METHODOLOGY OF FORECASTING TEMPERATURE CONDITIONS FOR USING ROAD SURFACE

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INTRODUCTION

The terms of construction, usage and repair of roads are largely determined by the temperature conditions of the air, soil and road surfaces[1]. Observation of the temperature of the atmospheric air has been conducted for over 100 years. According to the results of the observations, the seasonal, daily, and inter-day changes in the temperature of the atmospheric air, which are represented in[2] in the form of a quasi-stationary random process, are deeply studied. This probabilistic model allows determining the duration of different temperatures and to identify the estimated values of air temperature, which are required for the design of load-carrying structures and cladding structures of the buildings.

The soil temperature is also systematically measured at the meteorological stations of Ukraine, but the nature of its temporal and territorial variability has not been studied sufficiently. Equally important task is to study the temperature conditions for operating road surface. These conditions significantly affect the technical conditions of highways. The effect of significant loads caused by heavy vehicles at low winter temperatures results in fragile destruction of asphalt concrete, and during extreme summer heat it leads to the formation of corrugation and rutting.

The above-mentioned considerations lead to the study of the patterns of soil temperature changes and their impact on constructions that contact with the soil, particularly highways. Therefore, the objective of this work is to develop unified methods of probabilistic description of the air and soil temperatures on the basis of statistical analysis of the results of meteorological observations, as well as developing methods of taking into

[1] ДБН В.2.3-4:2015. Споруди транспорту. Автомобільні дороги. Київ, Мінрегіонбуд України, 2015. 101 с.

[2] Карюк А.М., Савенко Б.В. Методика оцінювання температурного режиму покриття автомобільних доріг. Збірник наукових праць (галузеве машинобудування, будівництво). Вип. 1(46). Полтава, 2016. С. 246–254.

account the impact of climatic temperatures on operating and maintenance conditions of highways.

1. Initial meteorological data

The soil temperature is measured on the surface. In the agro-technical zone it is measured at the depths up to 20 cm and deep measuring reaches up to 3.2m. For measuring instantaneous values, as well as daily maximum and minimum soil temperatures we may apply liquid, bimetal and electronic thermometers according to the standard methods. The temperature of the soil surface is measured by liquid thermometers which are in constant contact with the soil. The periodic monitoring of soil surface temperature is performed throughout the year on a specially prepared (loose and levelled soil) section of the meteorological site. The reservoirs with thermometers are placed at the distance of 5 ... 6 cm from each other in the direction of the West. They carry out timeline minimum and maximum measurements. As a result of eight-times per day observations, the temperature of the soil surface is received. The maximum and minimum temperatures in the interval of three hours between two consecutive observation periods are obtained as well.

The soil temperature is influenced by the following factors: geographic latitude, heat storage capacity, heat conductivity and soil colour, vegetation and snow cover, exposure of slopes, season, cloudiness and other factors. A significant number of factors of influence are caused by the random character of temperature changes in soil in time and space. Statistical processing and generalization of the results of the observations with prefix of time allow obtaining the daily and annual curve of temperature of the soil surface, as well as statistical characteristics of temperature distributions.

The daily curve of soil temperature is represented by periodic fluctuations with one maximum and one minimum. The minimum is observed before the sunrise, when the radiation balance is negative. With the sunrise, the temperature of the soil rises and reaches its maximum after about 13 hours. Then it begins to decrease due to the return of the heat from the surface to the air and deep into the soil.

The annual curve of soil temperature is conditioned by generation and losses of heat during seasonal changes in solar radiation and is determined by the sequence of average monthly values. In the northern hemisphere, the maximum average monthly temperatures of the soil surface are observed in July-August, and the minimum temperatures occur in January-February. The amplitude of the annual curve of soil temperature depends mostly on the latitude, increasing from the equator to the polar latitudes.

Currently, there are over 200 meteorological stations on the territory of Ukraine with the vast majority operating of the flatland. The generalized results of the observations of air and soil temperatures were published in the specialized meteorological publications. One of them is the reference book[3], which contains generalized data on air and soil temperature conditions at 207 meteorological stations in Ukraine. Odesa and Sumy meteorological stations were selected for further analysis as they are located in the south and north of Ukraine. Therefore, they represent a rather wide range of climatic conditions.

The meteorological database is generated in the Microsoft Excel software, which makes it possible to easily perform a statistical analysis of these data. The data in Tables 1 and 2 of the reference book[4] present air and soil temperatures that are used for further analysis:

– average monthly air and soil temperatures and their standards;

– absolute monthly maximum air and soil temperatures and their standards are averaged over all years of observation;

– absolute monthly minimum air and soil temperatures and their standards are averaged over all years of observation.

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[3] ДСТУ 4044-2001. Бітуми нафтові дорожні в’язкі. Технічні умови. Київ, Держстандарт України, 2001. 6 с.

[4] Настанова гідрометеорологічним станціям і постам. Випуск 3, частина 1. Метеорологічні спостереження на станціях. Київ: Державна гідрометеорологічна служба, 2011. 280 с.

Table 1

Statistical characteristics of air and soil temperatures at Odesa meteorological station (42 m above sea level, 44 years of observation)

Characteristics	Data on the months of the year											
	1	2	3	4	5	6	7	8	9	10	11	12
Average monthly air temperatures												
Average	-0,5	-0,4	3,1	8,8	15,2	19,0	21,3	21,4	16,6	11,5	5,0	1,0
Standard	1,7	1,8	2,0	1,0	0,9	0,7	1,3	0,9	0,8	0,9	1,7	1,5
Absolute monthly maximum air temperatures												
Average	10,8	10,7	15,4	20,5	25,9	28,9	30	31	26,4	21,2	15,5	11,6
Standard	1,7	3,9	3,3	1,9	1,5	1,6	1,9	1,6	1,7	1,1	1,8	2,0
Absolute monthly minimum air temperatures												
Average	-12,1	-10,8	-5,9	0,4	5,7	10,2	12,9	12,8	6,5	0,0	-4,8	-9,9
Standard	2,5	3,6	3,4	1,5	1,8	1,1	1,5	1,3	1,1	1,9	3,1	1,7
Average monthly soil surface temperatures												
Average	-1,2	-0,5	4,5	12,8	20,8	24,9	27,7	26,7	19,8	12,6	4,9	0,4
Standard	1,6	2,0	2,5	1,9	1,6	1,2	1,5	1,4	1,2	0,6	1,3	1,5
Absolute monthly maximum soil surface temperatures												
Average	13,5	16,6	30,0	40,8	53,0	56,0	56,1	6,3	48,2	36,4	23,4	13,4
Standard	3,0	5,3	5,0	4,0	2,8	2,2	6,3	,2	2,1	2,6	3,0	2,8
Absolute monthly minimum soil surface temperatures												
Average	-13,1	-11,6	-8,4	-1,9	3,3	8,0	10,9	,4	3,6	-2,5	-5,9	-10,2
Standard	3	3,8	4,2	0,5	0,8	1,3	1,7	,1	1,3	1,4	2,6	1,8

Table 2

Statistical characteristics of air and soil temperatures at Sumy meteorological station (180 m above sea level, 52 years of observation)

