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DIFFERENTIATION OF THE SOLAR CONDITIONS IN THE CARPATHIAN FOOTHILLS DURING 1971-1997

1. Introduction

The solar radiation coming to the Earth is the main and practically the only source of energy for the active surface and the atmosphere. By influencing their heat balance and thermal regime the radiation affects the formation of the specific climatic conditions of any area. The solar energy constitutes also an energy base of the photosynthesis conditioning the life functions and development of the plant cover.

The amount of the solar energy coming to the Earth surface is mainly dependent on the optical properties of the atmosphere; the degree of the air turbidity and its transparency, as well as the sunshine duration. The transparency of the atmosphere influences the intensity of radiation and the magnitude of its scattering. The sunshine duration is defined as the time when the direct radiation reaches the active surface.

2. Source materials

The characterization of sunshine duration variability in the Carpathian Foothills has been performed based on the data from two heliographic stations: Gaik-Brzezowa and Szymbark. The first of these stations represents the conditions of the Wieliczka Foothills, the second one those of the Ciężkowice Foothills. In order to characterize the changes against the background of longer observational series, the data from Cracow were also analysed, located outside the Carpathian Foothills. The co-ordinates of these stations are given in Tab. 1. The stations in Gaik-Brzezowa and in Cracow belong to the Institute of Geography and Spatial Management, Jagiellonian University, while the station in Szymbark is managed by Polish Academy of Sciences. The monthly and annual totals of sunshine duration and the number of days with the sunshine duration equal to or greater than10 hours as well as the number of days with no sunshine have been analysed for the period from 1971-1997. The sunshine duration, closely related

Tab. 1. Geographical characteristics of heliographic stations

Stations	a.s.l. (m)	φ	λ
Kraków	206	50 °04'	19 °58'
Gaik -Brzezowa	302	49 °52'	20 °04'
Szymbark	325	49 °38'	21 °07'

to the magnitude of the cloudiness, is highly variable both in the diurnal and annual course. It is also subject to the large oscillations from the year to year. Thus, in order to characterise the changes in sunshine duration in the period from 1971-1997 it is desirable to present it against the background of a longer period. This approach is facilitated by the very long series of the sunshine duration records collected in Cracow since 1881 (Karliński 1898; Gorczyński 1910). Using the relation between the cloudiness and the relative sunshine duration M. Morawska (1963) extended this series by 25 years – back to 1859, thus, at present it covers ca 140 years.

The results of the measurements performed in the years from 1971-1997 in Gaik-Brzezowa at noon of the local time have been used for characterising the radiation conditions. The measurements have been carried out using the thermo-electrical actinometric equipment: the intensity of the direct solar radiation – with Sawinow-Janiszewski actinometer AT-50, and the scattered and reflected radiation – with Janiszewski pyranometer M-80. The total radiation at the horizontal surface has been calculated as the sum of the direct and scattered radiation, while the radiation absorbed by the active surface – as the difference between the total and reflected radiation.

3. Multi-annual variability in sunshine duration

In southern Poland, located at the latitude between 49°-51°N, the annual totals of potential astronomically available sunshine duration are within the limits of 4472-4479 hours, changing in the particular seasons from 792-814 in winter and 980-987 hours in autumn to 1255-1265 hours in spring and 1416-1442 hours in summer. In the annual course, July is the month of the largest potentially available number of hours with the sunshine amounting to 487-497, while the lowest monthly sum of the potential astronomically available sunshine duration decreases to 248-258 hours.

According to M. Kuczmarski the real sunshine duration in southern regions of Poland has the largest spatial differentiation in the country. That is the effect of the very diversified relief of this region. When analysing the annual totals of sunshine duration from the years 1961-1970, M. Kuczmarski (1979) states that there is an increase in the number of hours with the sunshine from 1500 in the western part to over 1600 in the eastern part of this region. He is of opinion that the reason behind it might be the prevailing influence of the oceanic climate in the western part of the region and of the continental one in the eastern part of the region.

