minor ones. These are:

- Shading of Photovoltaic Power Plants *Photovoltaic power plant* (PVPP), and
- Insolation of Indoor Spaces.

4.1 Shading of Photovoltaic Power Plants

Due to the effects of Green Deal [51], and even before it became a hot topic, many Photovoltaic Power Plants PVPP have been built and are still continuously constructed all over Europe alongside wind turbines and other alternative sources of electricity, including the Czech Republic. These PVPP's were and are still built at different locations, may they be roof tops of buildings in suburban and urban areas, or fields in rural areas. Some are even constructed in black or brown-fields. Nonetheless, in each and every area including remote ones it might come to property development at any moment into the future, just because the location of suitable for logistics, living, agricultural or other purposes. And that property development might result in a reduction of PVPP's efficiency. Well not exactly PVPP's, but the Photovoltaic Panel PV Panel array.

Nevertheless, the Building Code [40] and follow-up legislation does not care about shading of PVPP's. It is usually looked after in cases of lawsuits for both, if the power plants are operated by companies or by individuals. Hence, at least in the Czech Republic there is no methodology defined to assess shading of these power plants by property development in their vicinity. Albeit, it is quite necessary, and the thesis is to propose a set of routines based on case studies for a year long assessment.

[1] Exposure to sunlight is sometimes referred to as insolation. The related quantity is called as SUNLIGHT EXPOSURE.

4.2 Insolation of Indoor Spaces

More often than not, living (and other selected) spaces do not have sufficiently high sunlight exposure time to them, resulting in an insolated room. There might be various reason why spaces do fail this analysis, like:

- Improper orientation of windows with respect to cardinal directions,
- Depth of overhanging elements, like balconies, or
- Simply because of unrealistic or not defined variables, like the height angle of Sun, referred to as solar altitude.

Improper orientation of windows is mainly caused by the boundary conditions of design, location. If the windows are facing the street which is for example towards the North, then daylighting systems can rarely point towards other cardinal directions. So the secondary objectives of the thesis revolve around aspects,that are to be verified on actual case studies where the daylighting systems orientation (or some structures and immediate surroundings) do limit sunlight exposure at the recommended solar altitude angle of $\gamma_s = 13°$, like:

- Effects of probe position of sunlight exposure, and,
- Effects of linear determination model on sunlight exposure.

Effects of probe position and linear determination model on sunlight exposure

When it comes to determination of sunlight exposure time of an indoor space (a room), a set of rules is to be followed. At the moment these rules are described in the ČSN EN 17037+A1 standard [1] and one of those rules is related to the position of evaluated point. This point is fixed for every daylighting system (i.e. window), and this is the only location where the exposure time is to be determined.

In plan it is supposed to be in the middle of the opening, although there are some ways, ideas how to overcome these limitations.

Albeit, is it really worth to determine exposure time at a fixed point? What would happen, if sunlight exposure time would be determined:

- at a floating location,
- or as a set of points over a linear model.

How would it total out? This is the topic for these objectives.

5 METHODOLOGY

Position of Sun on the Sky

Shading of Photovoltaic Power Plants

Insolation of Indoor Spaces

5 METHODOLOGY

The objectives listed in the previous chapter have a relation to issues having their roots in professional practice. To obtain the required effects the methods used are to follow a set of individual rules. Those are the formulae used to determine the Sun's position on the sky.

5.1 Position of Sun on the sky

Suns position on the sky is a result of many factors, variables, out of which the most important are the coordinates of the location of evaluated building or field, and the exact time.

Solar altitude and azimuth are derived to certain times of a day following a set of formulae [1]. The whole operation begins with deduction of true solar time TST, the units of which are hours [h], Eq. 5.1.

$$TST = LT + \frac{\lambda - \lambda_s}{15} + ET \tag{5.1}$$

Where:

LT is local clock time [h],

λ is geographical longitude of the site. Its value is positive when East or negative when West of Greenwich [°],

λ_s is longitude of standard meridian [°],

ET time relation [h].

Time relation ET and declination of the Sun δ are variables obtained through relations Eq. 5.2 and Eq. 5.3.

$$ET(J) = 0.0066 + 7.3525 \times \cos(J' + 85.9°) + 9.9359 \times \cos(2J' + 108.9°) + \\ + 0.3387 \times \cos(3J' + 105.2°) \tag{5.2}$$

$$\delta(J) = 0.3948 - 23.2559 \times \cos(J' + 9.1°) - 0.3915 \times \cos(2J' + 5.4°) - \\ - 0.1764 \times \cos(3J' + 26°) \tag{5.3}$$

Where J is the day number of the year. The value of J is increasing day after day. For 1[st]of January it is equal to 1, for 1[st]of March its value corresponds to 60, and for 31[st]of December it rises to 365. Leap years are not included.

The hourly angle ω [°] can be determined with the help of eq. 5.4. It can be both positive (in the afternoon) and negative (in the morning).

$$\omega_\theta = (12:00\text{h} - TST) \times 15° \tag{5.4}$$

Solar altitude angle γ is afterwards obtained with the help of relation eq. 5.5.

$$\gamma_s = \arcsin(\cos\omega_h \times \cos\varphi \times \cos\delta + \sin\varphi \times \sin\delta) \tag{5.5}$$

Where:

φ is geographical latitude of site [°].

For the determination of solar azimuth angle α_s two relations are to be used depending on the time of the day. For morning time ($TST \leq 12:00\text{h}$) it handles about relation eq. 5.6, whereas for afternoon ($TST > 12:00\text{h}$) it is eq. 5.7.

$$\alpha_s = 180° - \arccos\frac{\sin\gamma_s \times \sin\varphi - \sin\delta}{\cos\gamma_s \times \cos\varphi} \tag{5.6}$$

$$\alpha_s = 180° + \arccos\frac{\sin\gamma_s \times \sin\varphi - \sin\delta}{\cos\gamma_s \times \cos\varphi} \tag{5.7}$$

When these equations are properly used, there are at least four possibilities available how one can use them to determine sunlight exposure time (also referred to as insolation time).

These would be:

- stereographic projection Fig. 5.1,
- parallel projection,
- shading diagram Fig. 5.2,
- other, like 3D software setup.

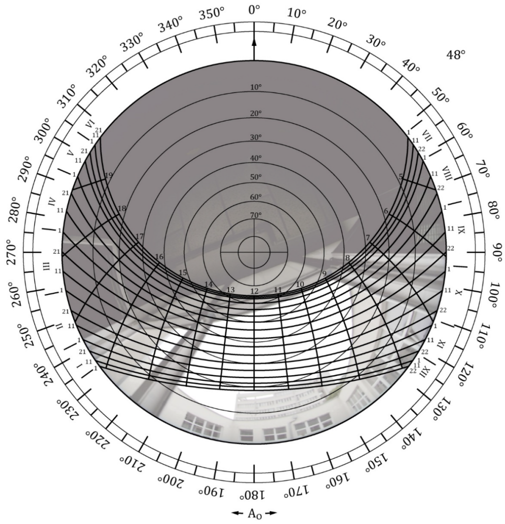


Fig. 5.1: Stereographic projection overlay of a fish-eye image [1].

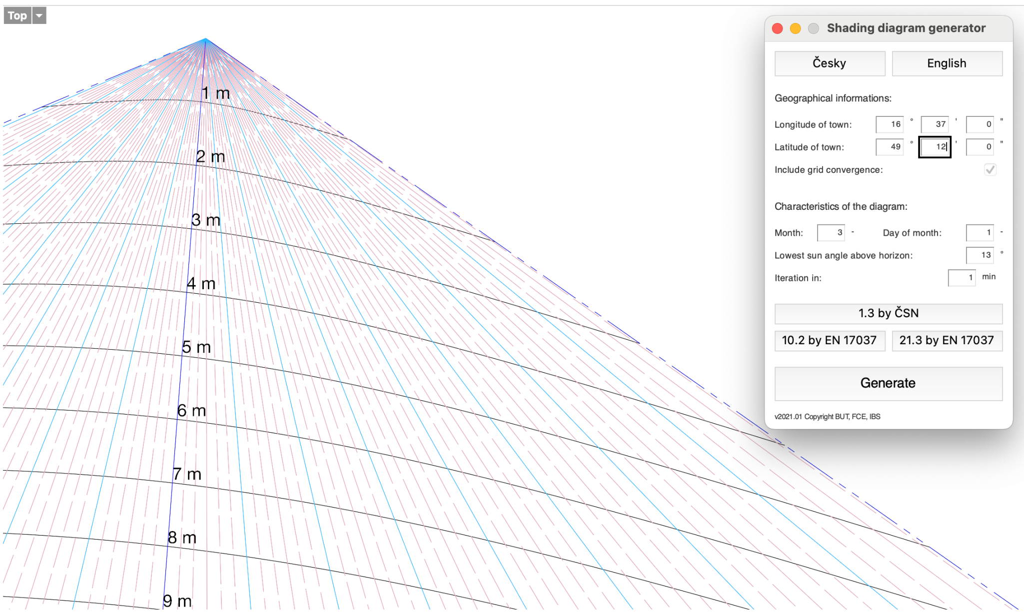


Fig. 5.2: Shading diagram for 1st of March generated by a tool called Shading Diagram Generator [Source: Author].

On Fig. 5.3 and 5.4 the application of previously described relations in Rhino 3D is demonstrated with the help of python modules developed by the author of this habilitation. The basic module is referred to as EXPOSURE TO SUNLIGHT EN 17037 LITE. The current version is v2021.01. There are follow up modules available, like the PRO version allowing multiple evaluations to take place (was never made public), or FIELDINS, which is used to determine insolation time of outdoor areas, just to mention some. A section of the source code is visible on Fig. 5.5. Generally the basic module allows modifications to the source code, changing it in ways how it is required for research for example.

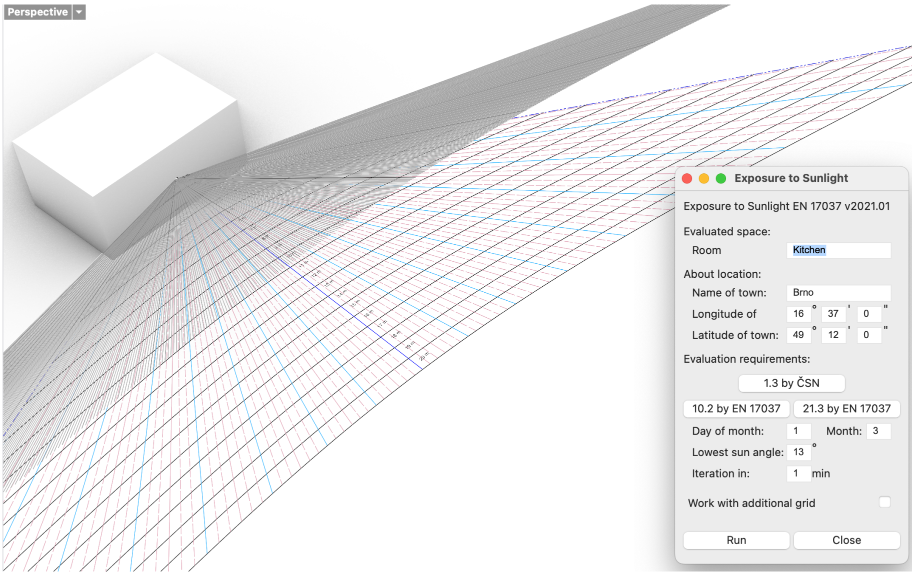


Fig. 5.3: 3D application of relations with Exposure to Sunlight EN 17037 (curves in grey). The curves in colour do represent the Shading diagram.

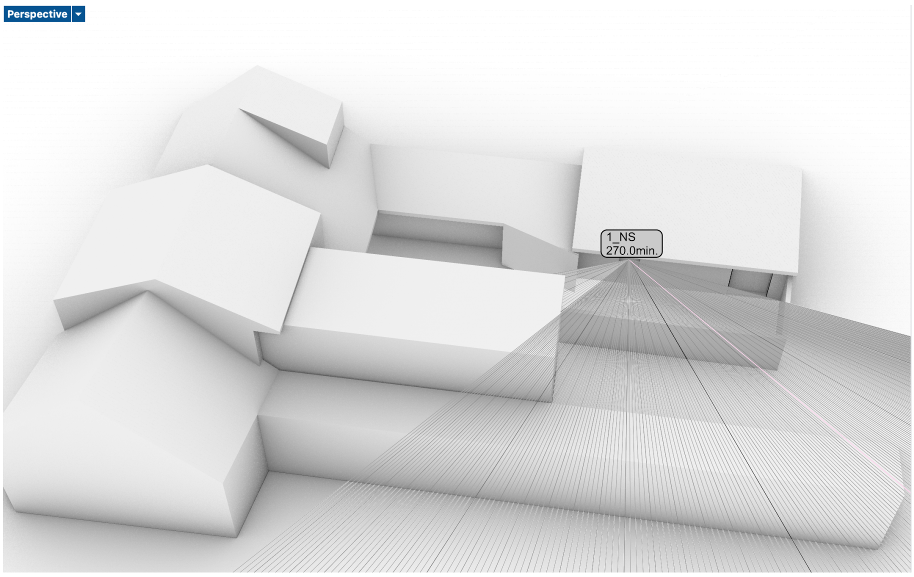


Fig. 5.4: Determination of sunlight exposure time of a window with Exposure to Sunlight EN 17037 in Rhino 3D.

```python
# - Exposure - #
def rays(spc,latDeg,lonDeg,htSel,base,normal,day,month,steps,grid):
    months = [[1,2,3,4,5,6,7,8,9,10,11,12],[0,31,59,90,120,151,181,212,243,273,304,334]]
    if month in months[0]:
        J = months[1][months[0].index(month)] + day
        Js = 360 * J/365

    etMin = 0.0066 + 7.3525 * math.cos(math.radians(Js + 85.9)) + 9.9359 * math.cos(math.radians(2 * Js + 108.9)) \
            + 0.3387 * math.cos(math.radians(3 * Js + 105.2))
    ethDeg = etMin / 60
    ethRad = math.radians(ethDeg)

    rdDeg = 0.3948 - 23.2559 * math.cos(math.radians(Js + 9.1)) - 0.3915 * math.cos(math.radians(2 * Js + 5.4)) \
            - 0.1764 * math.cos(math.radians(3 * Js + 26.0))
    rdRad = math.radians(rdDeg)

    # - Evaluation variables - #
    j0 = 0
    j1 = 0
    j2 = 0
    insTime = 0

    for i in range(min,max,steps):
        tst = i / 60 + (lonDeg - 15) / 15 + ethDeg

        haDeg = (12 - tst) * 15
        haRad = math.radians(haDeg)

        htRad = math.asin((math.cos(haRad) * math.cos(latRad) * math.cos(rdRad)) \
                + (math.sin(latRad) * math.sin(rdRad)))

        azimBRad = math.acos((math.sin(htRad) * math.sin(latRad) - math.sin(rdRad)) / (math.cos(htRad) * math.cos(latRad)))
```

Fig. 5.5: Segment of Exposure to Sunlight EN 17037 modules source code.

These modules were not developed by the AUTHOR because of missing software tools, because there were and still are some, like Ladybug and Honeybee, or Sunlis and EN17037 modules of Building Design software. No, these were created because the other tools available were not flexible enough when working on volumetric studies in early phases of building development.

Modules of Sketchup and ArchiCAD are not based on the previous set of relations to determine the position of Sun on the Sky, thus they should not be used in final evaluations.Nonetheless, Exposure to Sunlight EN 17037 Lite could be ported to Ruby or Perl, thus it would be usable in SketchUp as well.

5.2 Shading of Photovoltaic Power Plants

Except of verifying an interiors exposure to sunlight, it is also important to determine it for outdoor areas, which are not covered by the current Building Code [40] and follow-up legislation. Although there is a brief introduction about it in ČSN 73 4301 [52] standard.

Quite the opposite, evaluation of outdoor areas is mainly required when property owners of existing buildings who are individuals do make some remarks while pointing at Ad. 1 of §1014 of Civil Code [53]. These individuals are sometimes right, but often do not get to see the bigger picture. Because of them a more complex evaluation process has to take place, with the aim to state, whether their land is going to be shaded excessively or not.

What is their property? Primarily it handles about lands around residential object suited for recreation of inhabitants of these residential buildings. Secondarily, these individuals might just want to know how the output of PVPP installation on rooftops of their properties will drop when shaded by new development in their vicinities.

If the property owner would be a legal entity, then it gets a bit more troublesome. Legal entities are not secured by the Civil Code [53], therefore when these subjects do object the shading of their properties it is highly expected to reach the Courts. The PVPP installations by legal entities are greater than in case of individuals. So they expect losses with a viewpoint in income.

Determination of shading of outdoor areas including rooftops and PV Panel's can have two forms:

- Drawing of shadows from surrounding objects and new constructions. The shadows are drawn for every hour between $7:00$ and $17:00$ on the 1stof March to determine the outdoor areas shaded domain. Afterwards the selection will be narrower to determine the time intervals when it comes to exposure to sunlight over a domain greater than 50% of the total area of outdoor field, or surface. Part of this process is demonstrated on Fig. 5.6.
- A mathematical form, when through an application the terrain will be torn

down to elementary areas of certain dimensions (approximate dimensions), followed by the determination of sunshine exposure time in the elementary areas centroid. Demonstrated on Fig. 5.7 and Fig. 5.8.

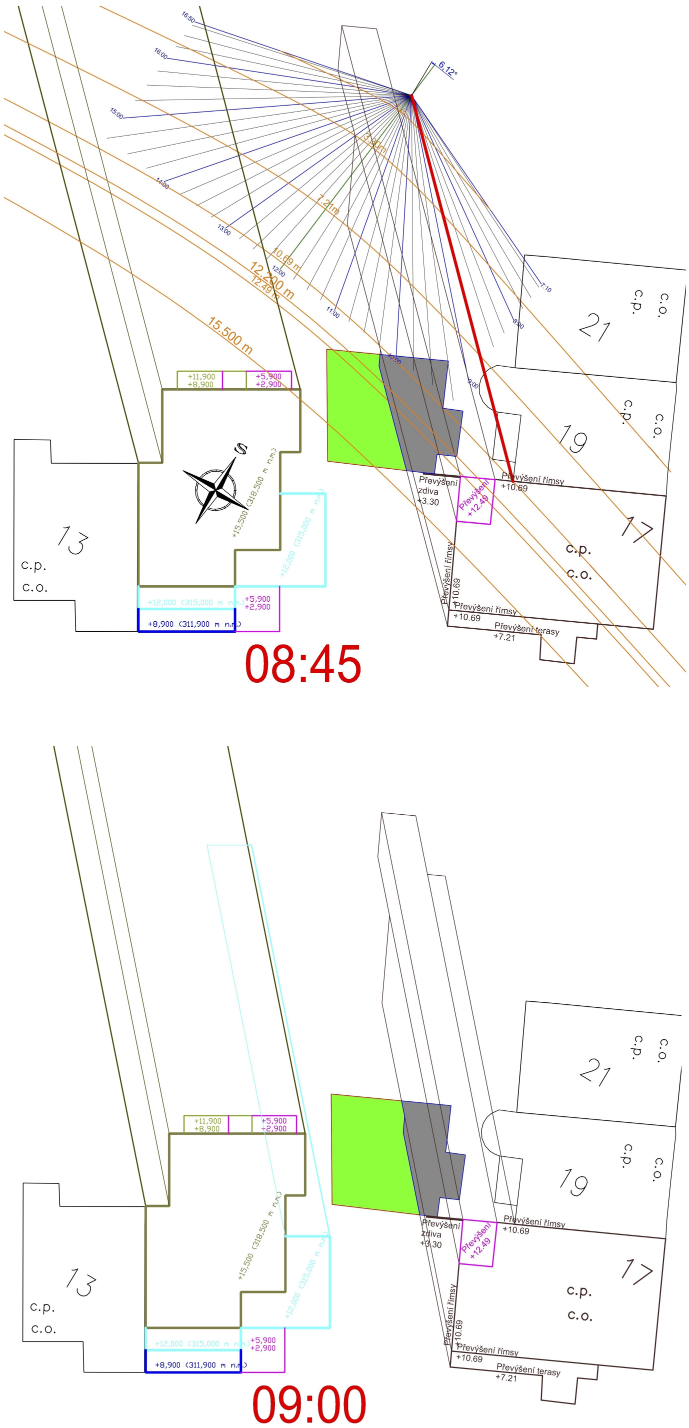


Fig. 5.6: Drawing of shades for determination of a fields insolated area, on 1st of March somewhere in Brno. TST $= 8:45\text{h}$ *and* $9:00\text{h}$.

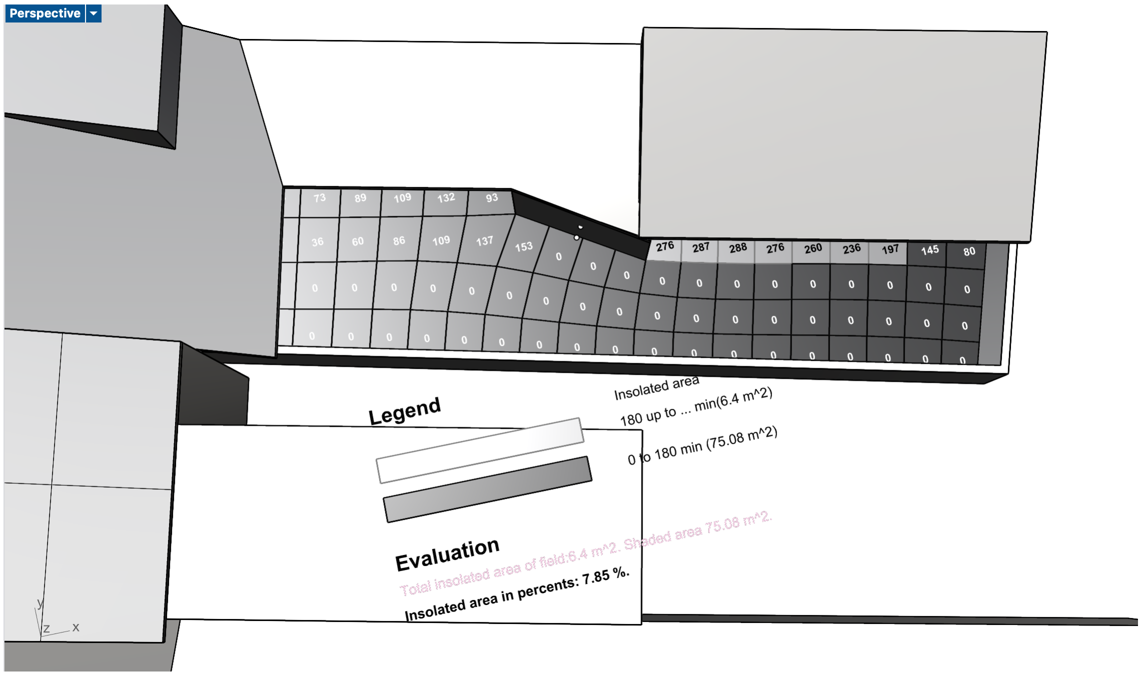


Fig. 5.7: Determination of insolated area of outdoor field with FieldIns EN 17037.

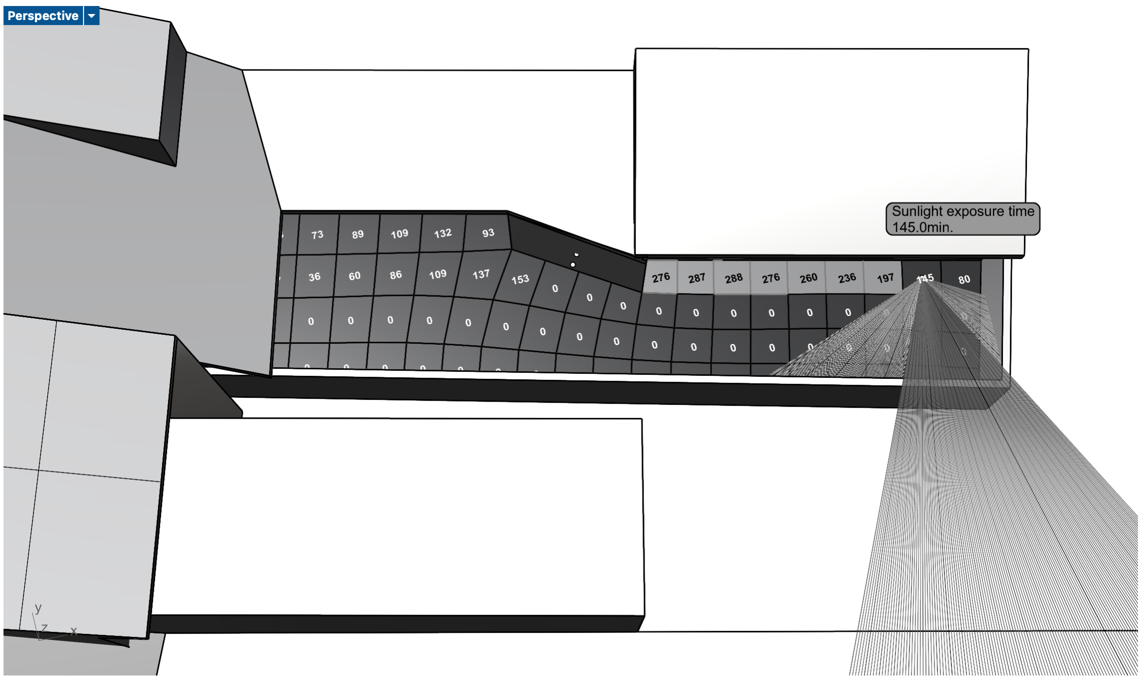


Fig. 5.8: Determination of insolated area of outdoor field. Verification of sunlight exposure time of elementary area.

PV Panel and PVPP's are usually referred to in evaluations done by professionals as outdoor areas. For small scale installations of photovoltaic panels on sloped roofs it might be feasible option, as a decline in solar exposure time can be easily obtained this way as demonstrated on Fig. 5.9 and 5.10.

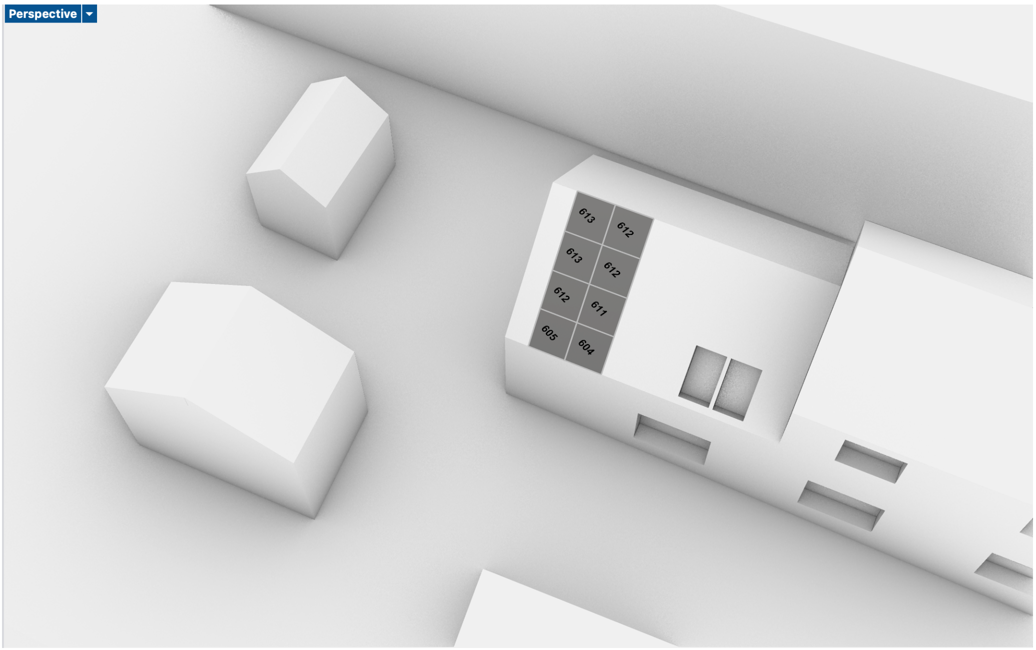


Fig. 5.9: Sunlight exposure time determination of PV Panel installation on a rooftop - 21st of September, original stage.

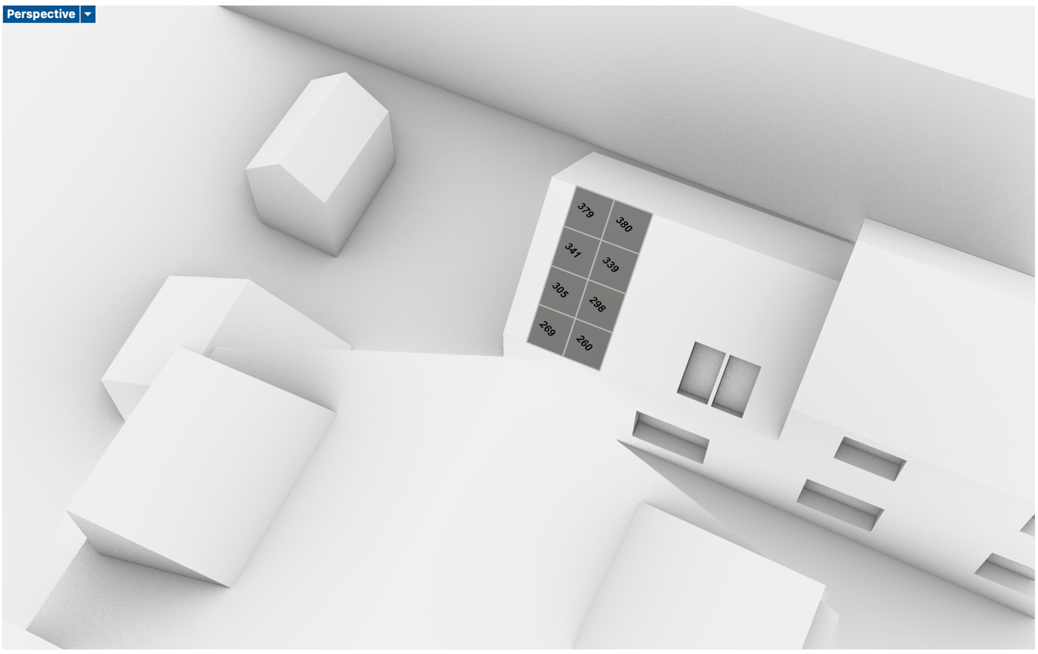


Fig. 5.10: Sunlight exposure time determination of PV Panel installation on a rooftop - 21st of September, designed stage.