Characteristics	Data on the months of the year											
	1	2	3	4	5	6	7	8	9	10	11	12
	Average monthly air temperatures											
Average	-6,1	-5,6	-0,5	7,8	14,7	17,6	18,7	18,2	12,8	6,5	-0,1	-4,5
Standard	2,8	3,0	1,6	1,7	1,6	1,6	1,1	0,9	1,1	1,0	2,0	2,0
	Absolute monthly maximum air temperatures											
Average	3,3	4,0	12,8	22,0	27,6	30,0	31,2	30,7	26,1	19,2	9,2	4,5
Standard	1,2	3,3	2,9	2,3	2,2	1,6	1,8	1,6	2,3	1,7	2,0	2,4
	Absolute monthly minimum air temperatures											
Average	-22	-19,4	-13,9	-2,2	1,8	5,7	9,0	7,3	1,4	-5,2	-11,7	-18,6
Standard	4,0	5,8	6,0	1,1	1,5	1,5	1,5	1,2	1,8	1,4	4,1	3,4
	Average monthly soil surface temperatures											
Average	-6,8	-6,7	-2,6	8,4	18,2	22,5	23,3	21,8	14,3	6,3	-0,6	-5,2
Standard	3,2	2,8	1,9	1,4	2,3	2,3	1,8	1,2	1,3	1,0	2,0	2,1
	Absolute monthly maximum soil surface temperatures											
Average	1,6	3,8	18,3	39,1	50,1	55,1	53,3	52,3	41,5	25,7	11,0	3,2
Standard	0,8	2,9	4,3	2,9	3,8	2,5	5,2	2,2	2,9	3,4	2,1	2,3
	Absolute monthly minimum soil surface temperatures											
Average	-25,6	-22,8	-17,9	-4,6	-0,7	4,6	7,6	6	-0,2	-5,6	-13,4	-20,5
Standard	6,1	5,3	6,5	1,0	2,3	1,5	1,5	1,5	2,2	1,6	5,2	4,5

Thus, each of the two tables contains 12 data lines (average values and standards of the three above-mentioned air and soil temperature indicators). Each line contains values for 12 months of the year and determines the annual curve of the corresponding characteristic.

2. Statistical characteristics of the air and soil temperatures

The qualitative analysis of the statistical characteristics of the air and soil temperatures is made according to Tables 1 and 2. Comparison of the average monthly values of the air and soil surface temperatures is presented in Figure 1. The seasonal temperature curve is of the same character, but the temperature in Sumy is 5 ... 7°C lower than in Odesa. On both meteorological stations, the temperature of the soil in summer months is higher than the temperature of the air, and in winter it is lower. It is reasoned by the solar radiation which in summer provides additional heat to the surface of the soil.

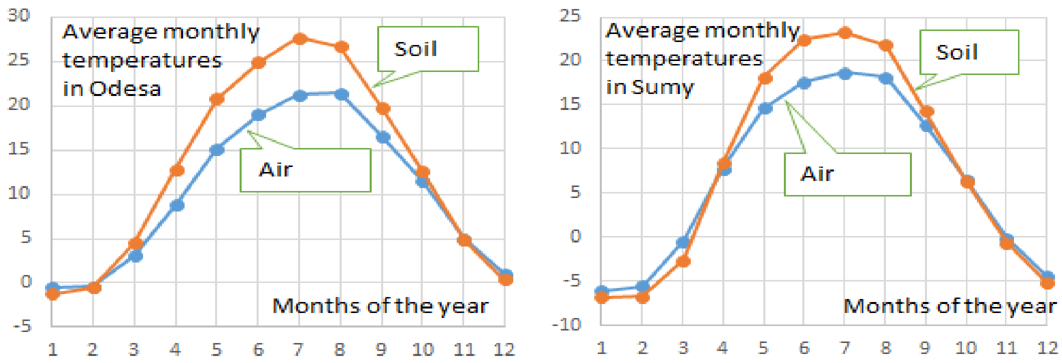

Fig. 1. Annual curve of the air and soil surface temperatures

The standards of the average monthly temperatures of the air and soil surface change over the year more chaotically, but Figure 2 presents two trends. Soil temperature standards are generally higher than air temperature standards. In winter, the standards of both temperatures are higher than in summer. These patterns are explained by the influence of solar radiation, the variability of which increases the variability of soil temperature.

The annual curve of the average values of absolute monthly maximum air and soil temperatures is shown in Figure 3. Comparison with Figure 1 shows that the maximum values of soil temperature always exceed the maximum air temperature.

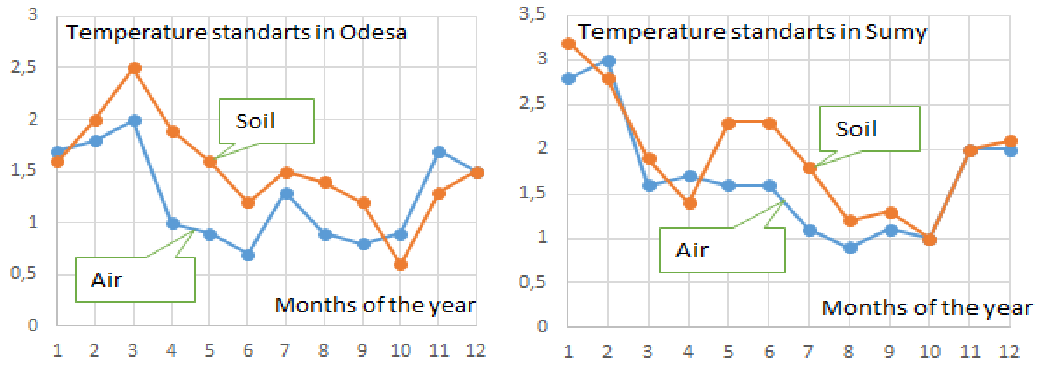

Fig. 2. Standards of the average monthly air and soil surface temperatures

The difference in maximum values in summer period is much greater than the difference between the average monthly temperatures. The minimum values of soil temperature are slightly lower than the minimum air temperature, but the difference between them is small. The annual rate of minimum and maximum air and soil temperatures in Odesa and Sumy has the same character. The maximum and minimum temperatures in summer are close to both meteorological stations, and winter temperatures in Sumy is 5 ... 10°C are lower than in Odesa.

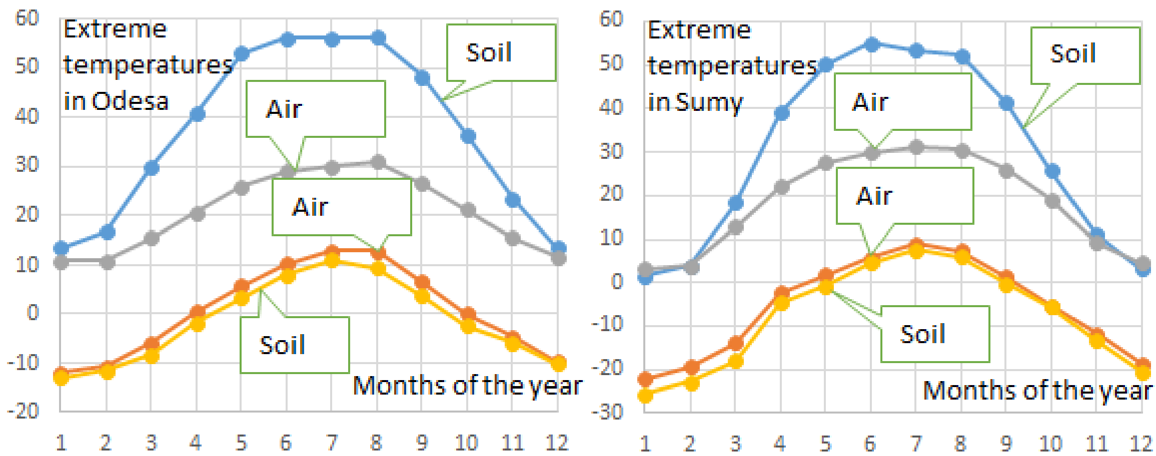

Fig. 3. Average values of monthly maximums and minimums of temperatures

Figure 4 shows the graphs of the dependencies of the average value and the standard temperature of the soil surface on similar air temperature characteristics constructed according to the data of both meteorological stations. From the graphs and approximating linear dependencies, it is evident that the average monthly temperature of the soil surface is quite closely related to the average monthly air temperatures, forming a linear dependence.