3.1. Monthly, seasonal and annual totals

The mean annual total of sunshine duration in Cracow from the period 1881-1997 reaches 34.6% of the potentially available sunshine duration for 50°N latitude and amounts to 1548.7 hours. From the analysis of the mean annual totals of sunshine duration

in the subsequent 10-year periods it results that the most sunny was the period from 1881-1890, and especially the decade of 1941-1950 when the average number of hours with the sunshine exceeded 1700 (Tab. 2). The year of 1943 was extremely sunny. The annual total of sunshine duration reached 1920.4 hours, i.e. 43% of the potentially available values, and so it was the highest value recorded in Cracow in the examined period. Such a high sum of the hours with sunshine resulted from a high, over 660-hour sunshine duration of the spring months (March-May) and that of the summer months (June-August) with over 690 hours. When comparing with the potential sunshine duration available in these seasons, it amounted to 53% and 48%, respectively.

The least favourable solar conditions during the whole period from 1881-1997 occurred during 1971-1980. The mean annual total of sunshine duration was almost 225 hours lower when comparing with the mean of the multi-annual period, and amounted only to 1324.4 hours (Tab. 2). The year of 1980, when the annual total of sunshine duration was 1067.2, i.e. declined below 24% of the potentially available sunshine duration, turned out to be particularly unfavourable. The annual total of sunshine duration, over 480 hours lower than the mean multi-annual total, was the result of the small number of hours with the sunshine in all the seasons of this year. The sunshine duration of the summer months was only 407.6 hours, and that of spring months – 338.8 hours. That is only 28.5% and 27%, respectively, of the values potentially available for this latitude. Autumn and winter were characterised by the small number of the sunshine hours, i.e. 223.6 and 97.2, respectively, which is only 23% of the potentially available sunshine duration in the first case, and 12% – in the second case.

When analysing the annual course of the sunshine duration totals in Cracow in the years from 1881-1997 two periods with high values, with the annual totals of sunshine duration usually 100-150 higher than the multi-annual mean, can be distinguished. The first of these subperiods occurred in the last 20 years of the 19th century, while the second period was during 1940-1950. In the initial years of the 20th century a gradual decrease in sunshine duration took place, so the annual totals of the decade from 1910-1940 became similar to the mean multi-annual total. Since 1950 a significant decline in sunshine duration has been observed. In the recent period the annual totals of sunshine duration were even 200 hours lower than the multi-annual mean (Obrębska-Starklowa *et al.* 1994).

In general, the sunshine duration in Cracow shows a declining tendency, which coincides with that in Central Europe (Brazdil 1991). Thus, the period from 1971-1997, examined in this paper, corresponds to the period of the lowest sunshine duration in the whole period from 1881-1997.

The mean annual sunshine duration in the studied part of the Carpathian Foothills of the period from 1971-1997 reached 1473.9 hours in Gaik-Brzezowa and 1423.6 hours in Szymbark, but it was slightly higher than in Cracow – 1412.3 hours (Tab. 3). In particular years the annual sunshine duration totals were subjected to large variations. The lowest sunshine duration in the whole area was recorded in 1980. At that time it reached 25-27% of the potentially available sunshine duration and amounted to 1222.2 hours in Gaik-Brzezowa and 1137.8 hours in Szymbark, but only 1067.2 hours in Cracow (Tab. 3). The most favourable sunshine duration conditions in the Carpathian Foothills

Tab. 2. Mean 10-year monthly and yearly sums of sunshine duration in Cracow

Period of observations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1881-1890	64.4	91.2	116.4	172.8	223.2	212.9	242.1	219.4	173.0	90.3	61.3	46.5	1 713.4
1891-1900	53.7	72.5	117.0	151.6	192.0	213.3	224.5	218.7	174.1	114.2	61.8	44.3	1 637.7
1901-1910	65.0	69.8	109.4	147.0	222.6	202.0	230.7	205.4	159.0	112.2	56.7	40.0	1 620.0
1911-1920	51.7	84.1	108.4	147.5	212.6	214.6	196.6	186.4	148.9	103.0	58.7	33.8	1 546.4
1921-1930	49.8	67.7	124.4	141.0	198.8	193.9	231.9	197.8	142.1	110.3	50.4	32.6	1 540.8
1931-1940	43.2	61.2	115.2	159.4	200.1	222.2	229.7	176.1	157.7	99.1	61.4	31.2	1 556.5
1941-1950	48.9	61.6	122.2	166.2	240.6	231.0	236.7	234.1	184.2	120.8	41.3	43.3	1 730.8
1951-1960	42.8	55.4	113.1	149.5	188.6	198.7	219.8	209.9	156.8	111.1	48.0	36.9	1 530.6
1961-1970	38.5	49.2	88.3	147.8	172.8	209.7	211.2	182.9	152.1	104.4	45.3	28.4	1 430.8
1971-1980	35.6	54.3	90.0	125.2	174.6	189.4	180.5	184.9	117.2	90.8	47.3	34.7	1 324.4
1981-1990	45.9	64.0	88.3	128.3	197.8	177.8	218.7	195.2	116.9	113.1	51.6	32.4	1 429.9

