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THERMAL ENERGY BALANCE MODEL OF DIFFERENT ROAD CONSTRUCTIONS

The Energy Balance Model is used for the purpose of forecasting road conditions and road surface temperature. The course of energy streams is estimated on the basis of meteorological parameters. It is very important that the meteorologist provides excellent synoptic input data to the Energy Balance Model.

The Energy Balance Model allows to distinguish five different road characteristics:
undisturbed road sectors with regular traffic, road sectors with small traffic, shaded sectors, bridges, road sectors with urbane influences.

MODEL TERMICZNEGO BILANSU ENERGETYCZNEGO RÓŻNYCH KONSTRUKCJI DROGOWYCH

Żeby prognozować warunki drogowe i temperaturę nawierzchni drogowej, używa się modelu bilansu energii. Przebieg strumieni energii jest szacowany na podstawie parametrów meteorologicznych. Jest bardzo ważne, że meteorolog dostarcza znakomitych synoptycznych danych wejściowych do modelu bilansu energii.

Model bilansu energii pozwala wydzielić pięć różnych charakterystyk drogi:
niezakłócane odcinki drogowe z regularnym ruchem drogowym, odcinki drogowe z małym ruchem, odcinki zacienione, mosty, odcinki drogowe z wpływami urbanistycznymi.

1. INTRODUCTION

The forecast of road conditions and road surface temperature forms part of the Road Weather Information System (*System Pogodowej Informacji Drogowej SPID*). The main function of the system is the improvement of the effectiveness of the road maintenance in winter, which encompasses: road protection, effective management of personnel, lower use of salt (which has a negative effect on vehicles, bridges and road infrastructure), reduction of environmental pollution.

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On the basis of the above system it is possible to prepare requirements related to the movement of the army, except for the air forces, in which case it is required to obtain more detailed and up-to-date weather forecasts at much shorter intervals.

Weather forecasts prepared by the Meteorological and Hydrological Institute (or other institutions) should include a set of forecasts (72-hour, 24-hour and 12-hour detailed local forecasts). News about road weather conditions should be broadcasted about 1 to 2 hours before the forecasted danger (e.g. slippery road). The forecast scheme includes the time span from 72 to 2 hours. The main part of the prognosis of the Road Weather Information System is the 24-hour detailed local forecast. It provides data related to a given climactic region with the help of stations installed along roads and used for weather monitoring. Data from this network is used for the purpose of supplementing synoptic data in order to prepare the road weather forecast. Additionally, this data is used for the purpose of verifying and specifying climactic conditions with the use of road weather monitoring stations.

One road station selected as representative for a given area of the known Energy Balance Model is used for the purpose of forecasting road conditions and road surface temperature. Obtained results representative for the whole forecast area are used by road maintenance engineers for the given road network, though personal experience is also taken into account. Input synoptic data is processed by the Numerical Weather Forecast Model; nevertheless meteorologists control the quality of data.

The Energy Balance Model is started once a day or whenever measurement results substantially differ from the forecast.

At a later stage the Energy Balance Model will be started in case of almost all road stations with the forecast period from 2 to 5 hours, which means that the system will be started several times during every 24h, and the synoptic data will be entered into the numerical model.

Within the last 10 years, many models for forecasting the road surface temperature and road conditions for standard asphalt and concrete pavement have been created.

Parameters such as icing or temperature of the road are not only the result of the synoptic situation, but also of numerous other meteorological factors, such as: road constructions, materials, albedo, heat accumulation, thermal capacity, etc.

Moreover, local topography and metrological factors, such as frosted undisturbed road section or cold air sections substantially influence road surface temperatures and road conditions. The effect of shading, the effect of city heat islands and the verification of results obtained from the IBM (Ice Break Model) also play an important role.

Moreover, the influence of the road traffic on the turbulent mixing of air caused by wheels and thermal vehicle radiation should not be neglected.

All the local effects must be taken into account in order to prepare very exact weather forecasts. This goal is very difficult to achieve, because many factors are influenced by the variety of synoptic situations. There are several solutions to this problem.

(a) Statistical Correction Method using a variable of average errors of forecasts prepared in course of the last seven days. This method reduces an average error, although it cannot describe in detail every individual synoptic situation.
(b) Statistical interrelations making it possible to estimate the influence of topoclimate on the road surface temperature and road conditions.

