# Methods for Design of Static Solar Shading Devices

**Sanja Paunović Žarić[1*], Veljko Radulović[2] and Milica Jovanović Popović[3]**

* Corresponding Author
1 Faculty of Architecture, University of Montenegro, Montenegro, paunovicsanja@gmail.com
2 Faculty of Architecture, University of Montenegro, Montenegro, radulovic.veljko@gmail.com
3 Faculty of Architecture, University of Belgrade, Serbia, milicajp@arh.bg.ac.rs

ABSTRACT **The existing condition of energy and environment requires that contemporary architecture pays particular attention to the exact parameters of energy optimisation, persistence, and sustainability of buildings and the built environment. One basic premise of sustainable development in architecture is the fulfilment of the requirement for luminous ambience – visual comfort in internal space, along with the optimisation of energy requirements. It is highlighted that it is important to integrate daylighting studies in the early design phases. Analyses and research have proved a connection between daily illuminance and heat losses/gains by emphasising the significance of the use of shading devices in the reduction of electrical energy consumption. In this way, the building envelope becomes unique and adaptable to climate, since it unifies and combines a myriad of specific patterns and methods of the location itself.**

**This work tackles the significance of the usage of daily illuminance in office buildings in Podgorica (capital of Montenegro) and daylight performance, in relation to an overview of the existing norms in this field. The second part of the paper will present basic formal typologies of external static shading devices and distribution of daily luminance and their use in office buildings, through the use of different software tools for the design and modelling of buildings. Conclusions are provided either as guidelines for the design of new projects, as general parameters, or as a verified method of adjustment of existing office buildings. The use of software has verified the respective research via simulations.**

KEYWORDS daily illuminance; daylighting methods; shading devices; visual optimisation; energy optimisation

## 1 Introduction

Daylighting is a visible part of the spectrum of solar radiation, which, after entering the Earth's atmosphere, passes through a series of transformations. There are three essential characteristics of daylight from which the basic influencing factors of daylight are defined: radiation spectrum, variability throughout the day, and light distribution within the atmosphere resulting from the distribution of brightness of the sky. Daylighting varies over time in terms of its intensity, brightness distribution, and light spectrum.

Daylighting factors are divided into two categories, quantitative: conditions of *macro location* (geographical position on Earth, position of the Earth in relation to the Sun during the day and the year, the current sky condition - cloud cover, slope of the terrain, surrounding objects, vegetation, etc.) and *local parameters* (micro location: building orientation, building morphology - layout of the volume of the building itself, geometry of the façade and interior space, size and arrangement of openings, morphology inside the building - materials from which transparent and non-transparent surfaces of the interior and façade are made) (Mudri, 1997), as well as a set of qualitative *parameters* (comfort, pleasantness, dynamics of light, games of light, and shadows, etc.). These parameters are important for the formation of the light ambience of a given space. From the analysis of the listed factors that influence the distribution of natural light and its distribution in the interior of a spatial volume, the conclusion has been made that the assessment of the light ambience is a complex task that is subject to further analysis. By using static shading devices, the aim is to undermine the light and heat comfort and the pleasantness of particular spaces.

The characteristics of natural light in any space can be divided into two other categories: static and dynamic (Veličković, Lenard, Mudri, 2011). *Static characteristics* represent the light ambience of a space at a precisely determined time during the day and the year, for precisely defined weather conditions. *Dynamic performance* describes the light ambience as a variable category that is conditioned: by time, i.e. weather conditions during the year. Before the emergence of computer tools, static characteristics were the only measure of the quality of light ambience, and their estimate was defined using formulas, tables, empirical formulas, and other similar methods. Today, computer tools enable the accurate calculation of the distribution of light in a designed space within a short period of time, based on climate characteristic data of a particular location on Earth. Dynamic characteristics more faithfully show the illumination of a space because they take into account the variability of daylight over time.

Some of the reasons for previous complications relating to the integration of daylight in buildings are outlined in the Report of IEA SHC Task 21 (2000) as well as: lack of data on the benefits of using daylight; lack of methods and computer tools that enable the design of shading design and daylight calculation; unfamiliarity with the strategies for controlling

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and manipulating daylight into the depth of the room; outdated data or lack of data on the climate characteristics of a particular location.

When analysing the significance of natural light, the risk of discomfort should not be forgotten, such as, for example, glare, unwanted reflections of sunlight, overheating of space, rapid changes in the intensity of light, among others. The instability of the state of natural light (flux) during the day makes its changeability very frequent. Another problem is the decrease in intensity of natural light along with the depth of the room, i.e. moving away from glazed surfaces, which is solved in practice by the introduction of artificial lighting.

A lighting simulation tool provides to architects a range of technical solutions that are applicable in the process of design and planning, providing huge aesthetic potentials. The understanding of the phenomenon of "façade aesthetics" in relation to climate parameters may lead architects and urbanists towards a better contextualisation of the building envelope and built environment, and thus improve visual and energy aspects by correct dimensioning and the optimum disposition of transparent surfaces, as well as by understanding basic terms, functionalities, and technological implementations and optimisations of shading devices. The genesis of such knowledge and skills may become a new idea, manner of work, valorisation of the existing, conceptual experimenting with new materials and technological achievements, in order to achieve a contextualisation of new architecture.

## 1.1 Local Aspects and Standards

Energy consumption in office buildings represents a significant share of the total electricity consumption. According to the IEA (World Energy Outlook, 2008), buildings are "responsible" for spending about 40% of total energy and 36% of $CO_2$ emissions in Europe. 25 - 40% of the energy expenditure of buildings is from artificial lighting. Therefore, improving the energy performance of buildings would contribute to significant energy savings, one of the main elements for achieving the climate and energy goal of the European Union by 2020, which plans to reduce gas emissions and save energy by 20% (European Commission Strategies 2010-2020). Over the past decades, daylighting methods have been recognised as a new potential for reducing energy consumption. The objective of the European Commission is to give guidelines for the better utilisation of daylighting in buildings with the aim of reducing electricity consumption. As an alternative to artificial lighting, natural light is the source of light most suited to the human eyes and makes the working environment most pleasant (Webb, 2006).

Unlike thermal performance, which represents binding requirements in the design and adaptation of objects, standards and recommendations related to the quality of interior lighting are only superficially mentioned. Only in the latter half of the $20^{th}$ century have the basic recommendations related to the quality of interior illumination been given. They recommend that the illumination of workspaces should be "adequate and sufficient" with the note that lighting should be natural, if feasible (The Workplace Regulations, 1992). The basic objectives of calculating the daylight in architecture are designed so that the function of the space is provided with a sufficient level of daylight, and that the proper dimensioning and optimum disposition of the light surfaces, i.e., openings are undertaken.

The U.S. Green Building Council defines a system of grading new and renovated buildings according to LEED™ standards. The LEED certificate recognises the criterion for improving the quality of lighting as a way to save electricity by which points are given: if a minimum DF (daylight factor) of 2% is achieved in at least 75% of the total office space intended for visually demanding tasks. One point is given if it is possible to achieve a view of the environment through a window from 90% of the total useful floor are of the building.

In France, the state institute Certivéa (n.d.) defines the characteristics that must be fulfilled in order for a building to achieve a HQE (High Quality Environment) mark. Depending on available daylighting level inside the offices, a building can get evaluation degrees from basic, to advanced, to highly advanced.

