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DEFICIT OF SOLAR RADIATION AND ITS IMPACT ON THE LIVES OF URBAN DWELLERS (CASE STUDY: THE CITY OF KRAKOW)

Abstract: Solar radiation is necessary for the proper development, maturing and functioning of the human body. A period of time when there was a deficit of solar radiation in the city of Krakow was identified and characterized. The period was selected based on diurnal values of cloudiness and sunshine duration from the years 1884–2009. An analysis of the impact of the deficit of solar radiation on the health and well-being of city dwellers was performed. Proposals were put forth on how to prevent the consequences of the lack of sunshine.

Key words: urban bioclimatic conditions, cloudiness, sunshine duration, deficit of solar radiation, hunger for sunshine

Słowa kluczowe: bioklimat miasta, zachmurzenie, usłonecznienie, niedobór promieniowania słonecznego, głód słoneczny

Introduction

Urbanization, industrialization, and the fear of the harmful effects of UV radiation are some of the factors that have prompted people to seek less exposure to solar radiation. Mass media broadcasts emphasize the negative aspects of sunbathing. This translates into fewer people who understand that the influence of the Sun's rays is beneficial to the human body. It is common knowledge that the Sun's rays are a source of heat, light, as well as life. Sunlight stimulates reduction processes and causes enzymes to be synthesized faster. Sunlight causes the intensification of metabolic processes in cells and organs. Detoxification processes are also accelerated by sunlight, which stimulates the production of red blood cells and causes increased excretion of urea. The deposition of calcium in bones is also intensified by sunlight. Moreover, sunlight contributes to an increase in the protective acidity of skin and stimulates secretion by mucous membranes. Sunlight is beneficial to blood circulation and respiratory systems, causing heart action to slow down. It also causes a deepening of breath and slows down breathing. The Sun, by affecting physiological processes, stimulates them, and increases the general vitality of the human body, causing it to be more active. Visible light also acts on the human psyche. It improves the mood and well-being via the action of the Sun's rays on the human body, which increase the amount of serotonin (the hormone of happiness) released into the bloodstream.

The lack of direct solar radiation over longer periods of time affects human health and mood in disadvantageous ways. That is why the primary goal of this research is to identify and characterize periods of solar radiation deficit in Krakow. A secondary goal is to determine how solar radiation deficits affect the lives of Krakow residents.

Source materials and methods

The results used in this paper come from the observations of cloudiness and sunshine duration performed between 1884 and 2009 at the Scientific Station of the Department of Climatology, which is a part of the Institute of Geography and Spatial Management of the Jagiellonian University in Krakow (φ=50°04'N, λ=19°58'E, elevation: 206 m a.s.l.). The aforementioned observations of cloudiness were performed from the terrace and the roof of the Śniadecki College (formerly the Astronomical Observatory). A Campbell-Stokes sunshine recorder is also located on the roof of the College.

Periods of solar radiation deficit were identified based on average daily cloudiness values and diurnal sunshine duration totals. The number of days with cloudy and overcast skies was identified, as were the longest sequences of such days in the multi-year period of interest. Daily and yearly sunshine duration patterns were analyzed, as were the number of days with no sunshine, the number of days with more than four hours of sunshine, and the number of days with more than ten hours of sunshine. An attempt was made to evaluate the impact of the deficit of solar radiation on Krakow residents. The literature in the field of biometeorology was used to make such an evaluation. Urban planning solutions were then proposed, tailored to minimize the deficiency of direct solar radiation in built-up areas.