The thermomapping method is employed as one of approximations used for the purpose of detecting local topoclimactic influences on the forecasted road surface temperatures with bench-mark measurements.

2. INPUT DATA

The Model operates on the basis of the 6-hour weather period. The course of energy streams is estimated with the use of meteorological parameters and controlled with the help of balance meters. Various types of input data are required.

(a) *Initiation values*. Some of the initiation values must be entered by the meteorologist. They describe the general road condition in the network described as "regular traffic" and are also used in case of other types of the network at the start-up of the model: road surface temperature, temperature 30 cm (11,8 inches) underground, conditions of the road surface. Additionally, the 09 UTC ground temperature profile obtained in the model used on the preceding day is automatically started.

(b) *Meteorological /synoptic/ input data*. Synoptic input data is entered with the help of the Weather Forecast Numerical Model with the use of Kalman filtration. It includes forecasted temperature values of the air, dew-point and atmospheric pressure for every 3-hour period. Additionally, average values (from the period of three hours) of the following parameters are entered: cloud cover (overcast, low, average, high), velocity and direction of the wind, the total value of rainfall and snowfall, as well as pressure near the ground (changes of about 80 hPa can raise the temperature of the road surface even by 2K during the day).

(c) Supplementary meteorological data. In order to improve the calculation of short- and longwave radiation we need data on the thickness of the snow cover and visibility. If we take into account the snow cover, we can introduce the parameter system of the radiation diffusion, which may lead to the increase in the surface temperature even by 3K. The visibility parameter does not substantially affect the surface temperature at night. However, changes in visibility from good to bad entail the decrease in the surface temperature by 5K in the afternoon.

(d) *Constant input data*. This data specifies the characteristics of the road station. It includes geographic coordinates and elevation above the sea level. Also data related to albedo, emission, heat conduction, heat capacity and the thickness of pavement is required, although at present standard values are used in case of all the networks.

3. INPUT DATA TABLE

The input table includes forecasted values from 12UTC on a given day to 12UTC on the next day at 3-hour intervals and corresponds to weather elements important for the purpose of the road maintenance.

The set of data contains meteorological parameters entered into the Weather Forecast Numerical Model, including the air temperature and other weather vectors, among others precipitation: rain, snow or sleet, as well as the wind velocity and direction. The Energy Balance Model introduces forecasted values of the surface temperature and road conditions (dry, damp, wet, rime, ice or snow) to five network types. The meteorologist can, if there is such a need, modify forecasted values, e.g. in case of a slippery road he can add a comment. Results obtained with the help of the Energy Balance Model for road sections classified as "regular traffic" are sent to local authorities.

4. PARAMETRISATION OF ENERGY STREAMS

The energy balance of the road surface is expressed by the following general formula:

$$G(0,t) = S\downarrow + L\downarrow - L\uparrow - H - V - W_M - W_P + W_A \quad (1)$$

where: $G(0,t)$ – the energy balance at the surface in t time, $S\downarrow$ - general received radiation, $L\downarrow$ - received longwave radiation, $L\uparrow$ - emitted longwave radiation, H – transportation of sensible heat, V – transportation of latent heat, W_M – loss of heat related to the melting of snow, W_P – energy loss or gain resulting from the increase or decrease of temperature caused by precipitation, W_A – inflow of anthropogenic energy.

T(z,t) temperature profile in time iteration with 60s step:

$$G(z,t) = -k(z)\frac{dT(z,t)}{dz}$$

$$\frac{dT(z,t)}{dt} = -\frac{1}{c(z)}\frac{dG(z,t)}{dz}$$

where: $G(z,t)$ – density of the thermal stream at the z depth and in the t time, $k(z)$ – thermal conductivity at the z depth, $c(z)$ – thermal capacity at the z depth, $T(z,t)$ – temperature at the z depth and in the t time.

Every parameter must be specified in order to enter it into the energy balance and obtain the road surface temperature. The calculations of the (H) sensible and the (V) latent heat transportation have been described by [10] and [15]. In the present model version no modifications of coefficients have been introduced, however, the radiation scheme can be changed. Additional elements are:

(a) the calculation of astronomical interrelations (the eccentricity of the Earth orbit),
(b) trigonometric interrelations (the angle of the zenithal height of the Sun in case of inclined surfaces),
(c) the calculation of the optical mass of atmosphere.