The dependence between standards is slightly expressed and can not be used to forecast soil temperature standards through the air temperature standards.

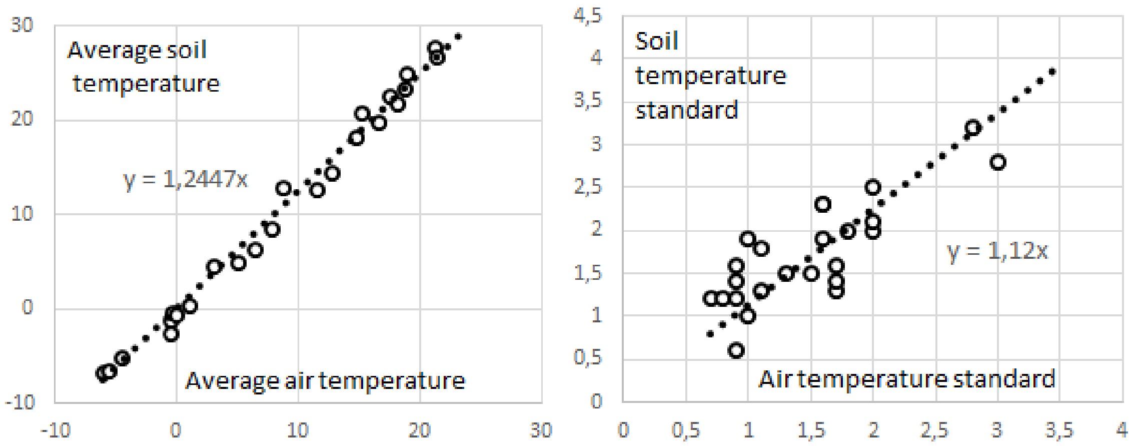

Fig. 4. Dependences between statistical characteristics of the air and soil temperatures

In general, the analysis shows that there are no qualitative differences in seasonal changes in the statistical characteristics of the air and soil temperatures at the meteorological stations located in the south and north of Ukraine. Summer temperatures are fairly similar, and winter temperatures in Sumy at 5 ... 10°C are lower than in Odesa. The available data allow analyzing the characteristic patterns of temperature changes in soil and develop a probabilistic model that will enable forecasting surface temperatures of highways in different geographical regions of Ukraine.

3. Methods of assessment of temperature conditions of surface highways

The available database in Tables 1 and 2 contains the average monthly air and soil temperatures and the standards of these values. Because of the averaging, the standards of the average monthly values presented in Tables 1 and 2 are lower than the standards of current values of temperature obtained according to the results of measurements of fixed hour. Approximate method for determining the statistical characteristics of the road surface temperature through the statistical characteristics of the average monthly values of the soil surface temperature is proposed in[5]. It takes into account the number of independent data in the monthly samples of the results of measurements of fixed hour and additional heating of the road surface from solar radiation.

It is shown in the monograph[6] that daily changes in temperature represent a sinusoidal process, which can be represented by the minimum and maximum values, and the correlation interval of the random process of the average daily air temperature is on average equals to 3 days. This allowed assuming in the work[7] that during a month, 20 independent values of the air and soil surface temperatures are realized. According to the methodology[8], which takes into account the intensity of solar radiation and the colour of the surface, it has been established in[9] that the increase in temperature from solar radiation directed onto a dark asphalt-concrete road surface may differ from the light sandy or covered with grass soil surface by 5 ... 9°C. Without solar radiation, this increase is zero, and it is presented as a random value with a uniform distribution law.

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[5] Карюк А.М., Савенко Б.В. Методика оцінювання температурного режиму покриття автомобільних доріг. Збірник наукових праць (галузеве машинобудування, будівництво). Вип. 1(46). Полтава, 2016. С. 246–254.

[6] Пашинський В.А. Температурні впливи на огороджувальні конструкції будівель: монографія/ В.А. Пашинський, Н.В. Пушкар, А.М. Карюк. Одеса, 2012. 180 с.

[7] Кінаш Р.І., Бурнаєв О.М. Температурний режим повітря і ґрунту в Україні, Львів, 2001. 800 с.

[8] Thornes JE. Thermal mapping and road-weather information systems for highway engineers. In Physical and Dynamical Meteorology, Perry AH, Symons LJ (eds). 1991.Taylor and Francis: London; pp. 39–67.

[9] Berrocal VJ, Raftery AE, Gneiting T, Steed RC. Probabilistic weather forecasting for winter road maintenance. J. Am. Stat. Assoc. 2010. Vol.105: pp. 522–537.

Taking into account the above considerations, based on the known formulas for statistical characteristics of the sum of random values of the soil surface temperature and the increase of temperature from the action of solar radiation, the work[10] suggests the following formulas for determining the mathematical expectation M_r and standard S_r of the current values of the surface temperature of the asphalt road through the mathematical expectation M_m and standard S_m of the average monthly temperature values of the soil surface:

$$M_r = M_m + 7\,;\; S_r = \sqrt{20 S_m^2 + 4}\,, \qquad (1)$$

Based on the normal distribution of temperature values, the number of cold days during which in a certain month of the year the surface temperature of the road will be lower than the given temperature X can be determined by the formula[11]

$$T_c = 30 F_r(M_r, S_r, X) \qquad (2),$$

where 30 is the number of days in a month;

$F_r(M_r, S_r, X)$ is the function of normal distribution of the road surface temperature with characters (1).

The number of hot days in which the road surface temperature in a certain month of the year exceeds the given value of X is equal to

$$T_w = 30\left[1 - F_r(M_r, S_r, X)\right] \qquad (3)$$

The risk of ice formation occurs at temperatures of the road surface in the range from -5ºC to 0ºC. The number of days with the these temperatures of road surface per month, can be determined by the formula

$$T_{ice} = 30\left[F_r(M_r, S_r, 0) - F_r(M_r, S_r, -5)\right] \qquad (4)$$

All the constituents of the formulas (3) and (4) are presented above.

The total annual number of cold or hot days, as well as days with potential danger of ice formation is equal to the sum of 12 monthly values calculated by formulas (2), (3) or (4).

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[10] Sherif A, Hassan Y. Modelling pavement temperature for winter maintenance operations. Can. J. Civil Eng. 2004.Vol.31: pp. 369–378.

[11] Карюк А.М., Савенко Б.В. Методика оцінювання температурного режиму покриття автомобільних доріг. *Збірник наукових праць (галузеве машинобудування, будівництво).* Вип. 1(46). Полтава, 2016. С. 246–254.

The given formulas allow forecasting the monthly and total annual periods of cold and hot periods, when the road surface temperature goes beyond the working temperature range of viscous bitumen used in the construction of road surface. During a cold period, there may be a fragile destruction of road surface. The effect of temperatures higher than the softening temperature of bitumen can lead to the formation of rutting and corrugation on the surface of the road. Together with the temperatures potentially hazardous under the conditions of ice formation, the data were obtained to forecast planning of transportation period with the limited traffic of heavy transport.

4. Parameters of temperature conditions of the road surface

The number of hot days when the surface temperature of the road exceeds the softening temperature of viscous bitumen, and cold days when the surface temperature of the road is lower than the temperature of the fragility of bitumen are sufficiently informative and convenient parameters of temperature conditions to forecast transportation. These parameters are calculated on the basis of the above methodology and data from Tables 1 and 2. The results of calculations for the districts of Odesa and Sumy cities are given in Tables 3 and 4, which contain:

– statistical characteristics of the road surface temperature in (1);

– the number of hot days in each month of the year in (3) and their annual quantity;

– the number of cold days in each month of the year in (2) and their annual quantity;

– the number of days with danger of ice formation for (4).