European Union countries prescribe recommendations and certificates for the construction of sustainable, green buildings, in accordance with the Directive (2002/91/EC), dated 19 May 2010 (EUR-lex, n.d.). Currently, there are more than 50 European standards relating to shading devices, and it should be noted that the documents are constantly being updated.

| SRPS.C.9 100 | | | DIN 5035 | BEL.ST.IES | IES CODE |
|---|---|---|---|---|---|
| Serbian | | | German | American | British |
| illumination (lx) | | daylighting factor (%) | illumination (lx) | illumination (lx) | illumination (lx) |
| Very low | 30 - 50 | 0.55 - 0.90 | 60 – 120 | 300 | 100 |
| Low | 50 - 80 | 0.90 – 1.50 | 120 – 260 | 500 | 200 |
| Middle | 80 – 150 | 1.50 – 2.70 | | | 400 |
| Large | 150 – 300 | 2.70 – 5.50 | 250 – 500 | 1000 | 600 |
| **Very large** | **300 – 600** | **5.50 – 11.0** | 600 - 1000 | 2000 | 900 – 1300 |
| Extremely large | over 600 | over 11.0 | | | 1300 – 2000 |
| Special | | | | | 2000 - 3000 |

TABLE 1.1 Comparative analyses of the defined standard requirements for illumination

According to local regulations, pursuant to Article 17 of the Law on Energy Efficiency (Official Gazette of Montenegro, no. 29/10), the Ministry of Economy has adopted the "Instructions on Energy Efficiency Measures and Guidelines for their Implementation". The provision of Article 2 of the Law stipulates the obligation to increase energy efficiency and the use of renewable energy sources through investments in "buildings (building cover, systems of heating, cooling and ventilation, interior lighting systems, domestic hot water supply systems, reduction of energy requirements through the introduction of bioclimatic principles, etc.)". The law also envisages investments that will increase the energy efficiency of the building cover with energy efficiency measures for new objects, according to which it is recommended that "buildings should be designed based on bioclimatic principles (orientation, natural light, natural ventilation for night cooling, passive bioclimatic solar systems)" (Official Gazette of Montenegro, no. 29/10).

## 2 Interior Luminous Ambience Qualities

High quality daylighting is created through a process of analysis and adequate design, in order to satisfy the required level of comfort, with the aim of increasing productivity at work. Adequate lighting is a relative term because the amount of daylight that is optimal for one type of work may not be adequate for another one. When calculating daylight, it should not be forgotten that spaces intended for different purposes require an appropriate distribution and quality of daylight, and that users of a certain space may perceive the comfort of its ambient light differently.

The term illumination is most often used when considering daylight and has an instantaneously changing value, because it changes from one second to another. Illumination is defined as an indicator of the light intensity that falls on a certain surface and equals the density of the light flux per unit area (E=Ø/S). Daylight factor (DF) represents the relationship between the illumination of a specific point in the interior of the room and the horizontal illumination outside a given object, for the distribution of brightness of the sky corresponding to the standard CIE cloudy sky. It is expressed in percentages (%). It represents the minimum available natural light, because it is counted in the case of the cloudy sky. Recommended minimum values for DF: from 2% to 5% in the least illuminated zones (Rakočević, 1989).

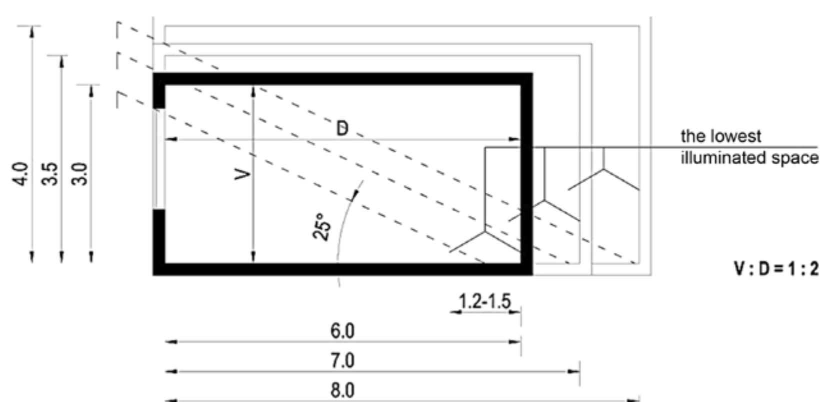


FIG. 2.1 Proportional relationship between the height of the opening and the depth of the office

The basic parameters of the interior that influence the quality of the ambient light are room geometry, index of the room, and internal reflection.

The geometry of the room defines the relationship of the shape, size, and room geometry, respectively the position of the opening concerning the height of the office. The depth of daylight intensity will depend on the orientation, height of the ceiling, and its relationship to the upper edge of the window (Fig.2.1).

The index of the room (i) depends on the height of the room *(Hp)*, the width of the room *(S)*, the length *(L)*, and the height of the working plane at 0.85 meters from the floor height. The index of the room is determined using the empirical pattern: *i=2S+L/6Hv*. The index of the room combines the influence of dimensions of the room and working plane. It represents a part of the light flux that enters the window and the part that falls on the work surface. The degree of utilisation () of the overall lighting depends on the coefficient of reflection of the walls and ceiling and index of the room. It is used to determine the coefficient of attenuation and the degree of use of daylight (Rakočević, 1989).

The reflection factor is indicated in percentages and depends on the colour, the brightness of the material, and the surface of the floor. The largest determining factor in the reflection of natural light is the surface of a ceiling, from which light is reflected and then dropped to the working surface (Rakočević, 1989). The wall that is opposite the opening (the rear wall) also has an important role, followed in importance by the side walls and, finally, the floor surface. The Illuminating Engineering Society (IES) recommends that ceilings need to be finished with a reflection rate greater than 80%, walls 50-70%, floors 20-40%, and furniture only 25-45% (the matt finish of the furniture is recommended in order to achieve good distribution of daylight and the reduction of glare) (O'Connor, Lee, Rubinstein, Selkowitz, 1998).

## 2.1 External Shading Devices as a Bioclimatic Response to Local Climatic Characteristics

The theme of "utilisation of the Sun" is not new, and has roots in the distant past. In fact, dating back to 2800 BC, solar orientation was one of the basic principles of Egyptian temples. Socrates, in 400 BC, reviewed the solar principles of a house called "Megaron House". This ancient principle, and the research of North African and Arab vernacular architecture, helped architect *Le Corbusier* to build a "pact with nature" and develop *"brise-soleil"* systems (Mohammad, 2013). He introduced ancient principles into a scientific framework, analysing specific climate and geographical parameters by identifying architectural problems associated with tropical climates and seeking an adequate solution. The parameters were divided into three categories: the first took into account natural factors (temperature, humidity etc.), the second was related to factors necessary for achieving comfort in the interior, and thirdly were architectural solutions, i.e. elements that would help achieve inner comfort.

Over the past 60 years, the building envelope, especially of administrative buildings, has been resolved by large glass surfaces (curtain wall).

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This complex technological façade system is often used completely uncritically, without any concern for the real needs of the users or for achieving the desired level of visual and thermal comfort.

As early as the 1960s, the World Environment Agenda was evaluated. The reconsideration of the use of natural resources and energy in buildings accelerated the economic crisis of the 1970s. Only at the end of the 20th century, the moral responsibility of such facilities, in relation to the environment, encouraged discussions on the problem of the use of fully glazed façades that are completely opposed to concepts such as beauty, place, ethics, and aesthetics.

From the aspect of thermal comfort, external shading devices are much more effective in blocking the Sun's radiation compared to internal shading systems. Radiation, once introduced to the interior, can hardly be excluded from it. Overhangs are designed as a basic element of façade. Overhangs are designed to represent an integral part of the architectural expression, and do not rely on the secondary elements of the control of daylight distribution. Secondary elements are subsequently applied daylighting systems that can be of the most diverse constructional, material, and design characteristics.

## 3 Methods of Designing External Static Shading Devices

On the basis of the analysis outlined earlier in this chapter, the possible solutions and proposals of bioclimatic interventions on the façade are considered for the purposes of adapting existing buildings and providing guidelines for the design of new ones, in the territory of Podgorica and beyond. The proposed interventions relate to both the administrative building in its entirety and to the work unit as a characteristic unit of the case study. Interventions are the answer to the observed problems of the existing facilities and they were made with the aim of improving their energy state, in terms of both thermal and visual comfort.

By solving identified problems, models were considered, which can provide a means to a higher standard in terms of comfort. The analysis will be carried out on the use of external static shading devices in the design of façades, using the example of a residential business building UNISTAN - Tower C in Podgorica.

