DEVELOPMENT OF A MODEL TO PREDICT PAVEMENT TEMPERATURE FOR ALKUFRAH REGION IN LIBYA

Hassan Awadat Salem
PhD Student
Department of Civil Engineering
Novi Sad University
Novi Sad, Serbia
Email: has712002@yahoo.co.uk

Djordje Uzelac
Teaching Professor
Department of Civil Engineering
Novi Sad University
Novi Sad, Serbia
Email: uzelac.djordje@gmail.com

Zagorka Lozanov Crvenkovic
Full professor
Department of Mathematics and Informatics
Faculty of Sciences, Novi Sad University
Novi Sad, Serbia
Email: zlc@dmi.uns.ac.rs

ABSTRACT

Asphalt pavements form an integral part of any transportation system. The structural capacity of the hot mix asphalt concrete layers depends on many factors including its temperature. Moreover, temperature can be a major contributor to several types of distress. Therefore, temperature is a significant factor that affects the performance and life span of a pavement. The Libyan road network expanded at a phenomenal pace from approximately 10,000 km of paved roads in 1980 to more 34,000 km in 2010, Al kufrah region is located on the southern east of Libya at latitude (24°17'N) in the desert of Libya. With the recent SHRP and LTTP research findings, it was necessary to investigate the applicability of the models developed from these research studies to Al kufrah region’s environmental conditions and more generally to the rest Libya desert reigns. This paper presents the research undertaken to develop models to predict high and low asphalt pavement temperatures in Al koufa region. A pavement monitoring station was set-up at the Al kufrah airport to monitor air, pavement temperatures in different depth, wind speed and solar radiation. Data were collected for 365 days. Daily minimum and maximum temperatures were recorded. A regression analysis was used to develop the minimum and maximum pavement temperature models, using air temperature, wind speed and solar radiation. This paper presents a new model for predicting maximum and minimum surface pavement temperature based on data collected by installed pavement monitoring station set-up at the Al kufrah airport.

Keywords: Pavement temperature, SHRP, LTPP, Asphalt concrete, Al kufrah

1. INTRODUCTION

Asphalt pavements form an integral part of any transportation system. A significant factor that affects the performance and life span of a pavement is the influence of temperature. Temperature can contribute to certain common types of asphalt pavement distresses such as permanent deformation or rutting (typically associated with high temperature environments), bleeding, and thermal cracking (associated with low temperature environments). The Strategic Highway Research Program (SHRP) established the Long Term Pavement Monitoring Program (LTPP) program in 1987 to support a broad range of pavement performance analyses leading to improved engineering tools to design, construct, and manage pavements Diefenderfer, *et al.* (2002).

The Seasonal Monitoring Program (SMP) was established as an element of LTPP in 1991 to measure and evaluate the effects of temperature and moisture variations on pavement performance and validate the available models (Mohesni, 1998; Diefenderfer, *et al*. 2002). From the initial SHRP testing and SMP data, several pavement temperature models were developed to assist in the proper selection of the asphalt binder performance grade (Mohesni, 1998; Mohesni and Symons, 1998a; Mohesni and Symons, 1998b; Lukanen, 1998; Diefenderfer, *et al*. 2002). Solaimanian and Kennedy (1993) proposed an analytical model based on the theory of heat and energy transfer. Shao *et al*. (1997) also developed a procedure based on heat transfer theory to estimate pavement temperatures. Regression models based on other sets of data were developed (Bosscher *et al*. 1998; Marshall *et al*. 2001). Asimulation model was developed. to calculate temperatures during summer conditions based on the heat transfer models developed by Solaimanian and Kennedy (Hermansson, 2000 and 2001; Diefenderfer, *et al*. 2002).

Al-Abdul Wahhab *et al*. (1994) conducted a study in two regions in Saudi Arabia to manually measure pavement temperatures in different pavement sections. The study concluded that the extreme pavement temperatures in arid environment ranged between 3 and 72°C, while in coastal areas, the temperature ranged between 4 and 65°C. In another study, Al-Abdul Wahhab *et al*. (1997) recommended five performance graded binder zones for the whole Gulf area. The study also proposed modification of the currently used binders to suite the proposed grades.

Libya as well as the Desert area, in general, possesses a different environment from that of the North America and Gulf area. The applicability of the recent SHRP and LTPP developments in the US to Libya's or the Desert area's environmental conditions needed to be evaluated. This paper presents the research undertaken to develop models to predict high and low asphalt pavement temperatures in Al kufrah region..

A pavement monitoring station was established at the Al kufrah airport to monitor air, pavement temperatures, wind speed and solar radiation figure 1 shown the Libya roads network and Al kufrah location. Data was collected for 365 days. Daily minimum and maximum temperatures were recorded. A regression analysis was used to develop the low pavement temperature model. A stepwise regression was used to develop high temperature models using air temperature, solar radiation, and duration of solar radiation as independent variables. The instrumentation used is described and collected data are presented. The developed models were compared with the SHRP and LTPP models.