However, on greater PVPP the previous procedure seems to be ineffective, since panels making up a power plant do have ideal tilt, orientation, height, etc. And what is the most important, it handles about money losses.

PVPP's are designed with care to get the highest power output throughout the whole year. So the proposed procedure for evaluation would be the following:

- Determination of sunlight exposure times of elemental areas making up the field in original and designed states, for one day each month. The aim is to locate the PV Panel sets which are shaded by development in their vicinities,
- Determination of sunlight exposure times in the area centroids of PV Panel sets in shaded locations. The reasoning behind this step is in the elimination of sun rays, which come from behind and have no effect on the general power output,
- If it comes to a loss to any PV Panel set, make daily calculations FROM-TO dates, when the panels were not shaded, so that the daily effects could be accountable.

THE AIM IS NOT TO DETERMINE THE IRRADIATION AVAILABILITY on PV Panel before and after property development, whereas those would be just a result of Energy Plus (*.epw) files application in simulations. What is looked up on the other hand is so called Solar availability. How long could the Sun shine over the panels.

The case study the proposal was based upon can be seen on Fig. 5.11.

Fig. 5.11: Panoramatic view of PVPP. Source: https://mapy.cz.

5.3 Insolation of Indoor Spaces

When it comes to determination of exposure time to sunlight of an indoor space, a room, a set of rules is to be followed. At the moment these rules are described in the ČSN EN 17037+A1 standard [1] and one of those rules is related to the position of evaluated point. This point is fixed for every daylighting system (i.e. window), and this should be the only location where the exposure time is to be determined.

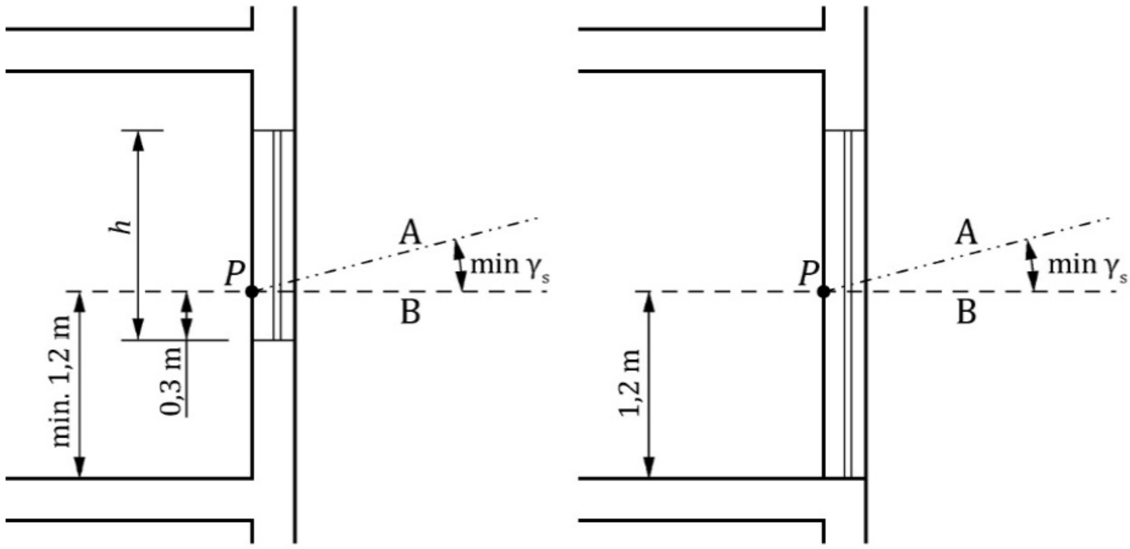


Fig. 5.12: Position of evaluated point in plan according to valid restrictions [1].

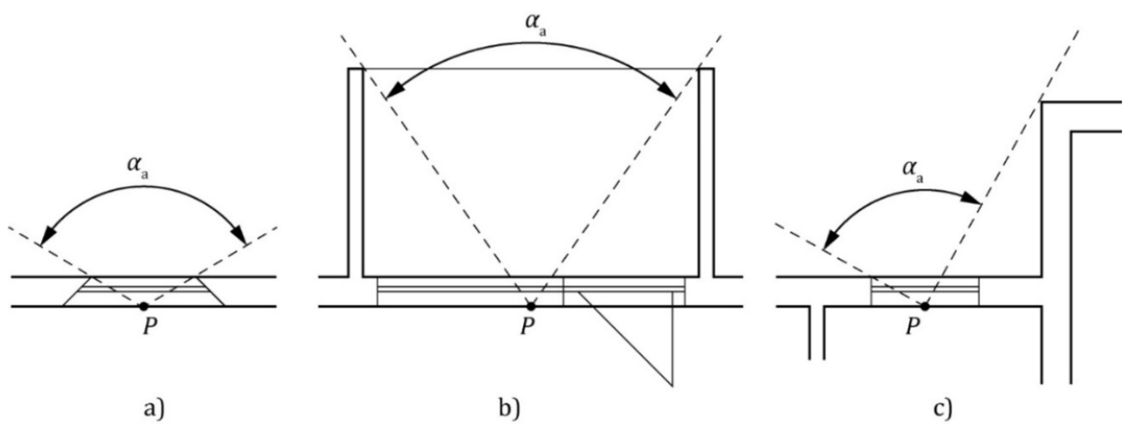
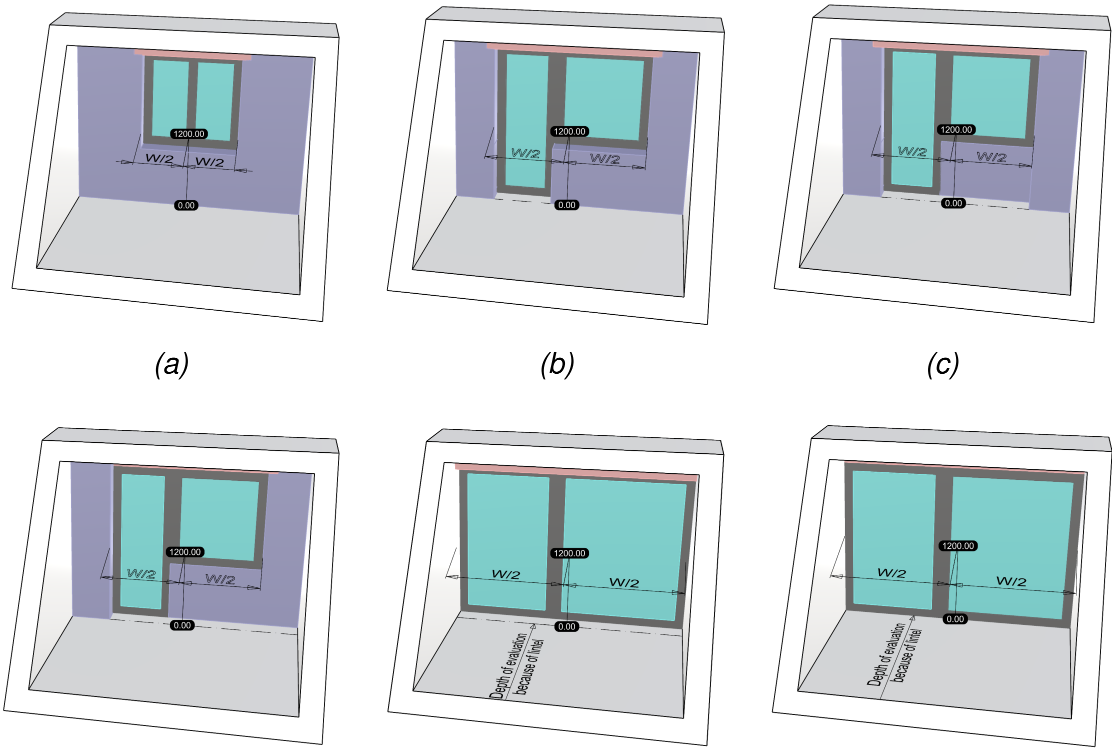


Fig. 5.13: Position of evaluated point in section according to valid restrictions [1].

In plan it is supposed to be in the middle of the daylighting system, flushed with the deepest edge of the peripheral structure containing the daylighting system Fig. 5.12. In section the point of evaluation should be at least 1200mm above the floor of the room and at least 300mm above the parapet of the window. Fig. 5.13. Possible combinations of external walls and daylighting systems with respect to position of evaluated points are visible on Fig. 5.14.



(a) *(b)* *(c)*

(d) *(e)* *(f)*

Fig. 5.14: A graphical depiction of possible setups. a) Normal size window in a wall with constant thickness. b) Balcony door next to a window in a wall with constant thickness. c) Balcony door next to a window in with parapet wall thinner than the rest of the wall. d) Balcony door next to a window in with thicker wall on one end of the opening. e) Window throughout the whole width of the room with narrow or no lintel above opening. f) Window throughout the whole width of the room with narrow or no lintel above opening.

To reach the secondary objectives, which are:

- Effects of probe position of sunlight exposure, and,
- Effects of linear determination model on sunlight exposure,

one has to properly work with the angle of minimal solar altitude $\gamma_{s,min}$. The members of the standardization committee could not come to an agreement to what angle use. This happened before the ČSN EN 17037 standard was made public in 2018, respectively 2019, replacing the old regional standards which were supposed to go through revisions, so that they might in accordance.

Why does this angle even exist?

Minimal solar altitude $\gamma_{s,min}$ was used for decades without any proper definition, and the professional community (including the Author) began to simplify its meaning. They thought that this angle acts as a countermeasure to eliminate possible shading by not so distant and distant objects, like hills, which if not included in the calculation procedure with a lower solar altitude angle might influence the results.

Those who know the real story are few, and most of them are already retired persons.

The real meaning behind this angle is simpler. That is to limit the effective solar azimuth α_s to the interval $\langle -120°, +120° \rangle$ in the countries of the European Union. Regardless, since it stayed unexplained in the ČSN EN 17037 standard. in the Czech Republic nobody realized this until 2021.

In 2021 doc. Kaňka [54] thought there there must be some deeper meaning and came across the Slovak mutation of ČSN 73 4301, the STN 73 4301 standard, in which explained how to work with minimal solar altitude $\gamma_{s,min}$.

If the members of normalisation committee would have had access to this information, they might have agreed on a value. Hence, compared to other countries which use 21stof March as an evaluation date, Czech Republic still sticks to 1stof March. And for the 1stof March professionals were only recommended to restrict $\gamma_{s,min}$ to $13°$ as it would be for 21stof March.

Doc. Kaňka as a result created an MS Excel spreadsheet referred to as GAMAMIN [55], which can be used to determine the minimal solar altitude value based on latitude and date. Through this he could find the actual values of minimal solar altitude $\gamma_{s,min}$ for Prague, which are represented in Tab. 5.1.

Tab. 5.1: Minimal solar altitude $\gamma_{s,min}$ angles for Prague from 1st of February until 21st of March [54].

Date	$\gamma_{s,min}$ [°]	Date	$\gamma_{s,min}$ [°]	Date	$\gamma_{s,min}$ [°]	Date	$\gamma_{s,min}$ [°]
1.2	0	14.2	0	27.2	3	12.3	8
2.2	0	15.2	0	28.2	3	13.3	9
3.2	0	16.2	0	1.3	3	14.3	9
4.2	0	17.2	0	2.3	4	15.3	10
5.2	0	18.2	0	3.3	4	16.3	10
6.2	0	19.2	0	4.3	5	17.3	11
7.2	0	20.2	0	5.3	5	18.3	11
8.2	0	21.2	0	6.3	6	19.3	12
9.2	0	22.2	0	7.3	6	20.3	12
10.2	0	23.2	1	8.3	7	21.3	13
11.2	0	24.2	1	9.3	7		
12.2	0	25.2	2	10.3	8		
13.2	0	26.2	2	11.3	8		

Albeit, Czech Republic is a bit peculiar, similar to bigger countries, given that:

- The value of 13° (applicable to 21st of March) should only apply to location South from parallel with a latitude of 50.25°. North from this parallel line the proper minimal solar altitude would be 12°. Fig. 5.15. Thus more than half of the area of Czech Republic has applicable 13°.
- For the date of 1st of March the results are different, though. The angle of latitude parallel where the turning point is at 49.97°. It passes through the republic just a bit under Prague, the capital. North from it the minimal solar altitude would be 3°, but South from it 4° would be preferable. Fig. 5.16.

Some case studies are located towards the North, some towards the South from these parallel latitudes. But to simplify the process of experiment activities the global values are going to be used.

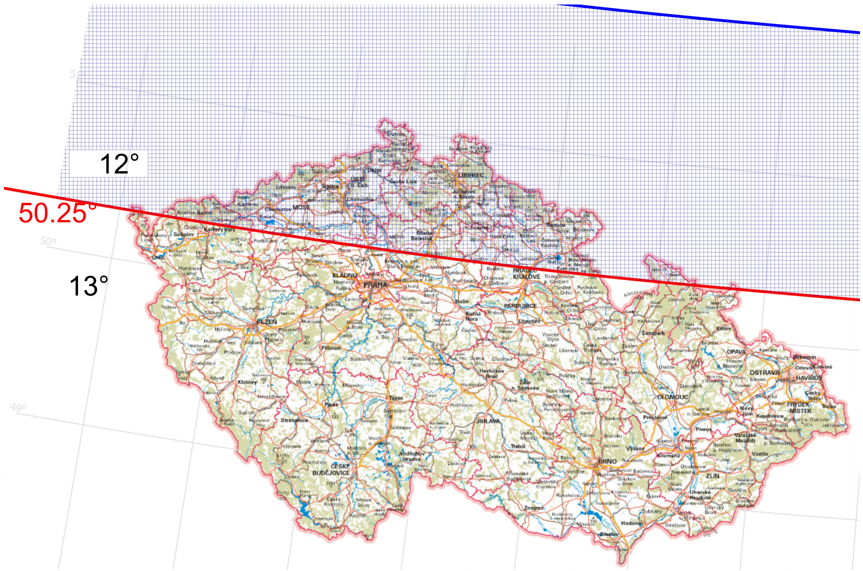


Fig. 5.15: Parallel of latitude for 21st of March.

Fig. 5.16: Parallel of latitude for 1st of March.

The case studies are all buildings, which are in the process of development over the country. Two are located in Southern Moravian Region (Fig. 5.17) and (Fig. 5.18), and the last one is in Central Bohemian Region (Fig. 5.19)[1].

[1] The models were deprived of the surroundings so that they could not be recognized.

Fig. 5.17: Case study No. 1 - Perspective view to the 3D model of the building in Moravia (the model was slightly altered).

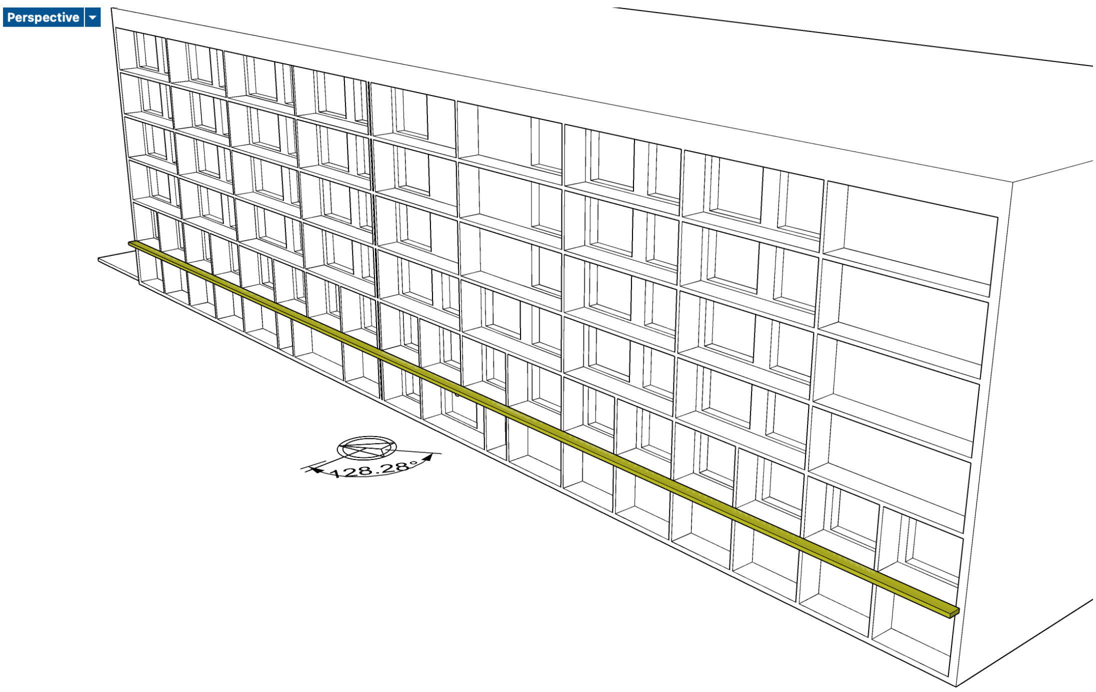


Fig. 5.18: Case study No. 2 - Perspective view to the 3D model of the building in Bohemia (the model was slightly altered).

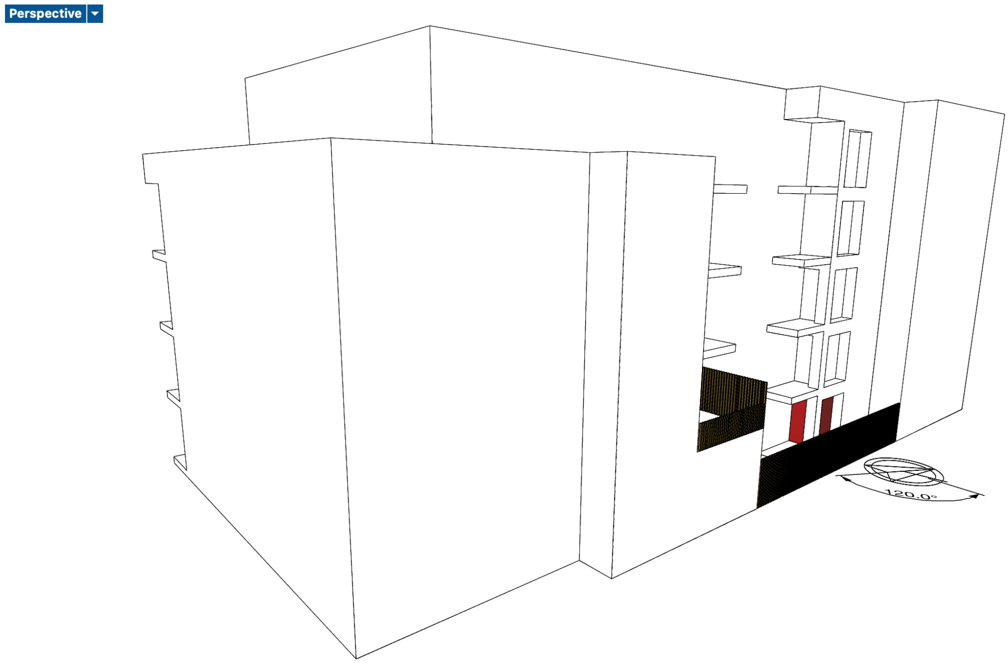


Fig. 5.19: Case study No. 3 - Perspective view to the 3D model of the second building in Moravia (the model was slightly altered).

All of the case studies are apartment buildings, and as it was already mentioned, in each and every case the sunlight exposure failed to meet the requirements on the 1st of March under the conditions of recommended minimal solar altitude, which is $\gamma_{s,min} = 13°$.

Effects of linear determination model on sunlight exposure

As it was already explained in the aims, there are times, when the windows are shaded by some special elements, or just that the orientation is such, that sunlight exposure time is lower than 90min.

What would happen, if the position of evaluated point would be floating? What if, the only limitation there would be was, that the point had to be in the distance of 450mm, so that the opening evaluated, or accountable area of opening would have at 900mm in width?

Actually there are two stages in which this evaluation is to take place:

- Stage 1 is, when the position of evaluated point changes its position in 50mm steps until it reaches the boundary of 450mm on both sides of the opening,while at the same time the minimal solar altitude is going to change as well to find a relation between position and minimal solar altitude (Fig. 5.20),

- Stage 2 is, when the evaluation is not going to be limited by the distance of 450mm from the openings sills, because the whole width is to be taken into consideration. Each and every minute of the day is to be counted only once when it reaches any of the evaluation points. To simplify this process, the evaluation described in the thesis is limited to one w = full width and $z = 0$ combination. (Fig. 5.21).

The minimal solar altitude angles will change between $3°$ and $13°$ (corresponding to a single value according to ČSN EN 17037+A1 [1]) and the date set is 1st of March [52].

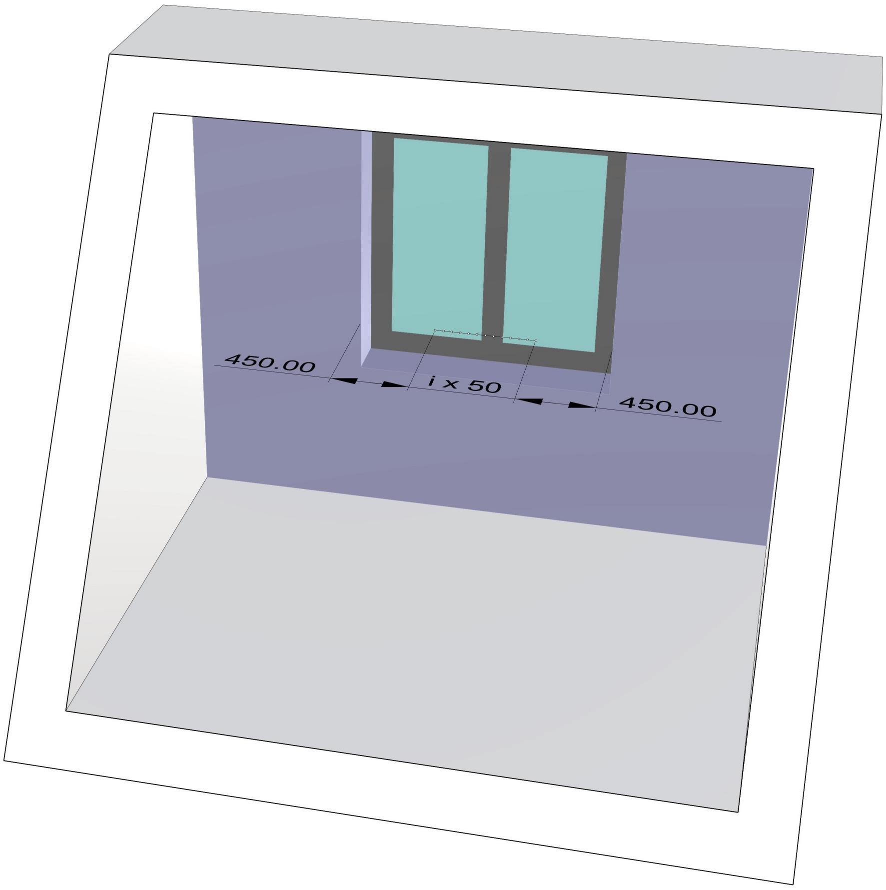


Fig. 5.20: Evaluation points location when they are floating.

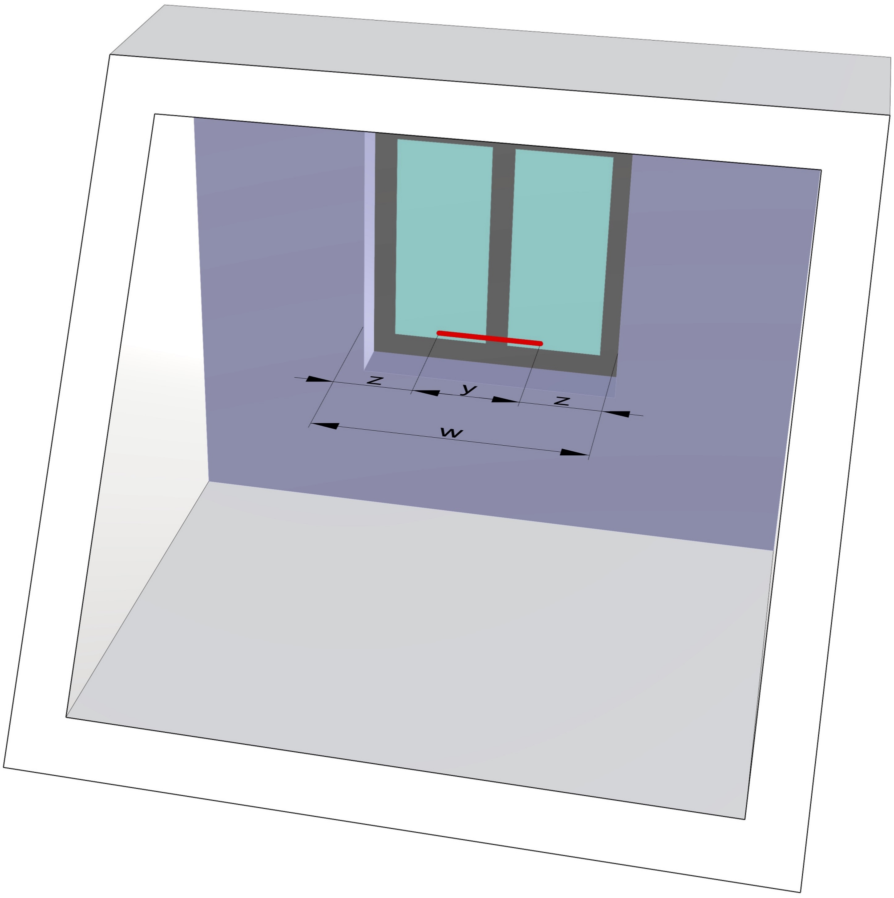


Fig. 5.21: Linear evaluation model scheme.

6 RESULTS

Shading of Photovoltaic Power Plants

Insolation of Indoor Spaces

6 RESULTS

6.1 Shading of Photovoltaic Power Plants - Experiments

The proposed methodology to assess shading of PVPP has three stages:

- 1st stage is about determination of exposure to sunlight of the land over which the Photovoltaic Power Plant (PVPP) was constructed.
- 2nd stage is related to evaluation of sunlight exposure time of Photovoltaic Panel Set (PV Panel), that make up the PVPP. The dates in this case are the same, as in the first stage, just to get a general overview how the PV Panel sets over the shaded areas are influenced.
- 3rd stage is a comprehensive evaluation stage, which overlaps the dates from previous stages by intervals.

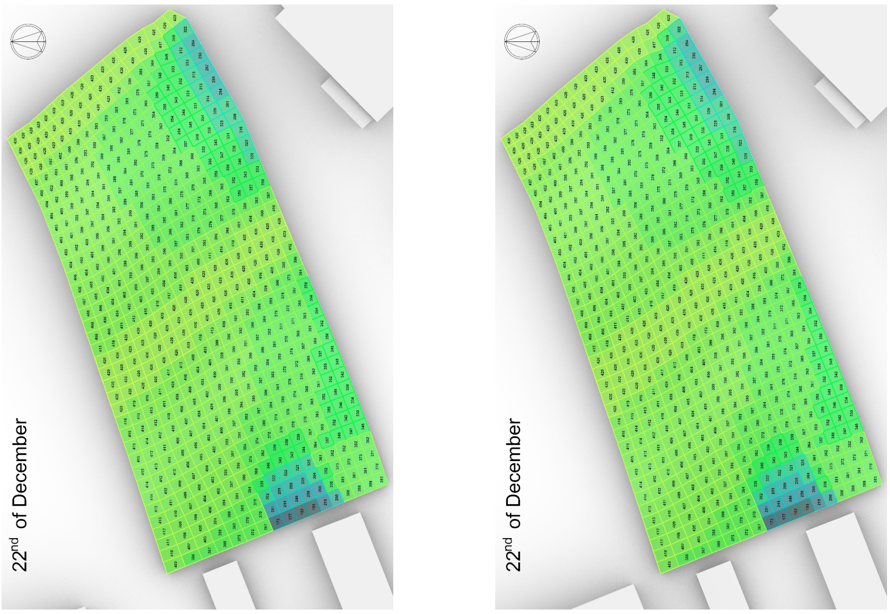
Each stage commences with the same input. Those are the terrain of property over which the PV Panel are positioned, and surrounding objects. The scenes of original and designed states were prepared in Rhino 3D nurbs modeller from available data, which were contours lines of the terrain and heights of buildings determined by a surveyor.

6.1.1 1st Stage - Exposure of Land Under PVPP

The evaluation presented in this section was carried out between 22nd of December and 21st of June, through spring time. The dates very chosen with respect to winter and summer solstices, since between these two dates the astronomical positions of the Sun are symmetrical. Therefore the results obtained for spring time will be applicable to autumn as well.