Using the software tools that enable the impact analysis and precise dimensioning and design of external static shading devices, the results of the calculation of various characteristics of natural light are provided, i.e. its visual components - daylighting, their impact on the reduction of electrical energy consumption, the impact of implemented shading devices on the ability to achieve views of the environment, as well as the impact of adjacent objects (built environment) on the observed building (office).

## 3.1 Computer Simulation as a Tool for Designing of External Shading Devices

Prior to the emergence of software tools, the calculation of illumination was done by mathematical geometric methods of calculating the spatial angle, daily factor, methods of fictitious openings, and so on. This method of calculation required a number of measuring instruments and input data, which were most often not available. Calculations were performed only for premises with a depth exceeding 5 metres, because it assumed that workspaces at such a great distance from the window were too compromised to meet the requirements for the required level of illumination, while it was assumed that if a workspace is within 5 meters of a window it is adequately illuminated. However, it has been shown that this assumption is not always correct. Therefore, the calculation of natural lighting should be done in parallel with the production of other project documentation, because it directly conditions the brightness, height of the room and the size of the opening, the correct fenestration, the orientation of the rooms in relation to the type of work and the required level of daylight, and other parameters of visual and thermal comfort.

Computer tools make it possible, within a short period of time, to calculate the distribution of light in the designed space for a period of one year, based on the climatic characteristics of a particular location on Earth. Models can be directly used in daylight analysis, using Building Information Modelling (BIM), a comprehensive design process that starts with the concept design and ends with the detail project documentation.

This paper has used models for analysis of the daylight factor (DF), which were simulated using computer tools. These simulations indicate how much natural light is available in the interior, and in practice are often used as a *measure of the quality of the natural lighting of the space*. The first data needed for the simulation is *Weather data* from the *Meteonorm27* database, in TMY2 format, which was updated only for Podgorica. Climate data is obtained from local weather stations and generate all the necessary data related to a particular climate area. By introducing local climatic characteristics, the precise simulation of solar radiation, based on latitude and longitude, will be enabled by the precise entering of the date and time for which the calculation is performed. In further work, two software packages from Autodesk were used for energy calculations: *AutoCAD 2011* and *Autodesk Ecotect Analysis 2011* - for Visual and *Energy Plus* with *Open Studio*. Shading models were performed by modelling within the *CAD platform* and then in the .dxf format introduced into the simulation program. The EcoTect program tool is not the standard program that architects use and by retrieving the data from the *Meteonorm27* database we have come up with data that defines the period of the year for which it is necessary to determine the requirement for shading devices (Fig.3.1).

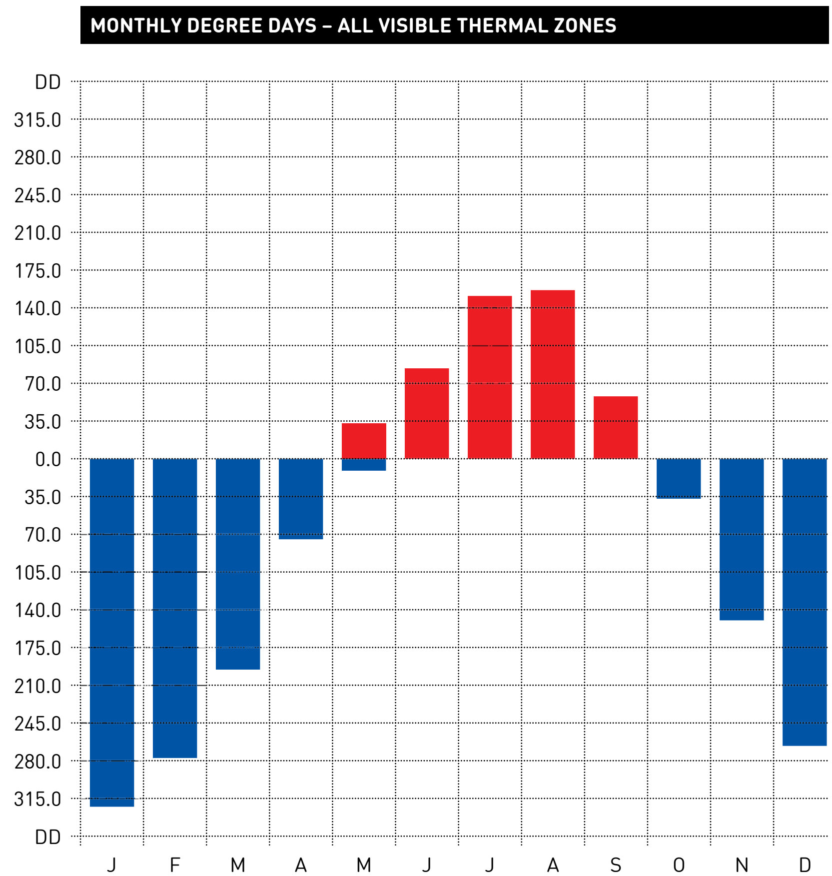


FIG. 3.1 Thermal zones for Podgorica by months in relation to the heating and cooling season

BLUE: for air temperature below 20°C, a heating set point is activated.
RED: for air temperature above 24°C cooling set point is activated. The graph shows that for the period from May 9 to September 21 it is necessary to anticipate shading devices that would prevent the decline of high solar radiation and reduce overheating

By analysing the graph, it is concluded that, for buildings in Podgorica, it is necessary to provide shading devices that block unfavourable solar radiation in the period from May 9 to September 21. This involves adjusting the envelope of the building to prevent overheating, thus reducing the use of electricity in the facility during the summer months. These data are used for dimension calculations of shading devices.

This data is especially important for DF calculation because, on the basis of accurately determined time intervals, the precise position of the Sun (incidental angles) is reached, on the basis of which further modelling and dimensioning of the sun protection system in relation to the orientation of the object is possible. Based on these angles, a proposal was made for the possible rehabilitation and dimensioning of the applied shading devices; the program then showed a distribution of the illumination across the depth of the office, in order to achieve the precise data of each individual solution. An interactive display that represents analytical results directly in the context of the model itself provides reliable information that can be used as a guideline for the dimensioning and use of different elements of architectural design, as well as in defining the exact time interval that results in the overheating of the room and the high values of daylighting factors (DF) for which it is necessary to incorporate shading devices.

As the paper emphasised the importance of understanding the environment and connecting users with the immediate building environment, the program also simulated the presentation of views from the position of the workplace, in relation to the implemented system. Stereographic diagrams show to what degree implemented systems are interfering, and, in relation to the field of vision, in which zones they are interfering, as well as the degree of indeterminacy (the ratio of background and figure) that can be caused in the field of vision.

The model defines all parameters of the interior space and the environment that are important for the calculation. Parameters and reflection of surfaces in the model are defined in accordance with standard DIN 5034-1, for all daylight level simulations, in the following way:

| PARAMETERS FOR SIMULATION | |
|---|---|
| **Value** | |
| ab - ambient rejection | 5 times |
| ar - ambient resolution | 256 px |
| at – ambient accuracy | 0.10% |
| **Brightness of the material** | |
| Floor | 20% of reflection |
| Walls | 50% of reflection |
| Ceiling | 70% of reflection |
| Transparency of the glass | 80% of transparency |
| Cleanness of glass | 90% of transparency |
| External shading devices | 40% of reflection |

TABLE 3.1 Parameters and brightness of materials used in the simulation *(details from Ecotect Software)*

## 4 Case Studies: Office Buildings in Podgorica

This chapter presents a case study of an office building in Podgorica (UNISTAN - Tower C), which aims to provide higher standards in terms of visual and energy characteristics for office buildings.

In order to gain a clearer picture of how the building will behave towards the environment, we must first understand how the environment will behave towards the building under the given circumstances, so the shadow simulation was strategically undertaken for four days of the year: March 21, June 22, September 21, and December 21.

