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Počet dusných dní na území Slovenska
(Number of Sultry Days in the Territory of Slovakia)

Kristína Szabóová, Slovenský hydrometeorologický ústav, kristina.szaboova@shmu.sk

Abstract: Sultriness is formed by the interaction of several weather factors. It is the state of the atmosphere when the water vapor pressure exceeds 18.7 hPa. This condition has adverse physiological effects on plants, animals and especially on the human body. For this reason, in this research, emphasis was placed on the time evolution of sultriness at the meteorological station Hurbanovo in the Slovak Republic. The paper will examine the 40-year period (1981–2020). The study is a continuation of the work of Štefan Kveták, who examined the previous 30-year period (1951–1980). We hypothesized that the number of sultry days is also increasing due to climate change. The basis of the whole assumption was hourly data from meteorological stations in the database of the Slovak Hydrometeorological Institute. As the scientific goals of the project, we preferred the categorization of sultriness according to various criteria, the evaluation of their frequency and time trends of occurrence, and we compared their development with the previous period.

Keywords: sultriness – bioclimatology – climate change

Abstrakt: Dusno vzniká pôsobením viacerých poveternostných faktorov. Je to stav atmosféry, keď tlak vodnej pary prekročí 18,7 hPa. Tento stav má nepriaznivé fyziologické účinky na rastliny, živočíchy a najmä na ľudský organizmus. Z tohto dôvodu sa v tomto výskume kládol dôraz na časový vývoj sultrín na meteorologickej stanici Hurbanovo v Slovenskej republike. V príspevku sa bude skúmať 40ročné obdobie (1981–2020). Štúdia nadväzuje na prácu Štefana Kvetáka, ktorý skúmal predchádzajúce 30ročné obdobie (1951–1980). Predpokladali sme, že počet dusných dní sa zvyšuje aj v dôsledku klimatických zmien. Základom celého predpokladu boli hodinové údaje z meteorologických staníc v databáze Slovenského hydrometeorologického ústavu. Ako vedecké ciele projektu sme uprednostnili kategorizáciu dusných dní podľa rôznych kritérií, vyhodnotenie ich frekvencie a časových trendov výskytu a porovnali sme ich vývoj s predchádzajúcim obdobím.

Kľúčové slová: dusno – bioklimatológia – klimatické zmeny

1. Introduction

With the increasing summer heat waves, the impact of the weather on the human body is coming into focus. With this work, we want to find out whether climate change is increasing the number of sultry days at the weather station, which may have a negative impact on the health of the population. If the increasing trend is confirmed, appropriate adaptation measures should be chosen. The results of the work can also be used as background material for further bioclimatic as well as technical analyses. The topic has a wide application not only for meteorologists, climatologists but also for example for health professionals, foresters, biologists and experts in many other scientific disciplines. The main aim of the work was to evaluate the temporal distribution of the sultriness and its evolution at the professional meteorological station Hurbanovo. Specifically, in which seasons it occurs most frequently,

which months are most affected by it and which hour. We also investigated what values are favourable for humans, in which situations we have the most pleasant conditions in terms of air temperature and relative humidity. Slovak Hydrometeorological Institute provided values for two climatic indicators for meteorological weather station in Hurbanovo, namely hourly data on air temperature and relative humidity. Both for the period 1981–2020, actually a 40-year period. Without them, it would not be possible to calculate the water vapour pressure, which is an indispensable data for specifying the occurrence of sultriness in our country.

The paper followed the work of K. Scharlau (Scharlau 1943). Within the domestic publications, a scientific article by Štefan Kveták, a former employee of the Slovak Hydrometeorological Institute, who in 1986 made a research on dry and sultry weather in Hurbanovo for the period 1951–1980, was taken as a basis for the research (Kveták 1986). From the foreign literature we had at our disposal during the processing a scientific article (Zarnowiecky 2003) in English version. From the literature used, the boundaries of the sultriness as established by K. Scharlau, where asphyxiation occurs when the water vapour pressure exceeds 18.7 hPa (Scharlau 1943).

2. Data

2.1 Geographical characteristics of meteorological station Hurbanovo

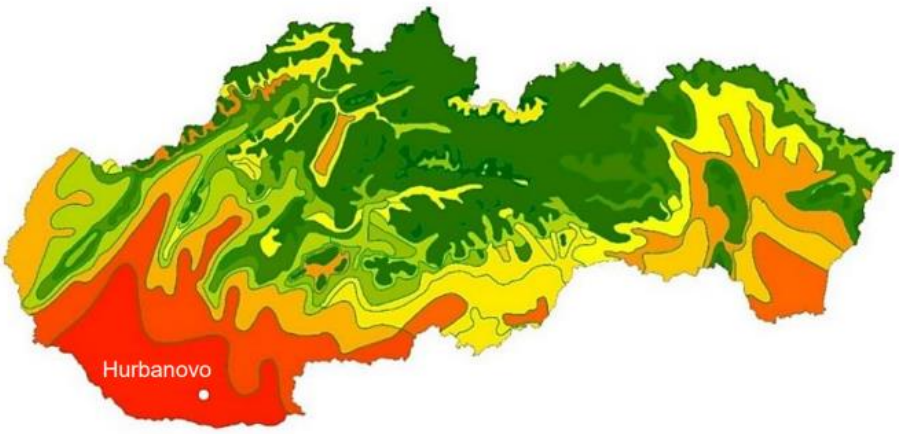


Fig. 1 Location of meteorological station Hurbanovo within Slovakia.