5. GLOBAL SHORTWAVE RADIATION

In order to calculate direct solar radiation in case of the cloudless sky, the parameters suggested by [13], [1] and [11] have been used.
The stream of direct solar radiation can be described with the formula:

$$I_n = 1367 \cdot \tau_r \cdot \tau_o \cdot \tau_g \cdot \tau_w \cdot \tau_a \cdot 0.975 \cdot d \cdot \cos(\theta_z) \quad (2)$$

where: τ_r - Rayleigh molecular dispersion, τ_o – ozone absorption, τ_g – absorption by regularly mixed gases (such as O_2, CO_2), τ_w - absorption by the vapor, τ_a – dispersion and absorption by aerosols, θ_z – the angle of the zenithal height of the Sun, d – the coefficient of the effect of the eccentricity of the Earth orbit, τ_a – can be defined in the following way:

$$\tau_a = \left[0.97 - \frac{1.265}{VV^{0.66}}\right]^{rm^{0.9}}$$

where: VV - visibility (≤ 5 km), $rma = rmr \cdot p/1013.25$, rmr – optical mass of the atmosphere, p – pressure near the road surface.

The general visibility is entered by the meteorologist in three possible categories. Every category is related to the 24h cycle simulation coefficient. Numerical experiments entail the following results:

Good visibility:	VV = 17 km + 24h
Average visibility:	VV = 12 km + 24h
Bad visibility:	VV = 08 km + 24h

The coefficient representing the 24h cycle is obtained in the following way:

$$24h = a\sin\left[\cos\left(\theta_{z,t-2h}\right)\right]\cdot\left(1-C_{eff}\right)\cdot\frac{\left(1-\frac{ff}{20}\right)}{15} \tag{3}$$

where: $\theta_{z,t\text{-}2h}$ – the angle of the zenithal height (2 hours after the local time); during the period between 2UTC and the sunrise, set at a constant minimal value obtained during certain nights ($a\sin[\cos(\theta_{z,t\text{-}2h})]$ in degrees), ff – the wind velocity (≤ 10m/s), C_{eff} – coefficient to estimate direct solar radiation.

C_{eff} coefficient is obtained in the following way:

$$C_{eff} = C_l + (1-C_l)\cdot 0.95\cdot C_m + (1-C_l)\cdot(1-0.95\cdot C_m)\cdot C_h\cdot 0.5 \tag{4}$$

where the sky coverage: C_l – low clouds, C_m – middle-level clouds, C_h – high clouds.

The diffusive radiation is specified in accordance with [8]. The parameters of the diffusive radiation have been described by [3], [1].

Methods of calculating the general radiation in case of clouds have been described by [4], [6], [3] and [1]. Some of the proposed constants could be changed, because the model results lead to an excessively low estimate of the road surface temperature with the approximate factor of 3K.

6. LONGWAVE RADIATION

The longwave radiation emitted by the Earth surface can be treated in accordance with Sefan-Boltzmann Law. Generally utilized emission value is 0.93.

The estimate of the received thermal radiation is based on the parameters specified by [7], [2] and [16]. Under conditions of the cloudless sky the received thermal radiation can be defined in the following way:

$$L\downarrow = \sigma\cdot T^4\cdot\varepsilon_{a,0}$$

where: σ - constant of Stefan-Boltzmann, T – air temperature, $\varepsilon_{a,0}$ - visible "atmospheric" emission of the sky.

The visible emission of the sky has been specified by [7]:

$$\varepsilon_{a,0} = a + 5.95 \cdot 10^{-5} \cdot e \cdot \exp\left[\frac{1500}{T}\right] \tag{5}$$

where: e – pressure of the vapor, a – a constant specifying the aerosol effect on calculations. The a constant changes accordingly to the forecasted visibility categories modified by the 24h cycle. The following a values have been specified in numerical experiments:

good visibility: $a = 0.69 - 24\text{h}\ 0.01$,
average visibility: $a = 0.73 - 24\text{h}\ 0.01$,
bad visibility: $a = 0.77 - 24\text{h}\ 0.01$.