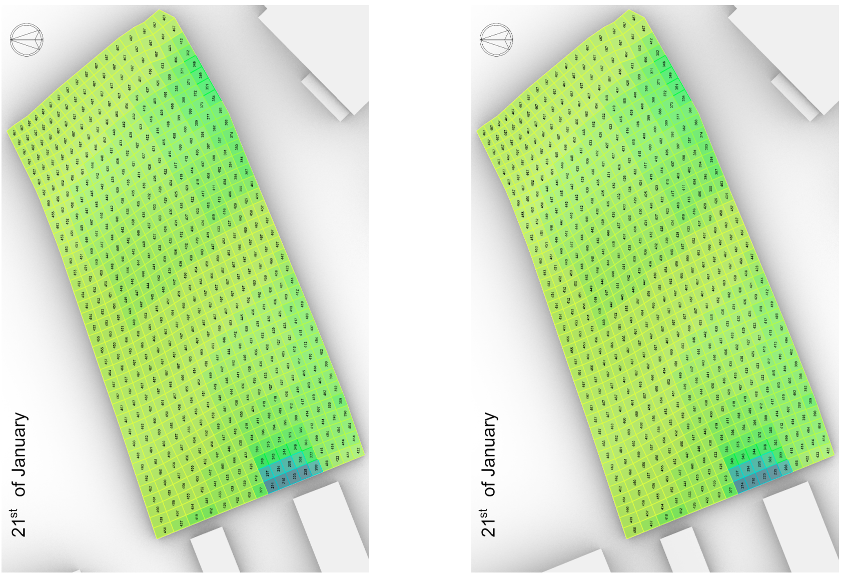
The fields area has been re-meshed resulting in 629 quad shaped elemental areas with similar dimensions. The sunlight exposure times were then determined in the centroids of these elemental areas under a single boundary condition, except for the dates, which that would be the minimal solar altitude angle. In urban areas a value of 13° would be used (as recommended), but in this case 3° were applied, since it handles about a rural, industrial and agricultural area. The value was chosen to rule out shading by distant topography, which would not limit sunlight accessibility.

The results are represented on figures from Fig. 6.1 to Fig. 6.11.



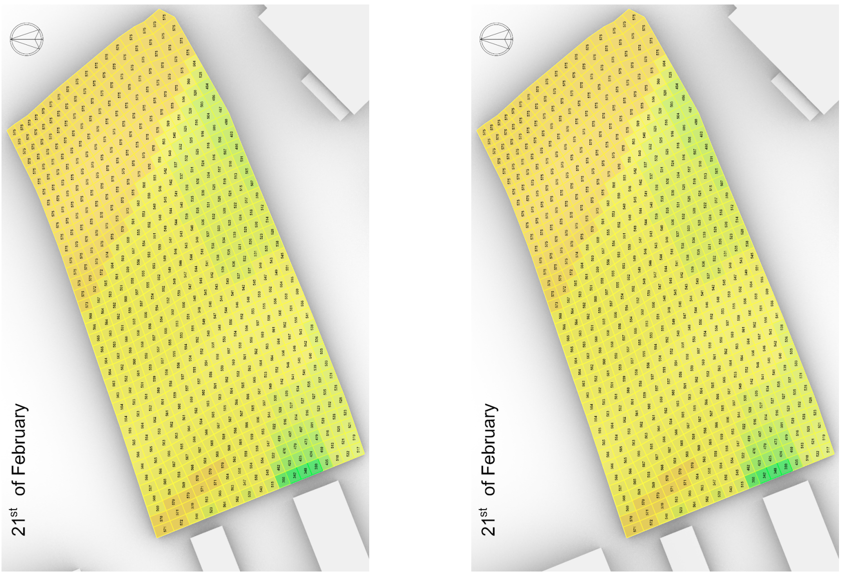
(a) *(b)*

Fig. 6.1: Results for 22nd of December. a) Original state, b) Designed state.



(a) *(b)*

Fig. 6.2: Results for 21st of January. a) Original state, b) Designed state.



(a) *(b)*

Fig. 6.3: Results for 21st of February. a) Original state, b) Designed state.

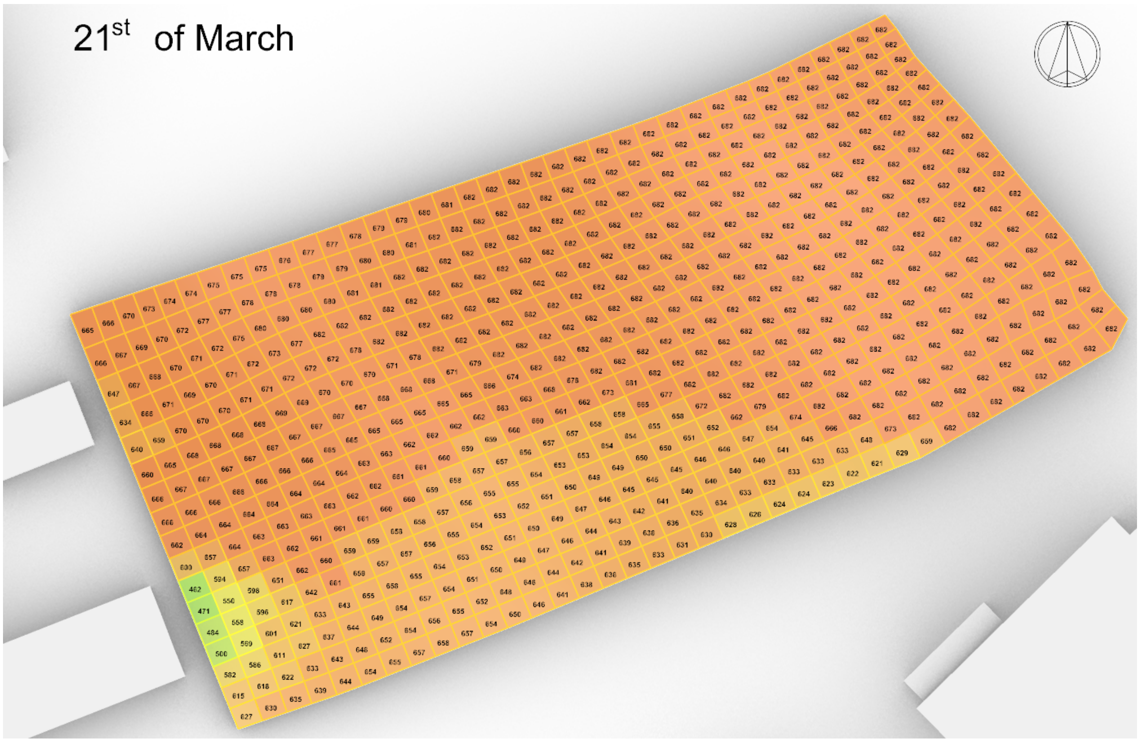


Fig. 6.4: Current state on 21st of March.

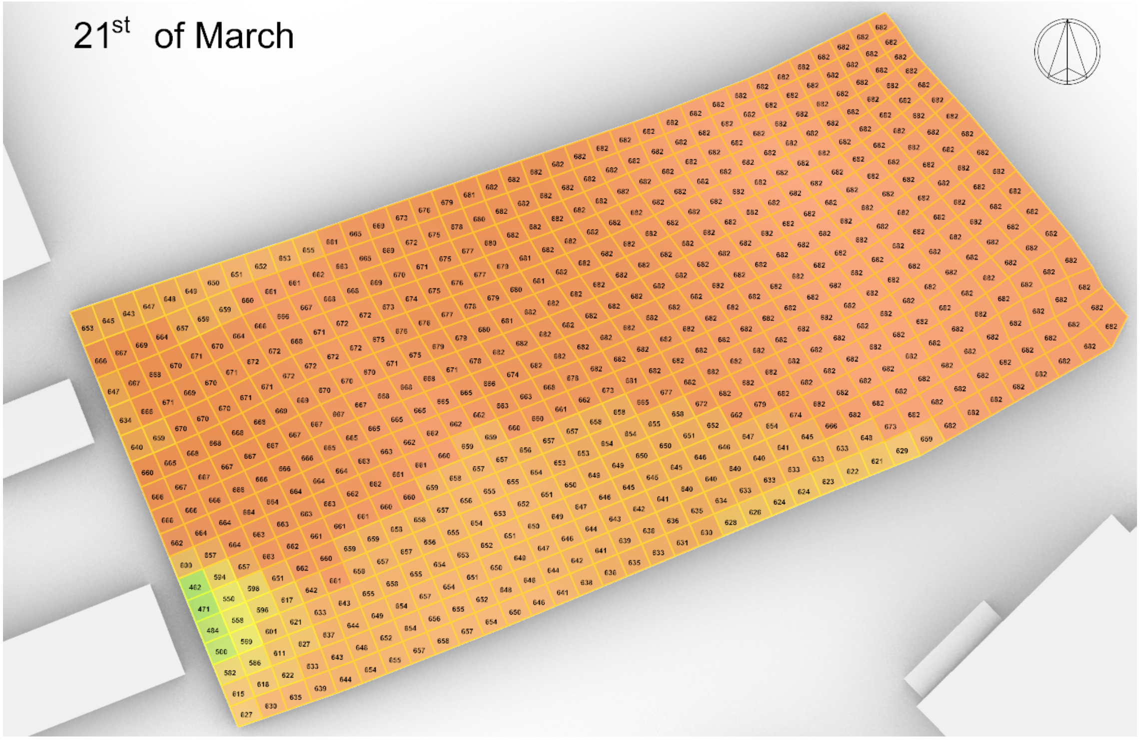


Fig. 6.5: Designed state on 21st of March.

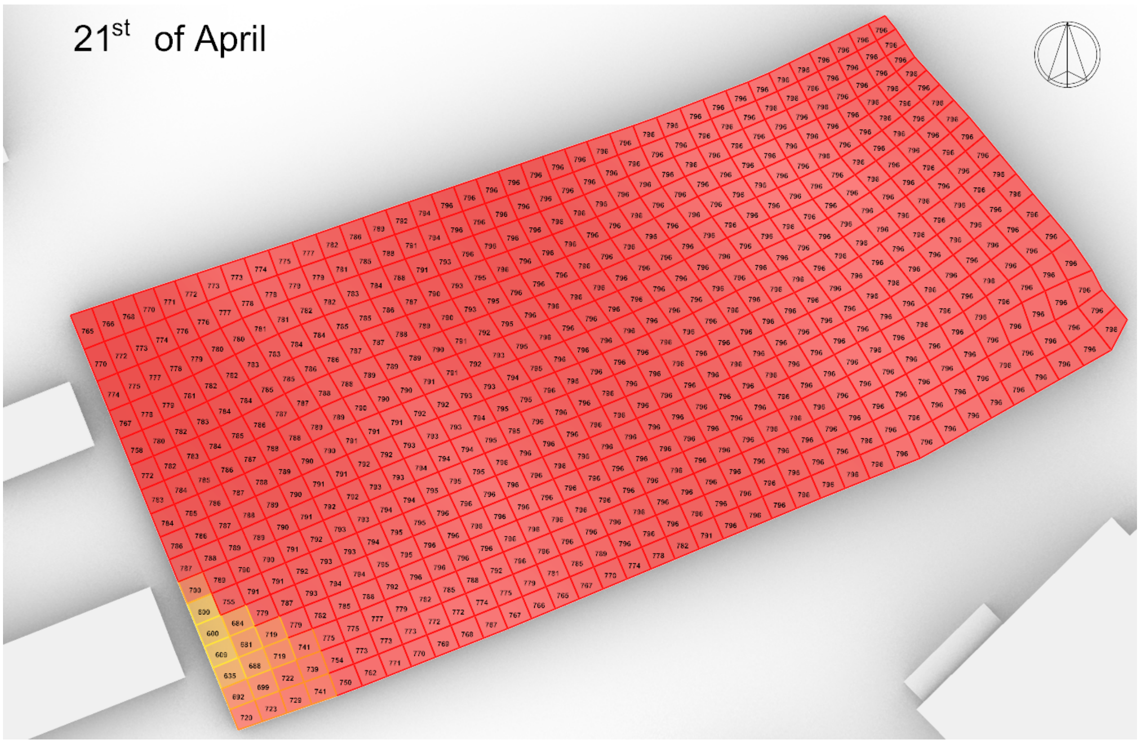


Fig. 6.6: Current state on 21st of April.

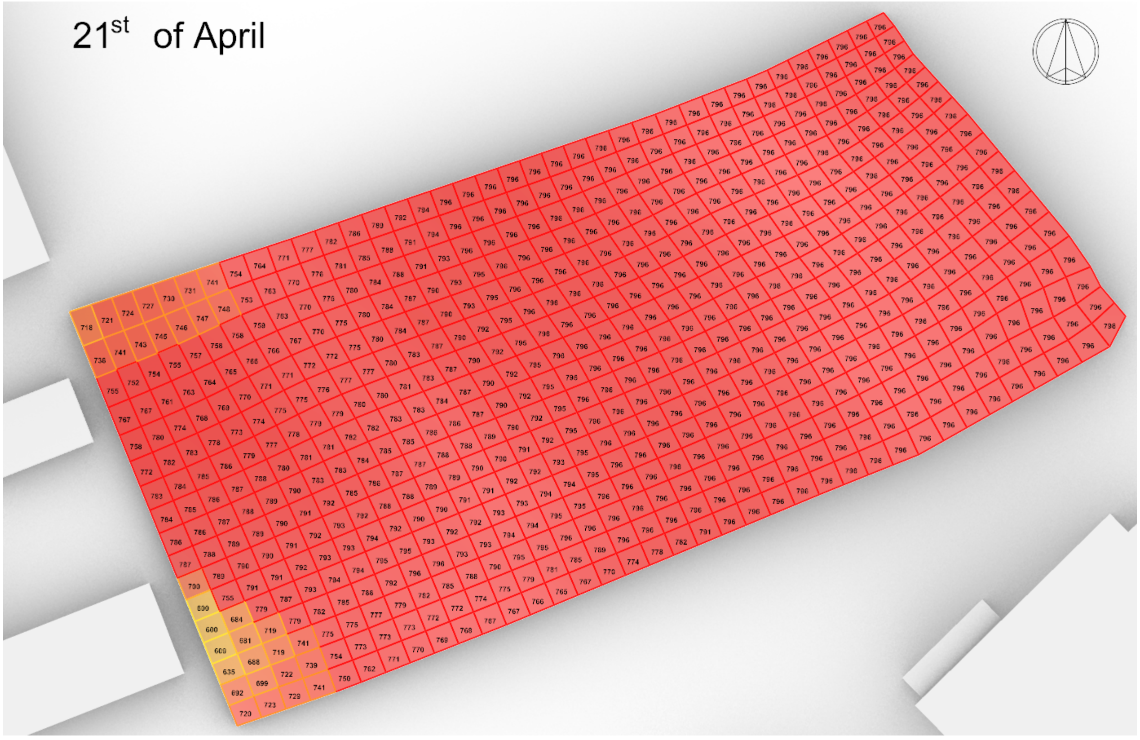


Fig. 6.7: Designed state on 21st of April.

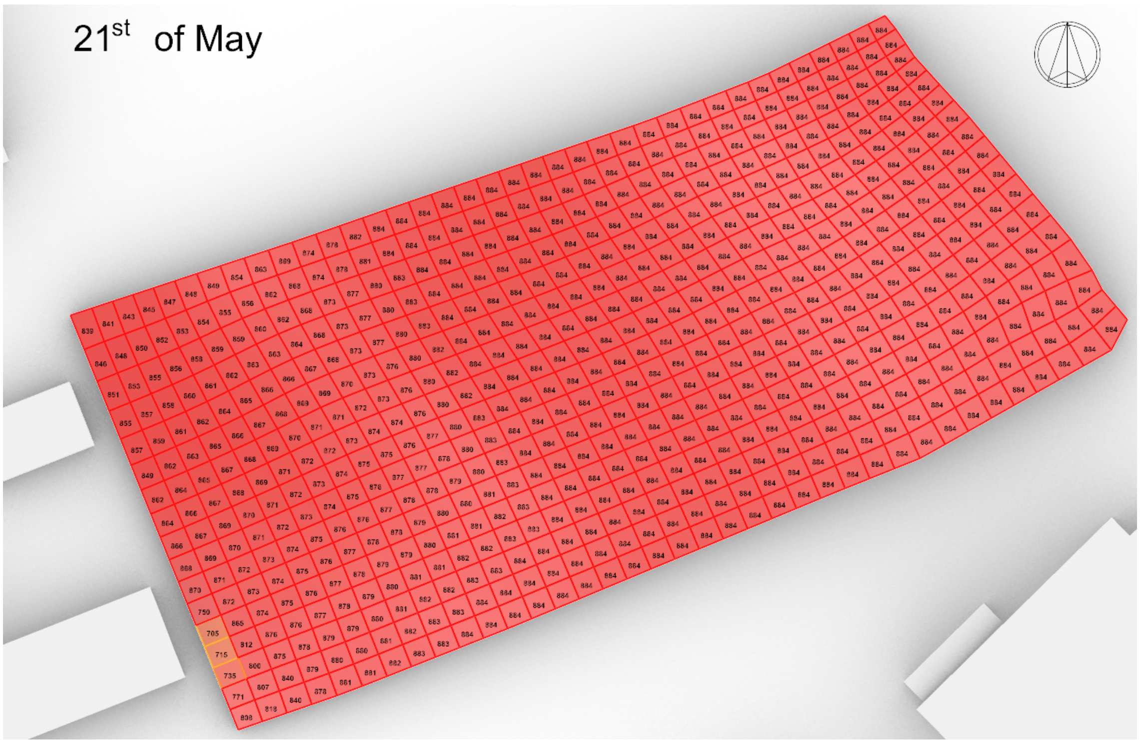


Fig. 6.8: Current state on 21st of May.

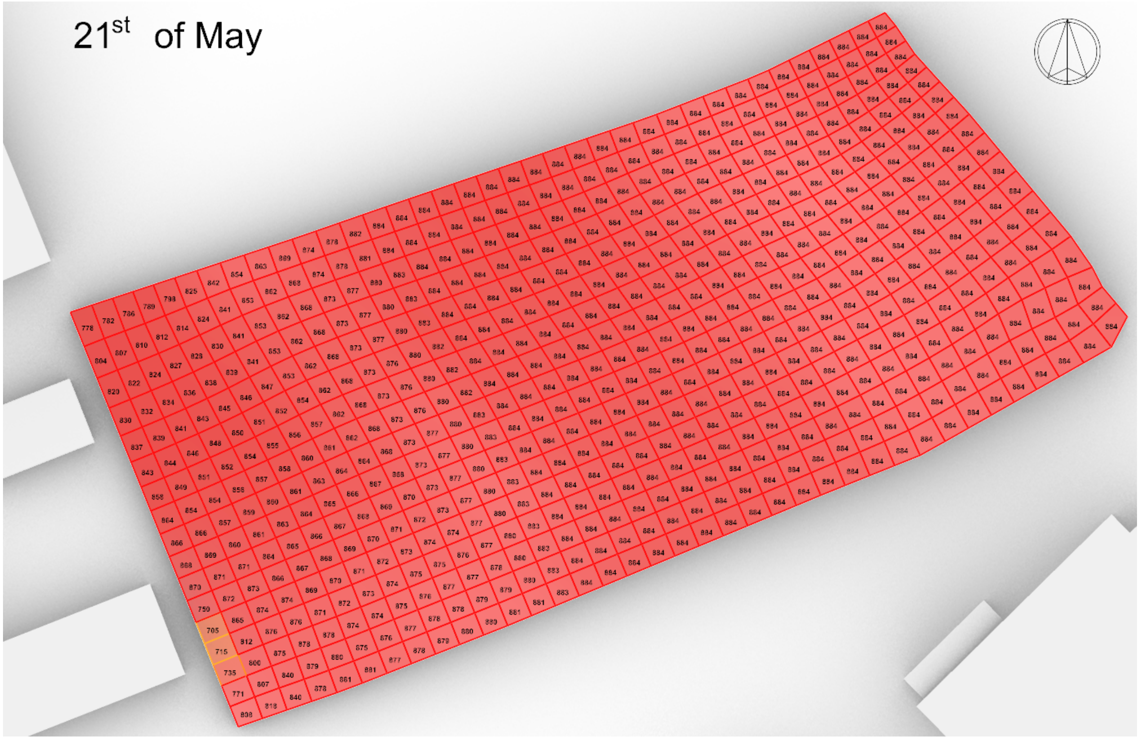


Fig. 6.9: Designed state on 21st of May.

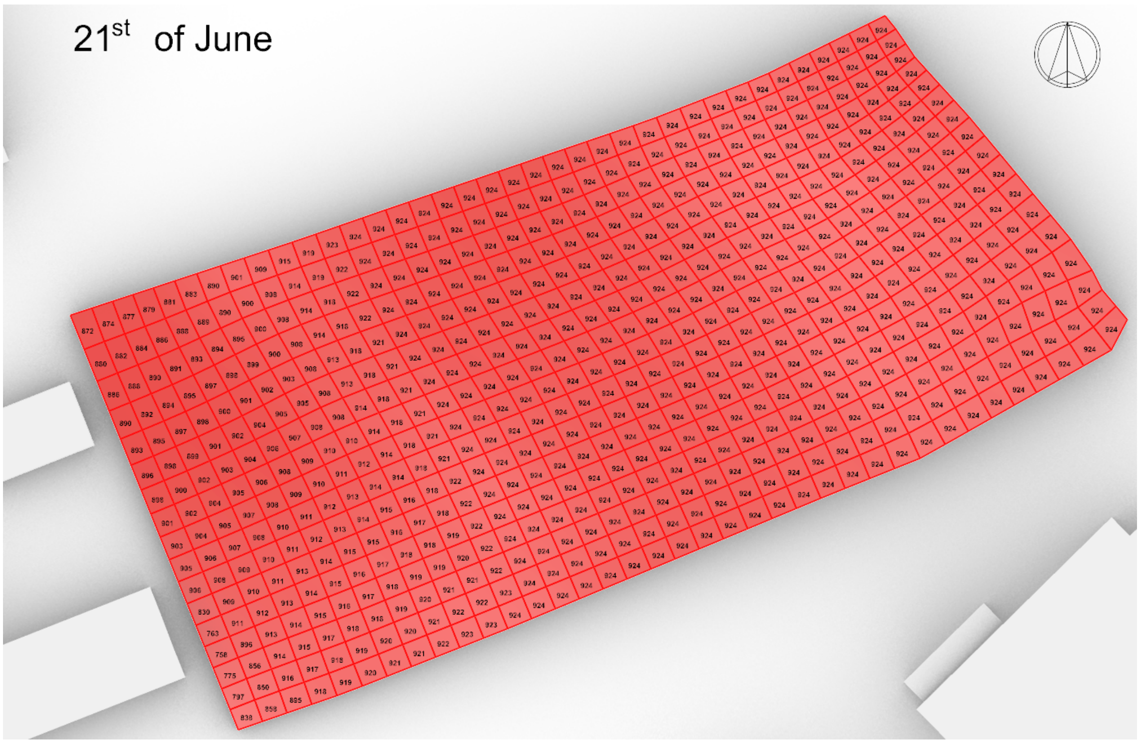


Fig. 6.10: Current state on 21st of June.

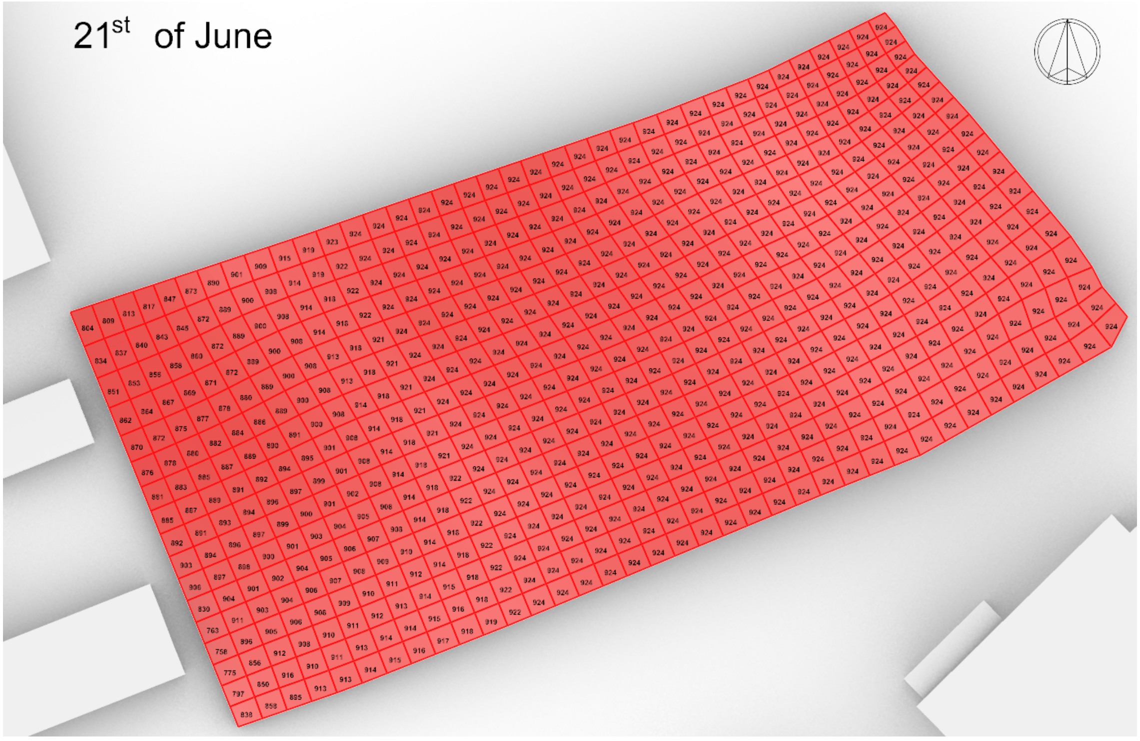


Fig. 6.11: Designed state on 21st of June.

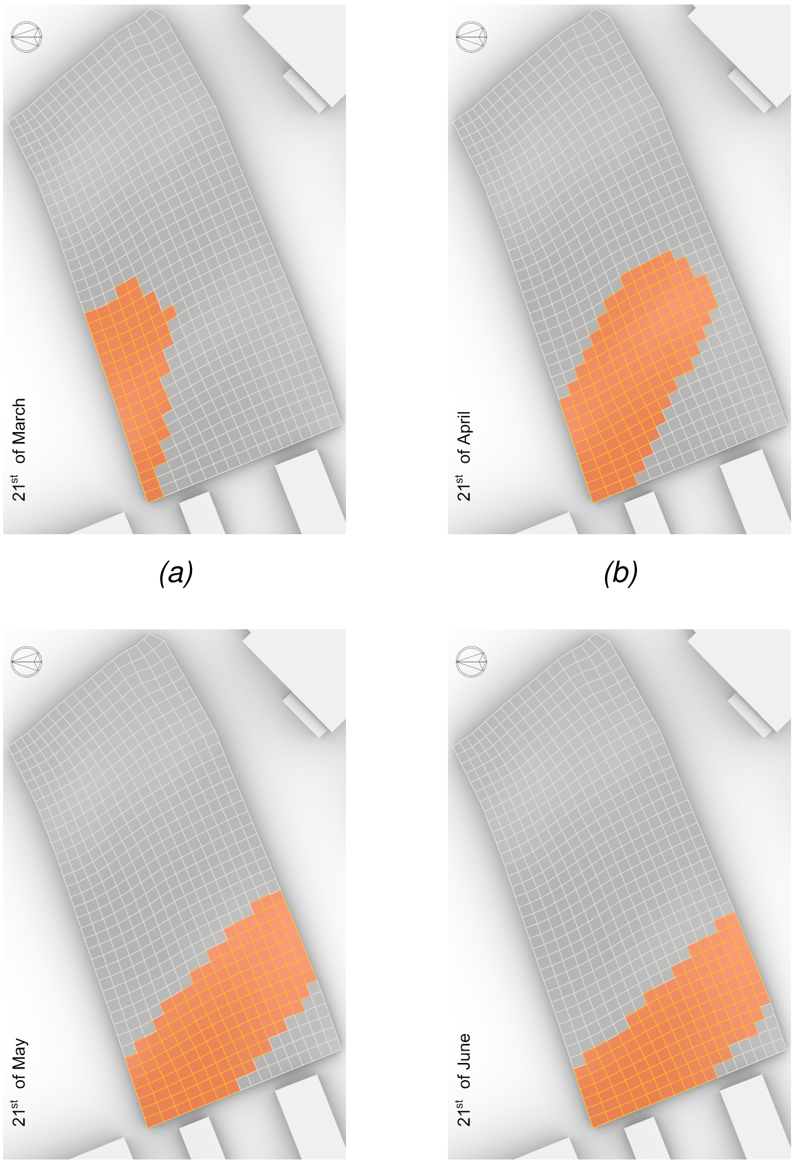
For winter month no changes were visible. On the other hand shading was clearly identified in case of:

- 73 elemental areas on 21st of March,
- 149 elemental areas on 21st of April,
- 157 elemental areas on 21st of May,
- and 137 elemental areas on 21st of June.

It is important to note down, that the sunlight exposure time did decrease by more than 20min only in a portion of cases. Precisely it handled about:

- 10 areas out of 73 on 21st of March, with a maximum difference of 26min,
- 23 areas out of 149 on 21st of April, with a maximum difference of 47min,
- 27 areas out of 157 on 21st of May, with a maximum difference of 61min,
- and 28 areas out of 73 on 21st of June, with a maximum difference of 68min.

The elementary surfaces/areas of the land with a decrease of exposure time are highlighted on the following figures.