The professional meteorological station Hurbanovo was chosen because it is our most southern located station, which belongs in terms of climatic regionalization to the warm region and to the climatic-geographical type of warm lowland climate. This station characterises a climatically extensive part of the Danube Plain, our warmest and most agriculturally productive area (Fig. 1). As previously mentioned, Hurbanovo is a professional station located in central Europe (47°52′23″N, 18°11′36″E). It is located at the climatically warmest point of the Danubian Lowland of southern Slovakia, at the confluence of the Žitava and Nitra rivers (Hurbanovo city 2021). Hurbanovo has a long-term observation station with more than 100-years of meteorological observations. Data from Hurbanovo, historically the most important station-observatory for meteorology and climatology on the territory of Slovakia, have been available practically continuously for a century and a half (Výberči et al. 2021). The oldest published weather data for Hurbanovo in the professional literature are from 1871, but we have daily Hurbanovo meteorological data since 1. 1. 1872. The Meteorological Observatory in Hurbanovo is a professional station with the most complete and best processed observational material in Slovakia. It is not only the basic station for Slovak climatological research, but also its flagship. The importance of the station is also evidenced by the fact that in September 2020 it was included in the important list of the so-called "*Centennial Observing Stations of the World*

Meteorological Organization (WMO)". As can be seen in Fig. 1, the station is characterized by a lowland relief. Its elevation is 115 m (Bochníček et al. 2015). As the whole Slovakia lies in the temperate zone, the weather is characterized by the regular alternation of four seasons. The distance from the sea causes that the climate here is transitional between oceanic and continental climate (Balážovičová 2015). In the west of Slovakia, where the station Hurbanovo is also located, oceanic and in the east continental airs have a greater influence masses, but altitude has the greatest influence on climate formation (Bochníček et al. 2015). Due to the high quality of soils, the area ranks among the most fertile and most agriculturally exploited in Slovakia. This causes that natural vegetation had to give way to human needs and the surroundings of the intravilan are mainly arable land. Animal species are abundantly represented here especially birds, which are the reason for the creation of the town's several protected areas (Jobbágy 2013).

2.2 Sultry weather

An indispensable step to find out where and when sultry weather has occurred is to calculate the water vapour pressure. For this calculation, we needed air temperature and relative humidity data. Water vapor pressure, like air temperature, decreases with increasing altitude (Chromov 1968). It reaches its maximum values on the lowlands in the summer months, lowest at high mountain altitudes in winter. Annual course of water vapour pressure is similar to the annual course of air temperature (Trizna 2012). It is characterised by one maximum occurring in July and one minimum in January. The water vapour pressure has its minimum in the morning hours, before sunrise. During day, as the air temperature rises evaporation increases, increasing the water vapour pressure up to reaching a maximum around 14:00. Later, it starts to gradually decrease towards morning minimum. This simple diurnal course of pressure water vapour pressure is particularly common in high mountain climates and, in winter, at lower (Wiederhold 1997). In the warm half of the year, thermal turbulence is manifested at lower altitudes, water vapour moving away from the earth's surface into the upper atmosphere, modifying the daily water vapour pressure.

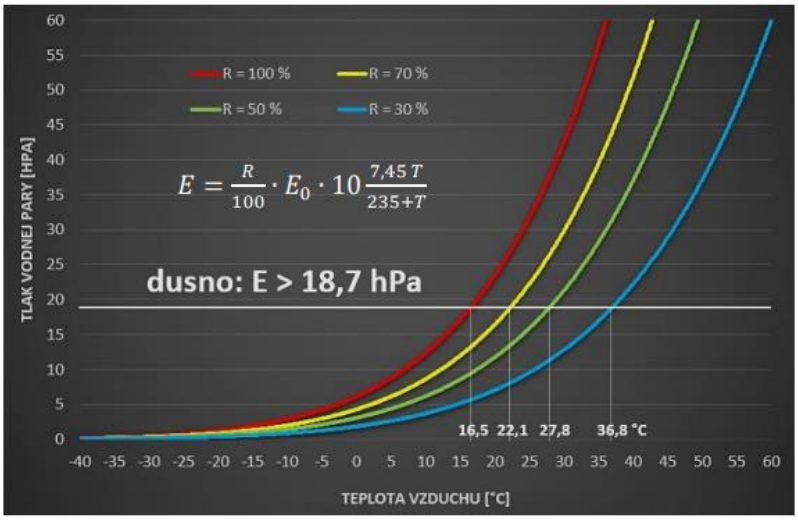


Fig. 2 Dependence of water vapor pressure on air temperature at a given relative humidity (M. Šinger 2016; taken from the official website of the Slovak Hydrometeorological Institute).

The daily run has two peaks, a major maximum in the morning around 9:00 h, a secondary one in the evening (around 20:00 h) and two minima, the main minimum is identical to that of the simple daily course, i.e. before sunrise, and the secondary minimum occurs at the time of the daily maximum air temperature around 15:00 h (Bochníček O. et al. 2015). As already mentioned, sultriness occurs when the water vapour pressure exceeds 18.7 hPa (all gases in

the atmosphere together form a total pressure of air (in our area an average of 1 013.25 hPa) and part of it water vapour). The amount of water vapour in a given volume of air is limited by its temperature, the higher it is, the higher the temperature, the more water vapour a given volume of air can contain. This dependence can be described by the so-called Clausius Clapeyron equation (SHMÚ 2016). In Fig. 2 we can be seen in a simplified expression of sultriness, because there are several variants. On the x-axis (vertical axis), the pressure of the water vapour. On the y-axis (horizontal axis) is the air temperature. The minimum value of sultriness is shown by the white line. On the graph we can see 4 more curves describing this dependence at different relative humidity (100, 70, 50, 30%). This shows that it is not possible for sultriness to occur at temperatures below 16.5 °C, because the water vapour pressure at 100% relative humidity would always be below 18.7 hPa. One hundred percent relative humidity during the day is rare (e.g. after/during rain, especially in summer), so the graph shows dependencies even for lower relative humidity values. For a given relative humidity, the minimum values of air temperature at which sultriness occurs are also given. It can be seen that in dry air (30% relative humidity), sultriness is reached at very high temperature values, up to almost 37 °C (SHMU 2016). It clearly has harmful physiological effects on humans and some animals. It adversely affects people with diseases of the cardiovascular system and puts a strain on the thermoregulatory mechanisms of the organism, which is reflected in the reduced working capacity of healthy people (Kveták 1986). It is largely related to the physiological process of thermal regulation in the human body. Heat dissipation is self-regulated by the body through evaporation, conduction, and last but not least, radiation. Heat dissipation from the body can be prevented by heat input from outside in very warm weather, which limits evaporation and thus the dissipation of excess heat. In such circumstances, an uncomfortable feeling of sultriness may arise. Climatological variables such as effective longwave radiation, wind speed, as well as body work and clothing are involved. As previously written, sultriness can occur at higher air temperatures (e.g. at an air temperature of 30 °C it occurs when the relative humidity reaches at least 45%) or at high humidity (e.g. at a relative humidity of 100% and an air temperature of at least 17 °C). It is not an easy job to identify and assess the threshold of sultriness, thermal comfort and cold in humans, because the thermal sensation in the same meteorological conditions may be different in different people, as it depends greatly on the human body and on the current physiological state of the person. It should be remembered that the human body gives off heat not only by conduction, convection and radiation, but also by evaporation. As a result of thermal regulation the organism reacts to external weather influences in such a way that heat expenditure in a warm environment increases and decreases in cold environments. The human body can, to a certain extent to protect itself from overcooling and overheating through thermoregulatory mechanisms. To be taken into account clothing, physical load, acclimatisation, etc. The fact is that increased temperature is more easily tolerated if the relative humidity is lower. But if the relative humidity is less than 20%, evaporation from the surface of the mucous membranes of the respiratory tract is so great that the mucous membranes begin to dry out. It is also worth pointing out the loss of water due to evaporation and perspiration of the human body. It is now known that air purity, ionisation, the electrical properties of the air environment, the magnetic field and the content of various impurities in the air also affect well-being. Several observations have shown that the thermal equilibrium of a person at rest is already difficult to maintain at an air temperature of 40 °C and a relative humidity of 30% or at 30 °C and a relative humidity of 85%. Beyond these limits, the subjective sensation of most people deteriorates. It is recommended to pay close attention to the measurement and recording of infrared radiation because it affects the thermal sensation of a person. It fluctuates strongly with changes in various atmospheric factors (e.g. cloud cover, content of water vapour, fog, airborne dust concentration). This circumstance is of particular importance in the occurrence of summer sultriness situations. For example, for a long time before a thunderstorm, an increase in the sensation of sultriness has