The coefficient representing the 24h cycle is specified in the following way:

$$24h = a\sin\left[\cos\left(\theta_{z,t-2h}\right)\right] \cdot \left(1 - C_{eff}\right) \cdot \frac{\left(1 - \frac{ff}{20}\right)}{15}$$

According to [16], the longwave radiation received from the cloud base in case of cloudy conditions can be specified in the following way:

$$L_{CL}\downarrow = L\downarrow \cdot \left[\left(1 + a_l \cdot C_l^{2.5}\right) + \left(1 - C_l\right)\left(a_m \cdot C_m^{2.5}\right) + \left(1 - C_l\right)\left(1 - C_m\right) \cdot a_h \cdot C_h^{2.5}\right]$$

The original a_l, a_m and a_h values specified by [2] have been used with the surface temperature estimate inaccurate by about 3K, hence the resulting modifications.

7. PRECIPITATION

In the current version of the model it is possible to estimate road conditions with a bigger exactitude depending on the quantity and types of precipitation admittedly introduced by synoptic input data. Moreover, for the purpose of calculations within the framework of the Energy Balance Model the energy loss or gain depending on warming up or cooling caused by precipitation (W_P) and melting of snow (W_M) has been used. The increase of energy related to the freezing of water is not taken into account.

$$W_P = \left[\left(RR + SS\right)\frac{\left(T_s - T\right)}{10800}\right] 4186.8$$

where: RR – the amount of precipitation for the 3-hour period, SS - the level of precipitation for the 3-hour period, T_s – temperature of the area surface, T – precipitation temperature (it is assumed that it is similar to the air temperature; in case of sleet and air temperature above 0°C, T is set at 0°C), *10800* - 3-hour period expressed in seconds, *4186.8* – energy needed to change the temperature of one liter of water by 1K.

$$W_M = 0 \qquad (T_S <= 0)$$
$$W_M = 335000\ SS/10800 \qquad (T_S > 0)$$

where: 335000 – the energy for melting one liter of water (under these conditions).

It should be remembered though that the effect of the above coefficients on the energy balance is taken into account only when substantial road surface temperature and precipitation discrepancies occur or when there is a higher level of precipitation.

8. SPECIFIC NETWORK CHARACTERISTICS

As it was mentioned before, the road surface temperature and road conditions are affected by various factors, such as topoclimactology and road construction. The Energy Balance Model can take into account five various road characteristics: undisturbed road sectors with regular traffic or small traffic, shaded sectors, urbane influences, bridges. On the basis of one set of input data submitted by the meteorologist for the characteristics of a road section such as “regular traffic”, five runs of the model are automatically performed, resulting in the road surface temperature and road conditions for the five characteristics of this road section.

9. REGULAR AND SMALL TRAFFIC

The characteristics of a road section such as “regular traffic” relates to straight undisturbed road sectors with the regular traffic density. The effect of traffic on the road surface temperature is related mostly to the turbulent mixing of the air, wheel friction and vehicle radiation. During windless and cloudless nights, when we use as input data the “synoptic” wind, the difference between the road surface temperature and the observed temperature is 3K. In case of the presented model, best results are obtained when using the standard wind velocity of about 5m/s during a business day, about 2.5m/s during holidays and at night between 23 and 03 UTC.

The characteristics of the “small traffic” section corresponds to road sections of a similar exposure but with the lower level of traffic (or without any traffic).

10. SHADED SECTORS

Calculations for the “shaded sectors” are done under assumptions that:

(a) the traffic is regular.

(b) during the whole forecast period the road is shaded by an obstacle (the value of the direct solar radiation is assumed to be null during the whole forecast period). The obstacle is parallel to the road and is 8m high with an undefined length. The distance between the obstacle and a hypothetical point of measurement on the road is 10m.

With these assumptions, the amount of the diffusive radiation from the sky received by the road surface will be reduced by 14.5%. It entails the decrease of the road surface temperature by about 1K under the clear sky. The shortwave radiation many times reflected between the road surface and the obstacle is not taken into account. For that reason the shortwave radiation received by the ($I_{sh}\downarrow$) shaded road sector is defined in the following way:

$$I_{sh}\downarrow = I_d\downarrow(1-0{,}145) + I_d\downarrow\cdot\alpha_{Wall}\cdot 0{,}145$$

where: $I_d\downarrow$ - total diffusive radiation, α_{Wall} - albedo of the obstacle (arbitrarily set at 0.2).