Figure 1: Libyan road network and Al kufrah location

2. PAVEMENT TEMPERATURE MONITORING STATION

A monitoring station was set-up to collect data on air temperature, wind speed, solar radiation and pavement temperatures at various depths. The enclosure was mounted on an instrumentation tower. The data logger was operated by a radiation solar battery. The following section describes the installation and sensor locations.

2.1. Installation of Station

Since the total thickness of pavement layers are 34cm, it was decided to install thermocouples in the lower portion of asphalt layers and use temperature probe in the upper portion. In the lower portion, thermocouples were embedded at the surface of AC, and at 20, 80, 140 mm down to the AC layer. A digital thermocouple probe was inserted in each hole for measurement. The air temperature and pavement surface temperature were obtained using an infrared temperature gun. Figure 1 shows the schematic of temperature measurement layout. All temperature data were recorded at 15-minute. A test area was selected for the station installation inside a newly runway at the Al kufrah airport.

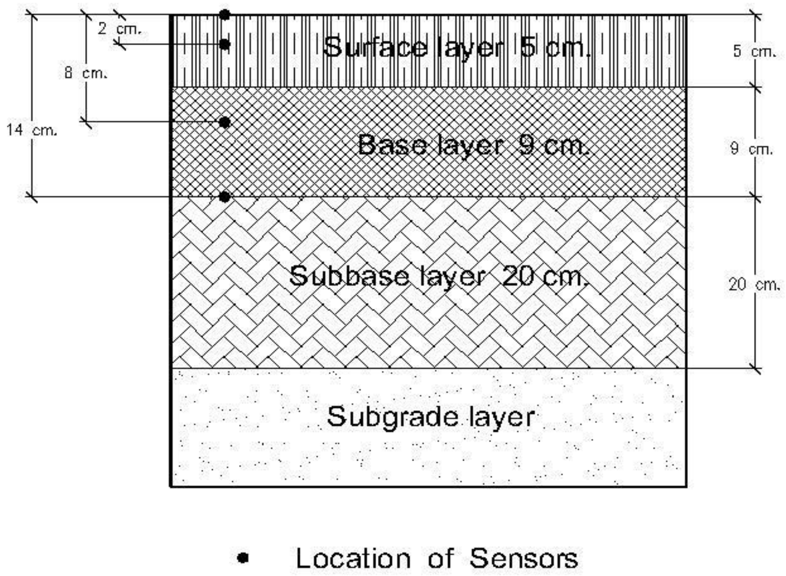

Figure 2 : Schematic of Four-layer Flexible Pavement Under Concentrated Load

3. DATA ANALYSIS

The temperature data used in analysis were collected in the period from 15rd of May 2012 to 15th of May 2013, at Al kufrah airport. The temperatures of the air and pavement at four different depth were registered each 15 seconds, as well as the wind speed and solar radiation. Collected data were used to investigate the different variability patterns between air and pavement temperatures, and to develop the models for predicting maximal and minimal daily pavement temperatures. Maximum and minimum daily temperatures of the air and pavement at four different depths were extracted for each day of observed period. Cumulative solar radiation was calculated for each day. Based on these data, using regression analysis, models for maximum and minimum daily temperatures were obtained.

3.1. Air and pavement temperature characteristics

Prior to discussing the temperature models, a brief summary of the air and pavement temperature data is presented. In tables 1 and 2 the descriptive statistics for maximal and minimal temperatures for Al kufrah airport are given, including the mean, 95% confidence interval (CI), minimum, maximum, standard deviation (St.Dev) and standard error (St.Err).

Table 1: Al kufrah airport maximal daily temperatures

Max temp	Mean	-95%CI	95%CI	Median	Min	Max	St.Dev	St.Err
Air	35.74	35.01	36.47	38.01	19.22	49.18	7.10	0.37
Surface	52.31	1.22	53.39	5.31	24.69	70.12	10.52	0.55
3cm	47.69	46.68	8.69	50.37	26.06	64.61	9.74	0.51
8cm	43.35	42.43	44.28	45.37	23.49	56.02	8.95	0.47
15cm	37.75	36.91	38.58	39.22	20.43	9.53	8.12	0.43

Table 2: Al kufrah airport minimal daily temperatures

Min temp	Mean	-95%CI	95%CI	Median	Min	Max	St.Dev	St.Err
Air	15.06	14.28	15.85	15.76	0.91	28.46	7.60	0.40
Surface	16.85	16.09	17.60	18.16	4.20	29.85	7.33	0.38
3cm	19.41	18.66	20.15	20.63	7.21	31.54	7.26	0.38
8cm	22.29	21.53	23.05	23.73	10.44	33.96	7.39	0.39
15cm	23.92	23.16	24.68	24.68	12.62	34.83	7.38	0.39

It is to be noted that the lowest pavement temperatures recorded in Al kufrah airport are well above the minimum pavement temperatures typically encountered in the US. This is due to the desert climate which does not have subfreezing temperatures.