been known to be associated with an increase in cloud cover and vapour in the air (Švec 2014). Sultriness is more common in large cities, where increased air pollution and increased infrared radiation due to hot asphalt and house walls contribute (Kolesár 1989). In our country, it occurs mainly in the summer half of the year, mainly in the lowlands. The number of sultry days with increasing altitude altitude decreases, in mountainous areas at 1 000 m above sea level rarely occurs. The most pleasant weather for man may be considered a state when the air temperature is around 17 °C and the humidity is on average humid, around 50% (Kveták 1986).

2.3 Relationship between climate change and sultry weather

The threat of climate change and its negative impacts is now a very serious and immediate problem. The most striking manifestation of climate change is undoubtedly global warming, manifested both on land and in the oceans. Warming on land brings with it a number of remarkable, particularly negative, consequences. The increase in average air temperature is having a particularly negative impact on natural ecosystems, which are finding it very difficult to adapt to this change, in addition to the increasingly frequent extreme weather events such as: heat waves, prolonged more prolonged and intense droughts, stronger and more violent storms, etc. (SHMÚ 2019). The occurrence of showers depends mainly on the temperature (Lapin 2001). Consequently, we assume that if a longer time series of increasing temperature is observed air in Slovakia, and the whole world, the sultry weather will show a similar trend. The sultry weather may, to a large extent promote the formation of thunderstorms, as sufficient moisture in the lower levels of the troposphere is one of the basic conditions for their development (SHMÚ 2016). As we can see in Fig. 3 The occurrence of sultriness has a similar pattern of development as temperature of air, which is of course not surprising, as long as the calculation of sultriness includes the element of air temperature.

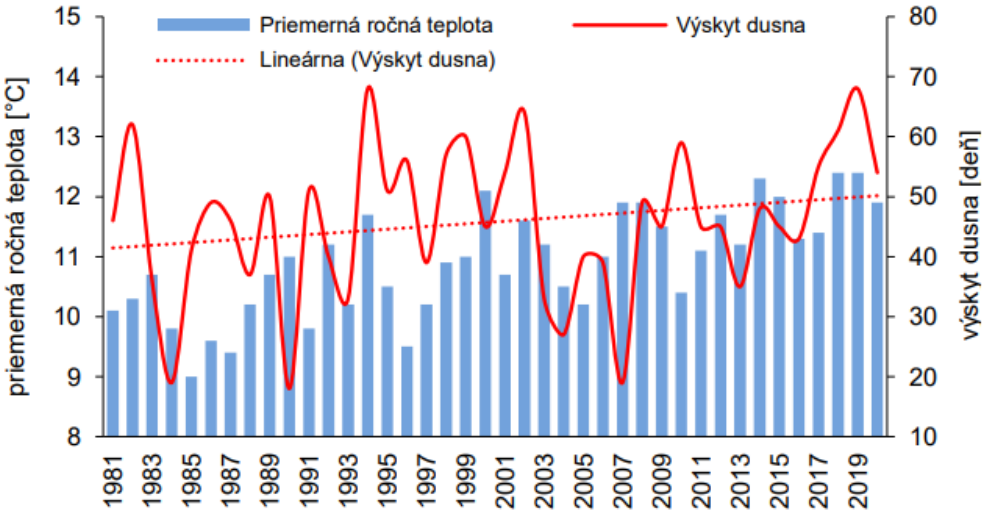


Fig. 3 Relationship between average of air temperature and occurrence of sultriness.

3. Methods

From the air temperature and relative humidity data, water vapour pressure was calculated as it is the basic data in detecting the occurrence of sultriness. Sultriness is the result of limited evaporation and is dependent on the water vapour pressure in the air. It is measured in Pascals (Pa) (Kvetak 1986). It has been calculated using the formulas below. We used 2 different formulas to calculate the water vapor pressure, depending on whether it was the summer (March to August) or winter (September to February) season. For the winter months, the formula for the flat ice surface has an exponent of the form:

$$e = R\left(6{,}1.10^{\frac{9{,}5t}{265{,}5+t}}\right) \quad (1)$$

and for the summer period:

$$e = R\left(6{,}1.10^{\frac{7{,}45t}{235+t}}\right) \quad (2)$$

where

e = water vapour pressure

R = relative humidity (%)

t = air temperature (°C)

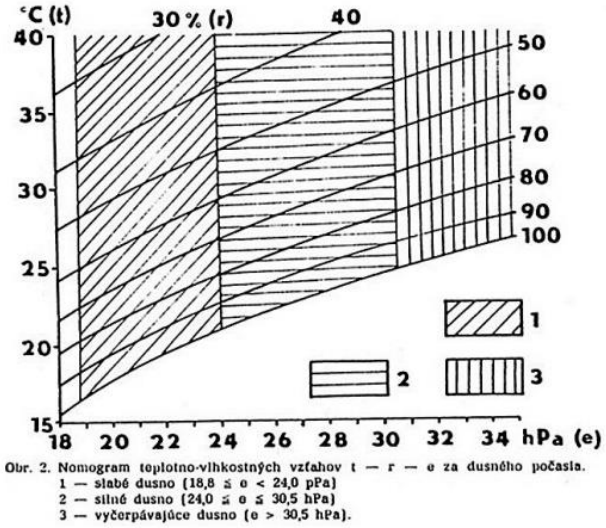
(Matveev, 1965).