By describing and analysing interventions for a case study on a precise example, through the guidelines and presented standards and norms, numerical indicators of DF will be obtained in relation to the implemented shading systems for the period from 9 May to 21 September, for which it is necessary to predict shading devices on the territory of Podgorica. By definition, the daylight factor is counted only in the case of the *cloudy sky*, which is crucial for understanding the results of the simulations. In the case of cloudy sky, direct light entering the interior of the office is not taken into account so the rotation of the building in a given direction will not significantly change the calculation. In relation to the SRPS.C.9.100 standard (Table 1.1), a very high illumination value of

300-600 lx and a daylight factor (DF) value of 5.5 - 11.5% will be taken as reference values. The system will also be valued in relation to the percentage coverage of the room by DF at a defined interval (5.5 - 11.5% in 80% of the room that has direct contact with the façade).

When introducing a daylighting system on the southern façades, it was considered that they should not be implemented at a height of less than 2.3m (if there was a possibility to do so) in order to minimise the interruption of possibility of linking users with the environment, i.e. understanding the environment.

## 4.1 Climatic Characteristics for Study Area: Podgorica, Montenegro

Based on temperature measurements, average daily, average monthly, and average mid-year values with basic static indicators are calculated. In this way, it is possible to recognise the thermal characteristics and the climate type of an area.

In Montenegro, the number of sunny hours is over 2,000 hours a year, especially in coastal and central areas, so the country has good preconditions for using natural lighting and justification for the implementation of shading devices as an integral part of the building shell.

Podgorica is located at an altitude of 44.5 meters. Coordinates of 42.26 northern latitude and 19.16 degrees eastern longitude determine the geographical position. Podgorica has a changeable Mediterranean climate with warm, dry summers and cold winters. The temperature exceeds 25 °C for 135 days a year while the mean daily temperature is 16.4 °C (Burić, Micev, Mitrović, 2012).

| CITY | AVERAGE VALUE | MAX | MIN |
|---|---|---|---|
| Podgorica | 15.3 | 16.1 | 14.3 |

TABLE 4.1 Average annual air temperature in ºC for Podgorica *(Burić et al., 2012)*

| CITY | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Podgorica | 4.9 | 6.7 | 10.0 | 14.0 | 19.0 | 22.8 | 26.0 | 25.5 | 21.3 | 16.0 | 10.5 | 6.5 |

TABLE 4.2 Average monthly air temperatures in ºC for Podgorica *(Burić et al., 2012)*

Podgorica is especially known for exceptionally warm summers: temperatures above 40 °C are frequent during July and August. The highest recorded temperature of 45.8 °C was measured on August 16, 2007. The maximum annual number of sunny days in Montenegro, about 157, was recorded in Podgorica – capital of Montenegro (Burić et al., 2012).

| CITY | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Podgorica | 19.2 | 23.6 | 27.4 | 30.0 | 35.4 | 37.8 | 40.4 | 41.4 | 38.8 | 31.2 | 23.8 | 20.8 |

TABLE 4.3 Extreme maximum monthly air temperatures in Podgorica in °C *(Burić et al., 2012)*

## 4.2 UNISTAN - Tower C

The office building UNISTAN - tower C is located on the corner of a new seven storey residential/ office building, oriented to the south and east, with one smaller part to the north. The 16.5m width of the building was designed in a linear way, with two tracts (the depth of the tract to the south (A) - 6.5m, north (C) - 6.35m and east (B) - 4.6m).

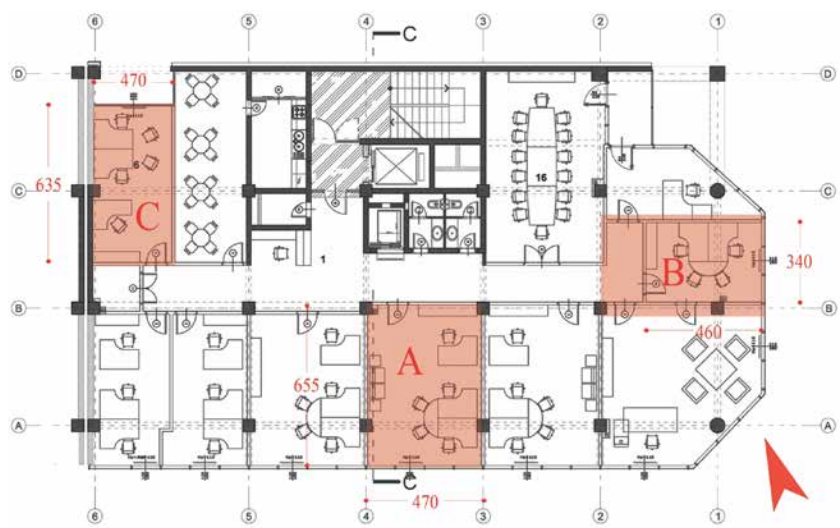


FIG. 4.1 Typical floor plan (north -22°)

From the floor plane it is obvious that most offices are orientated to the south. The north-orientated spaces were used to accommodate vertical circulation areas, and auxiliary and service rooms. The structural façade comprised highly-reflective glass, while on the inside a window parapet was formed at a height of 1.1m. Close to the ceiling level the room height is reduced to the height of the beam, in order to allow the implementation of HVAC. By doing so, the surface of the window opening is reduced, and, at the same time, it is possible to overheat the interior of the volume of the building. Visual quality is enhanced by moving pillars behind the façade. Since the designer did not create a possibility to incorporate external shading devices, the daylighting control intrusion was resolved using the internal shading devices in the form of a roll curtain. Semi-transparent curtains insufficiently block the penetration of solar radiation, resulting in heat accumulation and overheating of offices as well as frequent use of electricity in regulating heat comfort.

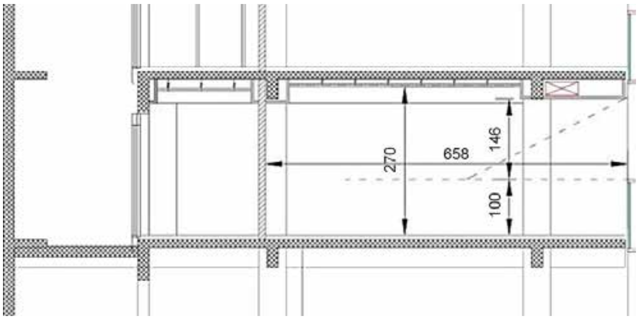


FIG. 4.2 Segment of the southern façade

FIG. 4.3 Photo of the residential and commercial building UNISTAN - Tower C

The inadequate organisation of workplaces contributes to the creation of glare, as direct sunlight falls directly on to working areas and computer monitors. As the employee faces away from the window opening, it is impossible to visually connect with the environment (Fig.4.1). Overheating caused by the lack of adequate daylight monitoring systems should be addressed by: adding control elements to the interior, improving the performance of glazing materials, and introducing external static shading devices. External systems for controlling and distributing daylight and their impact on specific offices, A, B, and C, will be further analysed.

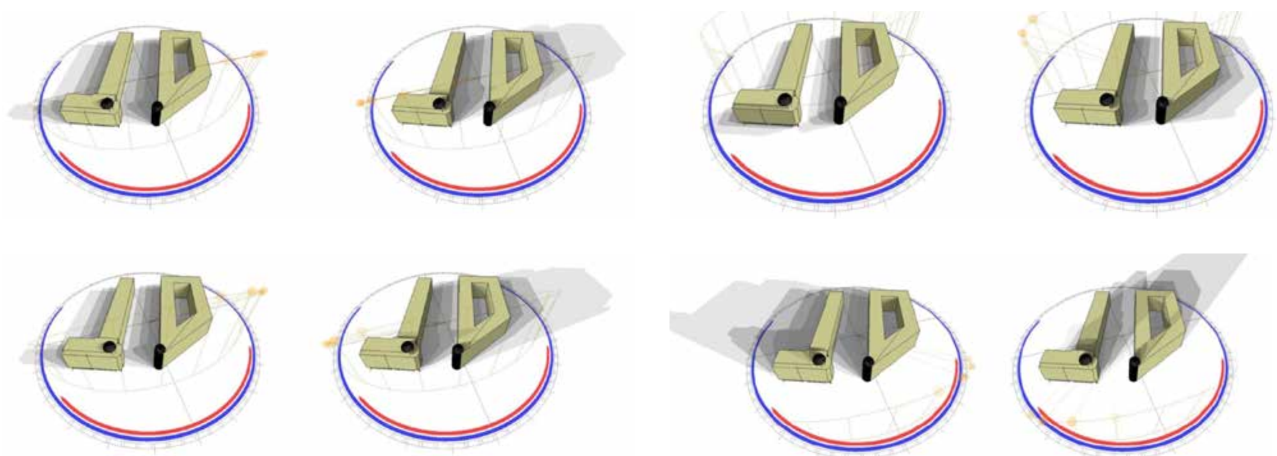

FIG. 4.4 The path of the sun and the position of the shadow, for March 21 from 08.00-12.00 and from 13.00-17.00 hours