Figure 3 presents the box plot of maximal daily temperatures at Al kufrah airport, for air temperature and four different layers, and figure 4 presents the box plot of minimal daily temperatures at Al kufrah airport. Figures show different behavior of maximum and minimum daily temperatures. While maximum surface temperature values (mean=52.31) are higher than maximum air temperature (mean=35.75), minimum surface temperature distribution (mean=16.85) is similar to the air temperature (mean=16.85). Thus, the maximum pavement temperature is recorded at the surface and is generally warmer than maximum air temperature, and the minimum pavement temperature is recorded at the surface but is generally warmer than minimum air temperature. Maximum temperatures of deeper layers are lower than the maximum surface temperatures, but minimum temperatures of layers increase with the depth from the surface

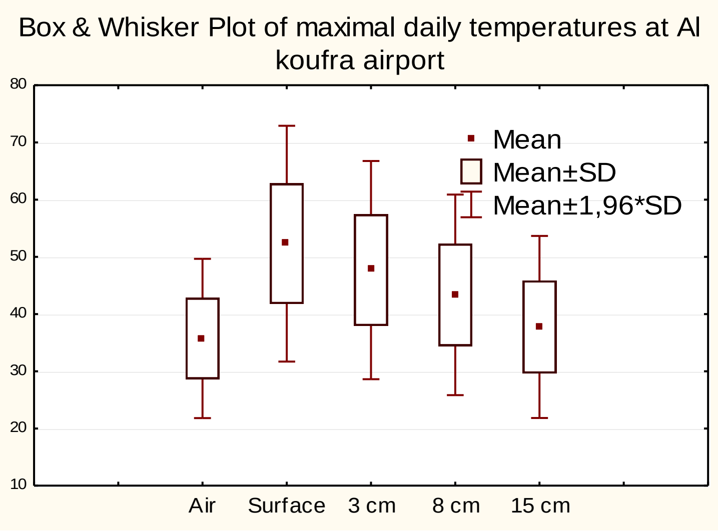

Figure 3: Maximum temperature distributions

For maximal temperatures, temperature of the surface layer is the most variable, (St.Dev=10.52) and air temperature has lowest variation (7.10). Variations of minimal temperatures are approximately the same.

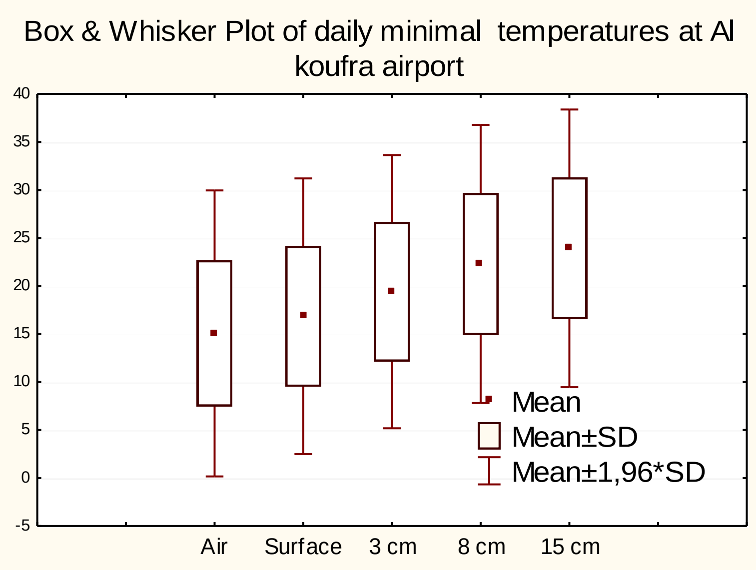

Figure 4: Minimum daily temperature distributions

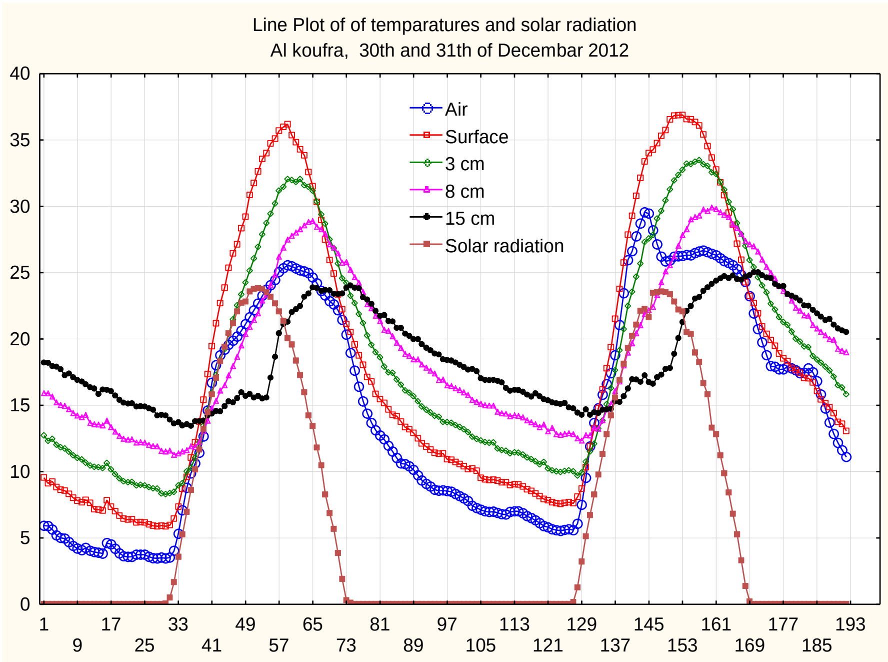

Figure 5: Air, pavement temperatures and solar radiation at Al kufrah airport on 30th and 31st December 2012.