Cloudiness

Cloudiness and cloud cover type influence the general health and psychological well-being of people. The health effects of clear sunny weather are beneficial while the effects of cloudy weather are disadvantageous (Błażejczyk 2004). The kind of weather with overcast skies for longer periods of time makes people tired – both biologically and psychologically. This is attributed to an insufficient level of visual stimuli or light. People whose bodies do not sufficiently benefit from solar radiation have symptoms of the so-called "hunger for sunshine". The symptoms of the "hunger for sunshine" include pale skin, sleep disorders, excessive excitability or tiredness and apathy, decreases in physical and mental fitness, and a lowered immunity of the body against infectious micro-organisms (Daniłowa 1988). A person affected by the "hunger for sunshine" becomes sick with the flu, catches a cold or other infectious disease more frequently. Chronic illnesses are also commonplace. Moreover, fractures and wounds are difficult to heal and affected individuals are more prone to develop swelling. Incidence of inflammation causing pus increases, even in people who under normal conditions would not develop such diseases. It has also been shown (Daniłowa 1988) that a deficiency of solar radiation may be one of the causes of arterial hypertension that is due to changes in kidneys. The deficiency of ultraviolet radiation is especially harmful to the bodies of children. A lack of ultraviolet radiation in infancy and pre-school age causes rickets and vitamin D deficiency. Vitamin D is necessary for proper calcium and phosphate metabolism.

The average yearly cloudiness in Krakow, based on the data from 1884–2009, is 67.8%. This value is similar to the multi-annual average cloudiness value for Poland (Żmudzka 2007) and neighboring countries situated at the same latitude (Matuszko 2009). Days with cloudiness values under 50% are most beneficial to the human body (Kozłowska-Szczęsna *et al.* 2004). The amount of solar radiation that reaches the surface of the Earth depends not only on cloudiness but also on cloud genera in the cloud cover.

High level clouds (*Cirrus* and *Cirrostratus*), composed of minute ice crystals, even when they cover the entire sky, transmit almost 100% of solar radiation. The most significant obstacle for radiation are low level layered clouds *Stratus* and *Stratocumulus* (Matuszko 2009). It is these two cloud genera that dominate the cloud cover structure in the winter. This makes the solar conditions even worse.

Two diurnal patterns of cloudiness have been identified for Poland (Olszewski 1990). In Krakow they are similar to the rest of the country, and they are as follows:

1. "summer" – from April to September, with maximum cloudiness around noon (mostly convective clouds, primarily *Cumulus*) and minimum cloudiness at night, with a large diurnal (day-night) amplitude;
2. "winter" – from October to March, with a maximum in the morning or before noon (mostly layered clouds, primarily *Stratus*) and a minimum in the evening or at night, with a small diurnal (day-night) amplitude.

During the course of a year (Fig. 1), cloudiness reaches its maximum in December (79.6%), while its minimum occurs in August (58.1%). In the multi-year period of interest, the range of changes in cloudiness values is smallest during the cloudy winter months: in December (35.3%) and in January (36.3%). The largest difference among average monthly cloudiness values in the multi-year period occurs in March (59.7%).

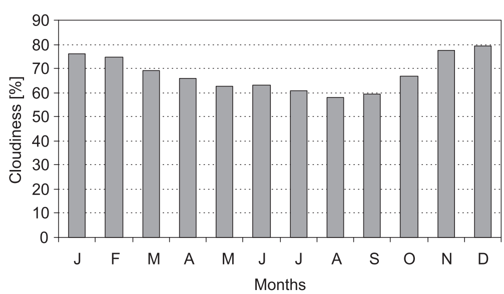

Fig. 1. Annual pattern of the mean monthly cloudiness in Krakow (1884–2009)

Ryc. 1. Przebieg roczny średniego miesięcznego zachmurzenia w Krakowie (1884–2009)

The pattern of cloudiness over the course of the year, composed of diurnal cloudiness values (Fig. 2), is characterized by significant variability from day to day. After a day with overcast skies, a cloudless day or a partly cloudy day may occur. Such scenarios occur especially often in March, June, September, and October. In terms of the influx of solar radiation, cloudiness of varying degree from day to day is more beneficial than a sequence of days with significant cloudiness composed of layered clouds, which is typical of the winter season in Poland.