According to the work of Stefan Kveták (Kveták 1986), the number of days with the occurrence of sultriness and the categorization into three types was found according to the value of water vapour pressure. K. Scharlau (Scharlau 1943) determined the beginning of the of the occurrence of sultriness when the water vapour pressure reaches the value of >18.7 hPa. The interval 18.8 ≤ ***e*** < 24.0 hPa he designated as weak sultriness, 24.0 ≤ ***e*** ≤ 30.5 hPa strong sultriness, and when *e* > 30.5 hPa exhaustive sultriness (Fig. 4).

4. Results

4.1 Temporal distribution of sultriness

When examining the diurnal pattern of the occurrence of sultriness over a single day, we found that sultry days occur most frequently in the morning at 7:00 am, 8:00 am and evening 7:00 pm, 8:00 pm. The most rarely occurring sultry days are occurring at 3:00 and 4:00. The most common onset of sultry weather is between 6:00 a.m. and 10:00 a.m. maximum onset is between 7:00 p.m. and 9:00 p.m. in the evening, and sporadic occurrences in the overnight and early morning hours. We have obtained a double daily water vapour pressure run with two minima and two maxima (Fig. 5). The cause of this of the double diurnal run may be that the soil is warming from the sunrise, around 7:00 to 9:00 h, when it increases evaporation and the water vapour pressure near the ground surface increases. Gradually, the temperature increases and convection intensifies. As a result of the increasing turbulence and convection, there is an increased transport of water vapour to altitude. In this case evaporation can no longer make up for the so-called loss and therefore the water vapour content drops to a second minimum, which becomes apparent around 15:00 to 16:00 h. Evening maximum around 19:00 to 20:00 h is related to a decrease in turbulence intensity. In the night hours we can again see a decrease in the content of water vapour in the air as the air begins to cool from the ground surface and condensation of water vapour occurs.



Obr. 2. Nomogram teplotno-vlhkostných vzťahov t — r — e za dusného počasia.
1 — slabé dusno (18,8 ≤ e < 24,0 pPa)
2 — silné dusno (24,0 ≤ e ≤ 30,5 hPa)
3 — vyčerpávajúce dusno (e > 30,5 hPa).

Fig. 4 Nomogram of thermal-moisture relations t - r - e for sultry weather. Taken from the Geographical Journal, Yearbook 38, Number 1 (1986) (own development).

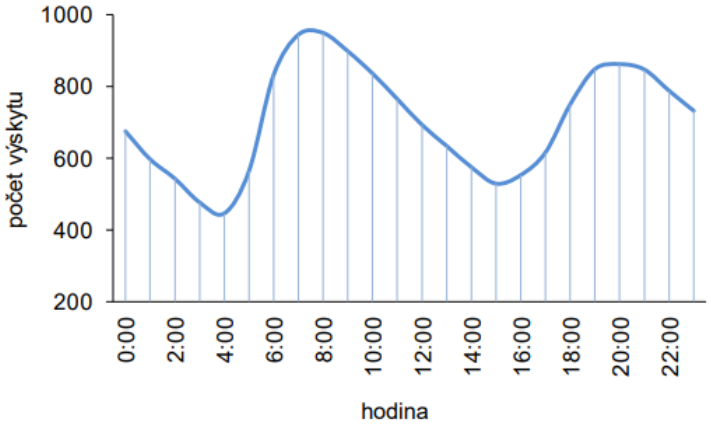


Fig. 5 Daily course of sultriness in the period 1981–2020 at meteorological station Hurbanovo.

4.2 Occurrence of sultiness in the individual categories

The highest total number of hours of sultry weather in Hurbanova over the 40-year period was in 2019 (987 h) and 2002 (722 h). The lowest number was recorded in 1990 (75 h) and the second lowest was 1984 (109 h). The average number of hours with sultry weather per year is approximately 424 h. It can be concluded that the number of hours with sultry weather increases from 1981 to 2020. This increase has been represented by a linear trend line (Fig. 6). From the value of the coefficient of determination also shown in the graph (*R2*) shows that the linear dependence is slight, insignificant, because the tightness of the dependence (*R2* = 0.0435) is close to zero, it is independence (Nováková 2013). The second way we examined the change in the number of sultry days was by comparing the data with the previous period, detailed below. As previously mentioned, the occurrence of sultriness by intensity can be categorized into 3 types – weak, strong, exhausting sultriness (Scharlau 1943). In our case, we have defined two groups similarly to S. Kveták in his work (Kveták 1986). The first group included the occurrence of sultry days, all days in which the water vapor pressure exceeded 18.7 Pa at least once (Fig. 6), and the second group represented the occurrence of severe and exhausting sultry days, i.e., cases in which the water vapor pressure exceeded 24.0 hPa (Fig. 7).

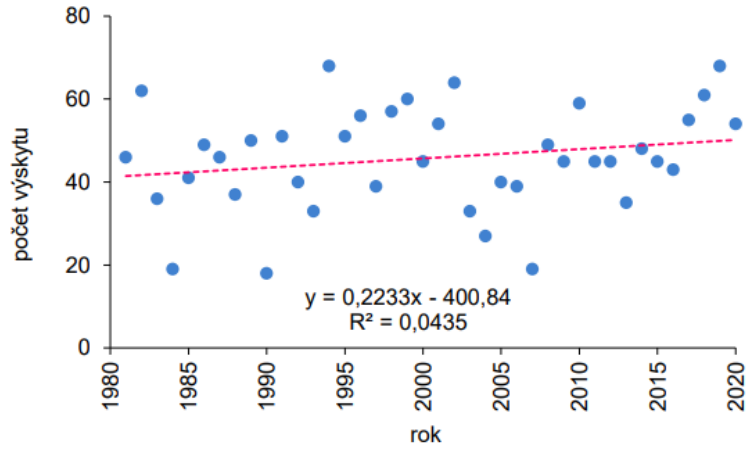


Fig. 6 Occurrence of sultry days in the period 1981–2020 for the station Hurbanovo.