(a) (b) (c) (d)

Fig. 6.12: Marking out of areas where it came to a decrease of sunlight exposure times. a) 21st of March, b) 21st of April, c) 21st of May, d) 21st of June.

6.1.2 2nd stage - Exposure to Sunlight of Photovoltaic Panel Sets

Taking into account the results presented in the previous section, some PV Panel sets were required to be evaluated in a simple manner, just like one would determine the sunlight exposure time of a windows, for example.

Why? - To answer this question it is necessary to look at the properties of photovoltaic panels, the slope of panels and the structure holding them in place.

The panels are mounted to a metallic frame, which is tightly secured to the ground. Each panel set consists of 2 row of panels and depending on their length about 11 columns. The panels are aligned, that means, that they have a tilt, and an orientation. The slope of these particular panels is around 31°, and our almost South facing.

Whereas the panels have such a small tilt, it is possible to assume, that the panels used in this particular power plant are not bi-directional ones. Thus, Sun rays indecent under angles that have no effect on the power output can be excluded from the calculations, for example the ones from behind. In case of lands exposure to sunlight it is not feasible though. See Fig. 6.13

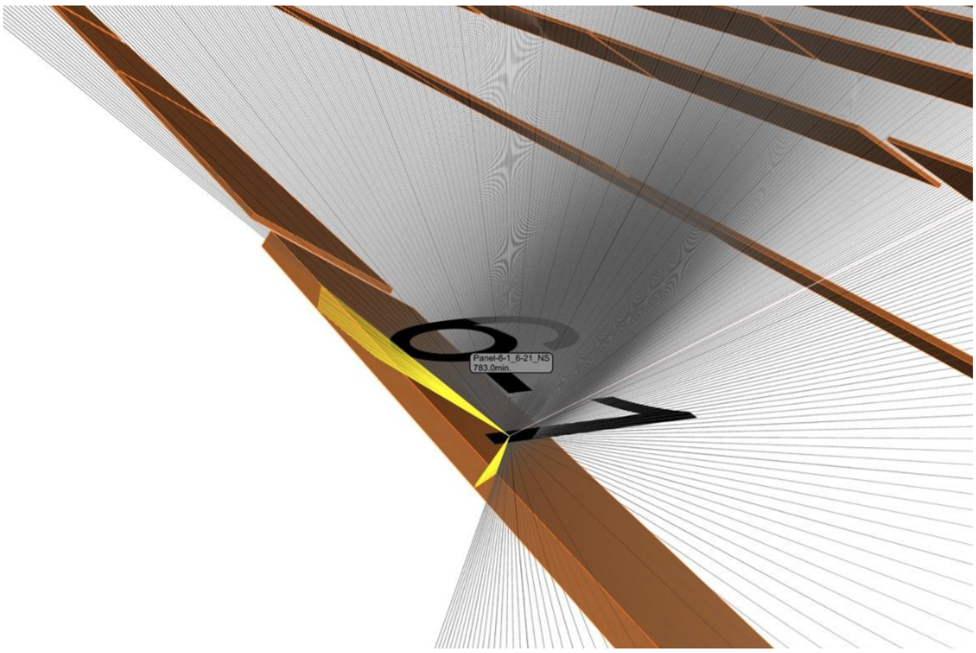


Fig. 6.13: Choice of panel set for 2nd Stage evaluation process.

So by merging the highlighted areas visible on the last four figures of previous section, it was relatively easy to select the panel sets which might be influenced by the newly developed construction over time. These are visible on the following figure (Fig. 6.14).

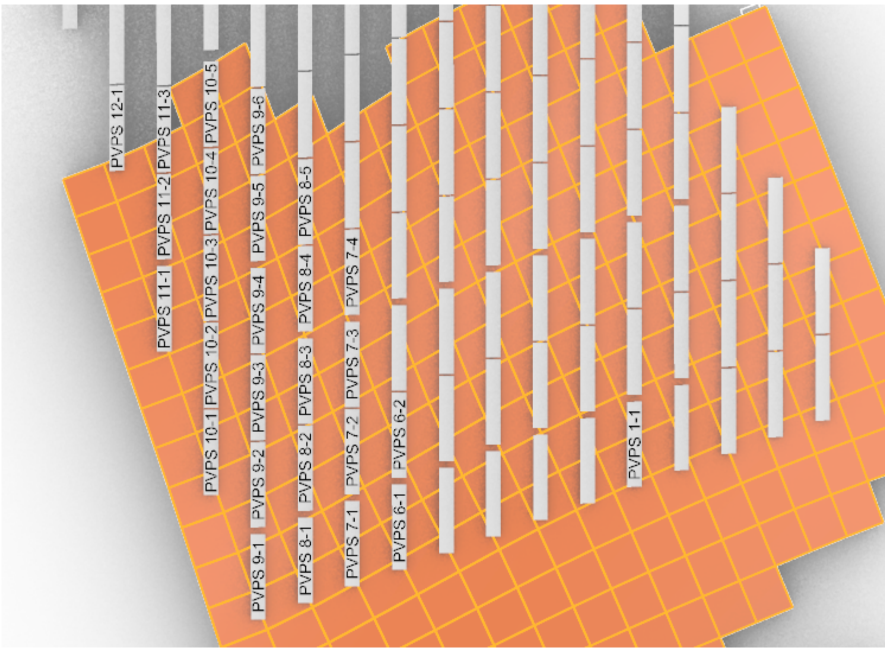


Fig. 6.14: Choice of panel set for 2nd Stage evaluation process.

On 21st of March all marked panel sets were evaluated. On 21st of April, and May only PVPS 6-1, 7-1, 8-1, 9-1, 10-1 and 11-1. As for June, none. The results of sunlight exposure time acquisition are visible in the following table.

Tab. 6.1: Results of the 2nd Stage evaluation process.

PV panel set	21st of March			21st of April			21st of May		
	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]
PVPS 6-1	681	681	0	750	750	0	773	773	0
PVPS 6-2	681	681	0						
PVPS 7-1	681	679	2	750	750	0	773	773	0
PVPS 7-2	681	678	3						
PVPS 7-3	681	677	4						
PVPS 7-4	681	680	1						
PVPS 8-1	681	667	14	750	750	0	773	773	0
PVPS 8-2	681	671	10						
PVPS 8-3	681	675	6						
PVPS 8-4	681	678	3						
PVPS 8-5	681	680	1						
PVPS 9-1	681	661	20	750	749	1	773	773	0
PVPS 9-2	681	667	14						
PVPS 9-3	681	671	10						
PVPS 9-4	681	675	6						
PVPS 9-5	681	678	3						
PVPS 9-6	681	681	0						
PVPS 10-1	681	663	18	750	750	0	773	773	0
PVPS 10-2	681	669	12						
PVPS 10-3	681	674	7						
PVPS 10-4	681	679	2						
PVPS 10-5	681	681	0						
PVPS 11-1	681	674	7	749	749	0	773	773	0
PVPS 11-2	681	680	1						
PVPS 11-3	681	681	0						
PVPS 12-1	681	681	0						

On Fig. 6.15 and 6.16 proofs of evaluation are visible.

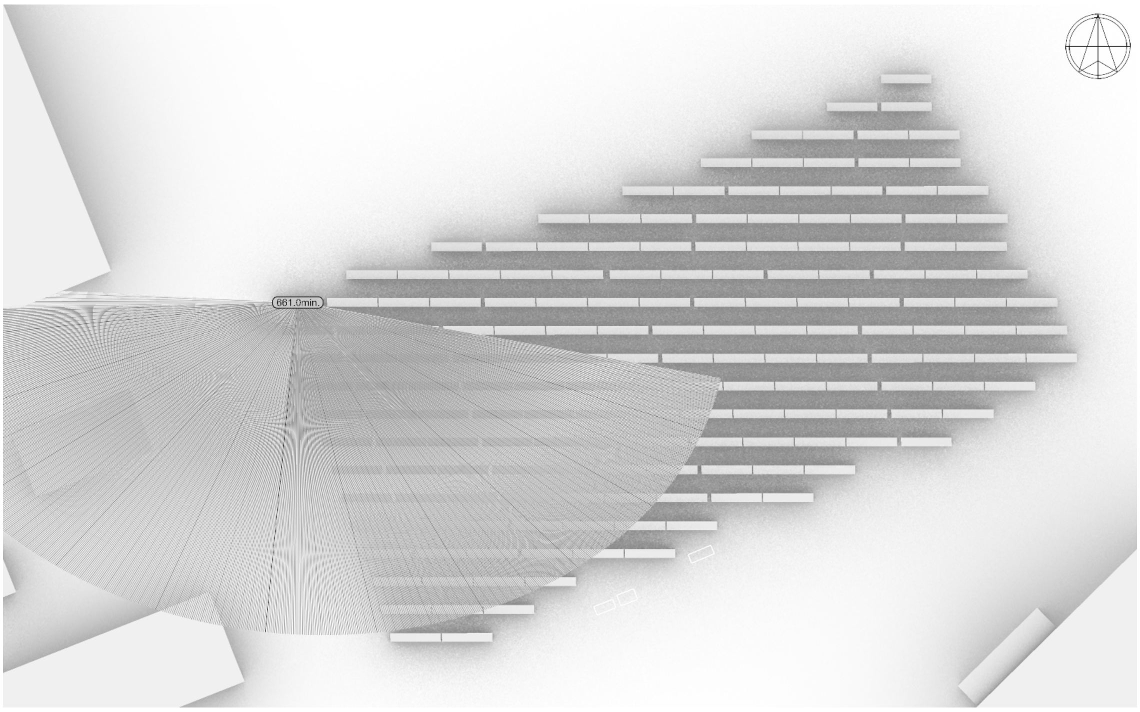


Fig. 6.15: Sunlight exposure determination of PVPS 9-1 in original state on 21st of March.

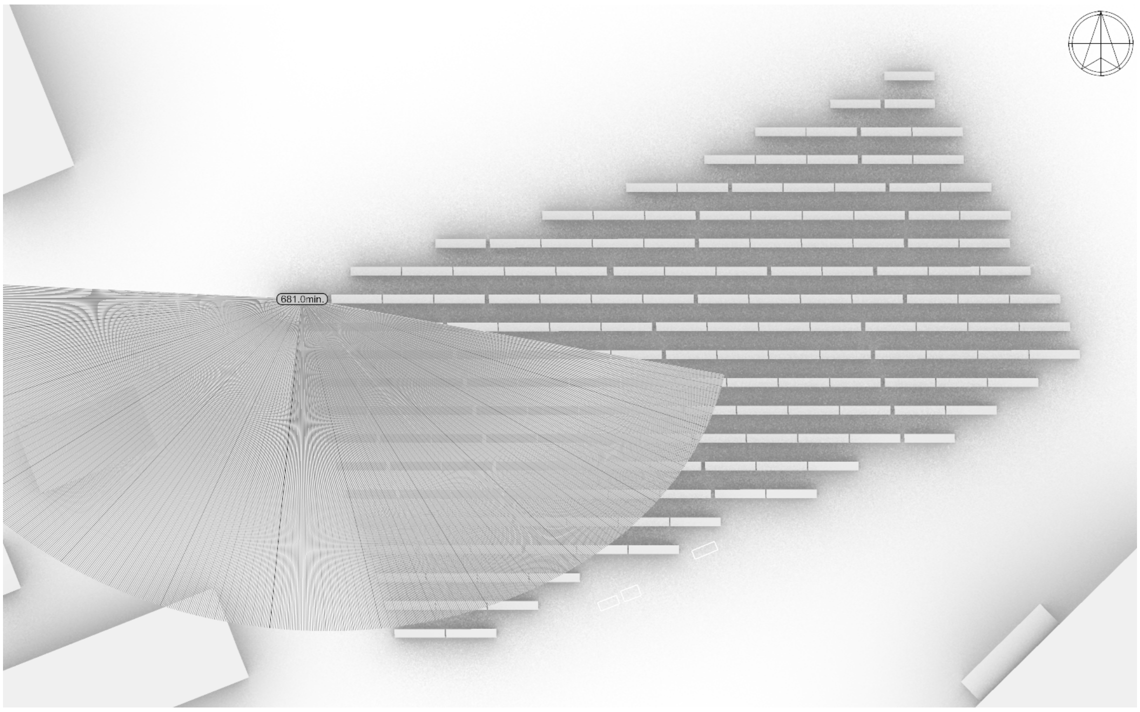


Fig. 6.16: Sunlight exposure determination of PVPS 9-1 in designed state the 21st of March.

By reviewing the findings it can be concluded, that:

- Panels sets 6-1, 6-2, 9-6, 10-5, 11-3 and 12-1 were unaffected by the newly designed building.
- The rest of panel sets have been influenced on 21st of March by a small margin. Only the closest panel sets (PVPS 9-1) exposure time fell by 20min.
- On 21st of April only one panel set showed any signs of influence. Once again it would be PVPS 9-1.
- In May and June no influence was being observed.

Some panel sets are influenced, but none is influenced on 21st of February, and only 1 is affected on 21st of March. Therefore, between the 21st of February and 21st of March it must come to shading, and between 21st of March and 21st of April the shading slowly disappears. Therefore, how far should the examination, simulation go. Will a 50 day long analysis starting with 1st of March be enough, or not?

6.1.3 3rd stage - 50 day long sunlight exposure determination

The results of simulation presented in this section were carried out with a modified version of FieldIns software tool. The tool was altered so it would perform a 50 day long calculation and save the results into a file, which then could be imported into and MS Excel spreadsheet for further evaluation.

The modifications were related to the J quantity, which is the number of day in the year. Originally the value of this quantity is a constant based on the day and month of set-up. In the modified version, regardless,it was replaced with an interval, thus a `for J in range (60,111,1):` loop, where 60 represents 1st of March, and 111 the day of 22nd of April. The last number is excluded from the loop, so instead it is 21st.

The results obtained by the calculations are presented in Tab. 6.2 to 6.9.

Tab. 6.2: Results of 50 day long exposure to sunlight - Part 1.

Date	Photovoltaic panel set								
	PVPS 11-1			PVPS 11-2			PVPS 12-1		
	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]
1st of March	597	597	0	596	596	0	602	602	0
2nd of March	601	600	1	601	601	0	607	607	0
3rd of March	605	604	1	606	606	0	610	610	0
4th of March	609	607	2	610	610	0	614	614	0
5th of March	614	611	3	616	616	0	619	619	0
6th of March	618	615	3	621	621	0	622	622	0
7th of March	625	621	4	626	626	0	626	626	0
8th of March	632	627	5	630	630	0	631	631	0
9th of March	635	630	5	633	633	0	634	634	0
10th of March	639	633	6	638	637	1	639	639	0
11th of March	643	636	7	642	640	2	643	643	0
12th of March	646	639	7	646	644	2	646	646	0
13th of March	651	644	7	650	648	2	651	651	0
14th of March	655	647	8	654	652	2	655	655	0
15th of March	658	651	7	658	656	2	658	658	0
16th of March	662	655	7	662	660	2	662	662	0
17th of March	666	659	7	666	664	2	666	666	0
18th of March	670	663	7	670	669	1	670	670	0
19th of March	674	667	7	674	672	2	674	674	0
20th of March	677	671	6	677	676	1	677	677	0
21th of March	681	674	7	681	680	1	681	681	0
22nd of March	686	679	7	686	684	2	686	686	0
23rd of March	689	683	6	689	688	1	689	689	0
24th of March	693	687	6	693	692	1	693	693	0
25th of March	696	690	6	696	695	1	696	696	0
26th of March	699	694	5	700	699	1	700	700	0
27th of March	703	699	4	704	704	0	704	704	0
28th of March	707	702	5	708	707	1	708	708	0
29th of March	710	706	4	712	711	1	712	712	0
30th of March	713	710	3	715	715	0	715	715	0
31st of March	715	713	2	717	717	0	717	717	0
1st of April	718	718	0	719	719	0	720	720	0
2nd of April	721	721	0	723	723	0	723	723	0
3rd of April	723	723	0	725	725	0	725	725	0
4th of April	725	725	0	727	727	0	727	727	0
5th of April	727	727	0	729	729	0	729	729	0
6th of April	729	729	0	731	731	0	732	732	0
7th of April	732	732	0	734	734	0	734	734	0
8th of April	734	734	0	736	736	0	736	736	0
9th of April	737	737	0	738	738	0	738	738	0
10th of April	738	738	0	740	740	0	739	739	0
11th of April	738	738	0	740	740	0	741	741	0
12th of April	740	740	0	741	741	0	742	742	0
13th of April	741	741	0	742	742	0	742	742	0
14th of April	742	742	0	743	743	0	743	743	0
15th of April	743	743	0	744	744	0	744	744	0
16th of April	745	745	0	744	744	0	746	746	0
17th of April	745	745	0	746	746	0	746	746	0
18th of April	746	746	0	747	747	0	747	747	0
19th of April	747	747	0	748	748	0	748	748	0
20th of April	748	748	0	749	749	0	749	749	0
21st of April	749	749	0	750	750	0	750	750	0
Drop max [min]			8			2			0
Day when drops			30			19			0
Average drop [min/day]			5,17			1,47			0,00

Tab. 6.3: Results of 50 day long exposure to sunlight - Part 2.

Date	Photovoltaic panel set								
	PVPS 10-2			PVPS 10-3			PVPS 10-4		
	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]
1st of March	595	595	0	594	594	0	594	594	0
2nd of March	599	599	0	599	599	0	598	598	0
3rd of March	603	603	0	602	602	0	602	602	0
4th of March	607	607	0	607	607	0	606	606	0
5th of March	612	610	2	611	611	0	611	611	0
6th of March	615	613	2	615	615	0	615	615	0
7th of March	620	617	3	619	619	0	620	620	0
8th of March	624	620	4	625	624	1	627	627	0
9th of March	628	624	4	630	629	1	633	633	0
10th of March	634	629	5	637	636	1	637	637	0
11th of March	639	633	6	643	641	2	642	642	0
12th of March	646	640	6	646	644	2	645	645	0
13th of March	651	644	7	651	648	3	650	650	0
14th of March	655	647	8	655	651	4	654	653	1
15th of March	658	650	8	658	654	4	657	657	0
16th of March	662	653	9	662	657	5	662	661	1
17th of March	666	656	10	666	660	6	666	664	2
18th of March	670	660	10	670	664	6	670	668	2
19th of March	674	663	11	674	667	7	674	672	2
20th of March	677	666	11	677	670	7	677	675	2
21th of March	681	669	12	681	674	7	681	679	2
22nd of March	686	673	13	686	679	7	686	684	2
23rd of March	689	677	12	689	683	6	689	687	2
24th of March	692	680	12	693	686	7	693	691	2
25th of March	696	684	12	696	690	6	696	695	1
26th of March	699	688	11	700	694	6	700	699	1
27th of March	703	693	10	704	698	6	704	703	1
28th of March	706	696	10	708	702	6	708	707	1
29th of March	709	700	9	710	706	4	712	711	1
30th of March	711	704	7	713	710	3	715	714	1
31st of March	713	707	6	715	713	2	718	718	0
1st of April	715	711	4	717	717	0	719	719	0
2nd of April	719	716	3	720	720	0	723	723	0
3rd of April	721	720	1	723	723	0	725	725	0
4th of April	723	723	0	725	725	0	727	727	0
5th of April	725	725	0	727	727	0	729	729	0
6th of April	728	728	0	729	729	0	732	732	0
7th of April	730	730	0	732	732	0	734	734	0
8th of April	732	732	0	734	734	0	736	736	0
9th of April	735	735	0	737	737	0	738	738	0
10th of April	737	737	0	737	737	0	739	739	0
11th of April	739	739	0	738	738	0	741	741	0
12th of April	740	740	0	740	740	0	741	741	0
13th of April	742	742	0	741	741	0	742	742	0
14th of April	742	742	0	742	742	0	743	743	0
15th of April	744	744	0	743	743	0	743	743	0
16th of April	745	745	0	743	743	0	746	746	0
17th of April	745	745	0	745	745	0	746	746	0
18th of April	746	746	0	746	746	0	747	747	0
19th of April	747	747	0	747	747	0	747	747	0
20th of April	749	749	0	747	747	0	749	749	0
21st of April	749	749	0	749	749	0	750	750	0
Drop max [min]			13			7			2
Day when drops			30			24			16
Average drop [min/day]			7,60			4,54			1,50

Tab. 6.4: Results of 50 day long exposure to sunlight - Part 3.

Date	Photovoltaic panel set								
	PVPS 9-4			PVPS 9-5			PVPS 10-1		
	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]
1st of March	592	592	0	591	591	0	596	596	0
2nd of March	597	597	0	596	596	0	600	600	0
3rd of March	600	600	0	599	599	0	603	601	2
4th of March	605	605	0	604	604	0	608	603	5
5th of March	609	609	0	608	608	0	612	606	6
6th of March	613	613	0	612	612	0	616	610	6
7th of March	617	617	0	617	617	0	620	613	7
8th of March	622	622	0	621	621	0	625	617	8
9th of March	625	625	0	625	625	0	629	621	8
10th of March	630	630	0	629	629	0	633	624	9
11th of March	635	634	1	635	635	0	638	628	10
12th of March	639	638	1	642	642	0	642	631	11
13th of March	646	644	2	650	650	0	650	638	12
14th of March	654	651	3	654	654	0	655	642	13
15th of March	658	655	3	658	658	0	658	645	13
16th of March	662	658	4	662	661	1	662	648	14
17th of March	666	661	5	666	665	1	666	651	15
18th of March	670	665	5	670	669	1	670	655	15
19th of March	674	668	6	674	672	2	673	657	16
20th of March	677	671	6	677	675	2	677	660	17
21th of March	681	675	6	681	678	3	680	663	17
22nd of March	686	679	7	686	682	4	684	667	17
23rd of March	689	682	7	689	685	4	687	670	17
24th of March	693	685	8	693	689	4	690	673	17
25th of March	696	688	8	696	692	4	693	676	17
26th of March	700	691	9	700	695	5	697	680	17
27th of March	704	695	9	704	700	4	701	685	16
28th of March	707	698	9	708	704	4	704	688	16
29th of March	709	702	7	712	707	5	707	692	15
30th of March	711	705	6	714	711	3	710	696	14
31st of March	713	709	4	717	716	1	712	700	12
1st of April	716	714	2	719	718	1	715	704	11
2nd of April	719	718	1	722	722	0	718	708	10
3rd of April	721	721	0	724	724	0	720	712	8
4th of April	723	723	0	726	726	0	722	716	6
5th of April	725	725	0	728	728	0	724	720	4
6th of April	728	728	0	731	731	0	726	723	3
7th of April	730	730	0	733	733	0	729	727	2
8th of April	732	732	0	735	735	0	731	731	0
9th of April	735	735	0	737	737	0	734	734	0
10th of April	736	736	0	738	738	0	736	736	0
11th of April	737	737	0	740	740	0	739	739	0
12th of April	739	739	0	740	740	0	741	741	0
13th of April	740	740	0	741	741	0	742	742	0
14th of April	741	741	0	742	742	0	743	743	0
15th of April	742	742	0	743	743	0	743	743	0
16th of April	744	744	0	745	745	0	745	745	0
17th of April	745	745	0	745	745	0	746	746	0
18th of April	746	746	0	746	746	0	747	747	0
19th of April	746	746	0	747	747	0	747	747	0
20th of April	749	749	0	748	748	0	749	749	0
21st of April	749	749	0	749	749	0	750	750	0
Drop max [min]			9			5			17
Day when drops			23			17			36
Average drop [min/day]			5,17			2,88			11,28

Tab. 6.5: Results of 50 day long exposure to sunlight - Part 4.

Date	Photovoltaic panel set								
	PVPS 9-1			PVPS 9-2			PVPS 9-3		
	Current	Design	Δ	Current	Design	Δ	Current	Design	Δ
	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]
1st of March	597	597	0	595	595	0	594	594	0
2nd of March	601	601	0	599	599	0	598	598	0
3rd of March	604	604	0	602	602	0	601	601	0
4th of March	608	608	0	607	607	0	606	606	0
5th of March	612	612	0	611	611	0	610	610	0
6th of March	616	616	0	615	615	0	614	614	0
7th of March	620	619	1	619	619	0	618	618	0
8th of March	625	620	5	624	623	1	623	623	0
9th of March	628	621	7	627	624	3	626	626	0
10th of March	633	622	11	632	625	7	631	628	3
11th of March	637	625	12	636	628	8	635	631	4
12th of March	641	629	12	640	632	8	639	635	4
13th of March	645	632	13	644	635	9	644	639	5
14th of March	650	635	15	649	639	10	649	643	6
15th of March	653	638	15	654	644	10	656	650	6
16th of March	659	643	16	660	649	11	662	655	7
17th of March	664	648	16	666	654	12	666	658	8
18th of March	669	653	16	670	658	12	670	662	8
19th of March	672	655	17	674	661	13	674	665	9
20th of March	675	658	17	677	664	13	677	668	9
21th of March	679	661	18	681	667	14	681	671	10
22nd of March	683	665	18	685	671	14	686	675	11
23rd of March	686	668	18	688	673	15	689	678	11
24th of March	689	670	19	691	676	15	693	681	12
25th of March	692	673	19	694	679	15	696	684	12
26th of March	695	676	19	698	683	15	699	687	12
27th of March	699	680	19	702	686	16	703	691	12
28th of March	703	682	21	705	689	16	705	694	11
29th of March	706	685	21	707	692	15	708	697	11
30th of March	709	688	21	709	695	14	710	700	10
31st of March	711	691	20	711	698	13	712	703	9
1st of April	713	694	19	714	701	13	714	706	8
2nd of April	717	697	20	717	704	13	718	711	7
3rd of April	719	700	19	719	707	12	720	715	5
4th of April	721	703	18	721	710	11	722	718	4
5th of April	723	706	17	723	713	10	724	722	2
6th of April	725	708	17	726	717	9	727	726	1
7th of April	727	711	16	728	720	8	729	729	0
8th of April	730	714	16	730	724	6	731	731	0
9th of April	733	718	15	733	729	4	734	734	0
10th of April	735	720	15	735	733	2	736	736	0
11th of April	737	723	14	738	737	1	738	738	0
12th of April	739	726	13	740	740	0	741	741	0
13th of April	742	729	13	742	742	0	742	742	0
14th of April	743	731	12	743	743	0	743	743	0
15th of April	744	734	10	744	744	0	743	743	0
16th of April	745	737	8	745	745	0	744	744	0
17th of April	747	740	7	746	746	0	746	746	0
18th of April	747	742	5	747	747	0	747	747	0
19th of April	748	745	3	747	747	0	747	747	0
20th of April	749	747	2	749	749	0	748	748	0
21st of April	750	749	1	750	750	0	750	750	0
Drop max [min]			21			16			12
Day when drops			46			35			28
Average drop [min/day]			14,04			10,51			7,75

Tab. 6.6: Results of 50 day long exposure to sunlight - Part 5.

Date	Photovoltaic panel set								
	PVPS 8-3			PVPS 8-4			PVPS 8-5		
	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]
1st of March	592	592	0	590	590	0	589	589	0
2nd of March	596	596	0	594	594	0	593	593	0
3rd of March	600	600	0	598	598	0	597	597	0
4th of March	604	604	0	602	602	0	601	601	0
5th of March	608	608	0	607	607	0	606	606	0
6th of March	611	611	0	610	610	0	609	609	0
7th of March	616	616	0	615	615	0	614	614	0
8th of March	620	620	0	619	619	0	618	618	0
9th of March	624	624	0	623	623	0	622	622	0
10th of March	629	629	0	627	627	0	627	627	0
11th of March	633	633	0	632	632	0	631	631	0
12th of March	637	637	0	636	636	0	635	635	0
13th of March	641	641	0	640	640	0	639	639	0
14th of March	646	646	0	645	645	0	646	646	0
15th of March	650	648	2	648	648	0	652	652	0
16th of March	654	650	4	657	656	1	660	660	0
17th of March	660	655	5	664	662	2	666	666	0
18th of March	668	663	5	670	668	2	669	669	0
19th of March	674	668	6	674	671	3	674	674	0
20th of March	677	672	5	677	674	3	677	677	0
21th of March	681	675	6	681	678	3	681	680	1
22nd of March	686	679	7	686	682	4	686	684	2
23rd of March	689	682	7	689	685	4	689	688	1
24th of March	693	685	8	693	688	5	693	691	2
25th of March	696	688	8	696	691	5	696	694	2
26th of March	700	691	9	700	694	6	700	697	3
27th of March	703	695	8	704	698	6	704	701	3
28th of March	705	698	7	706	701	5	708	704	4
29th of March	708	702	6	709	705	4	712	708	4
30th of March	710	704	6	710	708	2	715	712	3
31st of March	712	707	5	713	711	2	716	714	2
1st of April	714	710	4	715	714	1	719	717	2
2nd of April	717	714	3	718	718	0	722	722	0
3rd of April	720	718	2	720	720	0	724	724	0
4th of April	722	720	2	723	723	0	726	726	0
5th of April	724	723	1	725	725	0	729	729	0
6th of April	726	726	0	727	727	0	731	731	0
7th of April	728	728	0	729	729	0	733	733	0
8th of April	730	730	0	731	731	0	735	735	0
9th of April	734	734	0	735	735	0	737	737	0
10th of April	736	736	0	736	736	0	739	739	0
11th of April	738	738	0	737	737	0	739	739	0
12th of April	740	740	0	738	738	0	740	740	0
13th of April	742	742	0	739	739	0	741	741	0
14th of April	743	743	0	741	741	0	742	742	0
15th of April	745	745	0	742	742	0	744	744	0
16th of April	745	745	0	743	743	0	744	744	0
17th of April	746	746	0	744	744	0	745	745	0
18th of April	747	747	0	746	746	0	746	746	0
19th of April	748	748	0	746	746	0	747	747	0
20th of April	749	749	0	747	747	0	748	748	0
21st of April	749	749	0	748	748	0	749	749	0
Drop max [min]			9			6			4
Day when drops			22			17			12
Average drop [min/day]			5,27			3,41			2,42

Tab. 6.7: Results of 50 day long exposure to sunlight - Part 6.