Figures 5 and 6 present the variation of air and pavement temperatures at four different depths as well as solar radiation, with the time of day, at Al kufrah airport. In figure 5 are data obtained for two days during the cold season: the 30th and 31th of December, 2012, while figure 6 shows this variation for two days during the hot season: the 5th and 6th of Jun, 2012.

In Figure 5 it can be seen that there is a noticeable time lag between the maximum air temperature and maximum pavement temperature. The pavement heats more slowly than the air. Also, this time lag increases with the depth of the pavement layer. In figure 5 similar time lag can be observed between the minimum air temperature and pavement temperatures. The pavement surface cools quicker than other deeper layers. Figures 5 and 6 also indicate that the maximum or minimum pavement temperatures occur sometime after the occurrence of maximum or minimum air temperature, respectively.

Also, in Figures 5 and 6 the solar radiation is presented. Values of the solar radiation were scaled, in order to be presented on the same graph. It can be seen that the cycle of the solar radiation is similar to the temperature cycle, and that the solar radiation has an effect on air and pavement temperatures

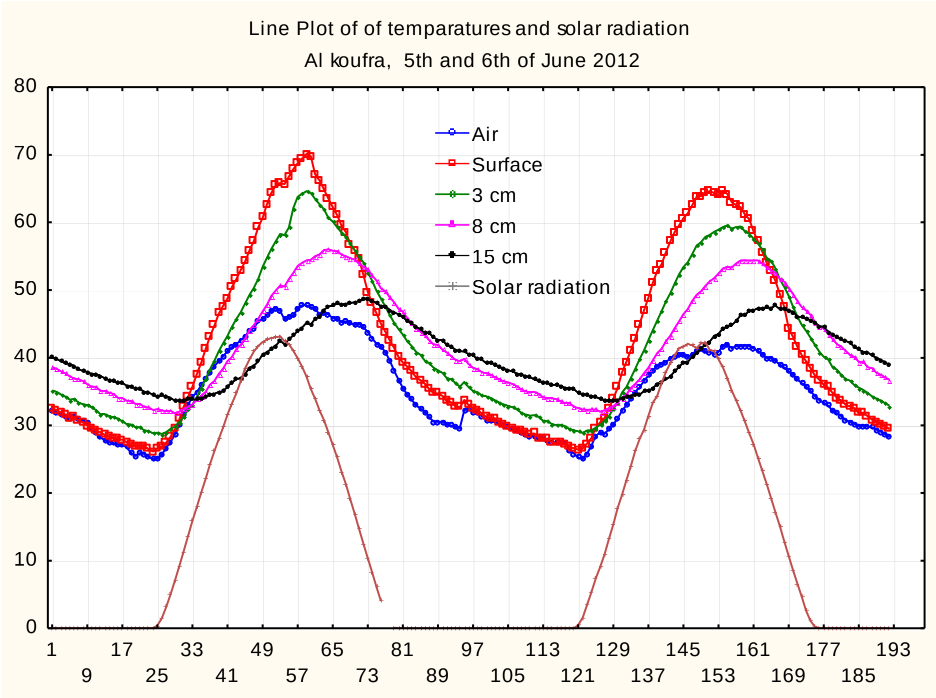

Figure 6: Air, pavement temperatures and solar radiation at Al kufrah airport on 5th and 6th June 2012.

3.2 Pavement temperature prediction models

Maximum and minimum temperatures of the air and the pavement at four different depth were extracted for each day of observed period. The models for predicting daily maximum and minimum daily temperatures from maximum and minimum daily air temperature and solar radiation were developed using statistical package Statistica 12 (StatSoft Inc., Tulsa, OK, USA), university license for Novi Sad University. The models for pavement temperatures for four layers were obtained. Here we will present the models for surface temperature.

3.2.1 Minimum daily pavement temperatures models

The first model to predict daily minimum surface pavement temperature is a linear regression relationship between the daily minimum air temperature and the daily minimum surface pavement temperature. It was established using daily minimum air temperature as an independent variable and daily minimum surface pavement temperature as the dependent variable. The model is of the following form:

$$T_{surf}^{min} = 2.502255 + 0.952306 * T_{air}^{min} \quad (1)$$

where T_{surf}^{min} is the daily minimum pavement surface temperature, and T_{air}^{min} is the daily minimum air temperature in °C. The adjusted coefficient of determination for this model is R^2= 0.97612415, that is 97% of the variability of the daily minimum pavement surface temperature is explained by the daily minimum air temperature. The standard error is Std.Error =1.1318, in other words, actual daily minimal surface pavement temperatures deviate from the true regression line by approximately 1.13°C (7%). The value of Fisher statistics is $F(1,362)$= 14841.6496, and the corresponding p-value is 0.00, indicating that there exists significant relationship between the variables in the equation. The analysis of the residuals showed that the standard conditions for performing the regression analysis are satisfied.