Tab. 3. Monthly and yearly sums of sunshine duration (in hours) in the years 1971-1997

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mean													
Kraków	43.4	61.5	90.5	130.5	187.1	192.8	209.9	194.5	119.4	99.8	49.2	33.5	1412.3
Gaik-Brzezowa	57.1	75.2	104.7	129.2	180.5	185.5	206.3	198.0	124.7	108.0	59.8	44.9	1473.9
Szymbark	60.5	71.4	107.3	124.3	172.4	171.0	190.2	186.4	124.4	107.2	61.2	47.3	1423.6
maximum													
Kraków	80.9	119.6	142.0	198.6	248.6	268.8	325.8	277.3	178.0	147.0	79.5	64.7	1664.7
Gaik-Brzezowa	99.8	116.4	156.7	180.4	239.5	259.6	311.1	269.1	191.4	154.8	101.5	118.1	1708.9
Szymbark	96.7	137.5	175.7	177.4	247.2	244.9	291.3	253.8	199.9	151.0	106.3	122.4	1656.0
minimum													
Kraków	17.2	23.4	45.4	83.0	128.1	120.3	103.3	130.4	39.6	53.7	16.7	9.0	1067.2
Gaik-Brzezowa	32.2	30.3	59.0	83.1	131.2	101.9	116.2	146.0	35.2	44.7	19.9	16.9	1222.2
Szymbark	27.5	36.9	58.0	77.3	112.3	100.0	95.6	117.7	36.3	41.8	29.4	20.0	1137.8

occurred in 1982. Then, the annual sunshine duration total was 1708.9 hours in Gaik-Brzezowa, 1656.6 hours in Szymbark, i.e. 37-38% of the sum available at this latitude. The slightly smaller sunshine duration reaching almost 1675 hours occurred in Gaik-Brzezowa in 1983, and that of 1644.5 and 1640.3 hours – in 1976 and 1986, respectively. In Szymbark the years of 1976 and 1986 also manifested in the high annual totals that amounted to 1629.6 hours in the first case, 1624.6 hours in the second case.

In the annual course, the mean monthly sunshine duration totals vary within the limits of ca. 33 hours in December to almost 210 hours in July (Tab. 3), which is 13% and 43% of the potentially available monthly totals, respectively. The Carpathian Foothills are characterised by a more favourable sunshine duration conditions than the municipal region of Cracow. The monthly sums of sunshine duration vary from 45 in Gaik-Brzezowa and 47 in Szymbark in December, to ca 190 in Szymbark and 206 in Gaik-Brzezowa in July.

In December the lowest sums of sunshine duration occurred in the Carpathian Foothills in 1988, and amounted to 16.9 hours in Gaik-Brzezowa and to 20.0 hours in Szymbark, but in the case of Cracow they only reached 9.0 hours in 1982. The most sunny December was recorded in the whole region in 1972 when the records were: 122.4 hours in Szymbark, 118.1 hours in Gaik-Brzezowa and 67.4 hours in Cracow (Tab. 3).

The most sunny month of the year and, simultaneously, very variable one is July when the maximum monthly sunshine duration totals can exceed 300 hours but they can also decrease to below 100 hours. During the period from 1971-1997 the largest sums of sunshine duration in July occurred in 1994 and 1995. In these years, the July sunshine duration in Cracow amounted to 325.8 and to 310.0 hours, respectively. In Gaik-Brzezowa the sunshine duration was only slightly smaller and reached 310.3 and 311.1 hours in the same years, but in Szymbark the appropriate values were 291.3 and 276.8 hours. The exceptionally low sunshine duration was in July 1980. The number of hours with the sunshine decreased to 116.2 in Gaik-Brzezowa, 103.3 hours in Cracow and 95.6 hours in Szymbark (Tab. 3). That is only 20-23% of the sunshine duration potentially available in this month. The very low sunshine duration in July1980 as well as in the other months of the summer season, when the number of hours with the sunshine reached slightly above 20% of the potentially available sunshine duration, made the year of 1980 to be characterised by the lowest number of the sunshine hours in the whole period from 1971-1997.