Date	Photovoltaic panel set								
	PVPS 7-5			PVPS 8-1			PVPS 8-2		
	Current	Design	Δ	Current	Design	Δ	Current	Design	Δ
	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]
1st of March	587	587	0	596	596	0	594	594	0
2nd of March	591	591	0	600	600	0	598	598	0
3rd of March	594	594	0	603	603	0	601	601	0
4th of March	598	598	0	607	607	0	606	606	0
5th of March	603	603	0	611	611	0	610	610	0
6th of March	606	606	0	615	615	0	613	613	0
7th of March	611	611	0	619	619	0	617	617	0
8th of March	615	615	0	623	623	0	622	622	0
9th of March	619	619	0	626	626	0	625	625	0
10th of March	624	624	0	631	631	0	630	630	0
11th of March	628	628	0	635	635	0	634	634	0
12th of March	632	632	0	639	639	0	638	638	0
13th of March	637	637	0	643	643	0	642	642	0
14th of March	641	641	0	648	647	1	647	647	0
15th of March	645	645	0	652	648	4	651	648	3
16th of March	649	649	0	656	648	8	655	649	6
17th of March	654	654	0	661	650	11	660	652	8
18th of March	662	662	0	664	653	11	665	657	8
19th of March	669	669	0	670	658	12	672	663	9
20th of March	677	677	0	676	663	13	677	668	9
21th of March	681	681	0	680	667	13	681	671	10
22nd of March	686	686	0	685	671	14	686	675	11
23rd of March	689	689	0	688	674	14	689	678	11
24th of March	693	693	0	691	677	14	693	681	12
25th of March	696	696	0	694	680	14	696	684	12
26th of March	700	699	1	697	683	14	699	687	12
27th of March	704	703	1	702	687	15	702	691	11
28th of March	708	706	2	705	690	15	705	694	11
29th of March	712	710	2	707	693	14	707	697	10
30th of March	714	713	1	709	696	13	709	700	9
31st of March	716	716	0	712	698	14	711	703	8
1st of April	719	719	0	714	701	13	713	706	7
2nd of April	722	722	0	717	705	12	717	710	7
3rd of April	725	725	0	719	708	11	719	713	6
4th of April	727	727	0	721	711	10	721	716	5
5th of April	729	729	0	724	714	10	723	719	4
6th of April	731	731	0	726	717	9	725	722	3
7th of April	733	733	0	728	720	8	728	726	2
8th of April	735	735	0	730	723	7	730	728	2
9th of April	738	738	0	733	727	6	733	732	1
10th of April	739	739	0	736	731	5	735	735	0
11th of April	739	739	0	738	732	6	737	737	0
12th of April	740	740	0	740	735	5	740	740	0
13th of April	741	741	0	742	738	4	742	742	0
14th of April	743	743	0	743	740	3	743	743	0
15th of April	743	743	0	745	742	3	744	744	0
16th of April	744	744	0	746	744	2	745	745	0
17th of April	745	745	0	746	745	1	746	746	0
18th of April	747	747	0	747	747	0	747	747	0
19th of April	747	747	0	748	748	0	748	748	0
20th of April	748	748	0	749	749	0	748	748	0
21st of April	749	749	0	750	750	0	750	750	0
Drop max [min]			2			15			12
Day when drops			5			35			26
Average drop [min/day]			1,40			9,40			7,58

Tab. 6.8: Results of 50 day long exposure to sunlight - Part 7.

Date	Photovoltaic panel set								
	PVPS 7-2			PVPS 7-3			PVPS 7-4		
	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]	Current [min]	Design [min]	Δ [min]
1st of March	593	593	0	591	591	0	589	589	0
2nd of March	597	597	0	595	595	0	593	593	0
3rd of March	600	600	0	598	598	0	596	596	0
4th of March	604	604	0	602	602	0	600	600	0
5th of March	609	609	0	607	607	0	604	604	0
6th of March	612	612	0	610	610	0	608	608	0
7th of March	616	616	0	614	614	0	612	612	0
8th of March	620	620	0	618	618	0	617	617	0
9th of March	623	623	0	622	622	0	620	620	0
10th of March	628	628	0	626	626	0	625	625	0
11th of March	632	632	0	631	631	0	629	629	0
12th of March	636	636	0	634	634	0	633	633	0
13th of March	640	640	0	639	639	0	638	638	0
14th of March	645	645	0	644	644	0	642	642	0
15th of March	648	648	0	647	647	0	646	646	0
16th of March	653	653	0	652	652	0	651	651	0
17th of March	658	658	0	657	657	0	655	655	0
18th of March	661	661	0	660	660	0	659	659	0
19th of March	666	666	0	665	665	0	666	666	0
20th of March	670	670	0	670	669	1	674	673	1
21th of March	676	673	3	679	675	4	681	680	1
22nd of March	684	677	7	686	681	5	686	684	2
23rd of March	689	682	7	689	685	4	689	687	2
24th of March	693	685	8	693	688	5	693	690	3
25th of March	696	688	8	696	691	5	696	693	3
26th of March	700	691	9	700	694	6	700	696	4
27th of March	703	695	8	703	698	5	703	701	2
28th of March	705	698	7	705	701	4	705	704	1
29th of March	707	701	6	707	704	3	708	707	1
30th of March	709	704	5	710	708	2	710	710	0
31st of March	712	709	3	712	711	1	712	712	0
1st of April	714	711	3	714	714	0	714	714	0
2nd of April	717	715	2	717	717	0	717	717	0
3rd of April	719	718	1	719	719	0	720	720	0
4th of April	721	721	0	721	721	0	722	722	0
5th of April	723	723	0	724	724	0	724	724	0
6th of April	726	726	0	726	726	0	726	726	0
7th of April	728	728	0	728	728	0	729	729	0
8th of April	730	730	0	730	730	0	731	731	0
9th of April	733	733	0	733	733	0	734	734	0
10th of April	735	735	0	736	736	0	735	735	0
11th of April	738	738	0	738	738	0	736	736	0
12th of April	740	740	0	740	740	0	738	738	0
13th of April	742	742	0	742	742	0	739	739	0
14th of April	743	743	0	743	743	0	740	740	0
15th of April	745	745	0	745	745	0	741	741	0
16th of April	746	746	0	745	745	0	742	742	0
17th of April	746	746	0	746	746	0	744	744	0
18th of April	747	747	0	747	747	0	745	745	0
19th of April	748	748	0	748	748	0	746	746	0
20th of April	749	749	0	749	749	0	746	746	0
21st of April	750	750	0	750	750	0	748	748	0
Drop max [min]			9			6			4
Day when drops			14			12			10
Average drop [min/day]			5,50			3,75			2,00

Tab. 6.9: Results of 50 day long exposure to sunlight - Part 8.

Date	Photovoltaic panel set								
	PVPS 6-1			PVPS 6-2			PVPS 7-1		
	Current	Design	Δ	Current	Design	Δ	Current	Design	Δ
	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]
1st of March	593	593	0	591	591	0	595	595	0
2nd of March	597	597	0	596	596	0	599	599	0
3rd of March	601	601	0	599	599	0	602	602	0
4th of March	605	605	0	603	603	0	606	606	0
5th of March	609	609	0	607	607	0	610	610	0
6th of March	612	612	0	610	610	0	613	613	0
7th of March	616	616	0	615	615	0	618	618	0
8th of March	621	621	0	619	619	0	622	622	0
9th of March	624	624	0	622	622	0	625	625	0
10th of March	628	628	0	626	626	0	629	629	0
11th of March	632	632	0	631	631	0	634	634	0
12th of March	636	636	0	634	634	0	637	637	0
13th of March	640	640	0	638	638	0	641	641	0
14th of March	644	644	0	643	643	0	646	646	0
15th of March	647	647	0	646	646	0	650	650	0
16th of March	652	652	0	651	651	0	654	654	0
17th of March	657	657	0	655	655	0	659	659	0
18th of March	660	660	0	659	659	0	662	662	0
19th of March	665	665	0	664	664	0	667	667	0
20th of March	668	668	0	667	667	0	671	671	0
21th of March	673	673	0	672	672	0	675	673	2
22nd of March	678	678	0	677	677	0	682	677	5
23rd of March	681	681	0	680	680	0	689	681	8
24th of March	686	686	0	687	687	0	692	682	10
25th of March	693	693	0	694	694	0	696	685	11
26th of March	700	700	0	700	699	1	699	688	11
27th of March	704	704	0	704	701	3	703	692	11
28th of March	707	705	2	706	701	5	706	695	11
29th of March	709	705	4	708	704	4	708	698	10
30th of March	712	706	6	710	707	3	710	701	9
31st of March	714	707	7	712	711	1	713	705	8
1st of April	716	710	6	714	714	0	715	707	8
2nd of April	719	714	5	718	718	0	718	711	7
3rd of April	721	717	4	720	720	0	720	714	6
4th of April	723	721	2	722	722	0	722	717	5
5th of April	726	724	2	724	724	0	724	720	4
6th of April	728	727	1	726	726	0	727	723	4
7th of April	730	730	0	729	729	0	729	726	3
8th of April	732	732	0	731	731	0	731	729	2
9th of April	735	735	0	734	734	0	734	733	1
10th of April	738	738	0	736	736	0	736	736	0
11th of April	740	740	0	738	738	0	739	739	0
12th of April	742	742	0	741	741	0	741	741	0
13th of April	742	742	0	743	743	0	743	743	0
14th of April	743	743	0	744	744	0	743	743	0
15th of April	745	745	0	744	744	0	745	745	0
16th of April	745	745	0	745	745	0	746	746	0
17th of April	746	746	0	747	747	0	746	746	0
18th of April	747	747	0	747	747	0	747	747	0
19th of April	748	748	0	748	748	0	748	748	0
20th of April	749	749	0	749	749	0	749	749	0
21st of April	750	750	0	750	750	0	750	750	0
Drop max [min]			7			5			11
Day when drops			10			6			20
Average drop [min/day]			3,90			2,83			6,80

From the results minor conclusion could be made:

- PVPS 6-1 is affected by the proposed construction minimally. The average declination is only 3.9min only and that between 28th of March and 6th of April.
- PVPS 6-2 is affected by the proposed construction minimally. The average declination is only 2.83min only and that between 26th of March and 31th of March.
- PVPS 7-1 is affected by the proposed construction between 21th of March and 9th of April. It maxes out around 26th of March with a drop of 11min from 696min to 685min. The average declination is equal to $6.8\,\mathrm{min\,d^{-1}}$.
- PVPS 7-2 is affected by the proposed construction between 21th of March and 3rd of April. It maxes out on 26th of March with a drop of 9min from 700min to 691min. The average declination is equal to $5.5\,\mathrm{min\,d^{-1}}$.
- PVPS 7-3 is affected by the proposed construction minimally. The average declination is only 3.75min only and that between 16th of March and 1st of April.
- PVPS 7-4 is affected by the proposed construction minimally. The average declination is only 2.0min only and that between 20th of March and 29th of March.
- PVPS 7-5 is affected by the proposed construction by 2min only.
- PVPS 8-1 is affected by the proposed construction between 14th of March and 17th of April. It maxes out around 27th of March with a drop of 15min from 702min to 687min. The average declination is equal to $9.4\,\mathrm{min\,d^{-1}}$.
- PVPS 8-2 is affected by the proposed construction between 15th of March and 9th of April. It maxes out around 25th of March with a drop of 12min from 693min to 681min. The average declination is equal to $7.6\,\mathrm{min\,d^{-1}}$.
- PVPS 8-3 is affected by the proposed construction between 15th of March and 5th of April. It maxes out on 26th of March with a drop of 9min from 700min to 691min. The average declination is equal to $5.3\,\mathrm{min\,d^{-1}}$.
- PVPS 8-4 is affected by the proposed construction minimally. The average declination is only 3.4min only.
- PVPS 8-5 is affected by the proposed construction minimally. The average

declination is only 2.4min only.

- PVPS 9-1 is affected by the proposed construction between 7th of March and 21st of April. It maxes out around 30th of March with a drop of 21min from 703min to 682min. The average declination is equal to $14.04\,\mathrm{min\,d^{-1}}$.
- PVPS 9-2 is affected by the proposed construction between 8th of March and 11st of April. It maxes out around 25th of March with a drop of 15min from 688min to 673min. The average declination is equal to $10.05\,\mathrm{min\,d^{-1}}$.
- PVPS 9-3 is affected by the proposed construction between 10th of March and 5th of April. It maxes out around 25th of March with a drop of 12min from 696min to 684min. The average declination is equal to $8\,\mathrm{min\,d^{-1}}$.
- PVPS 9-4 is affected by the proposed construction between 11th of March and 2nd of April. It maxes out around 27th of March with a drop of 9min from 700min to 691min. The average declination is equal to $5.1\,\mathrm{min\,d^{-1}}$.
- PVPS 9-5 is affected by the proposed construction between 16th of March and 1st of April. It maxes out on 26th of March with a drop of 5min from 700min to 695min. The average declination is equal to $2.88\,\mathrm{min\,d^{-1}}$.
- PVPS 10-1 is affected by the proposed construction between 3rd of March and 7st of April. It maxes out around 23rd of March with a drop of 17min from 677min to 660min. The average declination is equal to $11.28\,\mathrm{min\,d^{-1}}$.
- PVPS 10-2 is affected by the proposed construction between 5th of March and 3rd of April. It maxes out on 22nd of March with a drop of 13min from 686min to 673min. The average declination is equal to $7.6\,\mathrm{min\,d^{-1}}$.
- PVPS 10-3 is affected by the proposed construction between 8th and 31st of March. It maxes out around 20th of March with a drop of 7min from 674min to 667min. The average declination is equal to $4.54\,\mathrm{min\,d^{-1}}$.
- PVPS 10-4 is affected by the proposed construction by 2min only.
- PVPS 11-1 is affected by the proposed construction between 2nd and 31st of March. It maxes out on 14th of March with a drop of 8min from 655min to 647min. The average declination is equal to $5.17\,\mathrm{min\,d^{-1}}$.
- PVPS 11-2 is affected by the proposed construction by 2min only.

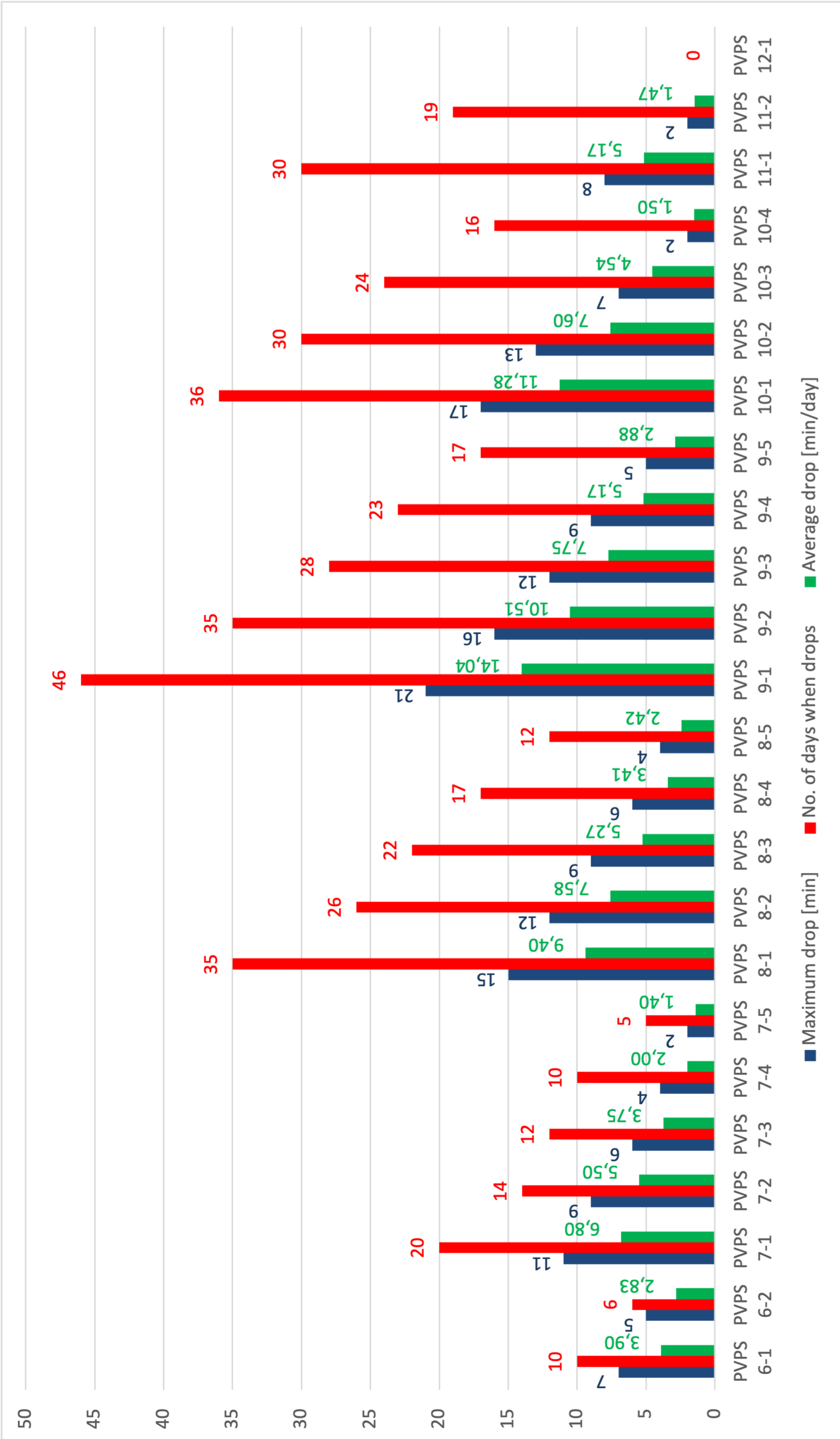


Fig. 6.17: Summary of results in the form of a chart.

The rest of panel sets are unaffected by the designed construction works. Another important information regarding the results is, that the results of the 50 day analysis are applicable to dates between 21th of August to 21st of September, since the solar altitude angles are the same.

6.1.4 INTERPRETATION OF RESULTS

It is worth to mention, that losses of sunlight exposure time does not really have to correlate with electricity production by the photovoltaic panels. The evaluation represents an ideal stage, which assumes, that a Sunny sky is going to shine over the panels all year long, just as is expected by the owners of PVPP's. Therefore, in the following table (Tab. 6.10 meteorological data are present from one of the closest unnamed meteorological stations.

Tab. 6.10: Meteorological data - Sunlight availability in the last 5 years [56].

Year	Sunlight hours in March	Sunlight hours in April
2019	98.8	221.6
2020	157.7	271.6
2021	127.5	126.5
2022	218.8	122.8
2023	101.6	116.0

In an ideal state Sun can shine around $10\,\mathrm{h}$ a day in March. But according to the data from the closest station Sun shone the most around $7\,\mathrm{h}$ a day of average in 2022. In other years less, only $4\,\mathrm{h}$ and $5\,\mathrm{h}$ in average. So it is questionable whether a maximum loss of $21\,\mathrm{min}$ of exposure time at Sun fall will have any effect on electricity production. It is possible to assume, that not.

But it still remains a fact, that from the point of view of civil engineers and architects, Exposure to Sunlight is the only feasible option to evaluate the effects of development on existing PVPP. Irradiance based calculation would be another option, but would the owners really accept that the losses will be small (for the presented case study the losses would amount to just $1\,\mathrm{MW\,h}$)?

6.2 Insolation of Indoor Spaces

The presented case studies are based on actual buildings, but were modified to make them ANONYMOUS. Albeit modifications, the windows dimension, as well as peripheral structures were left untouched, so that the presented results might still be credible, and if a need would arise also repeatable. Two of the case studies are located in Southern Moravian Region, and one in Central Bohemian Region.

In all case studies two approaches were considered:

- Floating point evaluation method,
- and linear evaluation.

The difference between these two procedures lies in the way the evaluation points are distributed and the results assessed. Both approaches do have the same foundation, that is a linear distribution, with a 50mm distance between two consecutive spots.

In the first approach there is a limit. The beginning and end of point array is restricted by the local requirement [52], according to which, the window analysed cannot be smaller than $900 \times 900\text{mm}$. Thus the points has to be at least 450mm away from the jambs.

Albeit this is valid for the first method, the second one goes beyond the limits of standards. It uses the whole width of the opening.

The aim of these evaluation methods is, either:

- To find a position, at which sunlight exposure time is greater or equal to 90min, and at the same time a minimum of 900mm window width could be applicable,
- or determine, how long would the Sun shine into the room, if the sun rays could shine over any point of the internal sill line. Although every sun ray would be counted only once. For example if a sun rays at $7:30$ would shine at 30 points of out of 50, then it would still count as 1min.

6.2.1 Case study No. 1

This particular building is located in Brno. The building was designed to be an apartment building with some spaces for premises on the 1st Floor. The orientation of façades, especially the one to the street does not really have the best of orientation, having an intense influence on internal layout.

Although most of the apartments (or just saying flats) have rooms with windows oriented towards South-West, ensuring proper exposure to sunlight, some were still planned with windows looking at the street only. This resulted in some issues when it came to assessment with respect to daylighting requirements, especially insolation.

The windows dimensions are $2 \times 1.5\mathrm{m}$ and the wall thickness is equal to $460\mathrm{mm}$. The tilt of the windows normal vector from South is $104.5°$,and around $110.62°$ including the local grid convergence C.

Window frame and glazing are excluded, just like in each and every country in European Union.

Normally, the evaluation would take place in the middle of windows width, $300\mathrm{mm}$ above the internal sill line, but ... - at that particular location the sunlight exposure time did not rose to a sufficient level, so that the requirements would be fulfilled (under the assumption of recommended minimal solar altitude angle of $\gamma_s = 13°$.) That is why, this apartment failed the evaluation, but it was still and ideal subject for experimental activities.

The results are organized and summarized in the following figure, chart and tables depending on the used approaches. Fig. 6.18 and Tab. 6.11 are related to both evaluation possibilities. Fig. 6.19 is related to floating point concept, whereas Tab. 6.12 and 6.13 are a summary for the linear model.

On Fig. 6.18 part of the 3D scene and evaluation process in the middle of the window is visible. The results of this calculation, as well the rest of were determined by a modified version of Exposure to Sunlight EN17037 in Rhino 3D.

On the chart in Fig. 6.19 and in Tab. 6.11 the values of sunlight exposure times are represented, although the chart is limited to the Floating point evaluation method. It is easy to identify, that this window failed at a small margin only. The RED dashed line is a representation of requirements, which is 90min.

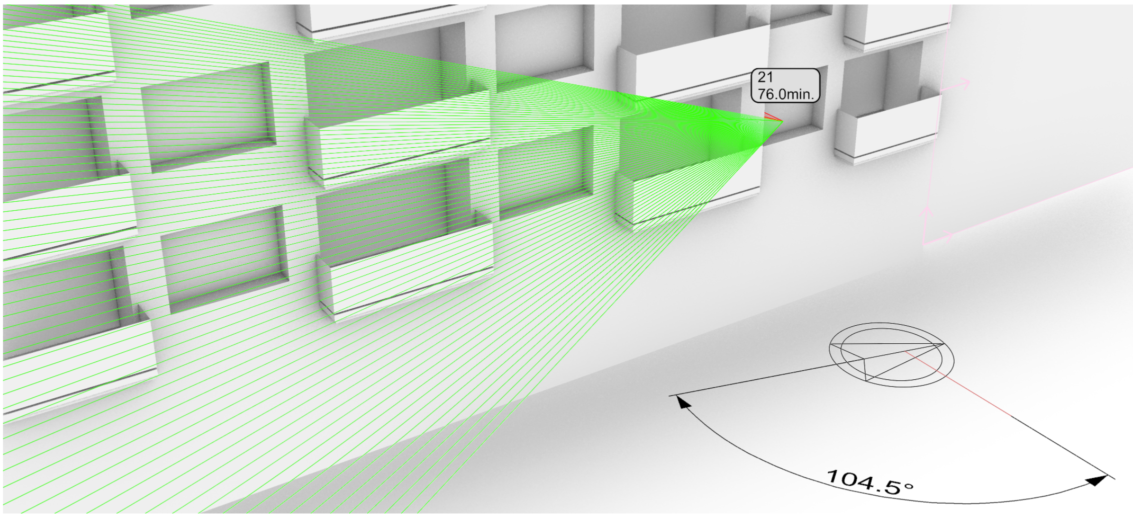


Fig. 6.18: Case study No. 1 - 3D model of scene with evaluation in the middle of windows, at $\gamma_s = 13°$.

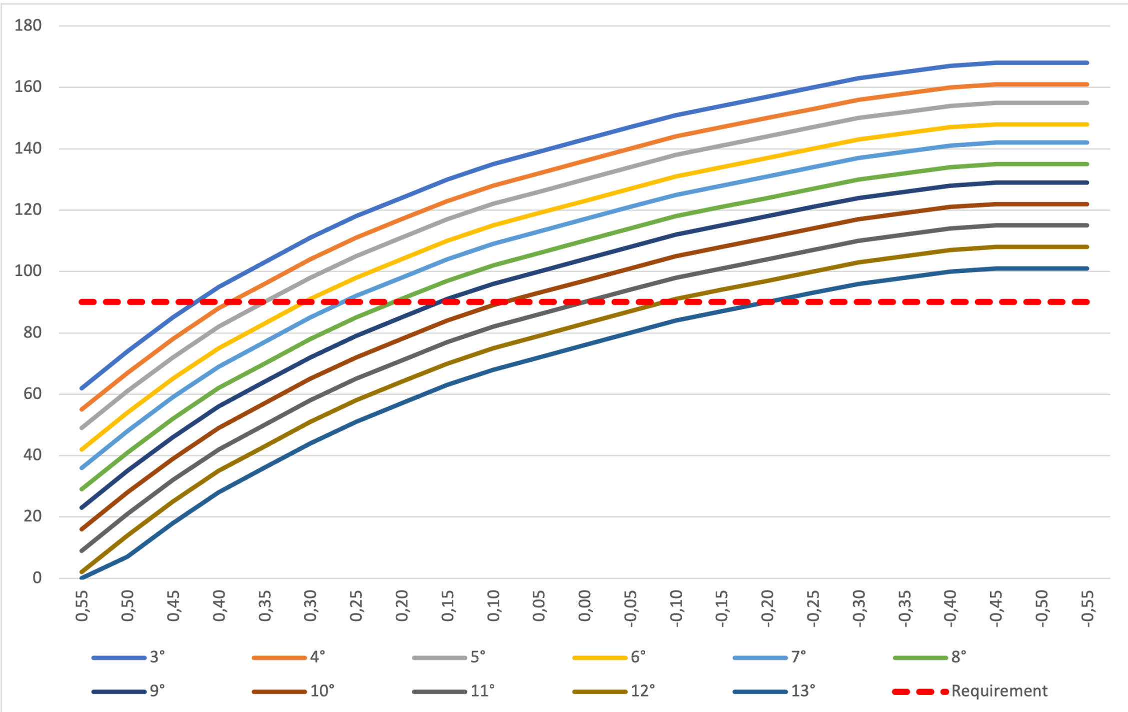


Fig. 6.19: Summary of results for floating point evaluation in the form of a chart.

Tab. 6.11: Case study No. 1 - Global results in all evaluation points.

Position	Sunlight exposure [min]										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
1,00	0	0	0	0	0	0	0	0	0	0	0
0,95	0	0	0	0	0	0	0	0	0	0	0
0,90	0	0	0	0	0	0	0	0	0	0	0
0,85	0	0	0	0	0	0	0	0	0	0	0
0,80	0	0	0	0	0	0	0	0	0	0	0
0,75	0	0	0	0	0	0	0	0	0	0	0
0,70	13	6	0	0	0	0	0	0	0	0	0
0,65	31	24	18	11	5	0	0	0	0	0	0
0,60	47	40	34	27	21	14	8	1	0	0	0
0,55	62	55	49	42	36	29	23	16	9	2	0
0,50	74	67	61	54	48	41	35	28	21	14	7
0,45	85	78	72	65	59	52	46	39	32	25	18
0,40	95	88	82	75	69	62	56	49	42	35	28
0,35	103	96	90	83	77	70	64	57	50	43	36
0,30	111	104	98	91	85	78	72	65	58	51	44
0,25	118	111	105	98	92	85	79	72	65	58	51
0,20	124	117	111	104	98	91	85	78	71	64	57
0,15	130	123	117	110	104	97	91	84	77	70	63
0,10	135	128	122	115	109	102	96	89	82	75	68
0,05	139	132	126	119	113	106	100	93	86	79	72
0,00	143	136	130	123	117	110	104	97	90	83	76
-0,05	147	140	134	127	121	114	108	101	94	87	80
-0,10	151	144	138	131	125	118	112	105	98	91	84
-0,15	154	147	141	134	128	121	115	108	101	94	87
-0,20	157	150	144	137	131	124	118	111	104	97	90
-0,25	160	153	147	140	134	127	121	114	107	100	93
-0,30	163	156	150	143	137	130	124	117	110	103	96
-0,35	165	158	152	145	139	132	126	119	112	105	98
-0,40	167	160	154	147	141	134	128	121	114	107	100
-0,45	168	161	155	148	142	135	129	122	115	108	101
-0,50	168	161	155	148	142	135	129	122	115	108	101
-0,55	168	161	155	148	142	135	129	122	115	108	101
-0,60	168	161	155	148	142	135	129	122	115	108	101
-0,65	168	161	155	148	142	135	129	122	115	108	101
-0,70	168	161	155	148	142	135	129	122	115	108	101
-0,75	168	161	155	148	142	135	129	122	115	108	101
-0,80	168	161	155	148	142	135	129	122	115	108	101
-0,85	168	161	155	148	142	135	129	122	115	108	101
-0,90	168	161	155	148	142	135	129	122	115	108	101
-0,95	168	161	155	148	142	135	129	122	115	108	101
-1,00	168	161	155	148	142	135	129	122	115	108	101

The summary of data in Tab. 6.11 complemented by analyses of the simulations is visible in Tab. 6.12 and 6.13. The numbers in these tables do represent and amount of sun rays hitting the sill line at given minutes and under different minimal solar altitude angles γ_s. The count refers to the final exposure time for various γ_s.