The coefficients of the model, their standard errors, values of test statistics and p values are given in table 3, and the graphical illustration of the equation (1) and the data ifs given in figure 6.

Table 3: Coefficient of the model in (1)

	Coefficients	Std.Error	t(362)	p-value
Intercept	2.502255	0.131849	18.9781	0.00
Min. air temp.	0.952306	0.007817	121.8263	0.00

p-values in table 3 of the coefficients of the regression line indicate that both coefficients, intercept and the slope, are significantly different from zero.

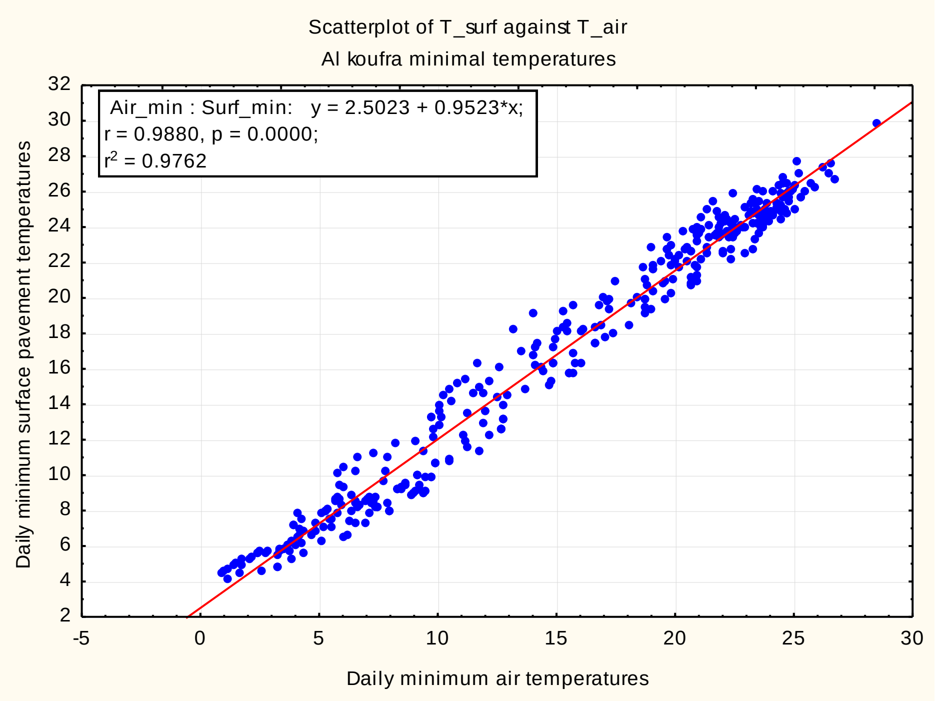

Figure 7: Minimum surface pavement temperature model

The next linear regression models to predict daily minimum pavement temperatures included, besides daily minimal air temperature, wind speed and solar radiation. The coefficient of wind speed was negative, indicating the temperature decreases with increase of the wind. The coefficient of solar radiation was small, indicating that solar radiation does not have strong influence on minimal temperatures, mainly because minimal temperatures occur early in the morning or late in the night when solar radiation is low. However, the increase of the adjusted coefficient of determination, and decrease of standard error was low for the new models, and therefore adding new variables did not improve the model.

3.2.1 Maximum daily pavement temperatures models

The first model to predict daily maximum surface pavement temperature is a linear regression relationship between the daily maximum air temperature and the daily maximum surface pavement temperature. It was established using daily maximum air temperature as an independent variable and daily maximum pavement surface pavement temperature as the dependent variable. The model is of the following form:

$$T_{surf}^{max} = 4.390290 + 1.340760 * T_{air}^{max} \qquad (2)$$

where T_{surf}^{max} is the daily maximum pavement surface temperature, and T_{air}^{max} is the daily maximum air temperature in °C. The adjusted coefficient of determination for this model is R^2=0.81890794, that is 82% of the variability of the daily maximum pavement surface temperature is explained by the daily maximum air temperature. The standard error of the model is Std.Error =4.4749, in other words, actual daily maximum surface pavement temperatures deviate from the true regression line by approximately 4.74°C (8.5%). The value of Fisher statistics is F(1,362)= 1642.50538, and the corresponding p-value is 0.00, indicating that there exists significant relationship between the variables in the equation. The analysis of the residuals showed that the standard conditions for performing the regression analysis are satisfied. The coefficients of the model, their standard errors, values of test statistics and p values are given in table 4, and the graphical illustration of the equation (2) and the data ifs given in figure 8.