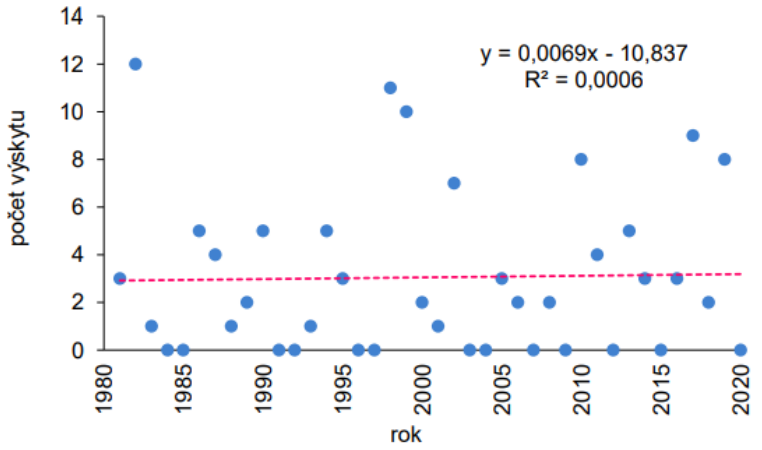


Fig. 7 Occurrence of strong and exhausting sultry days for the period from 1981 to 2020 for the station Hurbanovo

Comparison of sultriness occurrence (1981–2020) with the previous period (1951–1980)

Comparing the 1951–1980 period with the 1981–2020 period, we see that the number of days with sultry weather has in Hurbanovo increases by 1.9. Kveták's work (Kveták 1986) gives 43.9 days of sultry weather per year, and the last 40-year period shows us 45.8 days per year. With severe and debilitating sultriness, the situation is reversed. It decreases by −1.2 days. Previously it was 4.2 days per year, which is now 3.1 days per year for the 40-year period (Tab. 1).

Occurrence records

Extreme values of sultriness within the study period occurred mainly in 1987, 1998 and 2010, 2017, and most frequently in the months of July and August at 18:00 hours. The station recorded the highest value of the occurrence of sultriness when the water vapour pressure exceeded 29.65 hPa, which corresponded to an air temperature of 27.2 °C and 82% relative humidity. This record water vapour pressure occurred on 2 July 1987. Another extreme value (28.3 hPa) was recorded by the station at 85% relative humidity and an air temperature of 25.8 °C (Tab. 2).

Tab. 1 Comparison of the occurrence of sultriness 1981–2020) with the previous period (1951–1980) in Hurbanovo.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Rok
	s dusným počasím (e ≥ 18,8 hPa)												
1951 – 1980	-	-	-	-	1,4	10,6	14,3	12,2	4,8	0,6	-	-	43,9
1981 – 2010	-	-	-	-	2,1	9,7	14,9	13,9	3,5	0,3	-	-	44,4
1981 – 2020	-	-	-	-	1,8	10,5	15,3	14,5	3,5	0,3	-	-	45,8
rozdiel 30 rokov	-	-	-	-	0,7	-0,9	0,6	1,7	-1,3	-0,3	-	-	0,5
rozdiel 40 rokov	-	-	-	-	0,4	-0,1	0,9	2,3	-1,3	-0,4	-	-	1,9
	so silným a vyčerpávajúcim dusnom (e ≥ 24,0 hPa)												
1951 – 1980	-	-	-	-	-	1,1	1,5	1,5	0,1	-	-	-	4,2
1981 – 2010	-	-	-	-	-	0,6	1,2	1,0	0,0	-	-	-	2,9
1981 – 2020	-	-	-	-	-	0,7	1,2	1,1	0,0	-	-	-	3,1
rozdiel 30 rokov	-	-	-	-	-	-0,5	-0,3	-0,5	-0,1	-	-	-	-1,3
rozdiel 40 rokov	-	-	-	-	-	-0,4	-0,3	-0,4	-0,1	-	-	-	-1,2

Maximum duration

The longest continuous duration of the sultriness was 155 h from 5:00 pm on August 22, 2019 to 3:00 am on August 29, 2019 (Tab. 3). At that time, the sultry weather in Hurbanova persisted for almost 6.5 days. The next maximum is 127 h on 9/7/1999 9:00–14/7/1999 16:00, 5/8/1999 19:00–10/8/1999 22:00; further in 2013 (114 h on 18/6/2013 18:00–23/6/2013 12:00). Also significant are the years with continuous duration of the shower, namely: 2002 (95 h on 30/07/2002 15:00–3/08/2002 14:00) and 2016 (89 h on 25/07/2016 20:00–29/07/2016 13:00. In 40 years, more than 50 cases of sultry weather with a duration longer than 24 h have been recorded in Hurbanova. The longest continuous duration of severe sultriness was 16 h from 19:00 on 15 July 2010 to 10:00 on 16 July 2010 (Tab. 4). The next maximum in this category lasted 14 h on 14 Aug 2010 21:00–15 Aug 2010 10:00 in the same year; then in 1987 (12 h on 2 Jul 1987 8:00–2 Jul 1987 19:00) and in 1999 (12 h on 9 Aug 1999 15:00–10 Aug 1999 2:00). Significant years with continuous duration of heavy rain are 1998 (11 h on 3/8/98 17:00–4/8/98 3:00), 1994 (9 h on 29/6/94 18:00–30/6/94 2:00) and 1999 (9 h on 7/8/99 9:00–7/8/99 17:00).