Based on the analysis of the mean and extreme monthly sunshine duration totals it is evident that in Szymbark the sunshine duration in the winter months is slightly higher, and in the summer months slightly lower than in Gaik-Brzezowa. That is undoubtedly the result, as suggested by M. Kuczmarski (1979) of the features of the continental climate increasing its effects eastward.

3.2 Number of days with the sunshine duration ≥ 10.0 hours

Theoretically, the days with the sunshine duration reaching 10 hours can occur at this latitude from a mid-February till the end of October. In practice, they occur from March until September, and only in Gaik-Brzezowa one such a day was recorded

in February and one in October during the whole period from 1971-1997. In the full summer season, the average diurnal sunshine duration varies within the limits of 5.9-6.6 hours, but the maximum diurnal totals can reach 12.5-14.5 hours or even exceed 15 hours (Olecki, Rauczyńska-Olecka, 1999).

The days when the sunshine duration is equal to or greater than 10 hours occur rarely in this region. Their annual mean varies from 32 days in Szymbark to almost 38 days in Cracow, i.e. only 9-10% of the days during the year. In particular years this number, however, can vary in a wide range, from ca 20 to over 50 days (Tab. 4). The particularly low numbers of the days with the sunshine duration exceeding 10 hours occurred in 1980 and 1989. The years of 1976, 1994 and 1995 were characterised by their large numbers.

Tab. 4. Monthly and yearly number of days with sunshine duration ≥ 10.0 hours in the years 1971-1997

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mean													
Kraków	.	.	0.1	3.6	7.8	7.8	9.3	8.5	0.7	.	.	.	37.8
Gaik-Brzezowa	.	.	0.1	2.5	6.9	7.2	8.7	8.7	1.3	.	.	.	35.4
Szymbark	.	.	0.3	3.3	6.5	6.1	7.5	7.6	0.9	.	.	.	32.1
maximum													
Kraków	.	.	2	11	13	15	19	15	4	.	.	.	51
Gaik-Brzezowa	.	1	2	10	13	15	18	13	5	1	.	.	54
Szymbark	.	.	2	8	16	14	17	13	3	.	.	.	54
minimum													
Kraków	.	.	.	.	2	3	.	4	.	.	.	.	19
Gaik-Brzezowa	.	.	.	1	1	.	1	4	.	.	.	.	21
Szymbark	.	.	.	.	.	.	1	4	.	.	.	.	18

During the year, the days with the sunshine duration exceeding 10 hours concentrate in the period from May to August with the maximum in July. In these months, the number of the days with the sunshine duration exceeding 10 hours reached 17-19 days in certain years. Simultaneously, the years when such days did not occur in July at all or occurred only sporadically were also observed.

3.3 Number of days without the sunshine

The days without the sunshine happen to occur in the examined area 2.5 times as often as the days with the high diurnal sunshine duration totals. Their mean annual number is poorly differentiated and varies from about 86 days in Szymbark to 89 days in Gaik-Brzezowa. On the other hand, the frequency of the days without the sunshine varies in a wide range in the particular years. In some years, such days amount only to 60-70, while in others – reach even to 108-109, which is 17-19% and 30% of all the days in the year in the first and second case, respectively (Tab. 5).