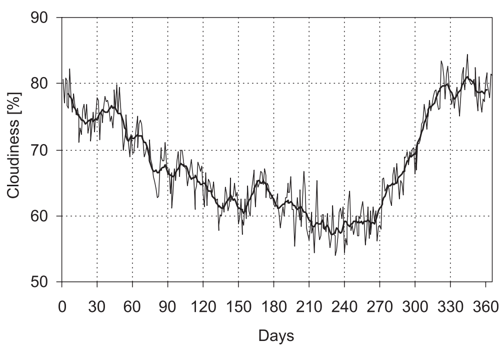

Fig. 2. Annual pattern of the mean diurnal cloudiness [%] and the 5-day moving average in Krakow (1884–2009)

Ryc. 2. Przebieg roczny średniego dobowego zachmurzenia [%] oraz średnia ruchoma 5-dniowa w Krakowie (1884–2009)

In the pattern of cloudiness observed over the course of the year (Fig. 2), there is a rather rapid increase in cloudiness in the autumn and a decrease in cloudiness in the spring and in the summer, which is much slower and features small fluctuations. The greatest mean diurnal cloudiness (over 80%) occurs at the end of November, in mid-December, and at the beginning of January. In February, mean diurnal cloudiness still exceeds 75% but later it gradually decreases to 60% in the middle of May. In June, cloudiness increases to 65% and then it slowly decreases, reaching a minimum in August (55%). In August and September, cloudiness values below 60% prevail. Then, starting at the beginning of October, cloudiness values quickly rise to 80%, which is reached at the end of November. Substantial cloudiness during the cool season of the year is related to the frequent presence of *Stratus* clouds that create a thick layer, which often persists for several days in a row.

This situation is particularly unfavorable for the residents of Krakow because it causes a solar radiation deficiency. In the summer, a persistent and thick cloud cover composed of layered clouds is a rare occurrence. Days are longer than in the winter and there are more factors involved (convection, for example) that contribute to the break-up of cloud cover.

During the course of the year, days with partly cloudy to mostly cloudy skies (mean diurnal cloudiness between 20% and 80%) and days with nearly overcast or overcast skies (mean diurnal cloudiness > 80%) are most common in Krakow. They account for almost 90% of days in a year. Days with overcast skies (about 86 days a year) occur rather frequently but in August and July they occur least frequently.

In terms of solar radiation deficits, it is especially disadvantageous when cloudy weather with nearly overcast or overcast skies persists for several days in a row. Most frequently these are 3-day sequences, but periods of cloudy weather lasting from

11 up to 19 days also occur. The longest sequences of cloudy days with nearly overcast or overcast skies occur in the winter. In this season of the year, the cloud cover is composed mostly of layered clouds (*Stratocumulus*, *Stratus*, *Altostratus*) and the sky is entirely overcast. Even under the conditions of high atmospheric pressure, a sub-inversion layer of *Stratus* clouds is present, limiting the influx of solar radiation.

Cloudy weather occurred in Krakow especially often in the 1950s and 1960s. One of the worst weather years was 1952 when the mean yearly cloudiness was greatest (78%), and in which the multi-annual maximum number of cloudy days occurred repeatedly during five separate months (February, May, September, October, November). February of 1952 was an especially cloudy month. Cloudiness often persisted for a whole day or even more than 10 days in a row. It was the month in which the longest sequence of days with entirely overcast skies occurred for the multi-year period, lasting 2 weeks from the 11th until the 24th of February.

During the entire month, only one day was not cloudy, and there were 25 fully overcast days. For this reason, there were only 10.2 hours of sunshine in February of 1952. This is the minimum value of monthly sunshine duration for the month of February since heliographic measurements were started in Krakow (Matuszko 2009). The year 1952 stands out as quite untypical due to the fact that there was, on average, the smallest number of completely overcast days (8) in February out of all winter months in the multi-year period. The other months of that year were also characterized by exceptionally high cloudiness because a record number of cloudy days was observed again in the autumn and winter.

In 1952 and 1953, a 29-day long sequence of cloudy days occurred, lasting from the 25th of December, 1952 until the 22nd of January, 1953. It was the longest such sequence in the multi-year research period. Two extremely long sequences of cloudy days also occurred in 1952. The two sequences lasted from the 28th of October to the 11th of November and from the 13th of November to the 24th of November.