The most pleasant conditions for humans and animals

Almost all meteorological elements influence the stay of man in nature. The humidity of the air in conjunction with the temperature has a considerable influence on the organism. The most pleasant conditions for humans are those where the relative humidity is 50% and the air temperature is 16–18 °C (and where the other values are $9.1 \geq e \geq 10.3$ hPa). Both cold and heat are more easily tolerated in dry climates than in humid climates. Taking into account the precision of the relative humidity measurement and its variability, we extended the value to the interval $48 \leq r \leq 52\%$. The selected criterion defining very pleasant conditions for humans ($48 \leq r \leq 52\%$, $16 \leq t \leq 18$ °C) occurs in all months in Hurbanov except January. These results were obtained after processing data for 40 years (1981–2020). Very pleasant conditions occur most often in spring (April and May) and autumn (September and October) over the 40-year period. This is when there is an almost synchronous occurrence of peaks in daytime temperature (16–18 °C) and relative humidity (48–52%) abundance, e.g. around midday in April. In winter, very pleasant conditions are practically absent, as high relative humidity and low air temperatures prevail.

In summer, temperatures of 16–18 °C occur most often at night and relative humidity 48–52% around midday. This temporal discrepancy in the daily timing of these intervals of meteorological elements results in the sporadic occurrence of very pleasant conditions for

humans in summer, which usually occur only under certain meteorological situations. The assessed criterion of very favourable conditions is defined by a relatively narrow range of air temperature and relative humidity, which results in relatively low frequencies of occurrence of this phenomenon compared to other similar criteria. Since 1981, very pleasant conditions have increased by 2.4 days in 40 years, as shown in tab. 5. In 30 years this has increased by 3.1 days. The average number of days per year for the period 1951–1980 was 19.2. For the period 1981–2020 it increased to 21.6 days. The table shows that these numbers decrease in August and October, i.e. the last examined period shows less pleasant conditions than in the previous period. The month of April shows the highest number of such pleasant days.

Tab. 2 Maximum values of sultriness for the period 1981 – 2020 at the meteorological station Hurbanovo.

dátum	čas	teplota vzduchu [°C]	vhkosť vzduchu [%]	tlak vodnej pary [hPa]
8-8-1981	18:00	23,6	0,94	27,44
19-7-1982	09:00	22,8	0,95	26,42
27-6-1983	17:00	23,0	0,93	26,18
12-7-1984	00:00	24,5	0,71	21,88
17-7-1985	08:00	22,8	0,84	23,36
18-6-1986	08:00	25,5	0,79	25,84
2-7-1987	10:00	27,2	0,82	29,65
2-9-1988	18:00	25,3	0,77	24,88
20-8-1989	19:00	23,6	0,84	24,52
30-6-1990	10:00	28,8	0,58	23,02
13-7-1991	19:00	24,2	0,90	27,24
2-8-1992	20:00	22,2	0,86	23,06
18-7-1993	12:00	22,4	0,91	24,70
29-6-1994	21:00	25,3	0,83	26,82
14-7-1995	20:00	21,6	0,97	25,07
15-7-1996	20:00	23,9	0,80	23,78
7-9-1997	12:00	20,1	1,00	23,57
3-8-1998	21:00	25,8	0,85	28,30
9-8-1999	21:00	25,1	0,85	27,14
14-8-2000	18:00	23,5	0,87	25,24
15-7-2001	08:00	30,2	0,61	26,24
16-7-2002	11:00	26,9	0,76	27,00
13-6-2003	18:00	27,2	0,60	21,69
25-7-2004	11:00	22,2	0,82	21,99
28-7-2005	06:00	24,8	0,78	24,47
26-6-2006	19:00	28,6	0,63	24,72
20-7-2007	17:00	33,2	0,42	21,42
15-8-2008	15:00	31,1	0,58	26,27
22-8-2009	17:00	23,7	0,81	23,79
15-8-2010	13:00	27,9	0,73	27,50
14-7-2011	23:00	23,5	0,90	26,11
25-7-2012	14:00	23,4	0,81	23,36
19-6-2013	19:00	29,9	0,63	26,64
18-7-2014	15:00	23,6	0,87	25,39
17-8-2015	13:00	24,4	0,76	23,28
25-7-2016	08:00	26,0	0,75	25,27
5-8-2017	03:00	23,8	0,93	27,47
3-8-2018	07:00	23,2	0,88	25,07
27-6-2019	11:00	32,6	0,55	27,12
15-8-2020	11:00	23,2	0,83	23,65

Tab. 3 10 longest periods with continuous duration of sultry weather for the period 1981–2020 for Hurbanovo.

	rok	počet hodín	počet dní	odkedy	dokedy
1.	2019	155	6,4	22-08-19 17:00	29-08-19 03:00
2.	1999	127	5,3	09-07-99 09:00	14-07-99 16:00
3.	2013	114	4,8	18-06-13 18:00	23-06-13 12:00
4.	2014	101	4,2	27-07-14 06:00	31-07-14 11:00
5.	2002	95	4,0	30-07-02 15:00	03-08-02 14:00
6.	2016	89	3,7	25-07-16 20:00	29-07-16 13:00
7.	1994	83	3,5	27-06-94 18:00	01-07-94 05:00
8.	2010	80	3,3	13-08-10 06:00	16-08-10 14:00
9.	2006	73	3,0	20-06-06 17:00	23-06-06 18:00
10.	2008	72	3,0	31-07-08 15:00	03-08-08 15:00

Tab. 4 10 longest periods with continuous duration of strong sultry weather for the period 1981–2020 for Hurbanovo.

	rok	počet hodín	počet dní	odkedy	dokedy
1.	2010	16	0,6	15-07-10 19:00	16-07-10 10:00
2.	2010	14	0,5	14-08-10 21:00	15-08-10 10:00
3.	1987	12	0,5	02-07-87 08:00	02-07-87 19:00
4.	1999	12	0,5	09-08-99 15:00	10-08-99 02:00
5.	1998	11	0,4	03-08-98 17:00	04-08-98 03:00
6.	1994	9	0,3	29-06-94 18:00	30-06-94 02:00
7.	1999	9	0,3	07-08-99 09:00	07-08-99 17:00