The number of hot days is calculated under the condition of exceeding the temperature in the range of + 20°C ... + 60°C, and the number of cold days includes the time during which the road surface temperature becomes less than + 10°C ... – 30°C. The chosen temperature values cover working temperature ranges of bitumen roads of all types. This allows using data from Tables 3 and 4 to forecast the number of days with the restriction of traffic of heavy vehicles. The number of days with the potential danger of ice formation is found by (4) as the duration of the period with the road surface temperature within the range -5 ... 0°C.

The nature of the dependencies of the calculated parameters of the temperature conditions of road surface on the month of the year and on the critical values of the temperature of the road surface is shown in Figures 5 ... 10, constructed according to Tables 3 and 4. The annual curve of the number of hot days shows in Fig. 5 shows that the significant period duration with temperatures of the road surface more than 30°C, which are close to the softening temperatures of road bitumen of different grades, is observed in the period from April to September. The number of hot days in Odesa (88 days with the temperature of more than + 30°C and 0,7 days with the temperature of more than + 50°C) is generally slightly higher than in Sumy (56 days with the temperature over + 30°C, and 3 days with a temperature above + 50°C).

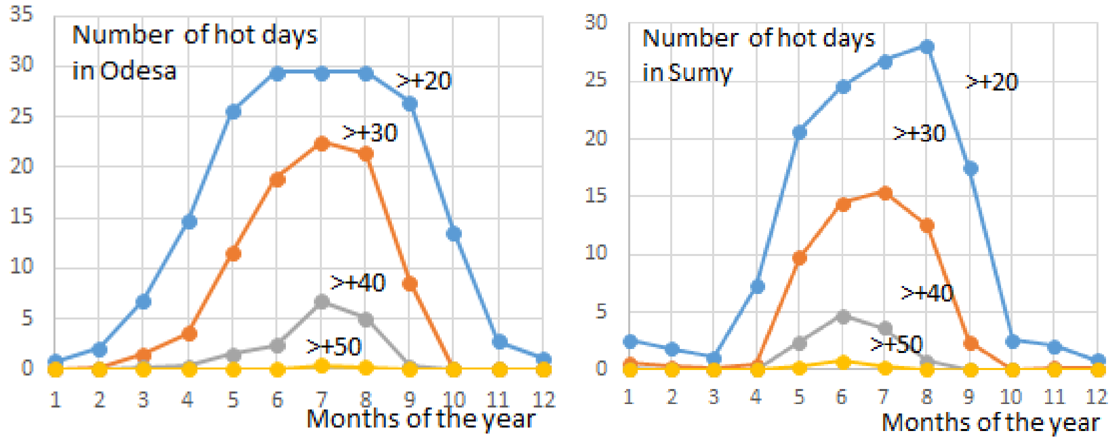

Fig. 5. Annual curve of monthly amount of hot days

Significant numbers of cold days are observed between November and March, while their number in Sumy is much higher than in Odesa (36 days versus 8.8 days with the road surface temperature below -5°C and 9.7 days vs. 0.7 days with the temperature lower than -15°C).

The selected for comparison temperatures are close to the temperatures of fragility of road bitumen. Having compared Figures 5 and 6 it can be concluded that the difference in the number of cold days in the zones of

Odesa and Sumy meteorological stations is much greater than the difference in the number of hot days. This can be explained by the fact that in summer period of active solar radiation the surface of the soil and road surface can warm up to high temperatures throughout the territory of Ukraine.

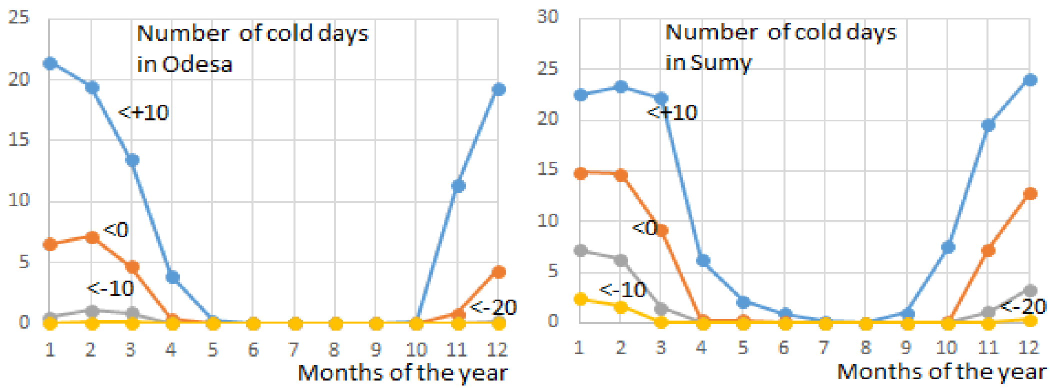

Fig. 6. Annual curve of cold days by months

Dependencies of the number of hot and cold days during all months of the year from the established critical temperature X_w or X_c are shown in Figures 7 and 8, which are constructed on a logarithmic scale for the purpose of displaying very small amounts of days.

Statistical characteristics of the road surface temperature and the number of hot and cold days in Odesa region

Road temperatures	Data on months of the year												Total for the year
	1	2	3	4	5	6	7	8	9	10	11	12	
	Statistical characteristics of the road surface temperature												
M_r=	5,8	6,5	11,5	19,8	27,8	31,9	34,7	33,7	26,8	19,6	11,9	7,4	
S_r=	7,43	9,17	11,36	8,73	7,43	5,73	7,00	6,57	5,73	3,35	6,15	7,00	
X_w	Number of hot days with temperatures higher then X_w												
+20	8,4E-01	2,1E+00	6,8E+00	1,5E+01	2,6E+01	2,9E+01	2,9E+01	2,9E+01	2,6E+01	1,4E+01	2,8E+00	1,1E+00	1,8E+02
+25	1,5E-01	6,5E-01	3,5E+00	8,3E+00	1,9E+01	2,7E+01	2,8E+01	2,7E+01	1,9E+01	1,6E+00	5,0E-01	1,8E-01	1,3E+02
+30	1,7E-02	1,6E-01	1,6E+00	3,6E+00	1,2E+01	1,9E+01	2,2E+01	2,1E+01	8,6E+00	2,8E-02	4,9E-02	1,9E-02	8,8E+01
+35	1,3E-03	2,8E-02	5,8E-01	1,2E+00	5,0E+00	8,8E+00	1,4E+01	1,3E+01	2,3E+00	6,3E-05	2,6E-03	1,2E-03	4,5E+01
+40	6,2E-05	3,9E-03	1,8E-01	3,1E-01	1,5E+00	2,4E+00	6,7E+00	5,1E+00	3,2E-01	1,6E-08	7,3E-05	4,8E-05	1,6E+01
+45	2,0E-06	4,0E-04	4,8E-02	5,8E-02	3,1E-01	3,3E-01	2,1E+00	1,3E+00	2,2E-02	4,8E-13	1,1E-06	1,2E-06	4,2E+00
+50	4,0E-08	3,1E-05	1,0E-02	8,1E-03	4,2E-02	2,4E-02	4,3E-01	2,0E-01	7,7E-04	0,0E+00	8,6E-09	1,7E-08	7,1E-01
+55	5,3E-10	1,8E-06	1,9E-03	8,3E-04	3,8E-03	8,2E-04	5,6E-02	1,8E-02	1,3E-05	0,0E+00	3,6E-11	1,6E-10	8,1E-02
+60	4,5E-12	8,0E-08	2,9E-04	6,2E-05	2,2E-04	1,4E-05	4,5E-03	9,4E-04	1,0E-07	0,0E+00	7,7E-14	8,6E-13	6,1E-03
X_c	Number of cold days with temperatures below X_c												
+10	2,1E+01	1,9E+01	1,3E+01	3,9E+00	2,5E-01	2,0E-03	6,3E-03	4,7E-03	5,0E-02	6,2E-02	1,1E+01	1,9E+01	8,9E+01
+5	1,4E+01	1,3E+01	8,5E+00	1,3E+00	3,2E-02	4,0E-05	3,3E-04	1,9E-04	2,1E-03	1,9E-04	3,9E+00	1,1E+01	5,2E+01
0	6,5E+00	7,2E+00	4,7E+00	3,5E-01	2,7E-03	3,8E-07	1,1E-05	4,4E-06	4,3E-05	7,1E-08	7,9E-01	4,4E+00	2,4E+01
–5	2,2E+00	3,1E+00	2,2E+00	6,7E-02	1,5E-04	1,8E-09	2,1E-07	5,9E-08	4,2E-07	3,0E-12	9,0E-02	1,1E+00	8,8E+00
–10	5,0E-01	1,1E+00	8,8E-01	9,6E-03	5,4E-06	3,8E-12	2,6E-09	4,4E-10	2,0E-09	1,4E-17	5,5E-03	1,9E-01	2,7E+00
–15	7,7E-02	2,8E-01	2,9E-01	1,0E-03	1,3E-07	3,9E-15	1,9E-11	1,9E-12	4,4E-12	7,1E-24	1,8E-04	2,1E-02	6,8E-01
–20	7,7E-03	5,8E-02	8,3E-02	7,7E-05	1,9E-09	1,9E-18	8,3E-14	4,6E-15	4,6E-15	4,0E-31	3,2E-06	1,4E-03	1,5E-01
–25	5,1E-04	8,8E-03	2,0E-02	4,3E-06	1,8E-11	4,4E-22	2,2E-16	6,3E-18	2,3E-18	2,4E-39	2,9E-08	5,5E-05	2,9E-02
–30	2,2E-05	1,0E-03	3,9E-03	1,7E-07	1,1E-13	4,7E-26	3,6E-19	4,9E-21	5,2E-22	1,6E-48	1,4E-10	1,4E-06	4,9E-03
	Number of days with potential danger of ice-slick												
–5…0°C	4,3E+00	4,0E+00	2,5E+00	2,8E-01	2,6E-03	3,8E-07	1,1E-05	4,4E-06	4,3E-05	7,1E-08	7,0E-01	3,2E+00	1,5E+01