Tab. 6.12: Case study No. 1 - Linear determination model - summary part 1.

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
7:02	35										
7:03	35										
7:04	35										
7:05	35										
7:06	35										
7:07	35										
7:08	35										
7:09	36	36									
7:10	35	35									
7:11	35	35									
7:12	35	35									
7:13	35	35									
7:14	35	35									
7:15	35	35	35								
7:16	34	34	34								
7:17	34	34	34								
7:18	34	34	34								
7:19	34	34	34								
7:20	34	34	34								
7:21	34	34	34								
7:22	34	34	34	34							
7:23	34	34	34	34							
7:24	34	34	34	34							
7:25	34	34	34	34							
7:26	35	35	35	35							
7:27	34	34	34	34							
7:28	35	35	35	35	35						
7:29	34	34	34	34	34						
7:30	35	35	35	35	35						
7:31	36	36	36	36	36						
7:32	38	38	38	38	38						
7:33	42	42	42	42	42						
7:34	56	56	56	56	56						
7:35	53	53	53	53	53	53					
7:36	42	42	42	42	42	42					

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
7:37	33	33	33	33	33	33					
7:38	33	33	33	33	33	33					
7:39	33	33	33	33	33	33					
7:40	33	33	33	33	33	33					
7:41	33	33	33	33	33	33	33				
7:42	33	33	33	33	33	33	33				
7:43	33	33	33	33	33	33	33				
7:44	33	33	33	33	33	33	33				
7:45	33	33	33	33	33	33	33				
7:46	33	33	33	33	33	33	33				
7:47	33	33	33	33	33	33	33				
7:48	33	33	33	33	33	33	33	33			
7:49	33	33	33	33	33	33	33	33			
7:50	32	32	32	32	32	32	32	32			
7:51	32	32	32	32	32	32	32	32			
7:52	32	32	32	32	32	32	32	32			
7:53	32	32	32	32	32	32	32	32			
7:54	32	32	32	32	32	32	32	32			
7:55	32	32	32	32	32	32	32	32	32		
7:56	32	32	32	32	32	32	32	32	32		
7:57	32	32	32	32	32	32	32	32	32		
7:58	32	32	32	32	32	32	32	32	32		
7:59	32	32	32	32	32	32	32	32	32		
8:00	32	32	32	32	32	32	32	32	32		
8:01	32	32	32	32	32	32	32	32	32		
8:02	32	32	32	32	32	32	32	32	32	32	
8:03	32	32	32	32	32	32	32	32	32	32	
8:04	32	32	32	32	32	32	32	32	32	32	
8:05	31	31	31	31	31	31	31	31	31	31	
8:06	31	31	31	31	31	31	31	31	31	31	
8:07	31	31	31	31	31	31	31	31	31	31	
8:08	31	31	31	31	31	31	31	31	31	31	
8:09	31	31	31	31	31	31	31	31	31	31	31
8:10	31	31	31	31	31	31	31	31	31	31	31
8:11	31	31	31	31	31	31	31	31	31	31	31

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
8:12	31	31	31	31	31	31	31	31	31	31	31
8:13	31	31	31	31	31	31	31	31	31	31	31
8:14	31	31	31	31	31	31	31	31	31	31	31
8:15	31	31	31	31	31	31	31	31	31	31	31
8:16	31	31	31	31	31	31	31	31	31	31	31
8:17	30	30	30	30	30	30	30	30	30	30	30
8:18	30	30	30	30	30	30	30	30	30	30	30
8:19	30	30	30	30	30	30	30	30	30	30	30
8:20	30	30	30	30	30	30	30	30	30	30	30
8:21	30	30	30	30	30	30	30	30	30	30	30
8:22	30	30	30	30	30	30	30	30	30	30	30
8:23	30	30	30	30	30	30	30	30	30	30	30
8:24	30	30	30	30	30	30	30	30	30	30	30
8:25	30	30	30	30	30	30	30	30	30	30	30
8:26	30	30	30	30	30	30	30	30	30	30	30
8:27	30	30	30	30	30	30	30	30	30	30	30
8:28	29	29	29	29	29	29	29	29	29	29	29
8:29	29	29	29	29	29	29	29	29	29	29	29
8:30	29	29	29	29	29	29	29	29	29	29	29
8:31	29	29	29	29	29	29	29	29	29	29	29
8:32	29	29	29	29	29	29	29	29	29	29	29
8:33	29	29	29	29	29	29	29	29	29	29	29
8:34	29	29	29	29	29	29	29	29	29	29	29
8:35	29	29	29	29	29	29	29	29	29	29	29
8:36	29	29	29	29	29	29	29	29	29	29	29
8:37	29	29	29	29	29	29	29	29	29	29	29
8:38	28	28	28	28	28	28	28	28	28	28	28
8:39	28	28	28	28	28	28	28	28	28	28	28
8:40	28	28	28	28	28	28	28	28	28	28	28
8:41	28	28	28	28	28	28	28	28	28	28	28
8:42	28	28	28	28	28	28	28	28	28	28	28
8:43	28	28	28	28	28	28	28	28	28	28	28
8:44	28	28	28	28	28	28	28	28	28	28	28
8:45	28	28	28	28	28	28	28	28	28	28	28
8:46	27	27	27	27	27	27	27	27	27	27	27

Count

Tab. 6.13: Case study No. 1 - Linear determination model - summary part 2.

Time	Exposure in No. of Cases											Time	Exposure in No. of Cases										
	γ min												γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
8:47	27	27	27	27	27	27	27	27	27	27	27	9:22	21	21	21	21	21	21	21	21	21	21	21
8:48	27	27	27	27	27	27	27	27	27	27	27	9:23	21	21	21	21	21	21	21	21	21	21	21
8:49	27	27	27	27	27	27	27	27	27	27	27	9:24	21	21	21	21	21	21	21	21	21	21	21
8:50	27	27	27	27	27	27	27	27	27	27	27	9:25	21	21	21	21	21	21	21	21	21	21	21
8:51	27	27	27	27	27	27	27	27	27	27	27	9:26	20	20	20	20	20	20	20	20	20	20	20
8:52	27	27	27	27	27	27	27	27	27	27	27	9:27	20	20	20	20	20	20	20	20	20	20	20
8:53	27	27	27	27	27	27	27	27	27	27	27	9:28	20	20	20	20	20	20	20	20	20	20	20
8:54	26	26	26	26	26	26	26	26	26	26	26	9:29	20	20	20	20	20	20	20	20	20	20	20
8:55	26	26	26	26	26	26	26	26	26	26	26	9:30	19	19	19	19	19	19	19	19	19	19	19
8:56	26	26	26	26	26	26	26	26	26	26	26	9:31	19	19	19	19	19	19	19	19	19	19	19
8:57	26	26	26	26	26	26	26	26	26	26	26	9:32	19	19	19	19	19	19	19	19	19	19	19
8:58	26	26	26	26	26	26	26	26	26	26	26	9:33	19	19	19	19	19	19	19	19	19	19	19
8:59	26	26	26	26	26	26	26	26	26	26	26	9:34	18	18	18	18	18	18	18	18	18	18	18
9:00	26	26	26	26	26	26	26	26	26	26	26	9:35	18	18	18	18	18	18	18	18	18	18	18
9:01	25	25	25	25	25	25	25	25	25	25	25	9:36	18	18	18	18	18	18	18	18	18	18	18
9:02	25	25	25	25	25	25	25	25	25	25	25	9:37	17	17	17	17	17	17	17	17	17	17	17
9:03	25	25	25	25	25	25	25	25	25	25	25	9:38	17	17	17	17	17	17	17	17	17	17	17
9:04	25	25	25	25	25	25	25	25	25	25	25	9:39	17	17	17	17	17	17	17	17	17	17	17
9:05	25	25	25	25	25	25	25	25	25	25	25	9:40	16	16	16	16	16	16	16	16	16	16	16
9:06	25	25	25	25	25	25	25	25	25	25	25	9:41	16	16	16	16	16	16	16	16	16	16	16
9:07	24	24	24	24	24	24	24	24	24	24	24	9:42	16	16	16	16	16	16	16	16	16	16	16
9:08	24	24	24	24	24	24	24	24	24	24	24	9:43	15	15	15	15	15	15	15	15	15	15	15
9:09	24	24	24	24	24	24	24	24	24	24	24	9:44	15	15	15	15	15	15	15	15	15	15	15
9:10	24	24	24	24	24	24	24	24	24	24	24	9:45	15	15	15	15	15	15	15	15	15	15	15
9:11	24	24	24	24	24	24	24	24	24	24	24	9:46	14	14	14	14	14	14	14	14	14	14	14
9:12	24	24	24	24	24	24	24	24	24	24	24	9:47	14	14	14	14	14	14	14	14	14	14	14
9:13	23	23	23	23	23	23	23	23	23	23	23	9:48	13	13	13	13	13	13	13	13	13	13	13
9:14	23	23	23	23	23	23	23	23	23	23	23	9:49	13	13	13	13	13	13	13	13	13	13	13
9:15	23	23	23	23	23	23	23	23	23	23	23	9:50	12	12	12	12	12	12	12	12	12	12	12
9:16	23	23	23	23	23	23	23	23	23	23	23												
9:17	23	23	23	23	23	23	23	23	23	23	23												
9:18	22	22	22	22	22	22	22	22	22	22	22												
9:19	22	22	22	22	22	22	22	22	22	22	22												
9:20	22	22	22	22	22	22	22	22	22	22	22												
9:21	22	22	22	22	22	22	22	22	22	22	22												
												Count	168	161	155	148	142	135	129	122	115	108	101

Since there are no tall buildings present on the other side of the street, which would be tall enough to influence the resulting values of sunlight exposure times,a clear correlation can be seen between the Floating point and Linear determination methods. The resulting exposure times for Linear determination model are equal to the maximum values obtained for Floating point analyses.

6.2.2 Case study No. 2

This residential building is located in Central Bohemian Region. In it foundation it is similar to CASE STUDY NO. 1,since there is no immediate surrounding, and no development is expected West from the building. The orientation of evaluated facade compared to the previous case is the opposite.

In place of an East-South East orientation it is West-South West. The tilt of the windows normal vector from South is $128.28°$,and approximately $121.25°$ including the local grid convergence C.

The building was originally planned to be a Hotel Resort next to a sporting facility. Albeit due to COVID-19 it came to declination to tourism activities in the area, and the property developer decided to change the utilisation of the building to an apartment building. Turning all of the accommodation into apartments. Nevertheless the original design did not account any daylighting design strategy, including exposure to sunlight.

It has to be mentioned, that the idea to modify the building from a Resort to and Apartment building was decided upon by the property developer already in the construction phase, when all of the load-bearing structures were constructed. The construction developer wanted to turn the most of accommodation facilities to apartments, so a request of their was to determine if a partial demolition could raise the number of flats to be sold.

Fortunately the dimensions of the windows are rather big $2.85 \times 2.4\mathrm{m}$, and the wall thickness is equal to $500\mathrm{mm}$. But most of it in the first basement was already shaded by walls between loggias and the big depth of balcony structure, as can be seen on the figures.

The following figure, chart and tables summarize the results of experimental activity depending on the used approach for the DESIGNED STRUCTURAL SOLUTION. Fig. 6.20 and Tab. 6.14 are related to both evaluation possibilities. Fig. 6.21 is related to floating point concept, whereas Tab. 6.15 is a summary of data obtained by calculations for the linear model.

On Fig. 6.20 part of the 3D scene and evaluation process at a distance of $450\mathrm{mm}$ from the jamb is visible. All of the calculations were provided by Exposure to Sunlight EN17037 in Rhino 3D. On the chart in Fig. 6.21 and in Tab. 6.14 the values of sunlight exposure times are represented, although the chart is limited to the Floating point evaluation method.

It is easy to identify, that this window failed extraordinarily. The RED dashed line is a representation of requirements, which is 90min.

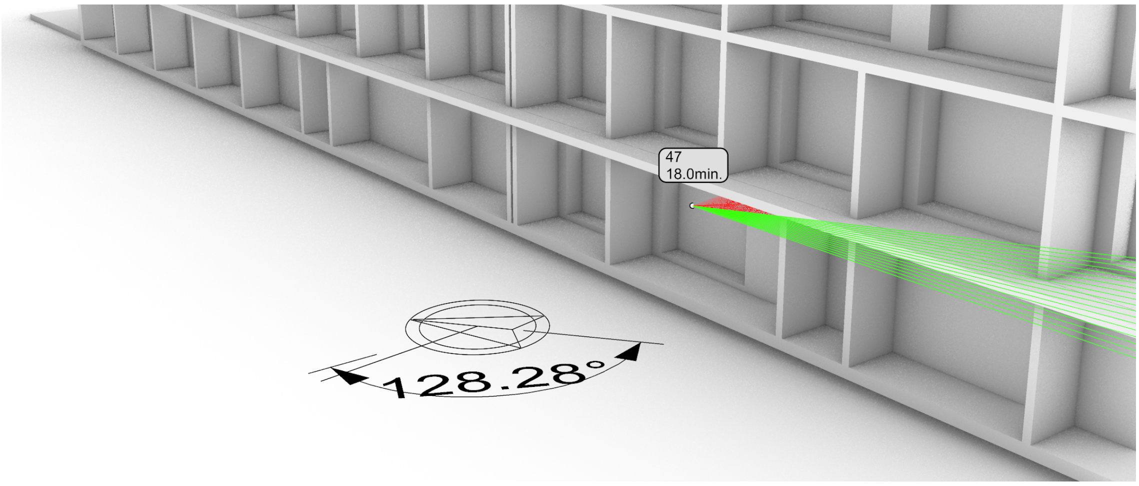


Fig. 6.20: Case study No. 2 v1 - Evaluation at 450mm *from jamb, with* $\gamma_s = 13°$.

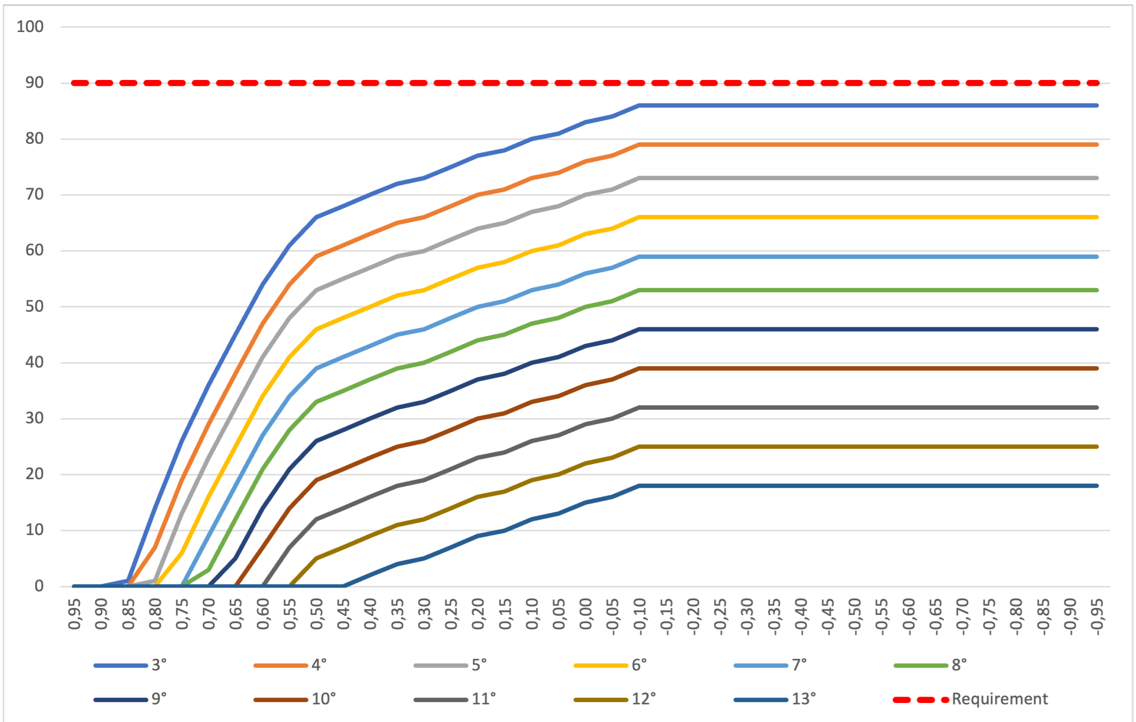


Fig. 6.21: Case study No. 2 v1 - Summary of results for floating point evaluation in the form of a chart.

Tab. 6.14: Case study No. 2 v1 - Global results in all evaluation points. Positions with same results were left out from the table.

Position	Sunlight exposure [min]										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
1,40	0	0	0	0	0	0	0	0	0	0	0
…	…	…	…	…	…	…	…	…	…	…	…
0,95	0	0	0	0	0	0	0	0	0	0	0
0,90	0	0	0	0	0	0	0	0	0	0	0
0,85	1	0	0	0	0	0	0	0	0	0	0
0,80	14	7	1	0	0	0	0	0	0	0	0
0,75	26	19	13	6	0	0	0	0	0	0	0
0,70	36	29	23	16	9	3	0	0	0	0	0
0,65	45	38	32	25	18	12	5	0	0	0	0
0,60	54	47	41	34	27	21	14	7	0	0	0
0,55	61	54	48	41	34	28	21	14	7	0	0
0,50	66	59	53	46	39	33	26	19	12	5	0
0,45	68	61	55	48	41	35	28	21	14	7	0
0,40	70	63	57	50	43	37	30	23	16	9	2
0,35	72	65	59	52	45	39	32	25	18	11	4
0,30	73	66	60	53	46	40	33	26	19	12	5
0,25	75	68	62	55	48	42	35	28	21	14	7
0,20	77	70	64	57	50	44	37	30	23	16	9
0,15	78	71	65	58	51	45	38	31	24	17	10
0,10	80	73	67	60	53	47	40	33	26	19	12
0,05	81	74	68	61	54	48	41	34	27	20	13
0,00	83	76	70	63	56	50	43	36	29	22	15
-0,05	84	77	71	64	57	51	44	37	30	23	16
-0,10	86	79	73	66	59	53	46	39	32	25	18
-0,15	86	79	73	66	59	53	46	39	32	25	18
-0,20	86	79	73	66	59	53	46	39	32	25	18
-0,25	86	79	73	66	59	53	46	39	32	25	18
-0,30	86	79	73	66	59	53	46	39	32	25	18
-0,35	86	79	73	66	59	53	46	39	32	25	18
-0,40	86	79	73	66	59	53	46	39	32	25	18
-0,45	86	79	73	66	59	53	46	39	32	25	18
-0,50	86	79	73	66	59	53	46	39	32	25	18
-0,55	86	79	73	66	59	53	46	39	32	25	18
-0,60	86	79	73	66	59	53	46	39	32	25	18
-0,65	86	79	73	66	59	53	46	39	32	25	18
-0,70	86	79	73	66	59	53	46	39	32	25	18
-0,75	86	79	73	66	59	53	46	39	32	25	18
-0,80	86	79	73	66	59	53	46	39	32	25	18
-0,85	86	79	73	66	59	53	46	39	32	25	18
-0,90	86	79	73	66	59	53	46	39	32	25	18
-0,95	86	79	73	66	59	53	46	39	32	25	18
…	…	…	…	…	…	…	…	…	…	…	…
-1,40	86	79	73	66	59	53	46	39	32	25	18

The summary of data in Tab. 6.14 complemented by analyses of the simulations is visible in Tab. 6.15. It is visible, that this particular windows fails the evaluation even when Linear determination model is used.

Tab. 6.15: Case study No. 2 v1 - Summary of results for linear determination model .

Time	Exposure in No. of Cases											Time	Exposure in No. of Cases											Time	Exposure in No. of Cases										
	γ min												γ min												γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
15:50	28	28	28	28	28	28	28	28	28	28	28	16:25	42	42	42	42	42	42	42	42				17:00	45	45	45								
15:51	28	28	28	28	28	28	28	28	28	28	28	16:26	42	42	42	42	42	42	42	42				17:01	45	45	45								
15:52	29	29	29	29	29	29	29	29	29	29	29	16:27	42	42	42	42	42	42	42	42				17:02	46	46	46								
15:53	30	30	30	30	30	30	30	30	30	30	30	16:28	42	42	42	42	42	42	42	42				17:03	46	46									
15:54	30	30	30	30	30	30	30	30	30	30	30	16:29	42	42	42	42	42	42	42					17:04	46	46									
15:55	31	31	31	31	31	31	31	31	31	31	31	16:30	42	42	42	42	42	42	42					17:05	46	46									
15:56	32	32	32	32	32	32	32	32	32	32	32	16:31	43	43	43	43	43	43	43					17:06	46	46									
15:57	32	32	32	32	32	32	32	32	32	32	32	16:32	43	43	43	43	43	43	43					17:07	46	46									
15:58	33	33	33	33	33	33	33	33	33	33	33	16:33	43	43	43	43	43	43	43					17:08	46	46									
15:59	34	34	34	34	34	34	34	34	34	34	34	16:34	43	43	43	43	43	43	43					17:09	46										
16:00	34	34	34	34	34	34	34	34	34	34	34	16:35	43	43	43	43	43	43	43					17:10	46										
16:01	35	35	35	35	35	35	35	35	35	35	35	16:36	43	43	43	43	43	43						17:11	46										
16:02	35	35	35	35	35	35	35	35	35	35	35	16:37	43	43	43	43	43	43						17:12	46										
16:03	36	36	36	36	36	36	36	36	36	36	36	16:38	43	43	43	43	43	43						17:13	46										
16:04	37	37	37	37	37	37	37	37	37	37	37	16:39	43	43	43	43	43	43						17:14	46										
16:05	37	37	37	37	37	37	37	37	37	37	37	16:40	44	44	44	44	44	44						17:15	47										
16:06	38	38	38	38	38	38	38	38	38	38	38	16:41	44	44	44	44	44	44																	
16:07	38	38	38	38	38	38	38	38	38	38	38	16:42	44	44	44	44	44	44																	
16:08	39	39	39	39	39	39	39	39	39	39		16:43	44	44	44	44	44																		
16:09	39	39	39	39	39	39	39	39	39	39		16:44	44	44	44	44	44																		
16:10	40	40	40	40	40	40	40	40	40	40		16:45	44	44	44	44	44																		
16:11	40	40	40	40	40	40	40	40	40	40		16:46	44	44	44	44	44																		
16:12	40	40	40	40	40	40	40	40	40	40		16:47	44	44	44	44	44																		
16:13	40	40	40	40	40	40	40	40	40	40		16:48	44	44	44	44	44																		
16:14	40	40	40	40	40	40	40	40	40	40		16:49	44	44	44	44																			
16:15	41	41	41	41	41	41	41	41	41			16:50	45	45	45	45																			
16:16	41	41	41	41	41	41	41	41	41			16:51	45	45	45	45																			
16:17	41	41	41	41	41	41	41	41	41			16:52	45	45	45	45																			
16:18	41	41	41	41	41	41	41	41	41			16:53	45	45	45	45																			
16:19	41	41	41	41	41	41	41	41	41			16:54	45	45	45	45																			
16:20	41	41	41	41	41	41	41	41	41			16:55	45	45	45	45																			
16:21	41	41	41	41	41	41	41	41	41			16:56	45	45	45																				
16:22	42	42	42	42	42	42	42	42				16:57	45	45	45																				
16:23	42	42	42	42	42	42	42	42				16:58	45	45	45																				
16:24	42	42	42	42	42	42	42	42				16:59	45	45	45																				
																								Count	**86**	**79**	**73**	**66**	**59**	**53**	**46**	**39**	**32**	**25**	**18**

The following figure, chart and tables summarize the results of experimental activity after partial demolition of overhanging structures was planned in accordance to spatial resolution of upper floors. Both evaluation possibilities: Fig. 6.22 and Tab. 6.16. Floating point concept: Fig. 6.23. Linear model: Tab. 6.17. Compared to the previous showcase values rose and at least some compliant locations were found for $\gamma_s \in \langle 3°, 5° \rangle$.

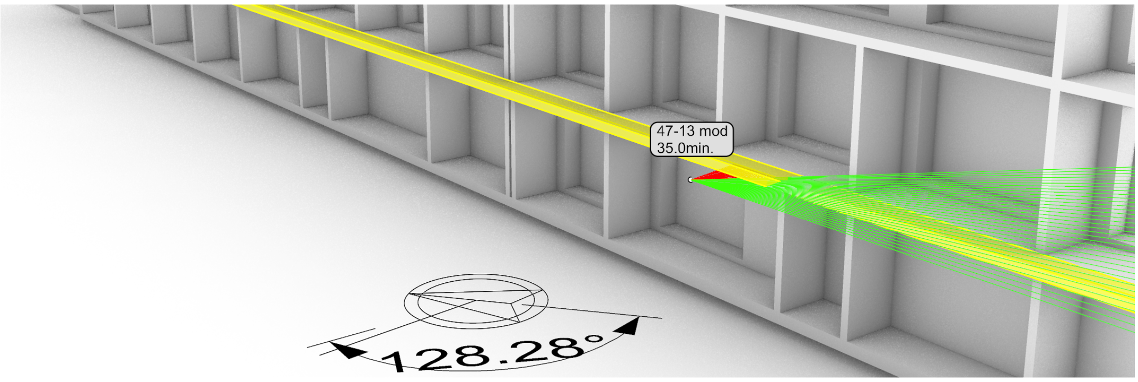


Fig. 6.22: Case study No. 2 v1 - Evaluation at 450mm *from jamb, with* $\gamma_s = 13°$*. (Yellow ghosted element marks the partial demolition.)*

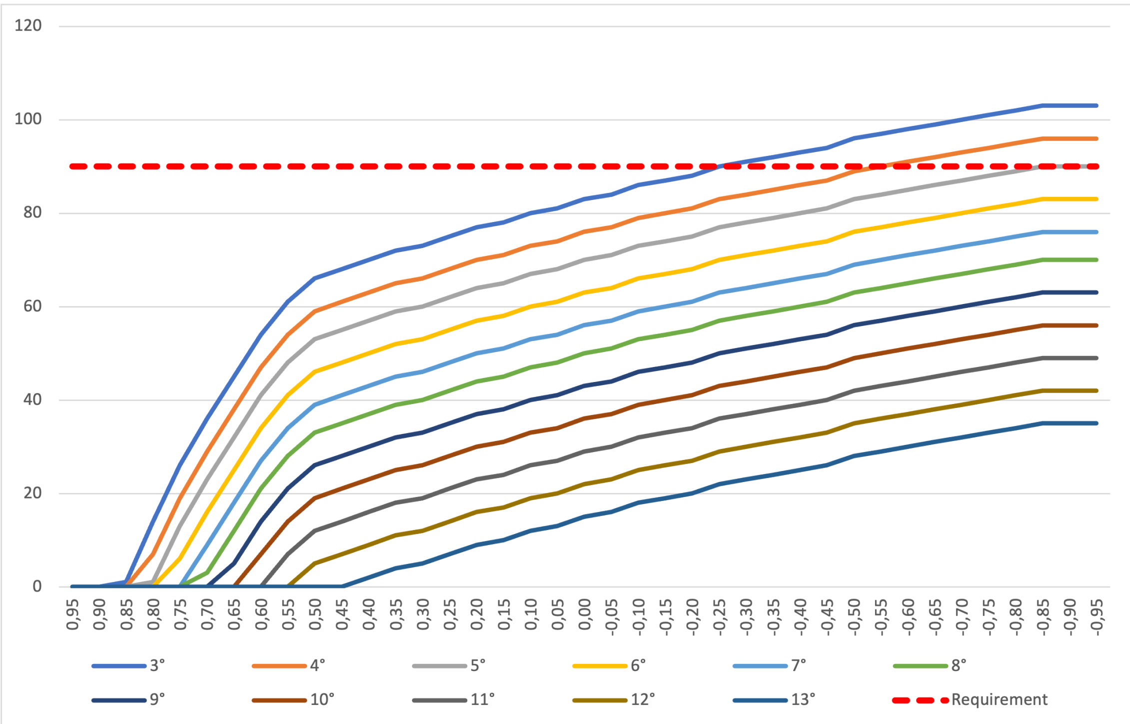


Fig. 6.23: Case study No. 2 v2 - Summary of results for floating point evaluation in the form of a chart.

Tab. 6.16: Case study No. 2 v2- Global results in all evaluation points. Positions with same results were left out from the table.