FIG. 4.5 Idem, for June 22 from 08.00-12.00 and from 13.00-17.00 hours

FIG. 4.6 Idem, for September 21 from 08.00-12.00 and from 13.00-17.00 hours

FIG. 4.7 Idem, for December 21 from 08.00-12.00 and from 13.00-16.00 hours

Figures 4.4-7 simulate the interaction between the building and the relevant neighbouring object in the specific environment in four typical days of the year (location of the object: latitude 42.442292, longitude 19.244573 degrees).

From Fig.4.4-7, we can conclude that on the southern side it is necessary to implement shading devices, while on the eastern and northern faces it is unnecessary due to the shading created by adjacent objects and the shadow created by the building itself, due to its orientation.

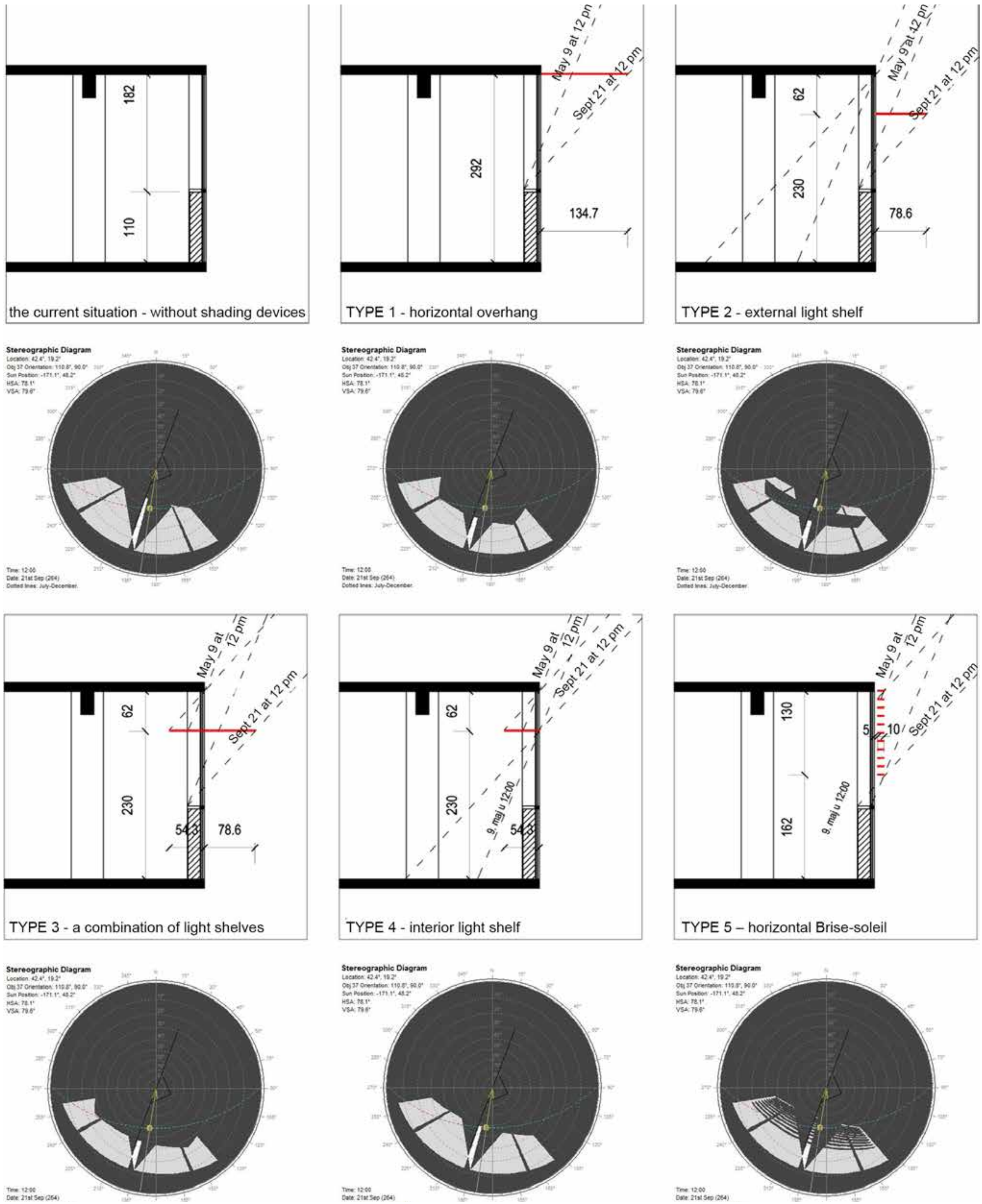


FIG. 4.8 External static horizontal shading devices (May 9 - September 21, 12: 00h), calculated by DF and view towards the environment

The relevant height of the incident angle of daylight was used to determine the systems of protection against unfavourable solar radiation that leads to overheating in internal spaces. This was done as follows: using the sun angle of incidence for May 9 at 12 pm (67.36$^{o}$) and for September 21 at 12 pm (47.86º) (noon is taken as a reference point due to the fact that it is the time when the Sun is in the zenith), a series of solutions for office A for reducing excessive daylight, and therefore overheating of the room, are given. Subsequently, 6 characteristic cases are defined, namely:

- the current situation - without shading devices;
- TYPE 1 - horizontal overhang;
- TYPE 2 - external light shelf;
- TYPE 3 - a combination of external and internal light shelves;
- TYPE 4 - interior light shelf;
- TYPE 5 – horizontal brise-soleil.