Table 4

Statistical characteristics of the surface temperature of the road and the number of hot and cold days in Sumy region

Road temperatures	Data on months of the year												Total for the year
	1	2	3	4	5	6	7	8	9	10	11	12	
	Статистичні характеристики температури поверхні дороги												
M_r=	0,2	0,3	4,4	15,4	25,2	29,5	30,3	28,8	21,3	13,3	6,4	1,8	
S_r=	14,45	12,68	8,73	6,57	10,48	10,48	8,29	5,73	6,15	4,90	9,17	9,60	
X_w	Number of hot days with temperatures higher then X_w												
+20	2,6E+00	1,8E+00	1,1E+00	7,3E+00	2,1E+01	2,5E+01	2,7E+01	2,8E+01	1,8E+01	2,6E+00	2,1E+00	8,7E-01	1,4E+02
+25	1,3E+00	7,7E-01	2,7E-01	2,2E+00	1,5E+01	2,0E+01	2,2E+01	2,2E+01	8,2E+00	2,5E-01	6,4E-01	2,4E-01	9,4E+01
+30	5,9E-01	2,9E-01	5,0E-02	3,9E-01	9,7E+00	1,4E+01	1,5E+01	1,3E+01	2,4E+00	9,8E-03	1,5E-01	5,0E-02	5,6E+01
+35	2,4E-01	9,3E-02	6,8E-03	4,3E-02	5,2E+00	9,0E+00	8,6E+00	4,2E+00	3,9E-01	1,4E-04	2,7E-02	8,2E-03	2,8E+01
+40	8,8E-02	2,6E-02	6,8E-04	2,7E-03	2,4E+00	4,7E+00	3,6E+00	7,6E-01	3,5E-02	7,6E-07	3,7E-03	1,0E-03	1,2E+01
+45	2,9E-02	6,4E-03	5,0E-05	1,0E-04	8,8E-01	2,1E+00	1,1E+00	7,0E-02	1,7E-03	1,5E-09	3,8E-04	1,0E-04	4,2E+00
+50	8,5E-03	1,3E-03	2,6E-06	2,1E-06	2,7E-01	7,6E-01	2,6E-01	3,2E-03	4,6E-05	1,0E-12	2,9E-05	7,8E-06	1,3E+00
+55	2,2E-03	2,4E-04	1,0E-07	2,5E-08	6,7E-02	2,2E-01	4,4E-02	7,2E-05	6,3E-07	0,0E+00	1,7E-06	4,5E-07	3,4E-01
+60	5,2E-04	3,8E-05	2,8E-09	1,7E-10	1,3E-02	5,4E-02	5,1E-03	7,7E-07	4,6E-09	0,0E+00	7,5E-08	2,0E-08	7,3E-02
X_c	Number of cold days with temperatures below X_c												
+10	2,3E+01	2,3E+01	2,2E+01	6,2E+00	2,2E+00	9,4E-01	2,2E-01	1,5E-02	9,9E-01	7,5E+00	2,0E+01	2,4E+01	1,3E+02
+5	1,9E+01	1,9E+01	1,6E+01	1,7E+00	8,1E-01	2,9E-01	3,4E-02	4,9E-04	1,2E-01	1,4E+00	1,3E+01	1,9E+01	9,0E+01
0	1,5E+01	1,5E+01	9,2E+00	2,9E-01	2,4E-01	7,3E-02	3,9E-03	7,4E-06	8,0E-03	9,9E-02	7,3E+00	1,3E+01	6,0E+01
–5	1,1E+01	1,0E+01	4,2E+00	2,9E-02	5,9E-02	1,5E-02	3,1E-04	5,4E-08	2,8E-04	2,8E-03	3,2E+00	7,2E+00	3,6E+01
–10	7,2E+00	6,2E+00	1,5E+00	1,7E-03	1,2E-02	2,5E-03	1,8E-05	1,9E-10	5,3E-06	3,0E-05	1,1E+00	3,3E+00	1,9E+01
–15	4,4E+00	3,4E+00	3,9E-01	5,6E-05	1,9E-03	3,3E-04	7,1E-07	3,1E-13	5,3E-08	1,1E-07	2,9E-01	1,2E+00	9,7E+00
–20	2,4E+00	1,6E+00	7,8E-02	1,1E-06	2,4E-04	3,5E-05	2,0E-08	2,4E-16	2,8E-10	1,6E-10	6,0E-02	3,5E-01	4,6E+00
–25	1,2E+00	6,9E-01	1,1E-02	1,2E-08	2,5E-05	3,0E-06	3,9E-10	8,7E-20	7,6E-13	8,1E-14	9,2E-03	7,9E-02	2,0E+00
–30	5,5E-01	2,5E-01	1,2E-03	7,4E-11	2,1E-06	2,0E-07	5,4E-12	1,5E-23	1,1E-15	1,5E-17	1,1E-03	1,4E-02	8,2E-01
	Number of days with potential danger of ice-slick												
–5…0°C	4,1E+00	4,6E+00	5,0E+00	2,6E-01	1,8E-01	5,8E-02	3,6E-03	7,4E-06	7,7E-03	9,7E-02	4,1E+00	5,6E+00	2,4E+01

The figures show that the amount of hot days decreases with the rise of the critical temperature X_w. The number of cold days decreases with the fall of the critical temperature X_c. The lower curves of the amounts of hot days in Figure 7 correspond to the cold months of the year, while the lower curves of the cold days in Figure 8 reflect the warm summer months.