Position	Sunlight exposure [min]										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
1,4	0	0	0	0	0	0	0	0	0	0	0
…	…	…	…	…	…	…	…	…	…	…	…
0,95	0	0	0	0	0	0	0	0	0	0	0
0,90	0	0	0	0	0	0	0	0	0	0	0
0,85	1	0	0	0	0	0	0	0	0	0	0
0,80	14	7	1	0	0	0	0	0	0	0	0
0,75	26	19	13	6	0	0	0	0	0	0	0
0,70	36	29	23	16	9	3	0	0	0	0	0
0,65	45	38	32	25	18	12	5	0	0	0	0
0,60	54	47	41	34	27	21	14	7	0	0	0
0,55	61	54	48	41	34	28	21	14	7	0	0
0,50	66	59	53	46	39	33	26	19	12	5	0
0,45	68	61	55	48	41	35	28	21	14	7	0
0,40	70	63	57	50	43	37	30	23	16	9	2
0,35	72	65	59	52	45	39	32	25	18	11	4
0,30	73	66	60	53	46	40	33	26	19	12	5
0,25	75	68	62	55	48	42	35	28	21	14	7
0,20	77	70	64	57	50	44	37	30	23	16	9
0,15	78	71	65	58	51	45	38	31	24	17	10
0,10	80	73	67	60	53	47	40	33	26	19	12
0,05	81	74	68	61	54	48	41	34	27	20	13
0,00	83	76	70	63	56	50	43	36	29	22	15
-0,05	84	77	71	64	57	51	44	37	30	23	16
-0,10	86	79	73	66	59	53	46	39	32	25	18
-0,15	87	80	74	67	60	54	47	40	33	26	19
-0,20	88	81	75	68	61	55	48	41	34	27	20
-0,25	**90**	83	77	70	63	57	50	43	36	29	22
-0,30	**91**	84	78	71	64	58	51	44	37	30	23
-0,35	**92**	85	79	72	65	59	52	45	38	31	24
-0,40	**93**	86	80	73	66	60	53	46	39	32	25
-0,45	**94**	87	81	74	67	61	54	47	40	33	26
-0,50	**96**	89	83	76	69	63	56	49	42	35	28
-0,55	**97**	**90**	84	77	70	64	57	50	43	36	29
-0,60	**98**	**91**	85	78	71	65	58	51	44	37	30
-0,65	**99**	**92**	86	79	72	66	59	52	45	38	31
-0,70	**100**	**93**	87	80	73	67	60	53	46	39	32
-0,75	**101**	**94**	88	81	74	68	61	54	47	40	33
-0,80	**102**	**95**	89	82	75	69	62	55	48	41	34
-0,85	**103**	**96**	**90**	83	76	70	63	56	49	42	35
-0,90	**103**	**96**	**90**	83	76	70	63	56	49	42	35
-0,95	**103**	**96**	**90**	83	76	70	63	56	49	42	35
…	**…**	**…**	**…**	…	…	…	…	…	…	…	…
-1,40	**103**	**96**	**90**	83	76	70	63	56	49	42	35

The summary present in Tab. 6.17 revealed that the resulting exposure times for Linear determination model are equal to the maximum values obtained for Floating point analyses. This is caused by non-existent immediate surrounding.

Tab. 6.17: Case study No. 2 v2 - Summary of results for linear determination model .

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
15:33	13	13	13	13	13	13	13	13	13	13	13
15:34	14	14	14	14	14	14	14	14	14	14	14
15:35	15	15	15	15	15	15	15	15	15	15	15
15:36	16	16	16	16	16	16	16	16	16	16	16
15:37	17	17	17	17	17	17	17	17	17	17	17
15:38	18	18	18	18	18	18	18	18	18	18	18
15:39	19	19	19	19	19	19	19	19	19	19	19
15:40	20	20	20	20	20	20	20	20	20	20	20
15:41	20	20	20	20	20	20	20	20	20	20	20
15:42	21	21	21	21	21	21	21	21	21	21	21
15:43	22	22	22	22	22	22	22	22	22	22	22
15:44	23	23	23	23	23	23	23	23	23	23	23
15:45	24	24	24	24	24	24	24	24	24	24	24
15:46	25	25	25	25	25	25	25	25	25	25	25
15:47	25	25	25	25	25	25	25	25	25	25	25
15:48	26	26	26	26	26	26	26	26	26	26	26
15:49	27	27	27	27	27	27	27	27	27	27	27
15:50	28	28	28	28	28	28	28	28	28	28	28
15:51	28	28	28	28	28	28	28	28	28	28	28
15:52	29	29	29	29	29	29	29	29	29	29	29
15:53	30	30	30	30	30	30	30	30	30	30	30
15:54	30	30	30	30	30	30	30	30	30	30	30
15:55	31	31	31	31	31	31	31	31	31	31	31
15:56	32	32	32	32	32	32	32	32	32	32	32
15:57	32	32	32	32	32	32	32	32	32	32	32
15:58	33	33	33	33	33	33	33	33	33	33	33
15:59	34	34	34	34	34	34	34	34	34	34	34
16:00	34	34	34	34	34	34	34	34	34	34	34
16:01	35	35	35	35	35	35	35	35	35	35	35
16:02	35	35	35	35	35	35	35	35	35	35	35
16:03	36	36	36	36	36	36	36	36	36	36	36
16:04	37	37	37	37	37	37	37	37	37	37	37
16:05	37	37	37	37	37	37	37	37	37	37	37
16:06	38	38	38	38	38	38	38	38	38	38	38
16:07	38	38	38	38	38	38	38	38	38	38	38

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
16:08	39	39	39	39	39	39	39	39	39	39	
16:09	39	39	39	39	39	39	39	39	39	39	
16:10	40	40	40	40	40	40	40	40	40	40	
16:11	40	40	40	40	40	40	40	40	40	40	
16:12	40	40	40	40	40	40	40	40	40	40	
16:13	40	40	40	40	40	40	40	40	40	40	
16:14	40	40	40	40	40	40	40	40	40	40	
16:15	41	41	41	41	41	41	41	41	41		
16:16	41	41	41	41	41	41	41	41	41		
16:17	41	41	41	41	41	41	41	41	41		
16:18	41	41	41	41	41	41	41	41	41		
16:19	41	41	41	41	41	41	41	41	41		
16:20	41	41	41	41	41	41	41	41	41		
16:21	41	41	41	41	41	41	41	41	41		
16:22	42	42	42	42	42	42	42	42			
16:23	42	42	42	42	42	42	42	42			
16:24	42	42	42	42	42	42	42	42			
16:25	42	42	42	42	42	42	42	42			
16:26	42	42	42	42	42	42	42	42			
16:27	42	42	42	42	42	42	42	42			
16:28	42	42	42	42	42	42	42	42			
16:29	42	42	42	42	42	42	42				
16:30	42	42	42	42	42	42	42				
16:31	43	43	43	43	43	43	43				
16:32	43	43	43	43	43	43	43				
16:33	43	43	43	43	43	43	43				
16:34	43	43	43	43	43	43	43				
16:35	43	43	43	43	43	43	43				
16:36	43	43	43	43	43	43					
16:37	43	43	43	43	43	43					
16:38	43	43	43	43	43	43					
16:39	43	43	43	43	43	43					
16:40	44	44	44	44	44	44					
16:41	44	44	44	44	44	44					
16:42	44	44	44	44	44	44					

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
16:43	44	44	44	44	44						
16:44	44	44	44	44	44						
16:45	44	44	44	44	44						
16:46	44	44	44	44	44						
16:47	44	44	44	44	44						
16:48	44	44	44	44	44						
16:49	44	44	44	44							
16:50	45	45	45	45							
16:51	45	45	45	45							
16:52	45	45	45	45							
16:53	45	45	45	45							
16:54	45	45	45	45							
16:55	45	45	45	45							
16:56	45	45	45								
16:57	45	45	45								
16:58	45	45	45								
16:59	45	45	45								
17:00	45	45	45								
17:01	45	45	45								
17:02	46	46	46								
17:03	46	46									
17:04	46	46									
17:05	46	46									
17:06	46	46									
17:07	46	46									
17:08	46	46									
17:09	46										
17:10	46										
17:11	46										
17:12	46										
17:13	46										
17:14	46										
17:15	47										
Count	**103**	**96**	**90**	**83**	**76**	**70**	**63**	**56**	**49**	**42**	**35**

6.2.3 Case study No. 3

The apartment building presented as a case study is only one building object out of some, which were designed over a designated area on the outskirts of a city in South Moravian Region. The orientation of the buildings with respect to cardinal directions were limited by safety zones of roads and utility networks.

The version introduced was one of the earliest *Work-in-Progress* (WIP) designs. All of the buildings designed were required to have 5 floors, and the aim was to make out the most of it. Because the dimensions of the buildings exceeding 12m the apartments rarely two opposing sides of the building. They were either concentrated around the corners, or were situated along the peripheral structure in neat rows.

All of the units designed in this WIP version had a terrace, balcony or loggia, increasing the functional area of the units. What made this version unique was that privacy of the terraces was to be maintained by fences made out of full timber or square shaped hot rolled sections of dimensions $60 \times 60\text{mm}$ with a spacing of 60mm. Albeit the design of these fences was not really finished at those time, since the design was still in the initial phases.

There were some apartment units, which did not meet the legislative requirements due to the orientation of the windows and terrace doors, or just because the designed fences did shade the evaluation locations more than it was healthy. This is the also the case of the presented living space, which even has two openings. The window $(2 \times 2\text{m})$ of the space has an East-North East orientation., while the terrace door $(1 \times 2\text{m})$ is oriented more towards the South.

The following figures, charts and tables summarize the results of experimental activity for both of the openings and both of evaluation possibilities. The first set of outputs represent the data obtained for the window, whereas the second set of outputs were prepared for the terrace door.

On Fig. 6.24 part of the 3D scene and evaluation process at a distance of 450mm from the jamb is visible. The results of this calculation, as well the rest of were determined by a modified version of Exposure to Sunlight EN17037.

On the chart in Fig. 6.25 and in Tab. 6.18 the values of sunlight exposure times are represented, although the chart is limited to the Floating point evaluation method. It is easy to identify, that this window failed totally. The RED dashed line is a representation of requirements, which is 90min.

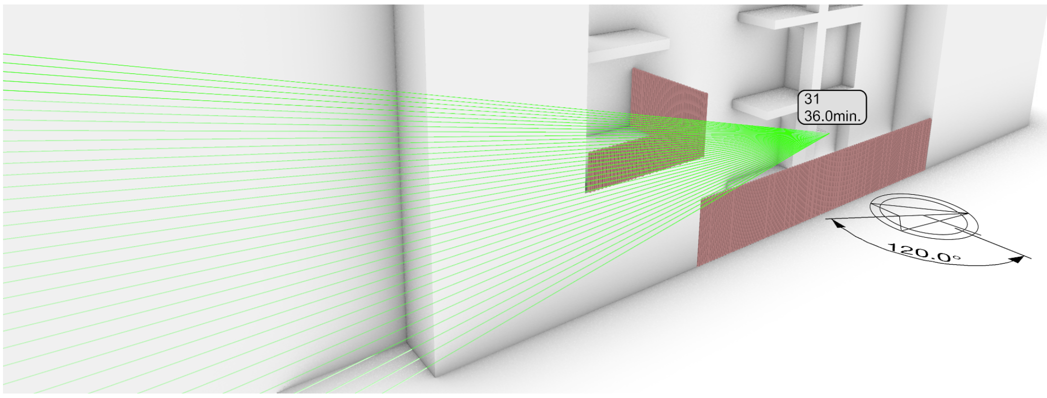


Fig. 6.24: Case study No. 3 W1 - Evaluation at 450mm *from Northern jamb of window, with* $\gamma_s = 13°$.

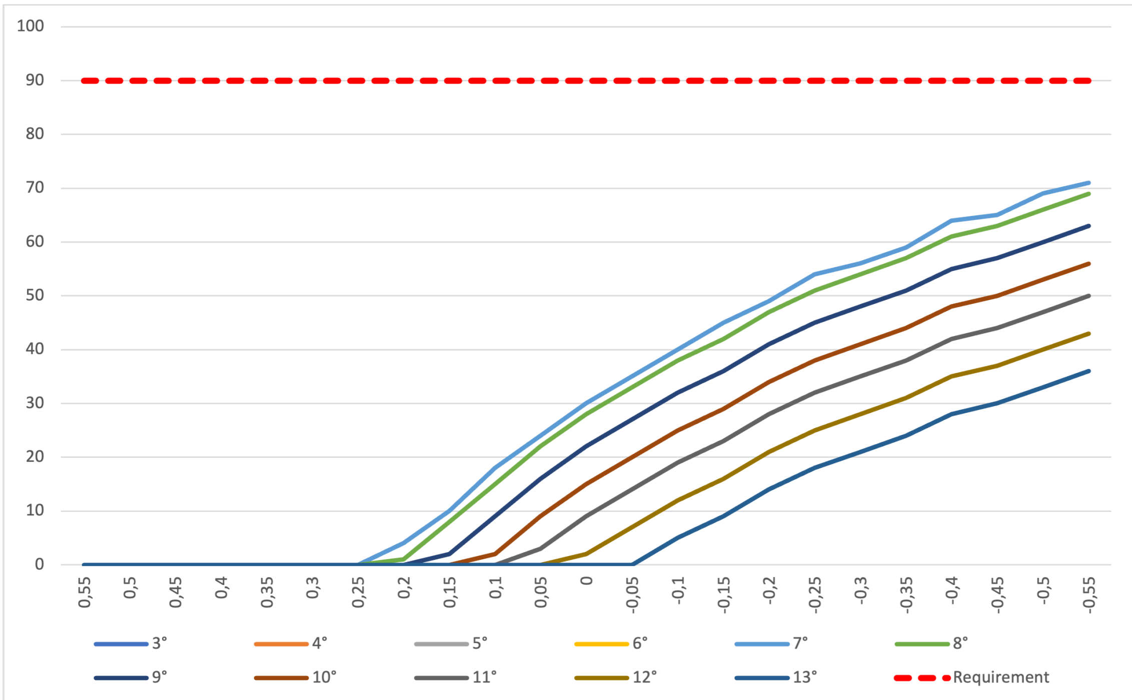


Fig. 6.25: Case study No. 3 W1 - Summary of results for floating point evaluation in the form of a chart.

Tab. 6.18: Case study No. 3 W1- Global results in all evaluation points. Positions with same results were left out from the table.

Position	Sunlight exposure [min]										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
1,00	0	0	0	0	0	0	0	0	0	0	0
0,95	0	0	0	0	0	0	0	0	0	0	0
0,90	0	0	0	0	0	0	0	0	0	0	0
0,85	0	0	0	0	0	0	0	0	0	0	0
0,80	0	0	0	0	0	0	0	0	0	0	0
0,75	0	0	0	0	0	0	0	0	0	0	0
0,70	0	0	0	0	0	0	0	0	0	0	0
0,65	0	0	0	0	0	0	0	0	0	0	0
0,60	0	0	0	0	0	0	0	0	0	0	0
0,55	0	0	0	0	0	0	0	0	0	0	0
0,50	0	0	0	0	0	0	0	0	0	0	0
0,45	0	0	0	0	0	0	0	0	0	0	0
0,40	0	0	0	0	0	0	0	0	0	0	0
0,35	0	0	0	0	0	0	0	0	0	0	0
0,30	0	0	0	0	0	0	0	0	0	0	0
0,25	0	0	0	0	0	0	0	0	0	0	0
0,20	4	4	4	4	4	1	0	0	0	0	0
0,15	10	10	10	10	10	8	2	0	0	0	0
0,10	18	18	18	18	18	15	9	2	0	0	0
0,05	24	24	24	24	24	22	16	9	3	0	0
0,00	30	30	30	30	30	28	22	15	9	2	0
-0,05	35	35	35	35	35	33	27	20	14	7	0
-0,10	40	40	40	40	40	38	32	25	19	12	5
-0,15	45	45	45	45	45	42	36	29	23	16	9
-0,20	49	49	49	49	49	47	41	34	28	21	14
-0,25	54	54	54	54	54	51	45	38	32	25	18
-0,30	56	56	56	56	56	54	48	41	35	28	21
-0,35	59	59	59	59	59	57	51	44	38	31	24
-0,40	64	64	64	64	64	61	55	48	42	35	28
-0,45	65	65	65	65	65	63	57	50	44	37	30
-0,50	69	69	69	69	69	66	60	53	47	40	33
-0,55	71	71	71	71	71	69	63	56	50	43	36
-0,60	73	73	73	73	73	71	65	58	52	45	38
-0,65	75	75	75	75	75	73	67	60	54	47	40
-0,70	77	77	77	77	77	75	69	62	56	49	42
-0,75	80	80	80	80	80	77	71	64	58	51	44
-0,80	81	81	81	81	81	79	73	66	60	53	46
-0,85	84	84	84	84	84	81	75	68	62	55	48
-0,90	85	85	85	85	85	83	77	70	64	57	50
-0,95	86	86	86	86	86	84	78	71	65	58	51
-1,00	89	89	89	89	89	86	80	73	67	60	53

The summary of data in Tab. 6.18 complemented by analyses of the simulations is visible in Tab. 6.19. It is visible, that this particular windows fails the evaluation even when Linear determination model is used.

Tab. 6.19: Case study No. 3 W1 - Summary of results for linear determination model .

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
7:31	9	9	9	9	9						
7:32	25	25	25	25	25						
7:33	25	25	25	25	25	25					
7:34	25	25	25	25	25	25					
7:35	24	24	24	24	24	24					
7:36	24	24	24	24	24	24					
7:37	24	24	24	24	24	24					
7:38	24	24	24	24	24	24					
7:39	24	24	24	24	24	24	24				
7:40	24	24	24	24	24	24	24				
7:41	24	24	24	24	24	24	24				
7:42	23	23	23	23	23	23	23				
7:43	23	23	23	23	23	23	23				
7:44	23	23	23	23	23	23	23				
7:45	23	23	23	23	23	23	23				
7:46	23	23	23	23	23	23	23	23			
7:47	23	23	23	23	23	23	23	23			
7:48	23	23	23	23	23	23	23	23			
7:49	22	22	22	22	22	22	22	22			
7:50	22	22	22	22	22	22	22	22			
7:51	22	22	22	22	22	22	22	22			
7:52	22	22	22	22	22	22	22	22	22		
7:53	22	22	22	22	22	22	22	22	22		
7:54	22	22	22	22	22	22	22	22	22		
7:55	22	22	22	22	22	22	22	22	22		
7:56	21	21	21	21	21	21	21	21	21		
7:57	21	21	21	21	21	21	21	21	21		
7:58	21	21	21	21	21	21	21	21	21		
7:59	21	21	21	21	21	21	21	21	21	21	
8:00	21	21	21	21	21	21	21	21	21	21	
8:01	21	21	21	21	21	21	21	21	21	21	
8:02	20	20	20	20	20	20	20	20	20	20	
8:03	20	20	20	20	20	20	20	20	20	20	
8:04	20	20	20	20	20	20	20	20	20	20	
8:05	20	20	20	20	20	20	20	20	20	20	

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
8:06	20	20	20	20	20	20	20	20	20	20	20
8:07	19	19	19	19	19	19	19	19	19	19	19
8:08	19	19	19	19	19	19	19	19	19	19	19
8:09	19	19	19	19	19	19	19	19	19	19	19
8:10	19	19	19	19	19	19	19	19	19	19	19
8:11	19	19	19	19	19	19	19	19	19	19	19
8:12	18	18	18	18	18	18	18	18	18	18	18
8:13	18	18	18	18	18	18	18	18	18	18	18
8:14	18	18	18	18	18	18	18	18	18	18	18
8:15	18	18	18	18	18	18	18	18	18	18	18
8:16	17	17	17	17	17	17	17	17	17	17	17
8:17	17	17	17	17	17	17	17	17	17	17	17
8:18	17	17	17	17	17	17	17	17	17	17	17
8:19	17	17	17	17	17	17	17	17	17	17	17
8:20	17	17	17	17	17	17	17	17	17	17	17
8:21	16	16	16	16	16	16	16	16	16	16	16
8:22	16	16	16	16	16	16	16	16	16	16	16
8:23	16	16	16	16	16	16	16	16	16	16	16
8:24	16	16	16	16	16	16	16	16	16	16	16
8:25	15	15	15	15	15	15	15	15	15	15	15
8:26	15	15	15	15	15	15	15	15	15	15	15
8:27	15	15	15	15	15	15	15	15	15	15	15
8:28	14	14	14	14	14	14	14	14	14	14	14
8:29	14	14	14	14	14	14	14	14	14	14	14
8:30	14	14	14	14	14	14	14	14	14	14	14
8:31	13	13	13	13	13	13	13	13	13	13	13
8:32	13	13	13	13	13	13	13	13	13	13	13
8:33	13	13	13	13	13	13	13	13	13	13	13
8:34	13	13	13	13	13	13	13	13	13	13	13
8:35	12	12	12	12	12	12	12	12	12	12	12
8:36	12	12	12	12	12	12	12	12	12	12	12
8:37	11	11	11	11	11	11	11	11	11	11	11
8:38	11	11	11	11	11	11	11	11	11	11	11
8:39	11	11	11	11	11	11	11	11	11	11	11
8:40	10	10	10	10	10	10	10	10	10	10	10

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
8:41	10	10	10	10	10	10	10	10	10	10	10
8:42	10	10	10	10	10	10	10	10	10	10	10
8:43	9	9	9	9	9	9	9	9	9	9	9
8:44	9	9	9	9	9	9	9	9	9	9	9
8:45	8	8	8	8	8	8	8	8	8	8	8
8:46	8	8	8	8	8	8	8	8	8	8	8
8:47	7	7	7	7	7	7	7	7	7	7	7
8:48	7	7	7	7	7	7	7	7	7	7	7
8:49	6	6	6	6	6	6	6	6	6	6	6
8:50	6	6	6	6	6	6	6	6	6	6	6
8:51	5	5	5	5	5	5	5	5	5	5	5
8:52	5	5	5	5	5	5	5	5	5	5	5
8:53	4	4	4	4	4	4	4	4	4	4	4
8:54	4	4	4	4	4	4	4	4	4	4	4
8:55	3	3	3	3	3	3	3	3	3	3	3
8:56	3	3	3	3	3	3	3	3	3	3	3
8:57	2	2	2	2	2	2	2	2	2	2	2
8:58	1	1	1	1	1	1	1	1	1	1	1
8:59	1	1	1	1	1	1	1	1	1	1	1
Count	**89**	**89**	**89**	**89**	**89**	**87**	**81**	**74**	**68**	**61**	**54**

This next set of figures and tables are a depiction of results for the rooms 2nd opening, the terrace door. On Fig. 6.26 once again a part of the 3D scene and evaluation process is depicted. On the chart in Fig. 6.27 and in Tab. 6.20 the values of sunlight exposure times are shown, although the chart is limited to the Floating point evaluation method. It is easy to identify, that the values are under the dashed RED line, and the door also failed the evaluation.

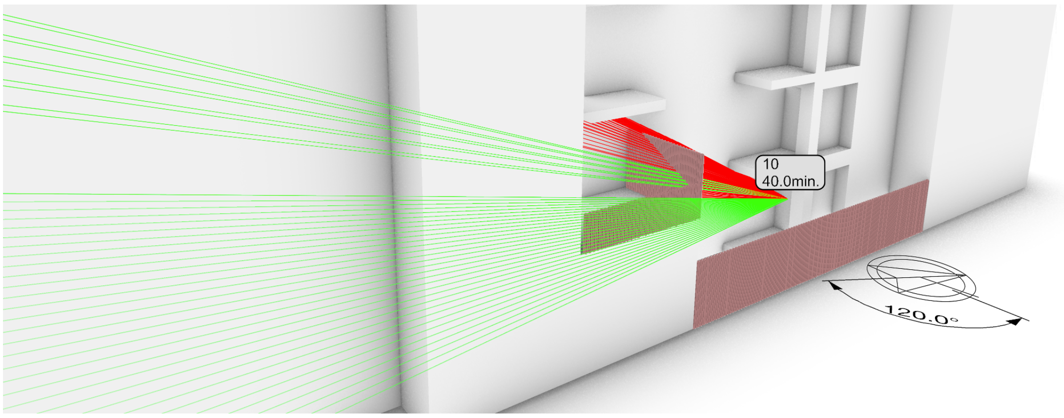


Fig. 6.26: Case study No. 3 W2 - Evaluation in the middle of terrace door, with $\gamma_s = 13°$.

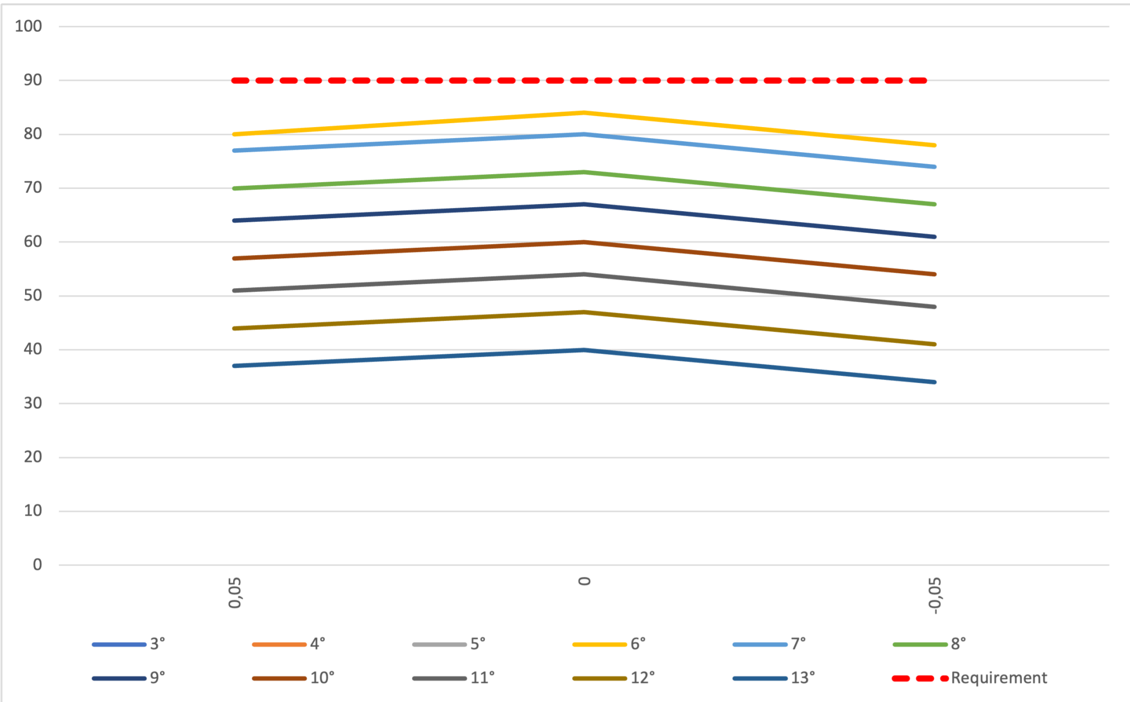


Fig. 6.27: Case study No. 3 W2 - Summary of results for floating point evaluation in the form of a chart.

Tab. 6.20: Case study No. 3 W2 - Global results in all evaluation points. Positions with same results were left out from the table.

Position	Sunlight exposure [min]										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
0,50	0	0	0	0	0	0	0	0	0	0	0
0,45	0	0	0	0	0	0	0	0	0	0	0
0,40	2	2	2	2	2	2	2	2	2	2	2
0,35	5	5	5	5	5	5	5	5	5	5	5
0,30	31	31	31	31	31	31	31	31	31	31	31
0,25	52	52	52	52	52	52	52	52	52	52	47
0,20	69	69	69	69	69	69	69	62	56	49	42
0,15	87	87	87	87	86	79	73	66	60	53	46
0,10	82	82	82	82	80	73	67	60	54	47	40
0,05	80	80	80	80	77	70	64	57	51	44	37
0,00	84	84	84	84	80	73	67	60	54	47	40
-0,05	78	78	78	78	74	67	61	54	48	41	34
-0,10	78	78	78	78	73	66	60	53	47	40	33
-0,15	81	81	81	81	75	68	62	55	49	42	35
-0,20	77	77	77	76	70	63	57	50	44	37	30
-0,25	75	75	75	74	68	61	55	48	42	35	28
-0,30	77	77	77	75	69	62	56	49	43	36	29
-0,35	72	72	72	70	64	57	51	44	38	31	24
-0,40	72	72	72	69	63	56	50	43	37	30	23
-0,45	72	72	72	69	63	56	50	43	37	30	23
-0,50	72	72	72	69	63	56	50	43	37	30	23

The summary of data in Tab. 6.20 complemented by analyses of simulations is presented in Tab. 6.21. The numbers the same way as earlier do represent the amount of sun rays hitting the whole edge of the sill at given minutes and minimal solar altitude angles.

From the results it can be seen, that in case of this opening through Linear determination method it is possible to achieve satisfactory results at minimal solar altitude angle $\gamma_s \in \langle 3°, 9° \rangle$.

Because the room is sunlit by two openings it came to a fusion of values as well. Tab. 6.19 and 6.21 were combined into one, and the result of this combination is visible in Tab. 6.22.

Since the sunlight exposure times were greater for the terrace door, than for the window, and at the same time the terrace door is being sunlit also by rays incident to the window, the resulting insulation times of the room are the same as for terrace door. Meaning satisfactory values for $\gamma_s \in \langle 3°, 9° \rangle$.

Tab. 6.21: Case study No. 3 W2 - Summary of results for linear determination model .