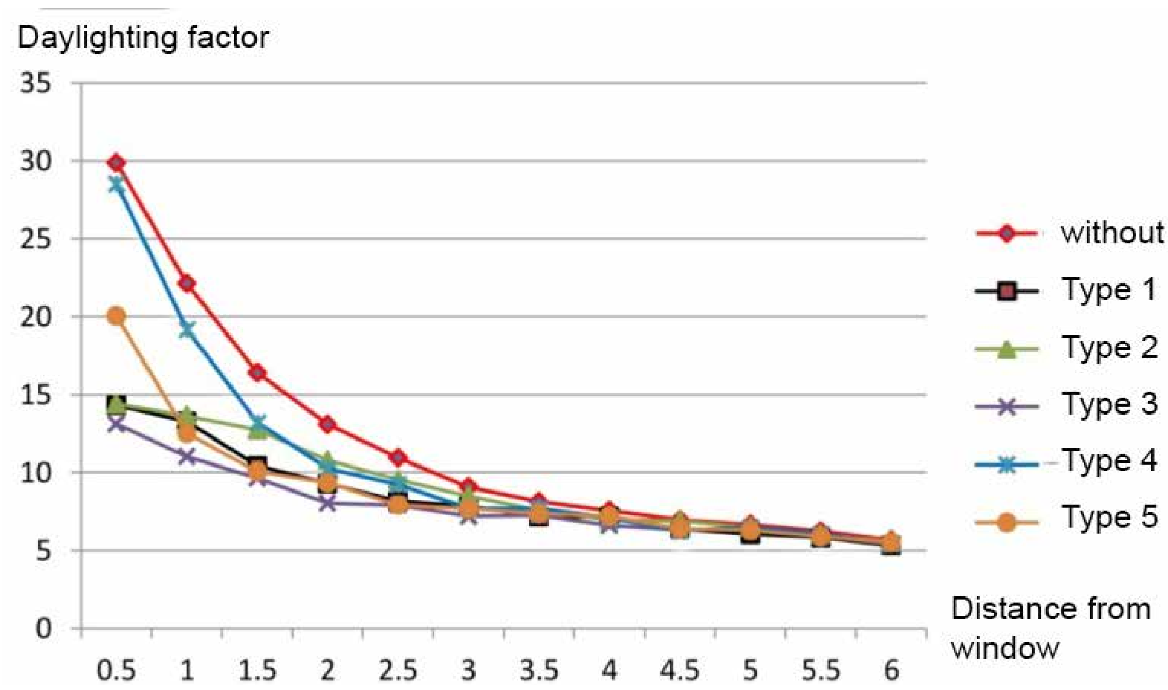


FIG. 4.9 DF value in the observed area

The DF diagram for the observed office varies in relation to the applied shading device. The daylight factor at a distance of 1m from the window ranges from 11.04 using a TYPE 3 shading device to 19.19 using TYPE 4. As TYPES 1, 3, and 5 show similar values of daylight distribution over the depth of the office, the choice of an adequate system depends on aesthetic, and urbanism and technical conditions (TYPE 1 would increase the volume of the building by 1.35m). TYPE 3 and TYPE 5 meet the basic criterion according to which 80% of the room meets the required range of DF values. TYPE 3 proved to be the system with the most regular distribution of daylight. TYPE 5 also meets the required criteria. Brise-soleil are commonly used in the adaptation of buildings because they are most easily incorporated into the existing structure. The disadvantage is that their use disrupts views and contact between the user and the environment.

| [m] | WITHOUT SHADING DEVICE 67 % | TYPE 1 75 % | TYPE 2 75 % | TYPE 3 83 % | TYPE 4 67 % | TYPE 5 83 % |
|---|---|---|---|---|---|---|
| 0.5 | 29.89 | 14.33 | 14.41 | 13.12 | 28.53 | 20.04 |
| 1 | 22.14 | 13.28 | 13.64 | 11.04 | 19.19 | 12.54 |
| 1.5 | 16.42 | 10.44 | 12.74 | 9.63 | 13.23 | 10.07 |
| 2 | 13.1 | 9.28 | 10.8 | 8.02 | 10.25 | 9.34 |
| 2.5 | 10.94 | 8.17 | 9.52 | 7.91 | 9.25 | 7.92 |
| 3 | 9.06 | 7.85 | 8.49 | 7.2 | 7.7 | 7.69 |
| 3.5 | 8.14 | 7.17 | 7.58 | 7.25 | 7.7 | 7.35 |
| 4 | 7.54 | 7.16 | 6.97 | 6.61 | 7.1 | 7.2 |
| 4.5 | 6.97 | 6.38 | 6.91 | 6.32 | 6.3 | 6.39 |
| 5 | 6.67 | 6.04 | 6.49 | 6.4 | 6.5 | 6.28 |
| 5.5 | 6.23 | 5.83 | 6.05 | 5.98 | 6.08 | 5.89 |
| 6 | 5.66 | 5.33 | 5.53 | 5.41 | 5.45 | 5.52 |

TABLE 4.4 DF of the observed area calculated at 0.5m distance intervals from the window

The energy optimisation check was made in programs for three characteristic cases:

- no shading devices;
- TYPE 1 - horizontal overhang; and
- TYPE 5 - horizontal brise-soleil.

In the simulations the following input parameters were used:

- the office has two distinct working areas;
- electricity consumption is calculated for heating, cooling, ventilation (HVAC), and additional artificial lighting;
- the time of calculation is limited to working hours from 7:00 am to 7:00 pm with a break of 1 hour from 12:00 pm to 1:00 pm;
- data on climate characteristics are downloaded from the *Meteonorm27* database.

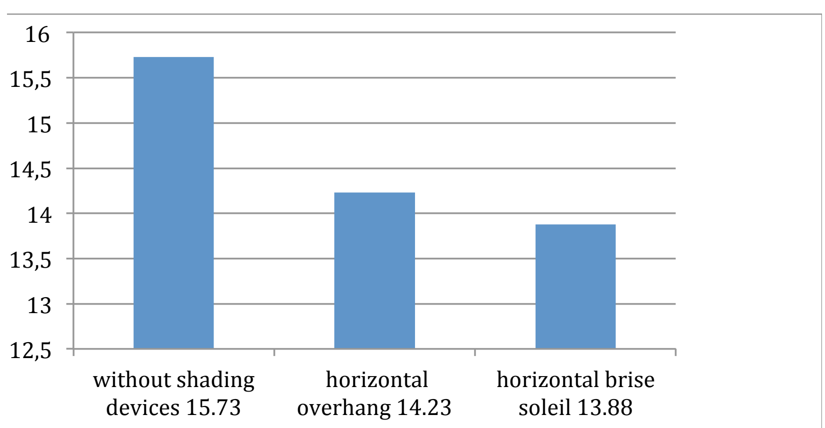


FIG. 4.10 Total energy consumption at the site (GJ)

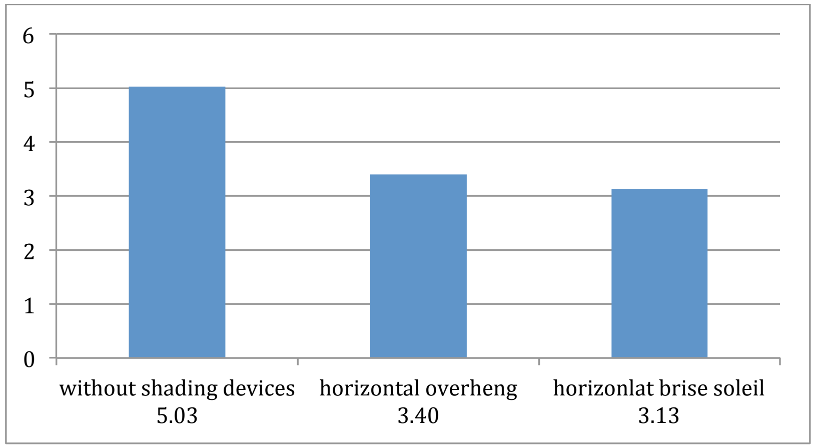


FIG. 4.11 Summary of annual energy consumption for cooling (GJ)

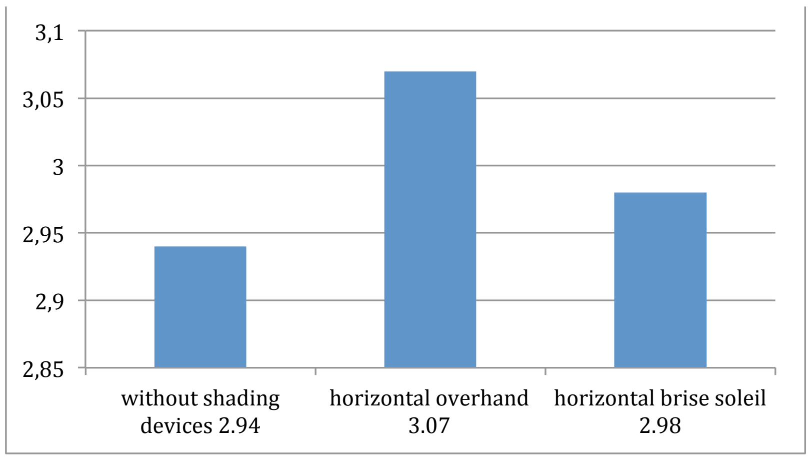


FIG. 4.12 Summary of annual energy consumption for heating (GJ)

The energy state of the object, i.e. office A indicates that by using horizontal brise-soleil (TYPE 5), the consumption of total annual electricity can be reduced to up to 12%. Independently, the parameters of energy consumption for heating and cooling were analysed on an annual basis. It has been proven that the use of horizontal overheads reduces the consumption of cooling energy to 32.41% while this percentage increases with horizontal brise-soleil to 37.78%. The use of shading devices has slightly increased the consumption of heating energy by 1.3 – 4.2%, caused by the constant blocking of harmful and direct sunlight. Through this example it has been proven that the use of static shading devices responds to building design requirements, according to the principles of high energy efficiency, sustainable construction, and energy savings, relying on the maximum utilisation of available natural light.