In order to calculate the total thermal radiation received by the road surface, two aspects should be taken into account. The first aspect is the thermal radiation of the obstacle, although the effect of the temperature of its surface seems to be insignificant. The change of the obstacle surface temperature by 5K entails the change of the road surface temperature by about 0.2K.

The second aspect is the suppression of the thermal radiation of the sky by the shading obstacle. It is important that the anisotropy of the thermal radiation and its dependence on the angle of the zenithal height are examined. Should this interdependence be neglected, the road surface temperature may be calculated with an error of even 3K.
The following interdependence is suggested for the atmospheric emission:

$$\varepsilon_{a,0}(\theta_z) = 1 - 0.5\exp\left\{-0.3\left[\frac{V}{\cos(\theta_z)}\right]^{0.5}\right\} \tag{6}$$

where: θ_z – the angle of the zenithal height, V=exp[(T-257.6)/15.47].
Assuming an average angle height of the obstacle at the level of 26° and, e.g. T = 273K, we receive V = 2.76. If we use this V value, we can calculate $\varepsilon_{a,0}$ for various sky sectors:

Hemisphere of the sky with the obstacle:	$\varepsilon_{a,0}(\theta_Z <= 64°) = 0.700$
Hemisphere of the sky without the obstacle:	$\varepsilon_{a,0}(\theta_Z <= 90°) = 0.777$
The whole sky	$\varepsilon_{a,0} = (0.700+0.777)/2 = 0.738$

The implementation of these results entails in general a percent decrease of $\varepsilon_{a,0}$ because of the obstacle (1-0.738/0.777), which is 0.050, i.e. about 5%.
This percent decrease is almost constant for temperature in the real range. To sum up, the range of the air temperature from 263 to 283K in wintertime entails the decrease in $\varepsilon_{a,0}$ by the 0.047 factor to 0.050.

Since the (5) equation is more accurate for the purpose of calculating the received radiation than the (6) equation, it is accepted that the assumptions for the (6) equation can also be used in the (5) equation. If we combine all those effects, the received thermal radiation can be finally defined in the following way:

$$L_{sh}\downarrow = L\downarrow(1-0{,}145)\left[1-0{,}05(1-C_t)\right] + \varepsilon_{Wall}\cdot\sigma\cdot T_S^4\cdot 0{,}145$$

where: c_t –overcast sky, σ - Stefan-Boltzmann constant, T_s – temperature of the obstacle surface, ε_{Wall} = the obstacle emission (set at 0.93).

It is necessary to correct the primary value of the road surface temperature, since the meteorologist uses the Energy Balance Model with the value for the unshaded road sector. In case of the maximum B_{max} angle of the Sun position (in degrees) with a clear sky the equation is as follows:

$$T_{sh} = T_{sun} - (0.47B_m - 1.5)$$

where: T_{sh} – surface temperature in the shaded sector, T_{sun} - surface temperature in the unshaded sector.

In the present model, the influence of the clouds effect on the direct solar radiation is expressed by the (1-C_{eff}) formula (C_{eff} is specified by the 4 equation). In the model, the following definition of $T_{sh,0900UTC}$ is used:

$$T_{sh,0900UTC} = T_{sun} - (0.47B_{max} - 1.5)(1 - C_{eff})$$

Tests have proved that this equation is sufficiently accurate for the period from November to February. But in March the value of $T_{sh,0900UTC}$ is too low. In order to avoid complications, special limits for the purpose of calculating the value of the initial temperature of the shaded road surface should be introduced. The temperature of the shaded road sector should be lower than or equal to the temperature of the unshaded road surface. Depending on the percent of the sky cloud coverage, differences between the temperature of the shaded and unshaded road surface should never exceed 5K.