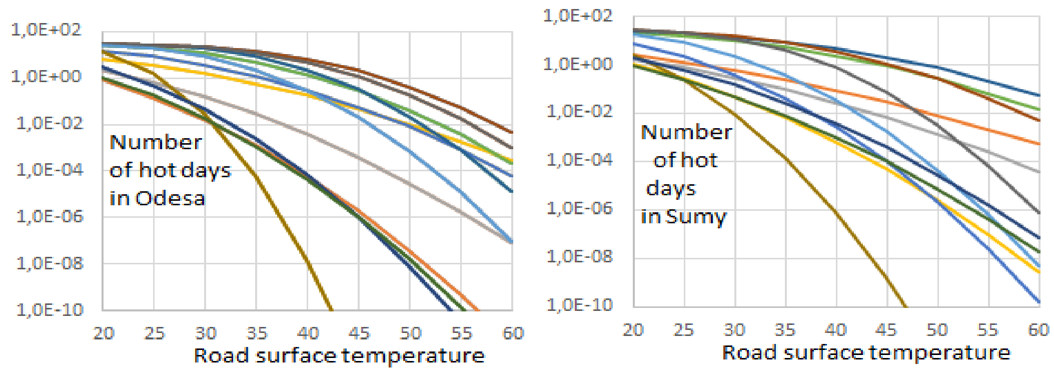

Fig. 7. Monthly amounts of hot days corresponding to different values of the temperature of the road surface X_w

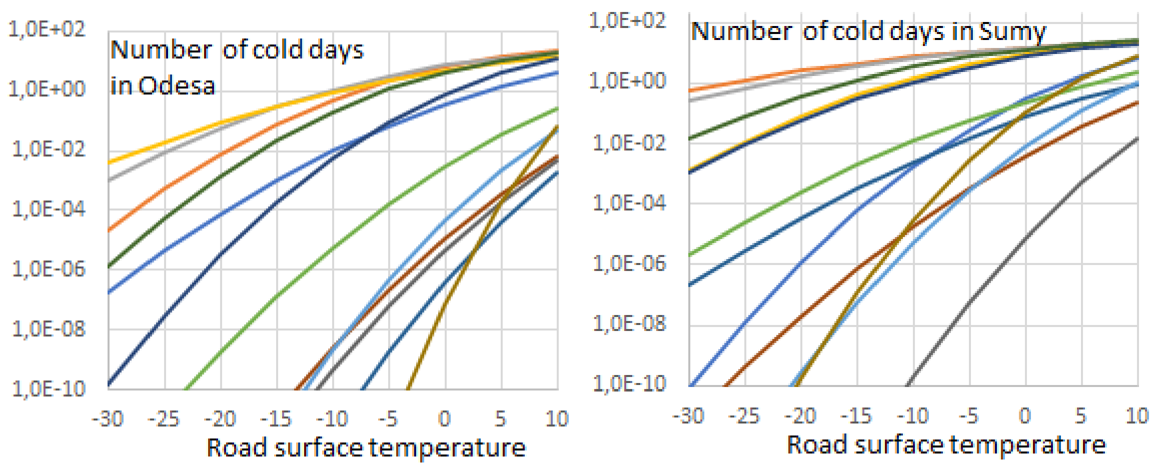

Fig. 8. Monthly numbers of cold days corresponding to different values of the temperature of the road surface X_c

Figure 9 shows the dependencies of the total annual amounts of hot and cold days on the given critical temperatures of the road surface X_w and X_c. At temperatures X_w = 30 ... 40°C, the duration of the hot period in Odesa is much longer than that of Sumy, but at higher values of critical temperature, these durations are practically aligned. Therefore, the period of very high temperatures on the road surface is common to the entire territory of Ukraine. With all values of the critical temperature of the road surface X_c, the annual cold period in Sumy is 2 to 3 times longer than in Odesa.

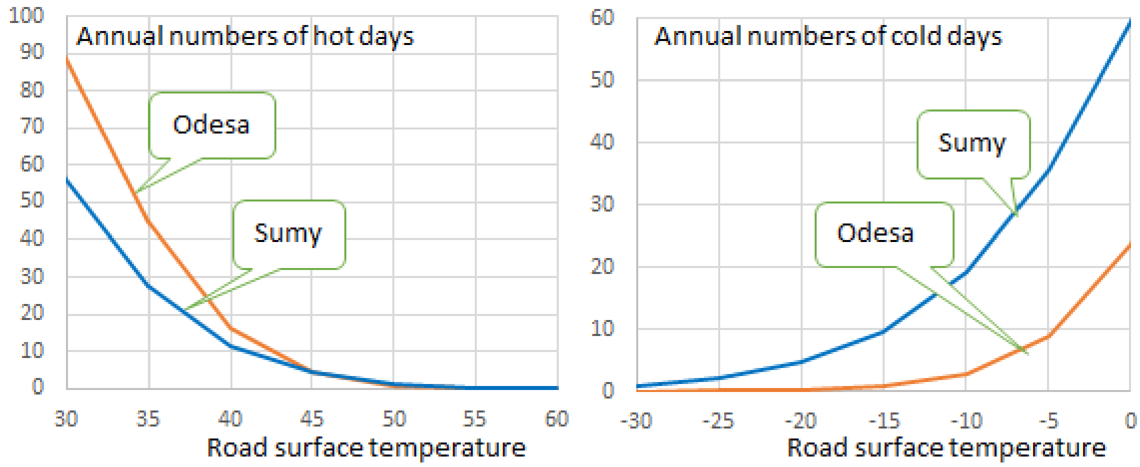

Fig. 9. Annual amounts of hot and cold days corresponding to different values of road surface temperatures X_w and X_c

The graphs in Figures 7, 8, and 9 allow forecasting probable amount of cold or hot days that are hazardous to asphalt concrete based on bitumen of a particular grade. To do this, it is necessary to identify the temperature of softening and the temperature of the fragility of the road bitumen used in the construction of the upper layer of the road according to the technical conditions. Then, in accordance with the indicated graphs, it is possible to identify the duration of the dangerously hot and dangerously cold periods during the specified month or the year as a whole.

The monthly numbers of days with a potential danger of ice, which can be formed at the road surface temperature from 0°C to -5°C, are indicated in the last lines of Tables 3 and 4 and in Figure 10.

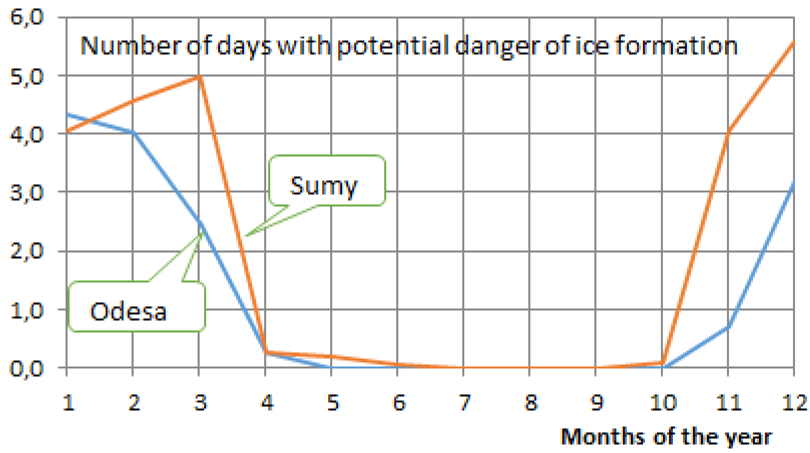

Fig. 10. Annual numbers of days with potential danger of ice

Ice may actually be formed in winter period from November to March in Odesa as well in Sumy. Due to the warmer climate, the period of ice-cold season in Odesa is noticeably shorter than in Sumy. The greatest number of days with the risk of ice in March is due to low temperatures (less than -5°C) in the area of Sumy meteorological station during January and February, which excludes it from the dangerous range of temperatures of the road surface 0°C ... -5°C. According to Tales 3 and 4, the total annual ice period is 15 days for Odesa meteorological station and 24 days for Sumy meteorological station. The period of rains and wet snow can be dangerous for the traffic.