There is a much smaller number of cloudy and overcast days in the summer than in the remaining part of the year. The cloud cover in the summer is composed primarily of convective clouds, which are vertically stretched. There are interstices between the clouds that let solar radiation flow through to the surface of the Earth. Moreover, even if the sky is largely covered with *Cumulus* clouds, high values of total radiation intensity are observed. In Krakow, maximum (above 1,000 $W \cdot m^{-2}$) instantaneous values of total radiation are recorded when convective cloudiness is equal to or greater than 40% (often 75%). However, this occurs exclusively from May until July, when the Sun is in the highest position over the horizon (Matuszko 2009).

Sunshine duration

Sunshine duration is one of the measures used to assess the influence of solar radiation on human beings (Błażejczyk 2004).

The mean annual sunshine duration total for Krakow, based on the data from 1884–2009 is 1,552.1 hours. As noted by M. Kuczmarski (1990), the mean annual sunshine duration total for Poland is 1,526 hours.

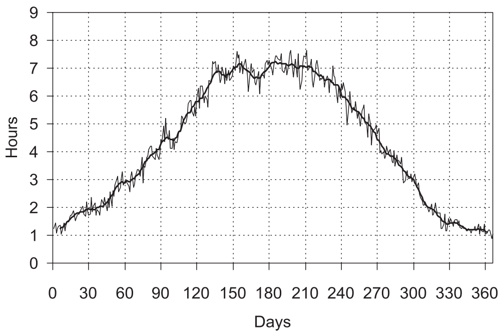

Fig. 3. Annual pattern of the mean daily actual sunshine duration in Krakow (1884–2009) and the 5-day moving average

Ryc. 3. Przebieg roczny średniego dziennego usłonecznienia rzeczywistego w Krakowie (1884–2009) oraz średnia ruchoma 5-dniowa

It is known that diurnal and yearly patterns of sunshine duration depend on the length of day, the altitude of the Sun over the horizon, the cloudiness and the kind of cloud cover, and the transparency of the atmosphere. The impact of these factors is shown in the pattern of hourly sunshine duration values for the particular days of the year (Fig. 3) based on the data from the multi-year period. The shape of the curve of sunshine duration with respect to time, although it varies significantly on a daily basis, reflects both the annual pattern of the Sun's highest position over the horizon and the pattern of the length of day in Krakow (Matuszko 2009). This fact proves that factors related to astronomy play a deciding role in determining the value of sunshine duration. For this reason, the most sunshine hours are counted during the longest days of the year, from May until the end of July. Meteorological factors were the cause for a small decrease in sunshine duration, observed in mid-June (Fig. 3), not only in Krakow but also in other cities i.e. Wroclaw, Szczecin, Suwalki, Lodz, and Przemysl (Degirmendžić 2004).

The cause for the decrease in sunshine duration in that period was an increase in cloudiness (Fig. 2) related to changes occurring in the atmospheric circulation system over Europe and the intensification of advection of an air mass coming from the west and the north-west (Kaszewski 1983). Along with the gradual decreases in day length, sunshine duration falls to its lowest value in December. However, already in November, the Sun shines on average not longer than 1 hour a day. Starting in January, sunshine duration gradually increases, with small fluctuations in mid-April and mid-May. In Krakow, just like all over Poland (Koźmiński, Michalska 2005), the curve representing the annual pattern of mean daily sunshine duration is characteristically flattened in the summertime. The flattened part starts after the 20th of May and ends before the 21st of August, with a noticeable decrease in sunshine duration between the 10th and the 20th of June and between the 10th and the 20th of July (Fig. 3).

In general, the best sunshine conditions occur in Krakow between the 1st and the 10th of June, between the 1st and the 10th of July, at the end of July, and at the beginning of August. The smallest sunshine duration values occur from the 11th of December until the 10th of January. The most significant solar radiation deficiencies in Krakow occur during this period. They are further intensified by the dense grid of buildings of the city center. In some areas of Krakow, the lower floors of apartment buildings are unreachable to direct solar radiation for over 2 months a year.