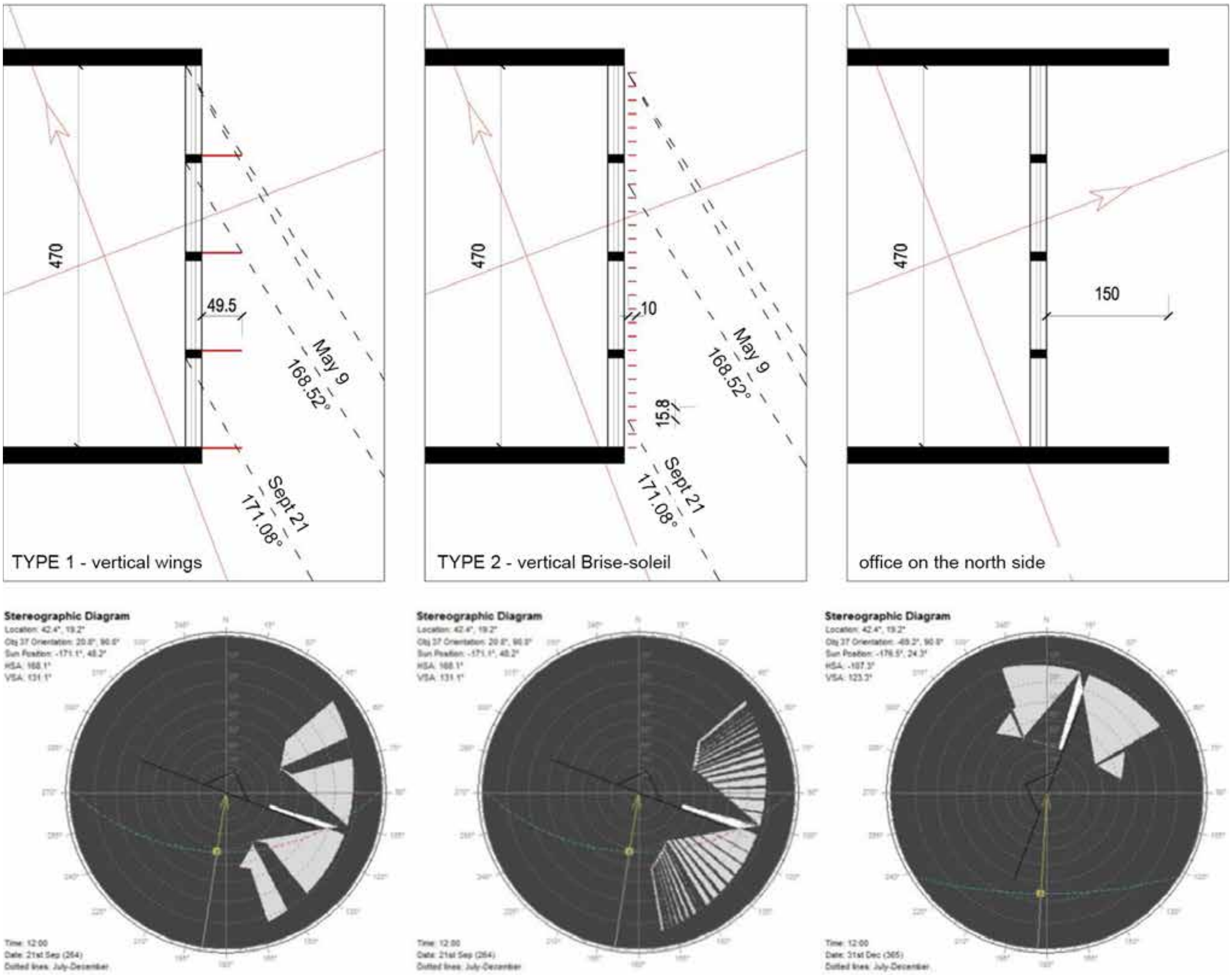


FIG. 4.13 Eastern and northern orientation (May 9 - September 21, 12: 00h) showing calculated DF and view towards the environment

The east façade is shaded by the neighbouring building in the morning, and shading caused by the building itself in the afternoon is noticeable. For the calculation of vertical shading devices on the east façade, the relevant values of the azimuth angle were used (which are for May 9 - 168.52º and for September 21 - 171.08º). A number of scenarios were examined: the east façade with the influence of the adjacent object; the east façade without the influence of the neighbouring object; TYPE 1 - the use of vertical wings associated with divisions of window openings; and TYPE 2 - the use of vertical brise-soleil. The diagram is also associated with DF analysis and a north-facing view for an office that sits 1.5m back from the façade line. The north office was also influenced by the eastern wing of the building during simulations.

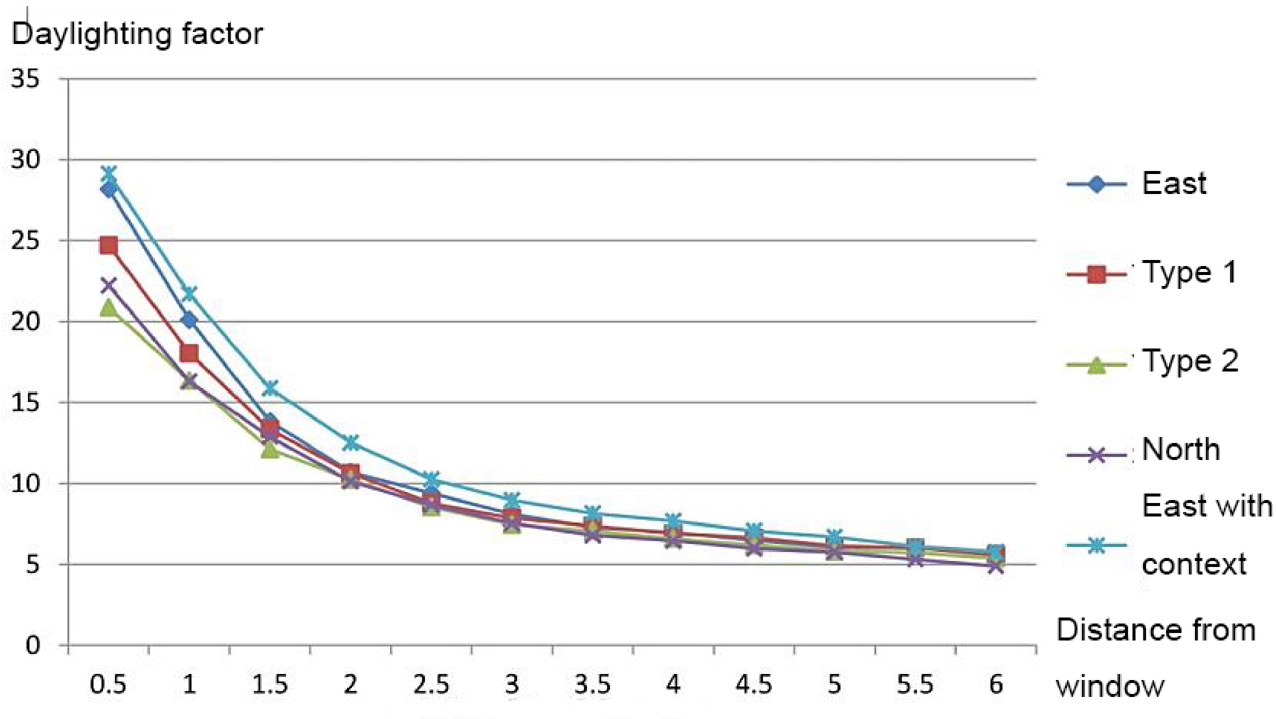


FIG. 4.14 DF in the observed area

The DF diagram for the observed east-facing work unit (office B), compared with the situation of the east façade, without the impact of the context in Table 11 shows that the DF is significantly reduced due to shading caused by the orientation and position of the neighbouring object.