Time	Exposure in No. of Cases							
	γ min							
[m]	3°	4°	5°	6°	7°	8°	9°	10°
7:17	1	1	1					
7:18	3	3	3					
7:19	5	5	5					
7:20	7	7	7	7				
7:21	8	8	8	8				
7:22	9	9	9	9				
7:23	11	11	11	11				
7:24	12	12	12	12				
7:25	13	13	13	13				
7:26	14	14	14	14	14			
7:27	14	14	14	14	14			
7:28	14	14	14	14	14			
7:29	14	14	14	14	14			
7:30	14	14	14	14	14			
7:31	14	14	14	14	14			
7:32	14	14	14	14	14			
7:33	14	14	14	14	14	14		
7:34	14	14	14	14	14	14		
7:35	14	14	14	14	14	14		
7:36	14	14	14	14	14	14		
7:37	14	14	14	14	14	14		
7:38	14	14	14	14	14	14		
7:39	14	14	14	14	14	14	14	
7:40	15	15	15	15	15	15	15	
7:41	15	15	15	15	15	15	15	
7:42	15	15	15	15	15	15	15	
7:43	15	15	15	15	15	15	15	
7:44	15	15	15	15	15	15	15	
7:45	15	15	15	15	15	15	15	
7:46	15	15	15	15	15	15	15	15
7:47	15	15	15	15	15	15	15	15
7:48	15	15	15	15	15	15	15	15
7:49	15	15	15	15	15	15	15	15
7:50	15	15	15	15	15	15	15	15
7:51	15	15	15	15	15	15	15	15

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
7:52	15	15	15	15	15	15	15	15	15		
7:53	15	15	15	15	15	15	15	15	15		
7:54	15	15	15	15	15	15	15	15	15		
7:55	15	15	15	15	15	15	15	15	15		
7:56	15	15	15	15	15	15	15	15	15		
7:57	15	15	15	15	15	15	15	15	15		
7:58	15	15	15	15	15	15	15	15	15		
7:59	15	15	15	15	15	15	15	15	15	15	
8:00	15	15	15	15	15	15	15	15	15	15	
8:01	15	15	15	15	15	15	15	15	15	15	
8:02	16	16	16	16	16	16	16	16	16	16	
8:03	16	16	16	16	16	16	16	16	16	16	
8:04	16	16	16	16	16	16	16	16	16	16	
8:05	16	16	16	16	16	16	16	16	16	16	
8:06	16	16	16	16	16	16	16	16	16	16	16
8:07	16	16	16	16	16	16	16	16	16	16	16
8:08	16	16	16	16	16	16	16	16	16	16	16
8:09	16	16	16	16	16	16	16	16	16	16	16
8:10	16	16	16	16	16	16	16	16	16	16	16
8:11	16	16	16	16	16	16	16	16	16	16	16
8:12	16	16	16	16	16	16	16	16	16	16	16
8:13	16	16	16	16	16	16	16	16	16	16	16
8:14	16	16	16	16	16	16	16	16	16	16	16
8:15	16	16	16	16	16	16	16	16	16	16	16
8:16	16	16	16	16	16	16	16	16	16	16	16
8:17	16	16	16	16	16	16	16	16	16	16	16
8:18	16	16	16	16	16	16	16	16	16	16	16
8:19	16	16	16	16	16	16	16	16	16	16	16
8:20	16	16	16	16	16	16	16	16	16	16	16
8:21	15	15	15	15	15	15	15	15	15	15	15
8:22	14	14	14	14	14	14	14	14	14	14	14
8:23	14	14	14	14	14	14	14	14	14	14	14
8:24	13	13	13	13	13	13	13	13	13	13	13
8:25	14	14	14	14	14	14	14	14	14	14	14
8:26	13	13	13	13	13	13	13	13	13	13	13

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
8:27	12	12	12	12	12	12	12	12	12	12	12
8:28	12	12	12	12	12	12	12	12	12	12	12
8:29	11	11	11	11	11	11	11	11	11	11	11
8:30	11	11	11	11	11	11	11	11	11	11	11
8:31	10	10	10	10	10	10	10	10	10	10	10
8:32	9	9	9	9	9	9	9	9	9	9	9
8:33	9	9	9	9	9	9	9	9	9	9	9
8:34	8	8	8	8	8	8	8	8	8	8	8
8:35	7	7	7	7	7	7	7	7	7	7	7
8:36	7	7	7	7	7	7	7	7	7	7	7
8:37	6	6	6	6	6	6	6	6	6	6	6
8:38	6	6	6	6	6	6	6	6	6	6	6
8:39	7	7	7	7	7	7	7	7	7	7	7
8:40	5	5	5	5	5	5	5	5	5	5	5
8:41	5	5	5	5	5	5	5	5	5	5	5
8:42	5	5	5	5	5	5	5	5	5	5	5
8:43	7	7	7	7	7	7	7	7	7	7	7
8:44	6	6	6	6	6	6	6	6	6	6	6
8:45	5	5	5	5	5	5	5	5	5	5	5
8:46	5	5	5	5	5	5	5	5	5	5	5
8:47	4	4	4	4	4	4	4	4	4	4	4
8:48	4	4	4	4	4	4	4	4	4	4	4
8:49	5	5	5	5	5	5	5	5	5	5	5
8:50	4	4	4	4	4	4	4	4	4	4	4
8:51	5	5	5	5	5	5	5	5	5	5	5
8:52	6	6	6	6	6	6	6	6	6	6	6
8:53	6	6	6	6	6	6	6	6	6	6	6
8:54	6	6	6	6	6	6	6	6	6	6	6
8:55	6	6	6	6	6	6	6	6	6	6	6
8:56	6	6	6	6	6	6	6	6	6	6	6
8:57	5	5	5	5	5	5	5	5	5	5	5
8:58	5	5	5	5	5	5	5	5	5	5	5
8:59	6	6	6	6	6	6	6	6	6	6	6
9:00	5	5	5	5	5	5	5	5	5	5	5
9:01	5	5	5	5	5	5	5	5	5	5	5

Time	Exposure in No. of Cases										
	γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
9:02	5	5	5	5	5	5	5	5	5	5	5
9:03	4	4	4	4	4	4	4	4	4	4	4
9:04	3	3	3	3	3	3	3	3	3	3	3
9:05	3	3	3	3	3	3	3	3	3	3	3
9:06	3	3	3	3	3	3	3	3	3	3	3
9:07	3	3	3	3	3	3	3	3	3	3	3
9:08	2	2	2	2	2	2	2	2	2	2	2
9:09	2	2	2	2	2	2	2	2	2	2	2
9:10	1	1	1	1	1	1	1	1	1	1	1
9:11	2	2	2	2	2	2	2	2	2	2	2
9:12	1	1	1	1	1	1	1	1	1	1	1
9:13	1	1	1	1	1	1	1	1	1	1	1
Count	117	117	117	114	108	101	95	88	82	75	68

Tab. 6.22: Case study No. 3 - Combined summary for linear determination model .

Time	Exposure in No. of Cases								Time	Exposure in No. of Cases											Time	Exposure in No. of Cases											Time	Exposure in No. of Cases										
	γ min									γ min												γ min												γ min										
[m]	3°	4°	5°	6°	7°	8°	9°	10°	[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	[m]	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°
7:17	1	1	1						7:52	37	37	37	37	37	37	37	37	37	0	0	8:27	27	27	27	27	27	27	27	27	27	27	27	9:02	5	5	5	5	5	5	5	5	5	5	5
7:18	3	3	3						7:53	37	37	37	37	37	37	37	37	37	0	0	8:28	26	26	26	26	26	26	26	26	26	26	26	9:03	4	4	4	4	4	4	4	4	4	4	4
7:19	5	5	5						7:54	37	37	37	37	37	37	37	37	37	0	0	8:29	25	25	25	25	25	25	25	25	25	25	25	9:04	3	3	3	3	3	3	3	3	3	3	3
7:20	7	7	7	7					7:55	37	37	37	37	37	37	37	37	37	0	0	8:30	25	25	25	25	25	25	25	25	25	25	25	9:05	3	3	3	3	3	3	3	3	3	3	3
7:21	8	8	8	8					7:56	36	36	36	36	36	36	36	36	36	0	0	8:31	23	23	23	23	23	23	23	23	23	23	23	9:06	3	3	3	3	3	3	3	3	3	3	3
7:22	9	9	9	9					7:57	36	36	36	36	36	36	36	36	36	0	0	8:32	22	22	22	22	22	22	22	22	22	22	22	9:07	3	3	3	3	3	3	3	3	3	3	3
7:23	11	11	11	11					7:58	36	36	36	36	36	36	36	36	36	0	0	8:33	22	22	22	22	22	22	22	22	22	22	22	9:08	2	2	2	2	2	2	2	2	2	2	2
7:24	12	12	12	12					7:59	36	36	36	36	36	36	36	36	36	36	0	8:34	21	21	21	21	21	21	21	21	21	21	21	9:09	2	2	2	2	2	2	2	2	2	2	2
7:25	13	13	13	13					8:00	36	36	36	36	36	36	36	36	36	36	0	8:35	19	19	19	19	19	19	19	19	19	19	19	9:10	1	1	1	1	1	1	1	1	1	1	1
7:26	14	14	14	14	14				8:01	36	36	36	36	36	36	36	36	36	36	0	8:36	19	19	19	19	19	19	19	19	19	19	19	9:11	2	2	2	2	2	2	2	2	2	2	2
7:27	14	14	14	14	14				8:02	36	36	36	36	36	36	36	36	36	36	0	8:37	17	17	17	17	17	17	17	17	17	17	17	9:12	1	1	1	1	1	1	1	1	1	1	1
7:28	14	14	14	14	14				8:03	36	36	36	36	36	36	36	36	36	36	0	8:38	17	17	17	17	17	17	17	17	17	17	17	9:13	1	1	1	1	1	1	1	1	1	1	1
7:29	14	14	14	14	14				8:04	36	36	36	36	36	36	36	36	36	36	0	8:39	18	18	18	18	18	18	18	18	18	18	18												
7:30	14	14	14	14	14				8:05	36	36	36	36	36	36	36	36	36	36	0	8:40	15	15	15	15	15	15	15	15	15	15	15												
7:31	23	23	23	23	23				8:06	36	36	36	36	36	36	36	36	36	36	36	8:41	15	15	15	15	15	15	15	15	15	15	15												
7:32	39	39	39	39	39				8:07	35	35	35	35	35	35	35	35	35	35	35	8:42	15	15	15	15	15	15	15	15	15	15	15												
7:33	39	39	39	39	39	39			8:08	35	35	35	35	35	35	35	35	35	35	35	8:43	16	16	16	16	16	16	16	16	16	16	16												
7:34	39	39	39	39	39	39			8:09	35	35	35	35	35	35	35	35	35	35	35	8:44	15	15	15	15	15	15	15	15	15	15	15												
7:35	38	38	38	38	38	38			8:10	35	35	35	35	35	35	35	35	35	35	35	8:45	13	13	13	13	13	13	13	13	13	13	13												
7:36	38	38	38	38	38	38			8:11	35	35	35	35	35	35	35	35	35	35	35	8:46	13	13	13	13	13	13	13	13	13	13	13												
7:37	38	38	38	38	38	38			8:12	34	34	34	34	34	34	34	34	34	34	34	8:47	11	11	11	11	11	11	11	11	11	11	11												
7:38	38	38	38	38	38	38			8:13	34	34	34	34	34	34	34	34	34	34	34	8:48	11	11	11	11	11	11	11	11	11	11	11												
7:39	38	38	38	38	38	38	38		8:14	34	34	34	34	34	34	34	34	34	34	34	8:49	11	11	11	11	11	11	11	11	11	11	11												
7:40	39	39	39	39	39	39	39		8:15	34	34	34	34	34	34	34	34	34	34	34	8:50	10	10	10	10	10	10	10	10	10	10	10												
7:41	39	39	39	39	39	39	39		8:16	33	33	33	33	33	33	33	33	33	33	33	8:51	10	10	10	10	10	10	10	10	10	10	10												
7:42	38	38	38	38	38	38	38		8:17	33	33	33	33	33	33	33	33	33	33	33	8:52	11	11	11	11	11	11	11	11	11	11	11												
7:43	38	38	38	38	38	38	38		8:18	33	33	33	33	33	33	33	33	33	33	33	8:53	10	10	10	10	10	10	10	10	10	10	10												
7:44	38	38	38	38	38	38	38		8:19	33	33	33	33	33	33	33	33	33	33	33	8:54	10	10	10	10	10	10	10	10	10	10	10												
7:45	38	38	38	38	38	38	38		8:20	33	33	33	33	33	33	33	33	33	33	33	8:55	9	9	9	9	9	9	9	9	9	9	9												
7:46	38	38	38	38	38	38	38	38	8:21	31	31	31	31	31	31	31	31	31	31	31	8:56	9	9	9	9	9	9	9	9	9	9	9												
7:47	38	38	38	38	38	38	38	38	8:22	30	30	30	30	30	30	30	30	30	30	30	8:57	7	7	7	7	7	7	7	7	7	7	7												
7:48	38	38	38	38	38	38	38	38	8:23	30	30	30	30	30	30	30	30	30	30	30	8:58	6	6	6	6	6	6	6	6	6	6	6												
7:49	37	37	37	37	37	37	37	37	8:24	29	29	29	29	29	29	29	29	29	29	29	8:59	7	7	7	7	7	7	7	7	7	7	7												
7:50	37	37	37	37	37	37	37	37	8:25	29	29	29	29	29	29	29	29	29	29	29	9:00	5	5	5	5	5	5	5	5	5	5	5												
7:51	37	37	37	37	37	37	37	37	8:26	28	28	28	28	28	28	28	28	28	28	28	9:01	5	5	5	5	5	5	5	5	5	5	5												
																																	Count	**117**	**117**	**117**	**114**	**108**	**101**	**95**	**88**	**82**	**75**	**68**

6.2.4 INTERPRETATION OF RESULTS

From the data presented in the previous sections it is possible do note down the following findings:

- Case study No. 1 was a prefect example, where both of the experimental evaluation models did meet the expectations. But according to the results what matters the most in this specific case study is the minimal solar altitude angle γ_S. By decreasing the value from 13° to 11° and less, the resulting sunlight exposure time was already greater in the middle of the opening, than $90\mathrm{min}$, just as it is required by local regulations.
  The floating point and linear determination models do have a meaning only in cases of higher minimal solar altitude angles γ_s, and the floating point method is more significant, because it is simpler to implement.
- For Case study No. 2 in the designed state it was futile to do any kind of experiment. As it can be seen on the adequate outputs. Both floating point and linear determination models failed to achieve the desired effect.
  Only in combination with partial demolition was it possible to obtain any kind of satisfying results. Both evaluation models failed until the minimal solar altitude angle was lowered to and under 5°. And under these circumstances it was possible to fulfil with either method.
  Nonetheless, at the end the structures were left untouched, because the property developer decided not to do a partial demolition. The expenses would have been enormously high, and the gains would have been low. Only 2 or 3 apartments. The rest would have failed even then.
- 3rd Case study is the one, where shading occurs from surrounding elements as the intended fence, as well as buildings. The space analysed has even got two daylighting systems, a window and a terrace (balcony) door. Both of the openings have bigger dimensions than the one required by the standard for exposure to sunlight analysis.
  As it can be seen on the results presented earlier both daylighting systems failed to meet the standards with respect to exposure to sunlight in the middle, and not only in the middle, but in each and every position for both float-

ing point and linear determination models. The minimal solar altitude angles γ_s had not played any role either. The window failed miserably having a sunlight exposure time between 0min and 71min when assessed by floating point evaluation model, while maintaining a distance of 450mm from the jambs of the opening. The values of sunlight exposure times stated were already bases on various minimal solar altitude angles γ_s. Nevetheless, with $\gamma_s \in \langle 3°, 7° \rangle$ the linear determination model resulted in sunlight exposure times equal to 89min, which is only a minute less, than required.

The terrace door also failed the evaluation in the middle, and in each location from start to end in 50mm steps, but the resulting values are slightly more advantageous. They vary between 34min and 84min, with the highest value being achieved in the middle of the opening at $\gamma_s = 3°$. But when looking at the linear evaluation model it is possible to realise, that this opening actually made it when $\gamma_s \in \langle 3°, 9° \rangle$, thus failing only at higher minimal solar altitude angles.

The combination of results on linear determination models only reflects the results of that of the terrace door.

From all of these, the following conclusions can be made:

- Floating point evaluation methods could be used and would be useful if the openings evaluated are wide enough and through the repositioning of evaluation location the effects of some shading elements can be neutralized.
- If the surroundings of the evaluated object are simple, and there are no complex shading elements, then there is not much of a difference between Floating Point and Linear Determination models. On the other hand, if the surroundings include complex shading elements,like fences, chimneys on rooftops, or balustrade parts, then Linear Determination Model might be more suitable, because through it it would be possible to exclude shading by these elements.

7 CONCLUSION

Shading of Photovoltaic Power Plants

Insolation of Indoor Spaces

Ideas to contemplate on

7 CONCLUSION

Shading of Photovoltaic Power Plants

With respect to evaluation of shading of Photovoltaic Power Plants the methodology proposed in this thesis actually works, even though it takes longer to process, than an energy based estimation would take, since compared to the later it requires human interference from time to time.

The proposed methodology consists of three stages:

- 1st Stage: Evaluation of insolation of field / area over which the panels are constructed - the aim of this stage is to locate the elemental areas, places, where it comes to a decrease of sunlight exposure as a result of shading by new development. This stage has to be carried out for at least half of the year, ideally from winter solar solstice to summer solar solstice. It does not matter whether the evaluation takes place through spring or autumn seasons, because solar altitude symmetrically falls or rises between the two main evaluation dates,
- 2nd Stage: Determination of exposure to sunlight of Photovoltaic panel array built above elemental areas of the land, where it can to losses in the 1st Stage of assessment. The main idea behind this stage is to eliminate the influence of sun rays, which does not have any kind of an effect to the power output of panels, for example sun rays shining upon the bottom side of the panel arrays, from behind. The assessment should be carried out for the same dates as in Stage No. 1,
- 3rd Stage, which is also the last, expects a long term evaluation. The length of this evaluation depends on the findings of the previous 2nd one. It can be shorter, even longer than 50 days as presented on the case study in this thesis. The choice is related to the number of how often were the PV Panel sets influenced earlier. In one month only, two or three or four, etc. consecutive months. The point is to ascertain how long of a decrease in exposure times can be expected. Whether the decrease is dominant or not.

A short decrease of sunlight exposure times would not matter, on the contrary, but if the decrease would be bigger than 60 minutes, then it would be dominant. A short loss does not matter, because the weather conditions are not ideal for most of the year. But property owners, especially holders of PVPP are interested in ideal conditions, and would like to hear what deficits they can expect, even if irradiance based calculations using energy plus data might show themselves more precise.

The proposed methodology was being tested out another experimental subject, but it was only after if was being used on the show case in the thesis.

There are two advantages of the proposed approach:

1. that it fully abides the Building Code of Czech Republic [40],
2. it allows a bit of flexibility.

At the same time, it has a major disadvantage, it is time consuming even if a lot a step are automatised.

Insolation of Indoor Spaces

Insolation of indoor spaces was a major issue in cities like Prague of Brno just before the new Building Code [40] and accompanying decrees came to be. With new Building Code the three major cities of the Czech Republic were given a task, that was to crate their own legislation, including daylighting. Prague and Brno already has these documents, whereas Ostrava is still waiting.

In Prague and Brno the authorities tried to rule out requirements for Exposure to Sunlight. But at the same time, it is true, that after that happened, there is still the Civil Code [53] which refrains anybody from shading their neighbours properties.

Country wide however, there are more greater cities, in which architects and engineering has to abide the regulations, including the demand on insolation. But in many cases the available free construction lands do limit sunlight availability, that is hard to overcome.

Sometimes, sunlight cannot access the interiors of a building because of its surrounding, in other times because of improper orientation of daylighting systems and there are cases when structures of the designed building do shade. There might simply be too many reasons. But to overcome these its neigh impossible, mostly because of the confines of regulations.

Some regulations can be overcome easily, but the aim of the experiments carried out through simulations were done to verify some ideas for further progress in the field.

Two ideas verified were:

- Floating points evaluation model, where exposure to sunlight is verified over an array of points limited by a distance of 450mm distance from the openings jambs,
- Linear evaluation mode, where exposure time is a combination result of analyses over an array of points. In this specific case each minute when sunlight hits the internal sill line 300mm above the sill and at least 1200mm above the floor is added to the sunlight exposure time.

From the results it is clear that both of these approaches could replace the established procedures, but ... .

In truth LINEAR EVALUATION MODEL has the upper hand, it gives more options to the building design, but it would be hard to implement on a global scale. It just takes too long to evaluate a window, even when computer tools are used to do the work. But since the workflow is only being verified at the moment, the procedure could fasten up with time.

FLOATING POINT evaluation model is being used even now by professional in Czech Republic, even in Slovakia. They are however not published. Because application currently requires another step, that is to divide the opening to two segments with a vertical post that appears to have a bearing function to it, as is shown on Fig. 7.1.

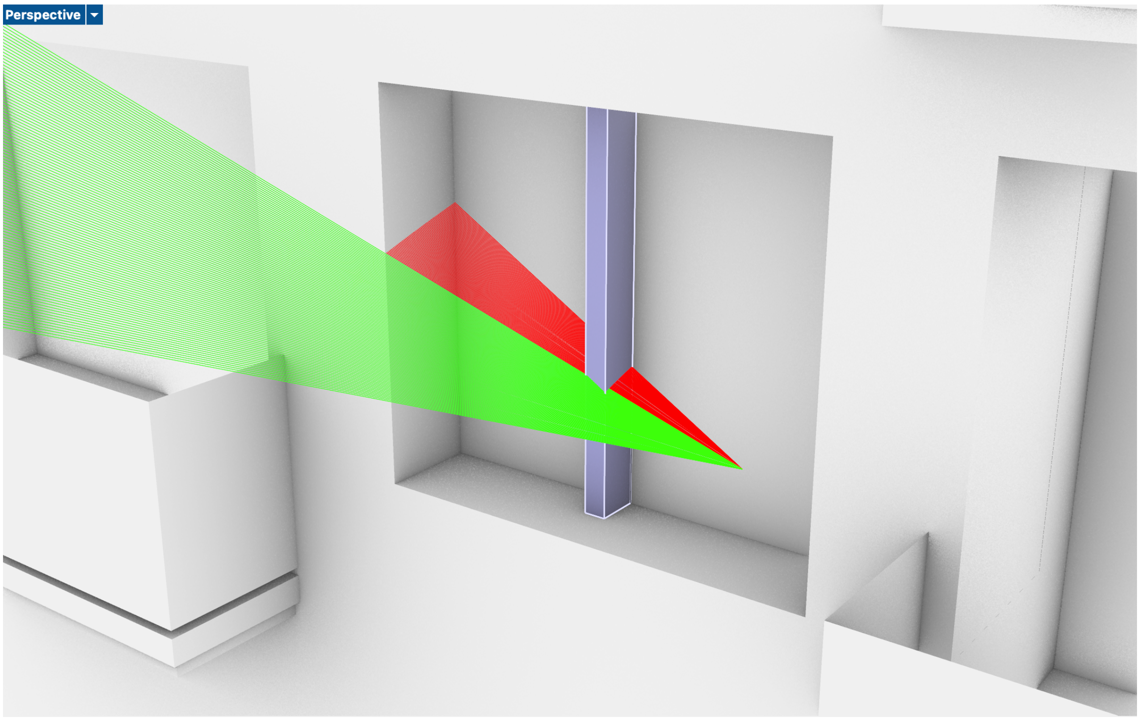


Fig. 7.1: Division of opening to two or more.

However the aim of this thesis was not to point out how to overcome the regulations, but to show ways how to possibly modify, improve the existing standards and regulations, so that there would be no need for such tricks. Since, if the floating point model is used as shown on the figure at the moment, then later it might come to lawsuits.

When? - Well, if the opening evaluated this way would be shaded by newly designed buildings into the future. From outside nobody could realise that such a trick was used to achieve a high enough sunlight exposure time. As shown on Fig. 7.2. The window frame and glazing covers up the post from the eyes of others. And not even the owners of residential units might be warned, that such a cheap trick was used.

That means, that the procedures would have to be changed globally without leaving out evaluation of shading on residential units in surrounding buildings.

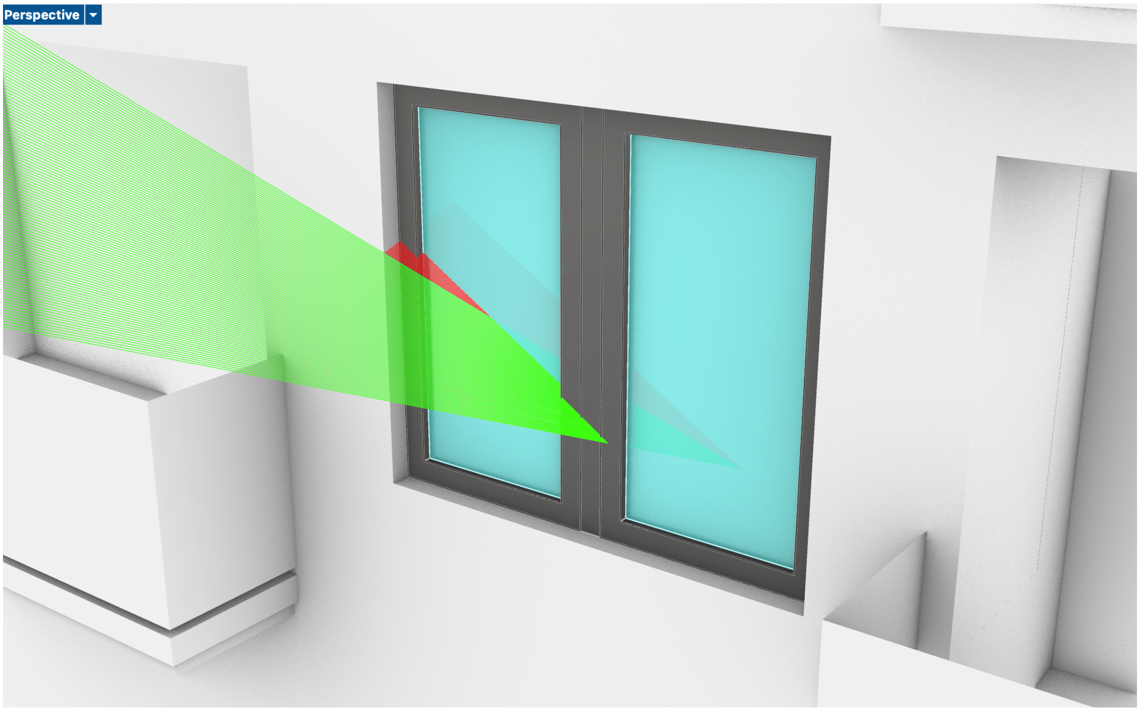


Fig. 7.2: Window frame covering up the post from outside.

IDEAS TO CONTEMPLATE ON

With respect to Photovoltaic Panels a direction to improve the proposed methodology could be based on effective solar angles of incidence. It is known, that PV Panel's generate power the most, when they are directly sunlit. But the top cover of panels, the protective screen for PV Cells is made out of glass or a similar material, transmitting, reflecting and absorbing light. And especially reflection and transmission are dependant on the angle, under which Sun shines upon these panels. The bigger the angle the less will pass through the top cover.

So an aim is to determine the effects of tilt upon efficiency and incorporate the data to the proposed procedure.

Another idea is to look verify more evaluation metrics for Exposure of Sunlight of indoor spaces, that could eventually replace the current procedures. For example exposure to sunlight determination over the glass pane of a window, or determination of exposure time over the floor of a room.

There is also the possibility of all year long exposure determination, whereas the legislations aim for spaces to be exposed to sunlight almoust all year long, but the author of this thesis came across cases, when sunlight exposure time was fulfilled on certain days only. And by the end of March the resulting time decreased continuously, until in summertime it actually hit 0min.

Or just the verify the effects of window frames, glazing and real dimensions of structures to Sunlight Exposure times. Currently the verification is based on documents sent to the professional by the engineers, architects, and those documents are only rarely drawn with real dimensions. More often than not, modular dimensions are used, thus the outputs have rarely something in common with reality. This is an aim to the future in the field.

List of Abbreviations and Symbols

Abbreviations

UV radiation Ultraviolet radiation

IR radiation Infra-red radiation

SoC System on Chip

PV Panel Photovoltaic panel

PVPP Photovoltaic power plant

TST True Solar Time

3D Three Dimensional

WIP Work-in-Progress

Symbols

E Illuminance [lx],

E_i Illuminance determined inside over the working plane with simulations or in situ measurements [lx],

E_e Iilluminance under the unobstructed sky determined by simulations or in situ measurements [lx],

D Daylight factor [%],

E_T, D_T Target illuminance of daylight factor [%],

$E_{T,M}$, $D_{T,M}$ Minimal target illuminance of daylight factor [%],

$C(x, t)$ Immediate deviation of electric waves,

C_m Amplitude of deviation,

C Angle of grid convergence,

ω Angular frequency of motion [$\mathrm{rad\,s^{-1}}$],

t Time [s],

x_E Displacement of current [m],

v Phase velocity of motion [$\mathrm{m\,s^{-1}}$],

ζ Beginning phase angle [rad],

λ Wavelength of motion [$\mathrm{m\,s^{-1}}$],

f Frequency of oscillation [Hz],

ϵ Permittivity of the environment [$\mathrm{F\,m^{-1}}$],

μ Permeability of the environment [$\mathrm{H\,m^{-1}}$],

T Time [s],

e_p Energy of a photon [eV],

H_p Planck's constants [eV],

f_p Frequency of oscillation of adequate electromagnetic radiation [Hz],

LT Local clock time [h],

λ Geographical longitude of the site. Its value is positive when East or negative when West of Greenwich [°],

λ_s Longitude of standard meridian [°],

ET Time relation [h],

J Day number of the year [-],

γ Solar altitude angle [°],

α Solar azimuth angle [°],

φ Geographical latitude of site [°],

TST True solar time [h].

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