5. Territorial variability of the parameters of temperature conditions of road surfaces

According to the method described above, the parameters of temperature conditions of the road surface were obtained according to 10 meteorological stations located in different geographical regions of Ukraine. The summarized results of these calculations are given in Table 5, which contains the following data:

– average annual air temperature;

– average annual temperature of the soil surface;

– annual amount of hot days temperatures higher than X_w = 30°C and X_w = 50°C;

– annual number of cold days with temperatures below X_c = -5°C and X_c = -15°C;

– annual number of days with potential icy roads.

The last lines in Table 5 contain the smallest and largest values of the given indicators, as well as the ratio of maximum values to the minimum ones. These data reflect the scope of the territorial variability of the investigated parameters of the temperature conditions within the territory of Ukraine. Table 5 shows that within the territory of Ukraine the average annual air and soil temperatures, as well as the number of days with the risk of ice formation, vary 1.6 ... 1.8 times. The number of hot and cold days at different meteorological stations can vary tens of times. According to the table, Figures 11 ... 14 show schematic maps that allow visually analyzing changes in the selected parameters of temperature conditions in the territory of Ukraine.

Table 5

Generalized parameters of the temperature conditions of the road surface

Meteorological stations	**Average annual temperature**		**Number of hot days**		**Number of cold days**		**Number of ice-slick days**
	air	**soil**	**>+30°C**	**>+50°C**	**<– 5°C**	**<– 15°C**	
Askania Nova	9,8	11,9	81,3	0,4	13,5	1,6	17,5
Lubeshiv	7,6	8,3	40,8	0,1	19,3	4,5	21,0
Novo-Myrhorod	7,8	9,0	58,9	1,4	28,7	5,7	22,4
Odesa	10,2	12,8	88,4	0,7	8,8	0,7	15,0
Poltava	7,7	8,9	64,5	1,0	31,0	6,8	23,4
Simferopol	10,4	13,0	85,8	1,7	5,6	0,3	13,4
Starobilsk	8,0	9,8	77,5	0,8	30,5	7,5	23,1
Sumy	6,6	7,7	56,0	1,3	35,6	9,7	23,9
Chernivtsi	8,2	9,0	46,5	0,03	20,7	4,3	20,3
Yavoriv	7,9	8,7	41,3	0,2	17,1	3,4	18,4
Minimum	6,6	7,7	40,8	0,03	5,6	0,3	13,4
Maximunm	10,4	13,0	88,4	1,7	35,6	9,7	23,9
Max / Min	1,6	1,7	2,2	51,4	6,3	38,6	1,8

Figure 11 shows the territorial variability of the average annual air and soil temperatures, which are generalized indicators of the climate of a particular area. At all meteorological stations the average annual temperature of soil is higher than the average annual air temperature. There is also a systematic increase in average annual temperatures in the direction from north to south of Ukraine. This corresponds to a well-known trend of climatic temperature variations, depending on the latitude and given in the work[12] regionalization maps of statistical characteristics and estimated values of air temperature.

The map in Figure 12 shows that the number of hot days dangerous for asphalt– concrete road is growing systematically from the northeast to the southwest of Ukraine. The number of cold days shown on the map in Figure 13 generally grows in the south-north direction, but remains fairly stable in the east of Ukraine, in the Precarpathian and Transcarpathian regions. Such a character of the territorial variability of the amount of hot and cold days in general corresponds to the map of the territorial division of Ukraine indicated in the norms[13] on the climatic conditions of the work of asphalt-concrete surface. According to this map, the norms regulate the use of harder road bitumen with higher softening temperatures in the south and south-east of Ukraine.

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[12] ДСТУ Б В.2.7-135:2007. Бітуми дорожні, модифіковані полімерами. Технічні умови. Київ, Мінрегіон України, 2007. 23 с.

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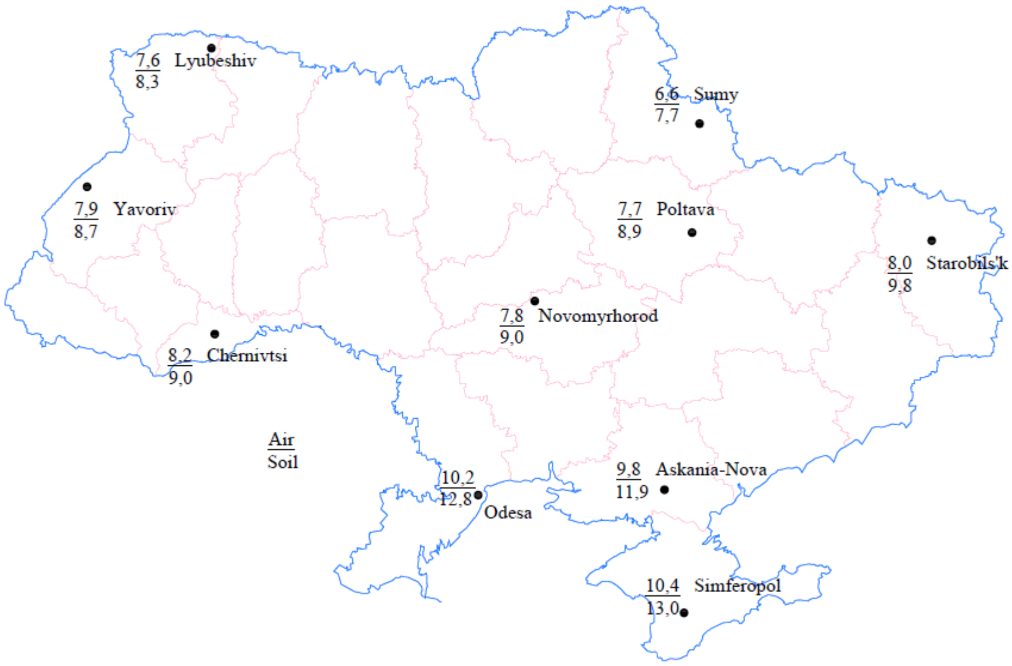