Table 4: Coefficient of the model in (2)

	Coefficients	Std.Error	t(362)	p-value
Intercept	4.390290	1.205327	3.64241	0.000310
Max. air temp.	1.340760	0.033082	40.52783	0.000000

p-values in table 4 of the coefficients of the regression line indicate that both coefficients, intercept and the slope, are significantly different from zero.

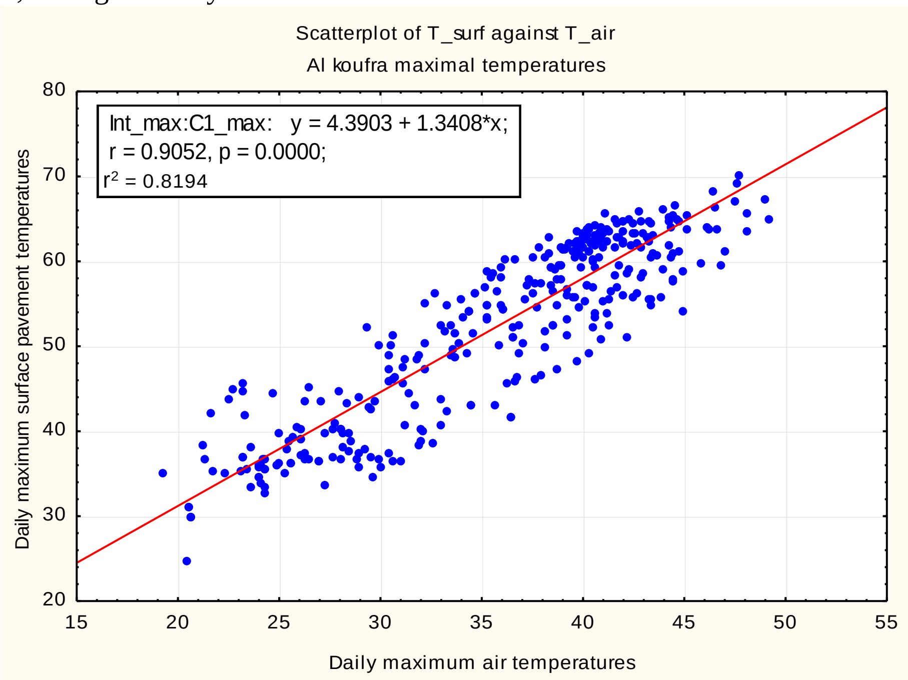

Figure 8: Maximum surface pavement temperature model

Since daily maximum surface pavement temperature is affected by factors other than daily maximum air temperature, other parameters were considered with the aim of improving R^2 and the standard error of the model. Therefore, the next linear regression models to predict daily maximum surface pavement temperatures included, besides daily minimal air temperature, wind speed and solar radiation.

The model is of the following form:

$$T_{surf}^{max} = 4.795755 + 0.947782 * T_{air}^{max} - 0.215036 * WS + 0.000591 * SR \qquad (3)$$

where T_{surf}^{max} is the daily maximum pavement surface temperature, and T_{air}^{max} is the daily maximum air temperature in °C, SR is the cumulative daily solar radiation in W/m2, WS is the wind speed in m/s. The coefficient of wind speed was negative, indicating the temperature decreases with increase of the wind. The adjusted coefficient of determination for this model is R^2=0.898705723, that is 89.9% of the variability of the daily maximum pavement surface temperature is explained the variables in the equation. The standard error of the model is Std.Error =3.34677426, in other words, actual daily maximum surface pavement temperatures deviate from the true regression line by approximately

3.35°C (6.4%). The value of Fisher statistics is F(3,360)= 1074.53935, and the corresponding p-value is 0.00, indicating that there exists significant relationship between the dependent variable and independent variables in the equation. The increased R^2 and lower standard error indicated that both the solar radiation and wind speed should be included in the model. The analysis of the residuals showed that the standard conditions for performing the regression analysis are satisfied. The coefficients of the model, their standard errors, values of test statistics and p values are given in table 5.

Table 5: Coefficient of the model in (3)

	Standardized Coeff.	Std.Err. of Stand. Coeff.	Coeff.	Std.Error	t(360)	p-value
Intercept			4.795755	1.047930	4.57641	0.000007
Max. air temp.	0.639893	0.023253	0.947782	0.034442	27.51838	0.000000
SR	0.382363	0.022569	0.000591	0.000035	16.94190	0.000000
WS	-0.039949	0.017392	-0.215036	0.093614	-2.29705	0.022189

p-values in table 4 of the coefficients of the regression line indicate that coefficients are significantly different from zero. One can use standardized coefficients in the equation to compare the effect of independent variables to dependent variable.