11. URBANE INFLUENCES

Since it is very difficult to simulate urbane influences upon the road surface temperature and road conditions, the notion of the area roughness is used. Calculations are similar to those used in case of sectors of "regular traffic". According to [12] and [14] the roughness increases by 52cm. In case of [5], the following values have been added to the Energy Balance Model:

(a) Additional constant anthropogenic energy (initially) equal to $WA = 14\text{Wm}^{-2}$ (the value characteristic for the urbane sector).

(b) Upper boundary of the distribution of the air temperature differences between the urbanized sector and rural sector has been specified (with the cloudless sky and light winds) at the level of 4K at night and 2K during the day, with the clouded sky and small wind velocity this difference decreases to 2 and 1K, respectively.

The changeability of differences of the daily air temperature (ΔT) between the urbanized and rural sector, depending on the wind velocity and clouds is expressed by the following equation:

$$\Delta T = \left\{4 - \frac{a\sin\left[\cos\left(\theta_{z,t-2h}\right)\right]}{15}\right\} \cdot 0,5 \cdot \left(1 - \frac{C_d}{4}\right) \cdot \left(1 - \frac{ff}{20}\right)$$

where: $\theta_{z,t-2h}$ – the angle of the zenithal height (two hours after the local time), during the period between 2UTC and the sunrise, the constant value for the whole night is set ($a\sin[\cos(\theta_{z,t-2h})]$ in degrees), ff – the wind velocity (<=10m/s), C_d – the dominant type of the sky cloud coverage.

The C_d dominant cloud type can be defined in the following way:

$$C_d = 3C_l + 2(1 - C_l)C_m + (1 - C_l)(1 - C_m)C_h$$

In case of the wind velocity exceeding 10m/s, the difference between the urbane and rural sector disappears.

12. BRIDGES

The main difference between the characteristics of the "regular traffic" and "bridges" sectors is that the number of levels of the road mass model is diminished from 20 to 10, which corresponds to the maximum depth of 32.5cm. Measurements with one sensor put under the bridge surface have proved that this temperature is equal to the ambient air temperature.

The test conducted with the help of the Energy Balance Model gave very interesting results: in case of the cloudless sky or the presence of clouds of the high or middle level, the model recalculates the temperature of the road surface at night. For that reason, the thermal capacity (c) and conductivity (k) are set in the model in form of c_{br} and k_{br} coefficients.

$$c_{br} = \frac{c}{\left[1+0,2\left(1-C_l\right)\right]}$$

$$k_{br} = \frac{k}{\left[1+0,2\left(1-C_l\right)\right]}$$

where: C_l – the quantity of low clouds

13. STATISTICAL CORRECTIONS

When the hindcast method was used in case of two winter seasons: 1995/96 and 1996/97, systematic errors were detected in the forecast of the road surface temperature for the afternoon and evening. Those errors were most of all the result of the use of the Energy Balance Model and the influence of anthropogenic factors. That is why, statistical correction has been introduced, which gives such an effect that in case of the forecast for the period from 15UTC to 21UTC the air temperature is artificially increased. After implementing those corrections, an average error of the road surface temperature is reduced to the maximum value of about –0.5K.

The following statistical corrections have been used:

$$T_{Corr,1500UTC} = T_{1500UTC} + 0.0 + 2,4C_{l,1500UT}$$

$$T_{Corr,1800UTC} = T_{1800UTC} + 1.0 + 1,0C_{l,1800UTC}$$

$$T_{Corr,2100UTC} = T_{2100UTC} + 0.0 + 1,0C_{l,2100UTC}$$

where: $C_{l,XX00UTC}$ – the quantity of clouds of the low level at XX UTC, $T_{XX00UTC}$ – the air temperature at XX UTC

In case of the characteristics of the "bridges" sector, statistical corrections are decreased by the 0.5 coefficient.

14. VERIFICATION

14.1. VERIFICATION PROCEDURE

In order to evaluate the quality of a model, the hindcast technique is used with the help of data related to the air temperature and the dew-point temperature measured on the preceding day (in the road weather monitoring station), as well as the observation of the cloud coverage and precipitation (in the nearby synoptic stations). The measurement database is obtained from the weather monitoring station.

The best results of the evaluation were obtained with the overcast sky and cloudless sky. At these times there are no differences in the level of cloud coverage between road stations and corresponding synoptic stations, on condition that the measurements and observations were correct. Synoptic data is then the basis for verifying the correctness of the model results.