Tab. 5. Monthly and yearly number of days without sunshine in the years 1971-1997

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mean													
Kraków	14.3	9.9	7.5	5.0	3.8	2.8	1.7	2.6	5.2	6.3	12.5	16.1	87.7
Gaik-Brzezowa	13.1	9.7	7.3	5.9	4.1	3.1	2.7	3.0	6.1	6.6	12.2	15.4	89.2
Szymbark	11.5	9.1	7.2	6.0	4.1	3.7	2.8	3.3	5.1	6.9	11.2	14.9	85.9
maximum													
Kraków	23	17	14	12	11	7	6	7	15	13	19	23	108
Gaik-Brzezowa	24	15	13	13	11	7	7	7	16	13	20	22	109
Szymbark	21	14	13	11	12	12	7	10	14	12	19	22	109
minimum													
Kraków	4	2	2	2	1	.	.	.	1	1	4	8	61
Gaik-Brzezowa	6	4	3	2	1	.	.	.	2	2	2	6	69
Szymbark	3	2	3	2	.	.	.	.	.	2	5	5	98

When considering the annual course, the largest number of the days without the sunshine occurs from November till February with the maximum in December when their average number reaches 15 and, in certain cases, can even exceed 20 days. In summer season the number of the days without the sunshine decreases significantly, and from May till August declines even down to 2-4 days or they do not occur at all in the particular years. When analysing the mean and the maximum monthly sums of the days without the sunshine, as presented in Tab. 5, one can say that the slightly more favourable conditions are characteristic of the surroundings of Szymbark in winter, but in the summer season less days without the sunshine occur in Gaik-Brzezowa and Cracow.

4. Transparency of the atmosphere

In the areas, which are located outside the range of the municipal and industrial effects, the transparency of the atmosphere depends on the water vapour content in the air. In order to characterise the transparency of the atmosphere to the solar radiation in the region of the Carpathian Foothills the transparency coefficient, calculated according to the Bouguer's law for the Sun height 30° above the horizon, i.e. for the conditions corresponding to two optical masses of the atmosphere, has been used.

In Gaik-Brzezowa, at noon hours, the mean multi-annual coefficients of the atmosphere transparency reach their lowest values of 0.64 only in summer months from June till August. In the remaining months of the summer season they range from 0.65 to 0.68. In autumn and in winter the transparency of the atmosphere increases significantly, and the transparency coefficients exceed 0.70, and reach the maximum – 0.74 – in December (Tab. 6). In particular years the transparency of the atmosphere can vary in a wide range, especially in the summer months. The transparency coefficients can decline even to 0.50 in summer, but they can also exceed the value of 0.70.

Autumn and winter are the seasons with the highest transparency of the atmosphere. From October till February the values of the coefficients exceed 0.70 in 60-70% of

Tab. 6. Mean monthly values of the coefficient of the atmospheric transparency in Gaik-Brzezowa in the years 1971-1997

Coefficient values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.72	0.71	0.68	0.66	0.65	0.64	0.64	0.64	0.67	0.71	0.73	0.74
Maximum	0.78	0.77	0.74	0.72	0.70	0.72	0.72	0.72	0.74	0.76	0.78	0.79
Minimum	0.63	0.64	0.55	0.53	0.57	0.49	0.48	0.55	0.59	0.55	0.61	0.67

the cases, in December – over 10% of the cases exceed the value of 0.80. The absolute maximum of the atmosphere transparency recorded in this region during 1971-1997 occurred on 29 November 1984. In the polar-maritime air mass incoming from the south-east under the influence of the anticyclonic system with the centre over the Black Sea, the coefficient of the atmosphere transparency reached the value of 0.856 on that day (Olecki 1992).

The annual variability of the atmosphere transparency in Gaik-Brzezowa, presented in Fig. 1, indicates that it does not change significantly from year to year. The transparency coefficients in the particular years are at average in within the limits from 0.60 to 0.75-0.78, and show the maximum and winter and minimum in summer, which is typical for the natural areas. Rare deviations from this evened pattern are undoubtedly the effects of the reservoir constructed in this region. The large decrease in the atmosphere transparency in 1981 was caused by a strong air pollution associated with the constructing of the reservoir (Olecki 1992). On the other hand, the slightly smaller transparency of the atmosphere in the mid-1990s resulted from the higher air humidity in the neighbourhood of the fully operating water reservoir.