4. COMPARISON OF DEVELOPED MODELS WITH SHRP AND LTPP MODELS

4.1 Comparison of minimum daily pavement temperatures models

In order to compare our model and SHRP and LTPP low temperature prediction models for pavement surface temperature, we consider the SHRP model,

$$T_{surf}^{min} = 0.859 * T_{air}^{min} + 1.7, \quad (4)$$

and LTPP model

$$T_{surf}^{min} = -1.56 + 0.72 * T_{air}^{min} - 0.004 * Lat^2 + 6.26 log_{10}(25), \quad (5)$$

where T_{surf}^{min} is the daily minimum pavement surface temperature, and T_{air}^{min} is the daily minimum air temperature in °C and *Lat* is latitude for Al kufrah airport and is equal to 24.2833 (24°17'N). The predicted models and collected data are presented in figure 9. It can be seen that the predicted daily minimal surface pavement temperatures by SHRP model are lower than both the measured values and the minimal surface pavement temperature predicted by the developed model in (1). The LTPP model underestimate high, and overestimate low minimal daily surface pavement temperatures both for the measured values and for predicted temperatures by the developed model in (1).

4.2 Comparison of maximum daily pavement temperatures models

In order to compare our model and SHRP and LTPP low temperature prediction models for pavement surface temperature, we consider the SHRP model,

$$T_{surf}^{max} = (T_{air}^{max} - 0.00618 * Lat^2 + 0.2289 * Lat + 42.4) * 0.9545 - 17.78 \quad (7)$$

and LTPP model

$$T_{surf}^{max} = 54.32 + 0.78 * T_{air}^{max} - 0.0025 * Lat^2 - 15.14 log_{10}(25), \quad (5)$$

where T_{surf}^{max} is the daily minimum pavement surface temperature, and T_{air}^{max} is the daily minimum air temperature in °C and *Lat* is latitude for Al kufrah airport and is equal to 24.2833 (24°17'N). The predicted models and collected data are presented in figure 10. It can be seen that the predicted daily minimal surface pavement temperatures by SHRP model are lower than both the measured values and the minimal surface pavement temperature predicted by the developed model in (1). The LTPP model underestimate high, and overestimate low minimal daily surface pavement temperatures both for the measured values and for predicted temperatures by the developed model in (2). Therefore, the developed model is more representative of Al kufrah climatic conditions. SHRP and LTPP models would be expected to result in a more conservative selection of the PG binder.

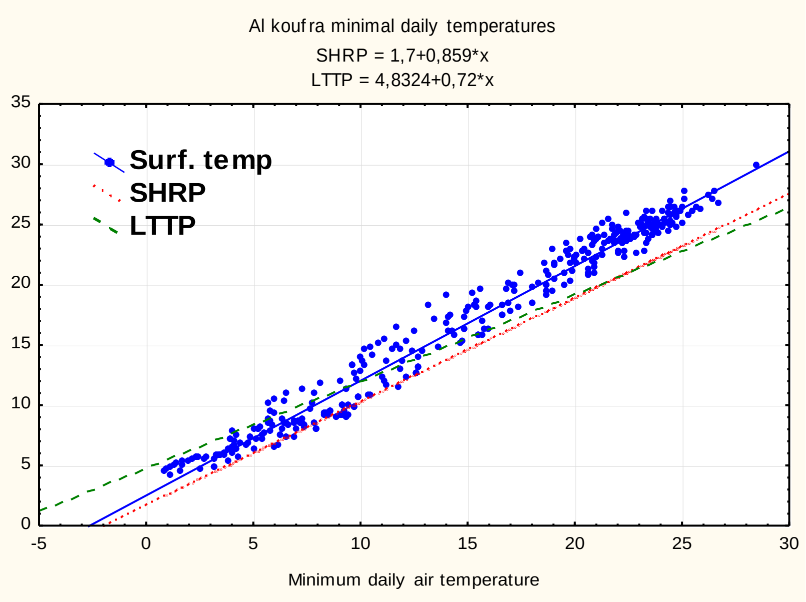

Figure 9: Comparison between daily minimum surface pavement temperature prediction model and SHRP and LTPP models.

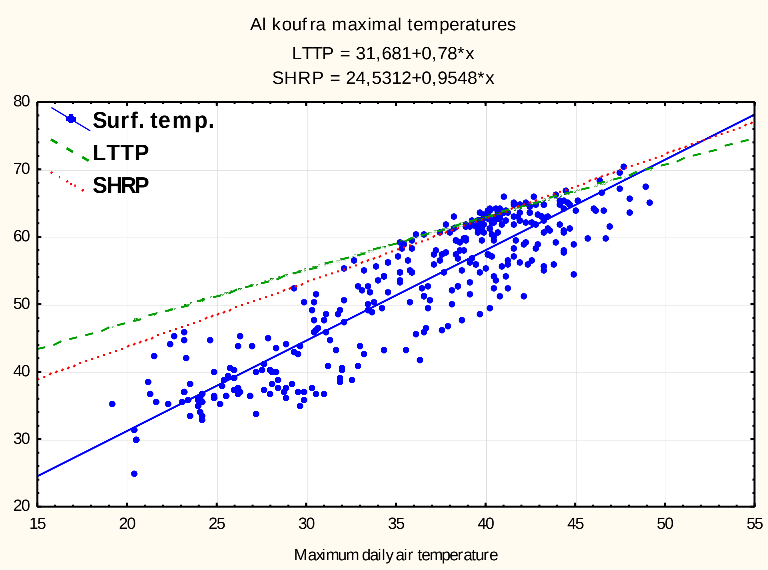

Figure 10: Comparison between daily maximum surface pavement temperature prediction model and SHRP and LTPP models.