As indicated by the average monthly values (Fig. 4), sunshine duration is the greatest in July (221.1 hours) and the smallest in December (36.9). However, monthly sunshine duration totals vary substantially from year to year. The largest difference in the number of sunshine hours occurs in July, because the greatest value of sunshine duration for the month was 361.8 hours (2006), and the smallest value was 103.3 hours (1980). The atmospheric circulation is the deciding factor responsible for the significant variability in sunshine duration during each year. The temperate warm transitional type of climate found in Poland is shaped by moving high and low atmospheric pressure systems and frontal systems associated with them, which occur with different frequency and intensity in different years. All of these factors cause that the differences between the monthly number of sunshine hours within a given year are very large. The difference among months from April until July exceeds 200 hours. This is more than a monthly total of sunshine duration for most of the winter months: January, February, March, April, September, October, November, December. In May, in spite of greater cloudiness (Fig. 2), and due to longer days, the Sun shines over one hour longer than in August. The spring is characterized by greater values of sunshine duration (by about 160 hours) than the autumn.

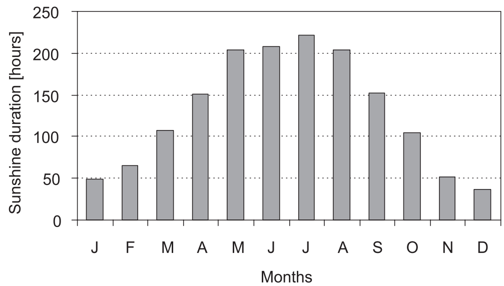

Fig. 4. Annual pattern of the mean monthly sunshine duration in Krakow (1884–2009)

Ryc. 4. Przebieg roczny średniego miesięcznego usłonecznienia w Krakowie (1884–2009)

When days are the longest in Krakow, in May and July, the Sun shines between 4 AM and 9 PM UTC+1. The hourly intervals are considered to be within these hours. In November, December and January, the number of sunshine hours in a day is smaller by one half. The maximum actual daily sunshine duration in Krakow is 15.3 hours. For reasons related to astronomy, the greatest daily values of potential sunshine duration are noted during the longest days of the year – between the 10th and the 25th of June.

The sunshine conditions of a given locality are determined not only by the daily total of sunshine duration but also its distribution pattern over time (Trybowski 1955). In Krakow, during the day, sunshine conditions are the best between 12:00 (noon) and 2 PM (Fig. 5). From April until September, the daily pattern of sunshine duration is gradually altered by the development of convective cloudiness. Most sunshine hours occur before noon – after the fog clears, and before convection occurs.

In the cooler part of the year, the morning fog decreases the number of sunshine hours before noon, and it is the reason for the occurrence of the diurnal maximum in the early afternoon hours. The above regularity in the change of pattern of the daily maximum of sunshine duration over the course of the year was observed at many

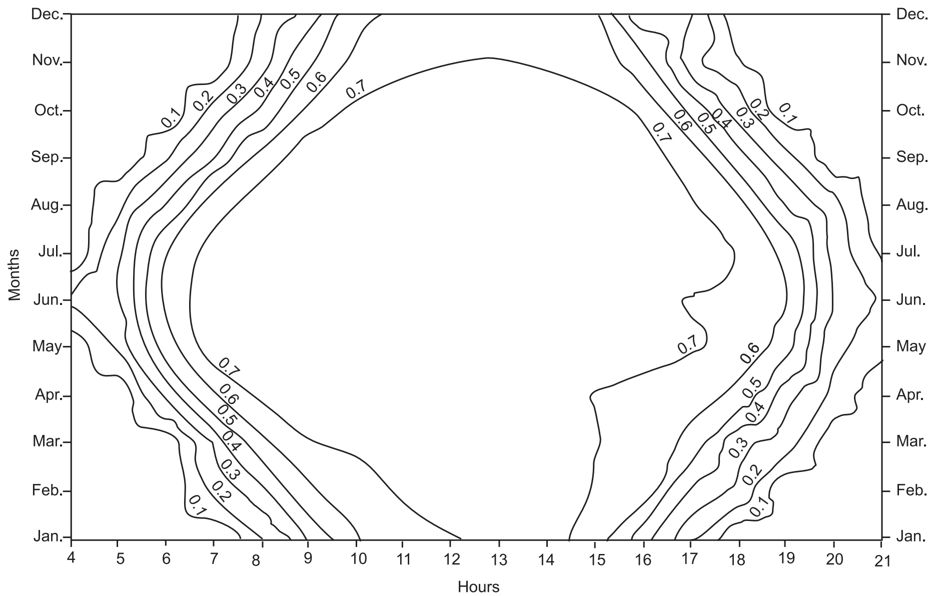

Fig. 5. Isopleths of average hourly values of actual sunshine duration over the course of the year in Krakow (1884–2009)