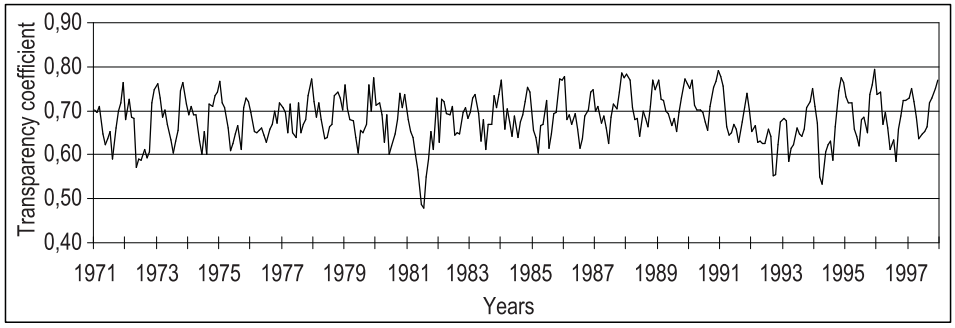

Fig. 1. Values of the coefficient of the atmospheric transparency in mid-day hours at cloudless weather

5. Direct solar radiation

Under the conditions of the weather without the cloud cover, the direct solar radiation is the fundamental stream of the solar energy reaching the active surface. Its intensity depends on the atmosphere transparency and the height of the Sun above the horizon that controls the number of the optical masses of the atmosphere. Because of that, the intensity of the total radiation varies in the diurnal and nocturnal cycles.

During the weather without the cloud cover or when the cloudiness is small, the intensity of the direct radiation in Gaik-Brzezowa varies during the day usually in agreement with the changes in the height of the Sun. It reaches the highest values during the afternoon hours. Only in the sporadic cases, the daily maximum can occur before noon hours due to the larger transparency of the atmosphere during this part of the day.

As in the case of the diurnal course, the differentiation of the direct radiation in the annual cycle is mainly controlled by the annual changes in the height of the Sun. In December, when the height of the Sun at noon decreases to 16°, and reaches only 22° in the last days of January, the beam of the Solar rays gets through 4 and 2.5 optical masses of the atmosphere, respectively and the direct solar radiation reaches the lowest values in the year. The intensity of the direct radiation varies from 609-610 $W \cdot m^{-2}$ (Tab. 7). Due to the higher transparency of the atmosphere in spring months than in summer, the annual maximum of the direct radiation shifts to May or April and reaches about 752 and 749 $W \cdot m^{-2}$. During the full summer season, i.e. from June till August, when the Sun is high above the horizon but provided the decreased transparency of the atmosphere, the intensity of the radiation is smaller. The physical properties of the atmosphere, varying in the particular years, and, first of all, the changes in the water vapour content in the air made the intensity of the direct solar radiation to be highly variable during 1971-1997. It is apparent from Tab. 7, which presents the highest and the lowest values, that the intensity varied in the wide range, increasing in certain years much over 800 $W \cdot m^{-2}$ and decreasing in others even below 500 $W \cdot m^{-2}$.

Tab. 7. Mean monthly values of the intensity of direct solar radiation ($W \cdot m^{-2}$) on a perpendicular surface in mid-day hours in Gaik-Brzezowa in the years 1971-1997

Intensity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	609.4	678.5	712.2	749.0	751.5	747.3	748.8	723.8	707.7	700.7	657.1	610.4
Maximum	750.6	801.8	812.9	834.7	829.7	867.0	825.9	831.6	818.8	813.9	771.1	715.3
Minimum	431.2	568.0	483.8	474.5	635.0	539.6	532.7	602.4	501.2	439.6	439.6	457.9

Under the favourable weather conditions and provided the high transparency of the atmosphere, the intensity of the direct solar radiation can reach very high values exceeding 900 $W \cdot m^{-2}$ in the discussed area which is 65% of the Solar constant. The highest value of this radiation, recorded in Gaik-Brzezowa in the period from 1971-1997, occurred on 15 April 1988 and amounted to 976.9 $W \cdot m^{-2}$, that is 71% of the Solar constant.

From the multi-annual course of the mean monthly intensity of the direct radiation it is evident that the intensity did not change significantly during the whole examined period and ranged within the limits from 500 $W \cdot m^{-2}$ in winter to 800 $W \cdot m^{-2}$ in late spring and summer (Fig. 2). In certain years only, the radiation intensity slightly exceeded 800 $W \cdot m^{-2}$ or declined even below 430-440 $W \cdot m^{-2}$, due to the decreased transparency of the atmosphere.