5. Conclusions

The paper formulates a new model for predicting maximum and minimum pavement surface temperatures using regression equation, in dependence on the air temperature, wind speed and solar radiation. Furthermore, model validation has been conducted. Based on the correlation coefficient, standard model deviation and the mean absolute error (MAE) between measured and predicted minimum pavement temperatures, it can be concluded that the model predict pavement surface temperatures in Libya better than all other models mentioned in this paper. Also these developed models are suitable for predicting pavement temperatures in Al kufrah region, and more generally in the southern east of Libya.

Acknowledgments. The work of the third author was supported by the grant No.174019 by Ministry of Education, science and technological Development Republic of Serbia.

6. REFERENCES

Al-Abdul Wahhab, H.I. and Balghunaim, F.A., 1994,"*Asphalt Pavement Temperature Related to Arid Saudi Environment,"* J. of Materials in Civil Engineering, American Society of Civil Engineers, 6 (1), pp. 1-14.

Al-Abdul Wahhab, H.I., Asi, I.M., Al-Dubabe, A. and Ali, M.F., 1997, "*Development of Performance-Based Bitumen Specifications for the Gulf Countries,"* Construction and Building Materials, 11(1), pp. 15-22.

Bosscher, P. J., Bahia, H. U., Thomas, S. and Russell, J. S., 1998, "*The Relation Between Pavement Temperature and Weather Data: A Wisconsin Field Study to Verify the Superpave Algorithm*," Transportation Research Record 1609, TRB, National Research Council, Washington, DC, pp. 1-11.

Diefenderfer, B.K., Al-Qadi, I.L., Reubush, S.D. and Freeman, T.E., 2002, "*Development and Validation of a Model to Predict Pavement Temperature Profile*," Presented at Transportation Research Board 82nd Annual Meeting, Washington DC.

Hermansson, A., 2000, "*Mathematical Model for Calculation of Pavement Temperatures: Comparisons of Calculated and Measured Temperatures*," Transportation Research Record 1699, TRB, National Research Council, Washington, DC, pp. 134-141.

Hermansson, A., 2001, "*Mathematical Model for Calculation of Pavement Temperatures: Comparisons of Calculated and Measured Temperatures,"* Transportation Research Record 1764, TRB, National Research Council, Washington, DC, pp. 180-188.

James, G., Witten, D., Hastie, T., Tibshirani, T., 2013. *An Introduction to Statistical Learning with Applications in R*, Springer New York Heidelberg Dordrecht London

Lukanen, E. O., Han, C. and Skok, E. L. Jr., 1998,"*Probabilistic Method of Asphalt Binder Selection Based on Pavement Temperature*," Transportation Research Record 1609, TRB, National Research Council, Washington, DC, pp. 12-20.

Marshall, C., Meier, R.W. and Welsh, M., 2001, "*Seasonal Temperature Effects on Flexible Pavements in Tennessee*," Presented at Transportation Research Board 80th Annual Meeting, Washington, DC.

Mohseni, A., 1998, "*LTPP Seasonal Asphalt Concrete(AC) Pavement Temperature Models*," Report FHWA-RD-97-103, Federal Highway Administration, U.S. Department of Transportation, p. 71.
Mohseni, A. and Symons, M., 1998a, "Effect of Improved LTPP AC Pavement Temperature Models on Superpave Performance Grades," Presented at Transportation Research Board 77th Annual Meeting, Washington, D.C.

Mohseni, A. and Symons, M., 1998b, "*Improved ACPavement Temperature Models from LTPP Seasonal Data*," Presented at Transportation Research Board 77th Annual Meeting, Washington, D.C.

Neter, J., Wasserman, W. and Kunter, M.H., 1990, "Applied Linear Statistical Models," Third Edition, Richard D. Irwin, Inc., Boston, p. 1181.

Shao, L., Park, S.W. and Kim, Y.R., 1997, "*A Simplified Procedure for Prediction of Asphalt PavementSubsurface Temperatures Based on Heat Transfer Theories*," Transportation Research Record 1568, TRB,National Research Council, Washington, DC, pp. 114- 123.

Solaimanian, M. and Kennedy, T.W., 1993, "*Predicting Maximum Pavement Surface Temperature Using Maximum Air Temperature and Hourly Solar Radiation*", Transportation Research Record 1417, TRB, National Research Council, Washington, DC, pp. 1-11.
Statistical software Statistica 12 (StatSoft Inc., Tulsa, OK, USA), university license for Novi Sad University.