Ryc. 5. Izoplety średnich godzinnych wartości usłonecznienia rzeczywistego w przebiegu rocznym w Krakowie (1884–2009)

weather stations in Poland (Parczewski 1957). In Krakow, such a sunshine duration pattern is additionally related to the high frequency of occurrence of low-level layered clouds (*Stratus* and *Stratocumulus*) and the fog that is formed due to the loss of radiation overnight. According to J. Słomka (1957), in the winter, it takes a long time for the morning clouds and fog to dissipate before the heat of solar radiation. The highest density of isopleths (Fig. 5) is typical for the morning hours and the late afternoon hours – which is a result of fog and the impact of the curtain effect, which is related to vertically developed clouds (Słomka 1957). A decrease in sunshine duration is clearly seen in mid-June between 5 PM and 6 PM (Fig. 4), which is caused by greater cloudiness and longer convection time. Although there are 160 more hours of sunshine in the spring than in the autumn, there are more sunshine hours in the afternoon in the autumn than in the afternoon in the spring, which is due to less cloudiness in autumn afternoons.

The number of days with four or more sunshine hours is an important characteristic of radiation conditions in bioclimatology, because it is a measure of a potential reception of solar radiation and such a long sunshine duration affects its antibacterial capabilities, and supports the production of vitamins. In Krakow, there are, on average, 165 such days a year. A record number of days with four or more sunshine hours occurred in 1943 – there were 205 such days. There were certain years, in which January and December were deprived of such days, but in other years, such days made up a maximum of about 90% of those months' days. The highest number of days with four or more sunshine hours occur in the summer (62) and on a monthly basis in July (22).

In the second part of the 20th century, an increase in the number of days with four or more sunshine hours was observed in the cooler half of the year, whereas a decrease was observed in the warmer half of the year, and overall per year. This is probably caused by an increase in the frequency of occurrence of convective clouds (Matuszko 2003).

Days with 10 or more sunshine hours occur in Krakow almost four times less frequently. They never occur in the winter due to short winter days. The highest number of such days (10) occur in July. It is worth noticing that the number of days with 10 or more sunshine hours increases, and it did so especially in the last two decades. On average, there are 47 such days a year. The largest number of days with 10 or more hours of sunshine was 83 and it occurred in 1942; the smallest number was 19 and it occurred in 1980.

On average, there are 90 days without sunshine a year. The largest number of such days (121) occurred in 1941, the smallest number (61) occurred in 1989 and in 2000. In the yearly cycle, days without sunshine occur mostly in the winter, and their number reaches its maximum in December (16). The smallest number of days without sunshine occurs in July and August (less than 3 days). An analysis of the seasonal pattern of the occurrence of days without sunshine shows that a half of the days occur in the winter, whereas only 10% occur in the summer. About 20% of the yearly total of days without sunshine occur in the spring and autumn each year.

Solar radiation deficits and ways of preventing them

The largest solar radiation deficits recorded in Krakow and in other cities in Poland occur from mid-November until the 20th of February. During this period, daily totals of sunshine duration do not exceed 2 hours, and the Sun's maximum angular altitude above the horizon is less than 20 degrees, which is due to causes related to astronomy and meteorology. For these reasons, direct solar radiation does not reach most rooms in the densely built-up city of Krakow. In the winter, people stay inside buildings most of the day. Even if sunlight enters inside, it does not have a beneficial effect. That is because an ordinary glass window virtually does not transmit the physiologically active band of the solar radiation spectrum. Moreover, the heating season creates significant pollution in cities, which limits the solar radiation that may get through. Krakow is located in the Wisla River Valley and it is very densely built-up. This creates difficult conditions in terms of air quality.