Fig. 11. Average annual air and soil surface temperatures

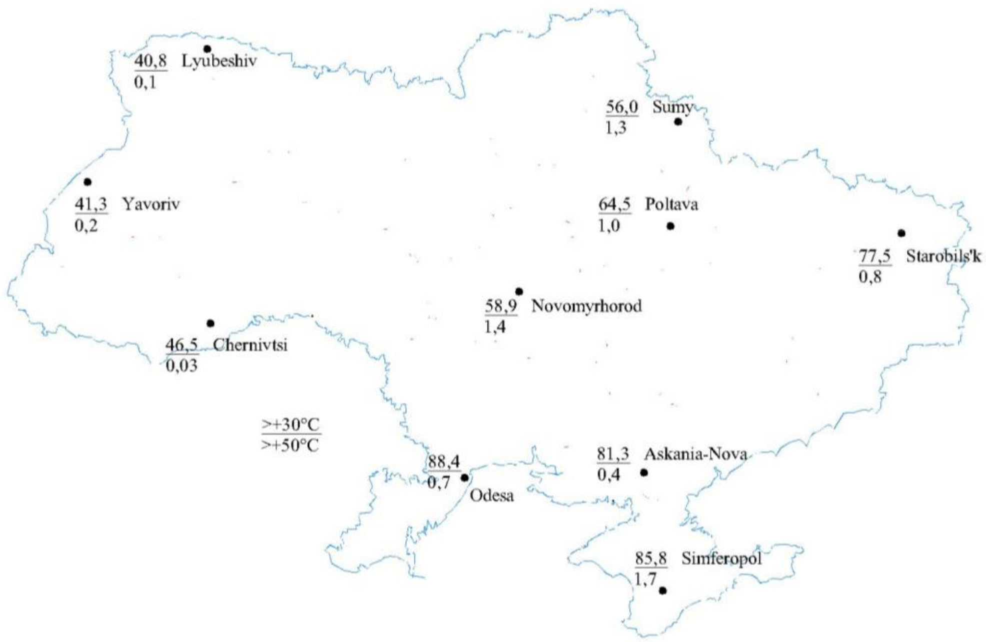

Fig. 12. Annual duration of the hot period

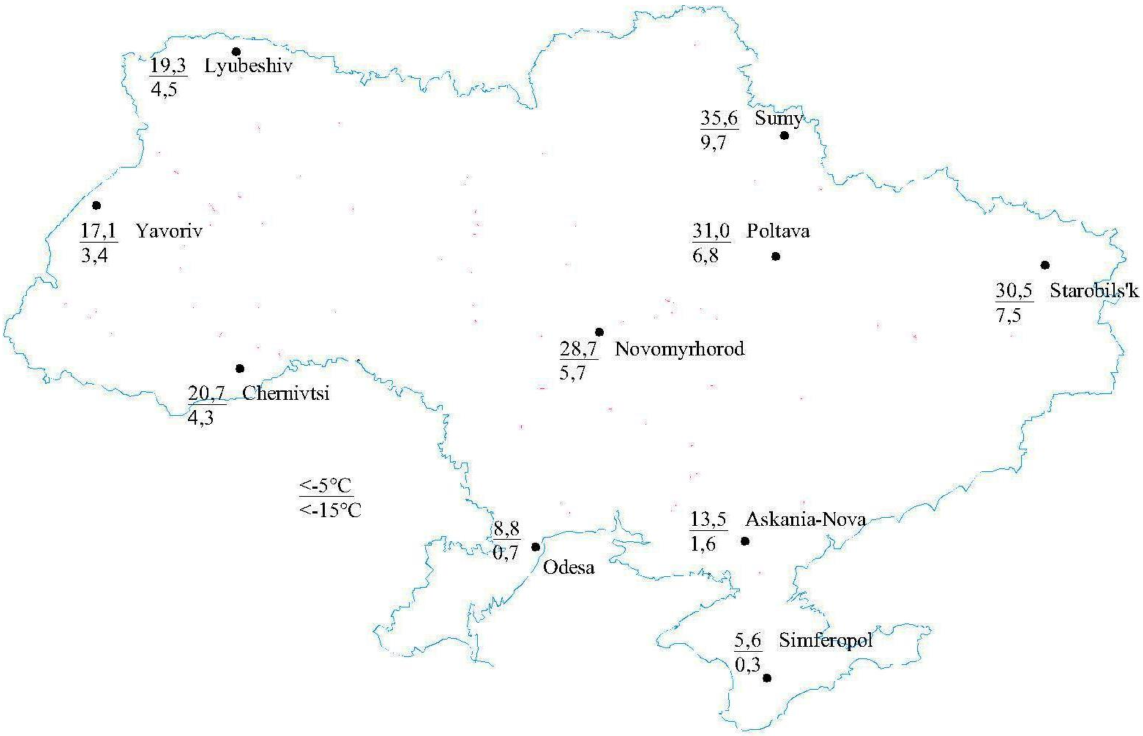

Fig. 13. Annual duration of the cold period

The map in Figure 14 shows that the periods with the danger of ice formation are changed in the territory according to the amount of cold days. They grow from south to north of Ukraine and change a little in the Carpathian region.

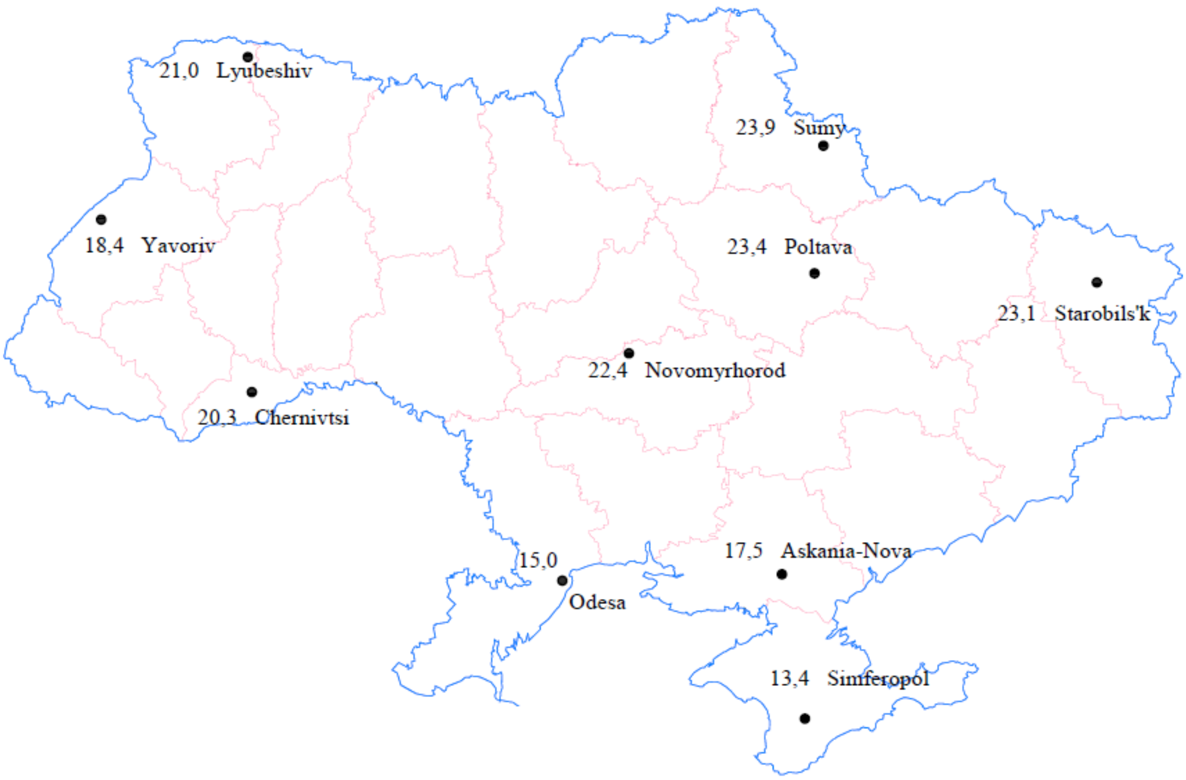

Fig. 14. Annual period with a potential danger of ice roads

In general, the analysis shows that there is a significant territorial variation in the characteristics of temperature conditions of the air, soil and road surface temperatures. The obtained periods of hot and cold periods allow estimating the probable number of days in each month, during which the traffic of heavy transport is dangerous for the integrity of road surface. These data, as well as the length of periods with the potential danger of ice formation, can be used in planning road transportation by taking into account the actual working time, when there are no restrictions on the movement of vehicles.

CONCLUSIONS

1. According to the data of two meteorological stations located in the south and north of Ukraine, regularities of changes in time of statistical characteristics of air and soil surface temperatures were identified. The mutual dependencies between them were also found out.

2. It was shown that in the function of practically useful characteristics of the temperature conditions for the use of asphalt concrete roads, it is advisable to use monthly and annual numbers of hot and cold days when the temperature of the road surface falls out of the working range of the viscous bitumen.

3. These characteristics, together with the duration of periods with the potential danger of the formation of ice, can be used in the planning of motor movement and maintenance of the road surface.

4. The analysis of the data of ten meteorological stations from different regions of Ukraine indicates that there is a need for a more detailed study of the selected characteristics of temperature conditions of the road surface using the database of a larger number of meteorological stations.

SUMMARY

The article is devoted to results of unified methods of probabilistic description of the air and soil temperatures on the basis of statistical analysis of the results of meteorological observations, as well as developing methods of taking into account the impact of climatic temperatures on operating and maintenance conditions of highways.

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