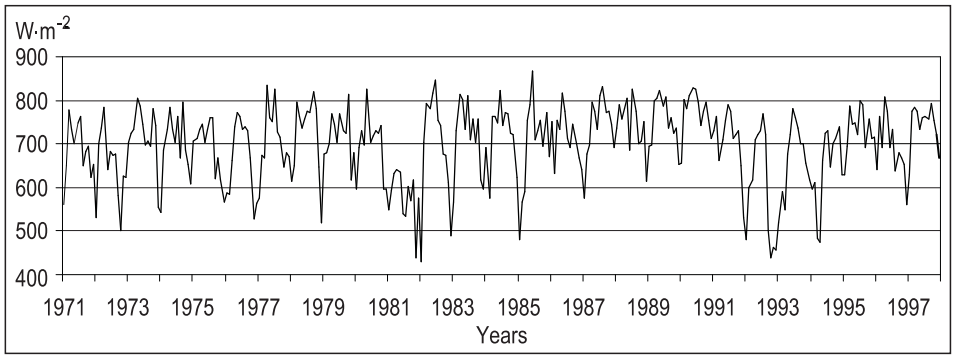

Fig. 2. Direct solar radiation on a perpendicular surface in mid-day hours at cloud-less weather

6. Total solar radiation

Besides the direct radiation, the total solar energy that reaches the active surface consists of the scattered radiation incoming from the entire atmosphere. Under the conditions of the weather without the cloud cover, the scattered radiation at the noon hours makes 30-35% of the total radiation in winter months, and 20-25% in summer. During the year the intensity of the scattered radiation in Gaik-Brzezowa under the conditions of the cloudless weather varies from 90-110 $W \cdot m^{-2}$ in winter months with its minimum in December to 190-210 $W \cdot m^{-2}$ in summer (Tab. 8).

The cloudiness increases the role of the scattered radiation. Its proportion in the total radiation rises at the noon hours to 70% in winter and amounts to 50-55% in summer. In the annual course, as in the case of the cloudless weather, its intensity is the lowest in December, and the highest in the summer months when it ranges from 260 to 280 $W \cdot m^{-2}$. In winter, due to the low height of the Sun above the horizon and, therefore, due to the good conditions for scattering, the intensity of the scattered radiation under both the conditions of the cloudless weather and the real cloudiness, does not show more significant differences. In summer, on the other hand, the intensity of the scattered radiation under the real cloudiness is 25-30% higher than under the conditions of the cloudless weather.

The insignificant role, which the scattered radiation plays in the total solar radiation during the cloudless weather, causes the changes in the total radiation to be in agreement with the variations in the direct radiation, and its intensity to depend on the height

Tab. 8. Mean intensity of solar radiation ($W \cdot m^{-2}$) at cloudless weather and in the conditions of real cloudiness in mid-day hours in Gaik-Brzezowa in the years 1971-1997

Weather conditions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
diffused radiation												
Cloudless	105	133	167	188	209	188	195	167	160	133	98	91
Mean cloudiness	112	160	230	251	272	258	265	251	202	147	105	91
total radiation												
Cloudless	300	433	642	782	865	879	858	795	663	475	328	258
Mean cloudiness	167	251	391	454	502	516	530	537	419	272	167	133
reflected radiation												
Cloudless	167	147	174	154	195	195	188	188	174	126	98	112
Mean cloudiness	98	105	105	98	112	126	119	126	105	70	49	56
absorbed radiation												
Cloudless	140	286	468	628	670	684	663	607	495	349	230	147
Mean cloudiness	77	147	286	356	391	391	412	412	314	202	119	77

of the Sun above the horizon. Therefore, the intensity of the total radiation in Gaik-Brzezowa ranges at average during the year from 260-300 $W \cdot m^{-2}$ in December and January to 860-880 $W \cdot m^{-2}$ in the summer months with the maximum in June. Because of the higher transparency of the atmosphere in spring, the curve of the annual course of the total radiation intensity is asymmetrical with respect to the maximum value in June. The more favourable conditions of sunshine duration are in spring when the input of the total radiation is about 35% higher than in autumn.