The fact that the city is located in a valley, which is a concave landform, as well as the occurence of frequent temperature inversions, a large number of foggy days, and a significant cloud cover of *Stratus* clouds in the winter sky, all limit the processes of the self-cleaning of air. They also make it difficult for winds to exchange the air over the city, causing high pollution concentrations to remain in the air for extended periods of time. During the heating season, the concentration of dust suspended in the air over Krakow increases and triples with respect to other months.

Generally, the highest concentration of dust in the winter occurs during weather characterized by a high pressure system, within continental polar air masses, coming from the southeast, as well as when the center of an atmospheric high pressure system hovers over southern Poland (Matuszko 2009).

The best ways of preventing solar radiation deficiency in the winter are active relaxation outdoors (mountains are best for this purpose) and phototherapy. During the winter half of the year, in the mountains and piedmont areas, there are better sunshine conditions than across lowlands, because often the clouds lie below the elevation of a given locality (Kuczmarski 1984). Bright-light therapy consists of the exposure of the eyes or the sensitive points underneath the knees to light using a special lamp (Anti-SAD) emitting a bright light similar to sunlight, the intensity of which ranges from 5,000 to 9,500 lux (Pużyński 2002).

Urban planners and architects should choose the best solutions available to optimize urban design while planning cities that would be beneficial to residents both in the summer and in the winter. Because of solar radiation deficits in the winter, it is preferred that a southern-facing orientation be used with possible minor deviations to the east and to the west. In order to avoid a mutual overshadowing of buildings it was agreed upon (Szponar 2003) that the distance between residential buildings on the 21^{st} of December, which is when the angle of incidence of the Sun's rays reaches 17°, should be 1.8 of the building's height. Otherwise, rooms on the ground floor of a neighbouring building will be overshadowed. The proper coefficient of illumination for a room may be secured by maintaining a proper ratio between the area of windows and the room's area, which should be 1:8. The function of a given room should be based on the exposure of the room to solar radiation. Living rooms should face E-S-W and kitchens W-N-NE.

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Niedobory promieniowania słonecznego i ich wpływ na życie mieszkańców miasta (na przykładzie Krakowa)

Streszczenie

Promieniowanie słoneczne jest niezbędne do prawidłowego rozwoju, dojrzewania i funkcjonowania organizmu człowieka. Na podstawie dobowych wartości zachmurzenia i usłonecznienia z lat 1884–2009 scharakteryzowano okres z niedoborem promieniowania słonecznego w Krakowie. Stwierdzono, że w Krakowie, podobnie jak w innych miastach Polski, największe niedobory promieniowania słonecznego występują od połowy listopada do drugiej dekady stycznia. W tym okresie ze względów astronomicznych i meteorologicznych sumy dzienne usłonecznienia nie przekraczają dwóch godzin, a Słońce góruje na wysokości poniżej 20 stopni nad horyzontem. Z tych powodów do większości pomieszczeń w gęsto zabudowanym mieście nie dociera promieniowanie bezpośrednie. Ponadto, ze względu na sezon grzewczy panuje duże zanieczyszczenie w mieście ograniczające promieniowanie słoneczne. Usytuowanie Krakowa we wklęsłej formie terenu, częste inwersje temperatury i duża liczba dni z mgłą oraz w zimie znaczne pokrycie nieba przez chmury *Stratus*, utrudniają naturalne przewietrzanie miasta, powodując dużą koncentrację zanieczyszczeń i utrzymywanie się ich w powietrzu przez dłuższy czas. Krótki dzień, niskie położenie Słońca w zimie oraz często całkowite pokrycie nieba chmurami warstwowymi i duże stężenia

zanieczyszczeń mogą być u wielu osób przyczyną złego samopoczucia i nasilenia dolegliwości związanych z tzw. głodem słonecznym. Najlepszymi formami zapobiegania niedoborom promieniowania słonecznego w zimie są aktywny wypoczynek na świeżym powietrzu i fototerapia. Urbaniści i architekci w projektach zabudowy miejskiej powinni uwzględniać optymalne rozwiązania, korzystne dla mieszkańców zarówno latem, jak i zimą.

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