Tab. 5 Average number of days in Hurbanovo with very pleasant conditions.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Rok
	s veľmi príjemnými podmienkami (48 ≤ r ≤ 52 %, 16 ≤ t ≤ 18 °C)												
1951 – 1980*	-	0,1	1,2	4	4,3	1,8	0,6	1,0	3,5	2,5	0,2	-	19,2
1981 – 2010	-	0,2	1,3	5,3	4,4	2,4	1,0	1,0	3,6	2,7	0,3	-	22,3
1981 – 2020	-	0,2	1,3	5,5	4,3	2,1	1,0	0,9	3,5	2,4	0,5	-	21,6
rozdiel 30 rokov	-	0,1	0,1	1,3	0,1	0,6	0,4	0,0	0,1	0,2	0,1	-	3,1
rozdiel 40 rokov	-	0,1	0,1	1,5	0,0	0,3	0,4	-0,2	0,0	-0,1	0,3	-	2,4

5. Discussion

The weather is constantly changing across the Earth and we are we have to adapt. Sometimes it makes life easier, but sometimes just the opposite. So it is with sultry weather. In the last few years of our century, the temperature has been rising continuously, and as the occurrence of sultry weather is related to the air temperature, the number of sultry days has also been increasing. Experts have not been studying sultry weather for long, although this state of the atmosphere has been present in the past. Nowadays, during the summer season, air-conditioning is used, which was rare twenty years ago and is now found in almost every shopping centre. The question arises, is air conditioning healthy for the human body? And what is the situation with sultriness? It has been mentioned many times that it is an unpleasant sensation when we do not feel well. The question arises as to how we can defend ourselves

against it. In our opinion, adaptation measures could be implemented more widely in cities, for example, in the form of more vaulted showers in the streets, which blow water and air at the same time and under which people can walk and freshen up. This could be expanded especially on asphalt surfaces. Unfortunately, we cannot escape the sultriness. And they don't have to be forty degrees Celsius right away, twenty-five is enough. With high humidity, sweat has nowhere to evaporate and the body can't cool itself. You can go in the water, but you go out and it's the same sweltering air again. The overworked body feels no relief. When it's sultriness, a thin, half-centimeter layer of air saturated with water vapor sticks over the skin and can't take in any more. You wait for the movement of the breeze as for a ready-made miracle. Even the slightest breeze is a refreshing gift because it blows away the vapor-saturated air and allows the body to let out more sweat (Čabajová 2011). Compared to the scientific work of Kvetak (1986), there were continuing developments rather than similarities. It can be seen that individual values shift to later periods. This can be clearly seen in the occurrence of sultriness, which shifts towards the month of August, whereas previously it was clearly the month of July. In recent decades, it has also been much more pronounced in the earlier autumn months, such as September and rarely October. However, on a day-to-day basis, we get similar results. Towards the limit of sultriness we have reached according to the Scharlau criterion and we have to note, that his classification only applies to climates in which Slovakia is located. In our latitudes the relative humidity depends significantly on the direction of the flow, the vegetation cover and the precipitation regime, the leeward effects, the presence of urban agglomerations or water areas. The potential evaporation (maximum possible under given meteorological conditions) depends on the relative humidity and air temperature. It is still sultriness in the equatorial region, where in places the water vapour pressure exceeds the above limit, sometimes even over 40 hPa (in our case it is exhaustive sultriness according to Scharlau's criterion). Periodic sultriness is in the subtropics in summer, especially in areas of monsoon rains. Episodic sultriness can occur in all other regions of the world except polar and high mountain areas, in Slovakia about 30% of days in summer (lowlands) and in 10% at 700 m a.s.l. (Lapin 2001). In the previous section we explained the spatial distribution of moisture characteristics in different parts of the world. We can add to this that mainly due to the change in air temperature in the last two decades, the incidence of sultriness has been increasing not only in our territory, but also in neighbouring countries such as Poland, Hungary and the Czech Republic (Zarnowiecki 2003). When characterizing sultry weather within the framework of bioclimatology, one sentence could be said to be: 'Sweat is, evaporation is not'. From the respiratory point of view, the ideal humidity is between 40–60%. If it is less than 40%, the mucous membranes dry out; if it is above 60%, the body risks overheating. Because of the high humidity, we cannot sweat normally, and one of the main functions of sweat is to cool the body. When the ambient temperature approaches the human body temperature (roughly 36 °C), our body starts to cool down. We start to sweat, blood circulation changes, breathing becomes faster.

However, the sweat cooling function only works if sweat evaporates from the skin. If the humidity is high, it will not be able to absorb the amount of liquid on the surface of the skin, so the sweat will not evaporate and our body will not be able to cool down. In addition, the lack of cooling effect leads to increased sweating and subsequent significant loss of fluids and mineral salts. High humidity not only worsens our comfort, but can also trigger serious health problems. Excessive sweating can cause the body's equilibrium to tip, and the continuous loss of fluids leads to thickening of the blood and lowering of blood pressure. Blood thickening is dangerous because it contributes to the formation of blood clots and blood clots can cause heart attacks, strokes, embolism, and blockage of blood vessels (Stvorecz 2014). In case of increased sweating, we lose not only liquid but also vital salts (*potassium*, *sodium* and *magnesium*). Their deficiency can cause arrhythmias. Less blood flows to the muscles, brain and other organs

when the body overheats, leading to impaired physical fitness and physical and mental fatigue. The severity of symptoms is influenced by the age and physical strength of the person concerned. Although the elderly are the most vulnerable, irresponsibility of the younger age group can often contribute to a more serious condition (e.g., performing heavy physical work in a warm, high-humidity environment). Heat-sensitive people with cardiovascular problems may be adversely affected by the sultry climate, so these people should avoid increased physical and mental exertion, burdensome foods and direct sunlight (Čabajová 2007). The increase in the average annual air temperature in Hurbanova has been the most pronounced in the last thirty years. Average annual air temperature for the period 1981–2010 reached 10.6 °C in Hurbanovo, an increase of 0.7 °C compared to the period 1951–1980 (Lieskovská 2017). In 2019 and also in 2018, the average annual temperature in Hurbanovo was 12.42 °C. This value is a record high for Hurbanovo in the entire history of measurements (Lieskovská 2020).