The hitherto conducted tests allow to present the verification types, for instance the road surface temperatures, whereas the verification of the road conditions has been excluded on account of:

(a) the incertitude of measurement results obtained from the road stations,

(b) the fact that the model cannot be used to calculate any factors affecting the road maintenance in winter,

(c) differences of the temperature under the surface of the ground at the depth of 30cm between the model calculations and corresponding measurements are no bigger than 0.5K.

The quality of the model is evaluated on the basis of an average error ('model' – 'measurement) and average quadratic error, representing the non-systematic part presented underneath.

For instance, the verification results for "regular traffic", "shaded sectors" and "bridges" sectors have been presented. Data from the road stations located in "small traffic" and "urbane influences" sectors was not available.

14.2. FREQUENCY OF DISTRIBUTION OF ERROR SPANS

There is a clear 24h cycle. The largest percent, e.g. the best forecasts within a given error span, is obtained at night. In case of "regular traffic" and "bridges" sectors from 50% to 90% of all the forecasts for the night resulted in errors smaller than 1K. For the day an error smaller than 1K was obtained only in case of 40%-60%. Much better results have been obtained for "shaded sectors".

Regarding the +/-2K forecast error span, it is noticeable that at night more than 90% of all the forecasts is accurate, whereas during the day this value oscillates between 60% and 80%.

A relatively high incertitude of results is caused by the fact that in winter there are more days with differences between observations of the cloud coverage in synoptic stations and road stations. Those differences more significantly affect the road surface temperature during the day than at night.

15. RECAPITULATION

The examined Energy Balance Model was prepared on the basis of the Energy Balance Models initially prepared by UKMO (UK Meteo Office) and DWD (Deutscher Wetterdienst). In accordance with [9], the resultant model version includes:

(a) more sophisticated radiation scheme.

(b) forecast period with 3-hour intervals (maximally 6 hours).

(c) model calculations for different road characteristics.

Results obtained with the Energy Balance Model were verified taking into account the hindcast method, combining correct synoptic data with correct measurements of road sensors. The results proved that the Energy Balance Model allows to prepare a better forecast of the road surface temperature at night than during the day (according to the sector characteristics type). For the period after 2100UTC the road surface temperature is forecasted with an average error between 0 and 1K and average quadratic error between 0.5 and 2K. The results are better when there is the cloudless sky than when the sky is partially or totally covered with clouds. For the forecast period till 21UTC, results are less accurate and the deviation is up to -2K, although in similar conditions on the subsequent day there is only a small average error. The reason is the necessity to take into account geotechnical conditions modeling the process of the energy re-radiation. That is why, till the time of calculating the above influence, a statistical correction has been introduced for the forecast period from 15 to 21UTC in order to minimize these mistakes. It should diminish both average errors and the average quadratic error characteristic for the places not much different than others. Which indicates that the Energy Balance Model gives results of a similar accuracy as the results of UKMO and DWD, when it is used for various road characteristics.

It should be emphasized though that the results herein presented are average values based on single road stations. In case of the "regular traffic" section, small deviations from average values were obtained. In case of "bridges", most of them are characterized by big individual differences, which results in deviations within the range from –1.7 to +2.3K after 18UTC. It may be explained by different types of bridge constructions.

The analyses indicate a relatively high level of inaccuracy of the day results in relation to the night results. We can assume that only every fourth forecast results in an error of about 1K and it will be lower than in case of every tenth forecast, where the expected error will be about 2K. In those tests the hindcast method was implemented on the basis of a relatively limited set of data, which should be regarded as preliminary. The present model version assures the preparation of forecasts that can be used in the operational winter maintenance of roads and airports. It should be noticed though that the Energy Balance Model can be used in local forecasts on the assumption that the forecast is representative for a larger area or for a longer road section of the same local characteristics. It should arouse interest of users that prepare forecasts for single points. For practical purposes, the road surface temperature should be forecasted with an average accuracy of about 0.5 to 1K.

The ability to forecast the road surface temperature for the period longer than 6 hours depends on the ability to correctly forecast synoptic input data for the Energy Balance Model (in practice, the cloud coverage of the sky and the air temperature). So, only the improvement of the model quality can bring better results.

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