| [m] | EAST 75% | TYPE 1 75% | TYPE 2 67% | NORTH 58% | EAST WITHOUT CONTEXT 67% |
|---|---|---|---|---|---|
| 0.5 | 28.17 | 24.71 | 20.87 | 22.23 | 29.13 |
| 1 | 20.1 | 18.04 | 16.35 | 16.29 | 21.69 |
| 1.5 | 13.82 | 13.34 | 12.11 | 12.88 | 15.87 |
| 2 | 10.69 | 10.63 | 10.23 | 10.13 | 12.51 |
| 2.5 | 9.39 | 8.77 | 8.54 | 8.66 | 10.25 |
| 3 | 8.11 | 7.87 | 7.46 | 7.54 | 8.96 |
| 3.5 | 7.28 | 7.38 | 7.07 | 6.79 | 8.15 |
| 4 | 6.97 | 6.9 | 6.58 | 6.46 | 7.68 |
| 4.5 | 6.49 | 6.65 | 6.2 | 5.98 | 7.07 |
| 5 | 6.04 | 6.14 | 5.81 | 5.76 | 6.69 |
| 5.5 | 6.03 | 6.02 | 5.73 | 5.32 | 6.1 |
| 6 | 5.62 | 5.6 | 5.37 | 4.89 | 5.77 |

TABLE 4.5 DF in the observed area is calculated at 0.5m intervals from the window

Adding shading device TYPE 1 would not significantly reduce the curve of daylight distribution. The use of shading device TYPE 2 fully corresponds to the distribution of daylight in the north-facing office. The use of brise-soleil would completely prevent the visual connection between the user and the environment while the north-oriented office (office C) has compromised lateral views towards the environment and it is recognised that the distribution of daylight is not adequate across the depth of the office (58% of the space has a satisfactory DF value). The analysis showed that the planned construction and the inclusion of a natural light study in the design phase can significantly influence the improvement of the quality of daylight in the interior.

## 5 Conclusions

It is important to note that the factors of daylighting shown in the previous chapter do not mean that the level of illumination for different geographic locations is shown by the same DF value; for Podgorica, it is 7754 lux.

The connection between DF and distribution of daily illumination across the depth of the office was analysed in relation to the simulated southern façade - without a shading devices. Also, the impact of adjacent objects was analysed in order to highlight the relationship between the building and the built environment, which must become an important factor in configuring the envelope of a future building. For the south-oriented façade, the total annual energy consumption is simulated for three characteristic cases, in order to prove that the harmonic relationship between the building shell, the climate characteristics of the site, and the daylight can significantly influence the reduction of the consumed electricity for heating, cooling, ventilation, and additional artificial lighting.

The daylight factor in the south-oriented office was tested using a shading device in the form of horizontal projections whose dimension is dependent upon the height of the angle of incidence and deviation from the south position by 20.78°. The DF at a distance of 1m from the window gave a value of 11.04 by using light shelves on both window sides, at a height of 2.3m from the floor, and reached up to 19.19 using the shading device of only the internal light shelf. At 2 metres from the window, the DF is between 8.02 and 10.25, depending on the applied system, and the differences in factor values across the depth of the room oscillate very little. Using light shelves on the outside and the inside, along with horizontal brise-soleil, the best distribution and the smallest oscillations of daytime illumination across the depth of the office were achieved. It was noted that the choice of an adequate system will depend on the aesthetic and urban-technical conditions of the location of the facility. Often the most appropriate intervention in the renovation is adding brise-soleil because it is easiest to incorporate them into the existing structure of the object. The predominant shortcoming of the brise-soleils is that their use disrupts views towards the environment. Analysis and simulations have shown that the distribution of daylight across the depth of the office can be corrected by 16% when using an adequate shading device.

For three characteristic cases: in terms of the consumption of electricity (for the example without shading device, such as horizontal overhang, and horizontal *brise-soleil*), the simulation showed that by using the horizontal *brise-soleil* the total electricity consumption for HVAC and additional artificial lighting can be reduced by up to 12%, while by using a horizontal shading device, the consumption of cooling energy can be reduced by 37.78%. The use of the shading device slightly increased the consumption of heating energy from 1.3 to 4.2% which was caused by the constant blocking of low winter solar radiation.

The DF diagram for the observed east-oriented work unit shows that the DF is significantly reduced due to shading caused by the orientation and position of the neighbouring object. Adding vertical wings would not significantly reduce the curve of daylight distribution, while the use of vertical brise-soleil would not significantly affect the distribution of daylight across the depth of the office.

The paper shows that new space has opened up for additional analysis in terms of thermal characteristics and a more comprehensive analysis of daylighting, which would connect the light and energy components of daylight and show their interdependence. This topic can be a good starting point for future research that can be also complemented by dynamic systems.

The dynamic nature of daylight, both during the day and throughout the year, makes the use of shading devices a complex process, with significant planning challenges. In order to ensure high-quality visual comfort, in designing, particular attention should be paid to the geographical location, orientation, and shape of the building, the area in its surroundings, overhangs, and window surfaces, the reflectivity of the interior space and the position of the workplaces. Specific façade elements, with particular attention given to their influence on the southern orientation of the typical work unit at the location in Podgorica, for 30th April at 10:15 am, are thoroughly analysed.

Despite the fact that the overall results of the study were not completely unexpected, the analysis was made to test the existing objects, the shading device characteristics, and achievement of better energy efficiency, understanding the importance of software support and design verification.

Static shading devices should be designed as an integral part of architectural plastic, an inseparable part of the building shell that affects the distribution of daylight, based on the blocking of negative direct sunlight. The use of these systems is indispensable for objects designed in the Mediterranean climate - such as Podgorica - in order to find a compromise between summer heat and winter energy (heat) losses. As the number of sunny hours in Montenegro exceeds 2,000 hours per year, good preconditions for the use of natural light are set and the implementation of the shading device is justified. Consequently, the applicative guidelines for the correct and innovative approach in planning façade envelopes in the Mediterranean area are given. This way, the envelope of the building becomes a climate-adaptive façade and is treated as a medium that both connects and divides the interior of the building from the environment, creating comfortable working spaces using the external environmental conditions. Each climate-adaptive façade is unique because it unites and combines a variety of specific patterns and methods.

The strategy to naturally illuminate the building can be changed after the completion of its construction, but with significant financial expenses. From the point of view of using renewable energy sources, energy consumption, overheating, environmental pollution, and indirect impact on health, it is important to conduct natural light studies in the early stages of design, while understanding the importance of software support when checking the design of static shading devices as an integral element of architectural design. If a natural light study is not included in the early stages of design, the adaptation and pre-design (redesign) of the façade shell can be an opportunity to significantly improve the visual and thermal comfort within the facility, and correct the shortcomings of the original solution, with the maximum utilization of the location conditions.

Using shading devices in Podgorica, the consumption of total annual energy can be reduced by up to 12% while using horizontal shading devices, and the consumption of cooling energy can be reduced to 37.78%, in the south-oriented façade of the building.

Potential fields of further research:

1 Updating the CIE (International Commission on Illumination) report - getting familiar with relevant CEE standards, technical committees and the application of standards in Montenegro;
2 The relationship between applied shading devices and visual comfort;
3 The relationship between applied shading devices and thermal comfort for the purpose of proper use of energy and sustainability;
4 Technical solutions and methodology for establishing sustainability, durable and functional envelope of the facility;
5 Getting familiar with and working on modern technical solutions for the distribution and reduction of daylight - mobile shading devices as an integral part of envelope of the facility;
6 Building shell and its aesthetic characteristics: a shell as a medium of architectural plastic;
7 The connection between the actual energy state and the actual architectural - design response;
8 Researching daylighting as a balance between energy, visual environmental parameters, and user health without neglecting the design and aesthetic potential of these solutions.

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