6. Conclusion

In the annual course of water vapour pressure in Hurbanovo (1981–2020) reaches its highest values in July (the previous 40-year period (1951–1980) also, (hereafter referred to as the previous period)) and coincides with the annual course of air temperature, which can be seen in tab. 5. In the daily water vapor pressure run at Hurbanovo (1981–2020), the maximum appears around 7:00 and 8:00 a.m. (previous period 9:00 a.m.) and the minor maximum around 19:00 and 20:00 h (previous period 21 h), minimum at 3:00 and 4:00 h (previous period 4:00–5:00 h) and a minor minimum at 15:00 and 16:00 h (previous period 17:00 h). In the period 1981–2020, the in Hurbanovo 16 952 h (previous period 11 607 h) with sultry weather ($e \geq$ 18,8 hPa). In the daily run we recorded sultry weather at 8:00 h (949 times) (previous period 10:00 h (746 times)) and most rarely at 4:00 h (446 times) (previous period 5:00 (155 times). Fig. 5 informs us about the double daily progression of clock frequencies ($\sum$ h) with sultry weather and shows an analogous trend with the daily progression of water vapor pressure. We observed sultry weather ($e \geq 18.8$ hPa) in April–October (previous period May–October) and it can occur throughout the day (24 h). Sultry weather occurs most frequently in summer with peak abundances in July, when the probability of occurrence of hours with sultry weather reaches 35.7% (previous period 19.0%). The most frequent onset of sultry weather is between 7:00 and 9:00 am, with a minor peak of onsets between 7:00 and 9:00 pm, and sporadic occurrences during nighttime hours. A one-hour duration of sultry weather is most common. Opposite contrast, the longest continuous duration reached 155 h between 22 Aug 2019 17:00 and 29 Aug 2019 3:00 (Tab. 3). Sultry weather lasting more than 1 day occurs approximately once or twice per year. Continuous duration of severe sultry weather was manifested in 2010. At that time, the water vapour pressure in Hurbanova was continuously above 24.0 hPa for more than half a day (16 h) (Tab. 4).

Exhaustive sultry weather ($e >$ 0.5 hPa) in Hurbanovo did not occur, the water vapour pressure only approached 30.50 hPa (29.65 hPa) in July 1987. In the previous period (1981–2020) this most burdensome category of sultriness lasted only a few hours at the time of the occurrence of the absolute maximum water vapour pressure (34.5 hPa). Fig. 7 mainly informs us about the evolution of the strongly sultry weather 24.0 ≤ e ≤ 30.5 hPa) in Hurbanova. We recorded strong sultry weather in the months of June to September, with peak abundances in July (previous period in August). The onset of severe sultry weather most often occurs between 8:00–9:00 h (previous period 10:00–12:00 h) and the minimum occurrence at night at 5:00 am. In 40 years in Hurbanova, there have been only 2 cases of severe sultriness with a duration longer than 12 h (previous period also). The longest duration of severe sultry weather was 16 h on 15–16 July 2010 (in the previous period it was 19 h on 19–20 August 1974). Of the total number of sultry days in Slovakia, weak sultry weather is the most frequent, followed by strong sultry weather. Exhaustive sultriness did not occur, i.e. the water vapour pressure of 30.5 hPa line was not crossed, only approached it. The most frequent droughts occurred in July and

August. Conversely, the lowest numbers of hours with sultry weather were found in the winter months: December, January and February + March and November. Within the seasons, sultriness was most frequent in summer (87.7%) in the month of July (33.3%), closely followed by the month of August (31.6%) with only a difference of 1.69%. In the autumn period, sultriness occurred much more frequently than in the spring. Autumn has recently been much warmer than spring (Pecho et al., 2018). Within the year, the warmer period does not begin until May, and does not end until late October. Sultry weather occurs in 8.19% in autumn and 4.04% in spring. This can be explained by the presence of singularities. These are deviations from the smooth (idealised) curve of the long-term annual behaviour of a meteorological element, mainly air temperature and atmospheric precipitation. In central Europe, the more significant singularities include the Medard weather, then Indian summer and Christmas warming. All of the above also influence the sultry weather. For example, Indian summer results in more sultry days occurring in autumn than in spring. The reason for the frequent occurrence of Indian summer is the extensive and temporally stable pressure high over central and southern Europe during this period. With little cloud there is a relatively large temperature amplitude of 15 to 18 °C, which means that nights are already cold, there may be ground frost or fog in the morning, but the afternoons are calm, sunny and pleasantly warm. In the first half of September, the sunshine is still so strong that the temperature rises up to 30 degrees in low cloud pressure. This is the so-called late summer. A typical Indian summer does not occur until the second half of September and the first half of October (Department of Climatological Service, 2018). Heat radiation is considered as one of the main causes of the occurrence of sultry weather in May, particularly because at that time the rise in radiation is already very high and the organism has not yet had time to adapt to these conditions. The most pleasant conditions for humans are those where the relative humidity is 50% and the air temperature is 16–18 °C (and where the other values are $9.1 \geq e \geq 10.3$ hPa) (Kveták 1986). Very pleasant conditions occur most often in spring (April and May) and autumn (September and October) over a 40-year period. In winter, very pleasant conditions are practically absent (17 h over a 40-year period) because high relative humidity and low air temperatures prevail. In summer, temperatures of 16–18 °C occur most often at night and relative humidity 48–52% around midday. Extremes occurred mainly in 1987, 1998, 2010 and 2017 and most frequently in July and August at 18:00. Maximum values are most likely to occur at 8:00–11:00 am and 6:00–7:00 pm. Conversely, they are most rare between 1:00 h and 2:00 h at dawn. It can be concluded that the occurrence of sultriness is also related to the ongoing climate change, as it has a similar trend to the air temperature. When the evolution of the occurrence of sultry days from 1981 to 2020 at the Hurbanovo station was investigated, it was found that the occurrence of sultry days is slightly increasing. A statistically insignificant increase was observed for heavy and exhausting sultry days.

In the past, larger extremes were less frequent, which is now becoming a natural part of the weather, especially summer weather. A similar increase in the number of weakly and strongly sultry days was also noted by Kveták (1986) in his work when processing the results from the previous period (1951–1980). The hypothesis was confirmed. The gradual increase in air temperature influences the more frequent occurrence of sultry weather in our area. Further research on these days in terms of bioclimatology will be needed (e.g., by using additional climatological elements such as wind strength in the processing). We will also focus research on other bioclimatological indices to get a clearer picture in terms of thermal comfort of the organism.

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