The cloudiness, because of the moderating or complete elimination of the income of the direct radiation, results in a much lower intensity of the total solar radiation under the real weather conditions than under cloudless weather. The differences reveal the changes in the cloudiness. In Gaik-Brzezowa the highest cloudiness during the year occurs in winter months when it ranges within the limits of 75-80%. The largest number of the cloudy days and the lowest number of the days with the clear weather also occur in this season. In summer the cloudiness is the lowest and amounts to 55-60%, and the number of cloudy days is also lower as out of 150 of such days during the year only 20% occur in summer. Spring is more cloudy than autumn (Hess *et al.* 1979).

Under the conditions of the real cloudiness, the intensity of the total solar radiation varies in the annual course at average from 130 $W \cdot m^{-2}$ in December to 515-540 $W \cdot m^{-2}$ in summer months (Tab. 8). In winter these values are twice as low in the case of the cloudless weather. In summer, however, due to the lower cloudiness, the differences in the intensity of the total radiation between both the weather types do not exceed 40%.

7. Albedo, radiation reflected from and absorbed by the active surface

The amount of the solar energy that is absorbed by the active surface depends on its ability to reflect the total radiation. The numerical characteristic of this property is albedo. The albedo of the active surface varies relative to its nature and structure, i.e. to the colour, roughness, humidity etc. The mean albedo of the winter months is controlled by the duration of the snow cover. In the warm half-year the albedo depends on the development phases of the plant cover. Therefore, the albedo varies during the year in the very wide range.

In Gaik-Brzezowa, the albedo ranges annually at average from 40-50% in winter months (from December to February) to 20-25% in the remaining part of the year. While the albedo changes in a small range in the summer season which does not exceed 5% in the particular years, then, in the cool season, it is characterized by a very high variability from year to year. The long-lasting snow cover can result in the mean monthly albedo exceeding 70%. If during the winter months, however, due to the frequent thawing periods, the number of the days with the snow cover is low or if the snow cover occurs sporadically, the albedo can decrease below 20%.

The high values of the albedo of the winter months and low one in the remaining part of the year result in the evened annual course of the intensity of the radiation reflected from the active surface, and the amplitude of the annual oscillations does not exceed 100 $W \cdot m^{-2}$. In Gaik-Brzezowa the intensity of the radiation reflected under the conditions of the cloudless weather ranges during the year from ca 100-110 $W \cdot m^{-2}$ in November and December to 190-195 $W \cdot m^{-2}$ in the period from May till August (Tab. 8). Under the conditions of the real cloudiness the amount of the reflected energy is 40-50% lower in winter, and 30-35% in summer.

The part of the solar energy that is not reflected but absorbed by the active surface, is converted into the heat energy and controls the thermal conditions of this surface and of the adjacent surfaces of the atmosphere. The amount of the absorbed energy mainly depends on the total solar radiation and albedo. Therefore, in Gaik-Brzezowa in the summer season when the values of the albedo are low, the active layer absorbs about 75%, but in winter when the albedo is high – it absorbs 50-60% at average, and in certain years only 30% of the total incoming radiation.

When there is the cloudless weather, during the noon hours, the intensity of the absorbed radiation varies during the year from 140-150 $W \cdot m^{-2}$ in December and January to over 680 $W \cdot m^{-2}$ in June (Tab. 8). Under the conditions of the real cloudiness, the mean intensity of the radiation absorbed by the surface in summer is 40%, and in winter even 50% lower than under the conditions of the cloudless sky. Then, it ranges from 75-80 $W \cdot m^{-2}$ in winter to 410-420 $W \cdot m^{-2}$ in July and August.

8. Conclusions

The analysis of the series of sunshine duration records in Cracow and in other parts of Europe indicates that the sunshine duration has the tendency to decline in its multi-

annual course. The analysis of the monthly and annual totals of sunshine duration and particular streams of the solar radiation in the period from 1971-1997, performed against such a background, shows the evened out nature of these parameters, without a define direction of the changes. Although the annual and monthly values diverge from the mean values in certain years, they are related to the short-lasting influences of the local factors and do not affect the general direction of the changes. A very good example can be the decreasing transparency of the atmosphere and weakening of the incoming direct radiation in Gaik-Brzezowa in 1981. That was the effect of the high air pollution with dust due to the intensive works carried out when constructing the water reservoir at that time.

In the discussed part of the Carpathian Foothills one can notice the slightly more favourable solar conditions in the east (Szymbark) in winter, and in the west (Gaik-Brzezowa) in summer. That can be the result of the climate continentality increasing eastward.

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