Use of Pavement Temperature Measurements for Winter Maintenance Decisions

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Formation of ice and frost on roadways and bridges presents a significant potential impediment to safe winter travel in Iowa. Roadway surface temperatures are not measured routinely by the National Weather Service and are not part of public forecasts of winter conditions, but highway maintenance personnel must make frost suppression and antiicing decisions based on expectations of future roadway temperatures. Pavement temperatures are now measured at numerous locations in the state of Iowa and reported in real time to maintenance offices. One difficulty in use of such data is the question of how representative measurements made at one location are for other roadways in the vicinity. We have analyzed January pavement temperature data from urban/rural sites for both bridges and roadways in/near Cedar Rapids and Des Moines to evaluate nighttime trends and differences of temperatures at different locations and under different weather conditions. Preliminary results show that urban roadway pavement temperatures near both Des Moines and Cedar Rapids are 2 to 5°F higher than rural roadway pavement temperatures under clear sky conditions but only 1 to 2 or 1 to 3°F higher under cloudy conditions or when cloud cover is changing.

INTRODUCTION

Literature Review

Northern latitudes of North America and western Europe experience frequent snow, sleet, ice, and frost events from late autumn to early spring. Impacts of these conditions on highway safety have stimulated numerous studies of road surface temperatures (*1, 2, 3*). Topography is a key factor controlling the variation of road surface temperature (RST). Winter nighttime RSTs can vary more than 25.4°F (10°C) across a road network depending on factors such as exposure, altitude, traffic and changes in the road-surface characteristics. Such variable pavement temperatures can create significant variations in surface traction when moisture is present on the surface and the range of pavement temperatures span the freezing point of water. Numerous studies (*4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14*) have led to development of road-surface models to predict the occurrence of frost, wet, dry, and icy conditions on the roadways.

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Present Study

This study focuses on analysis of pavement temperatures in Iowa. We have examined differences between urban and rural patterns of temperature and temperature changes under different types of weather conditions. The cooling part of the temperature-change cycle is most critical for maintenance decisions, so we focus on pavement temperature behavior from late afternoon to early morning.

Data from roadway weather information systems (RWIS), maintained and disseminated under the auspices of the Iowa Department of Transportation (IDOT), provide a valuable resource for numerous winter maintenance decisions. We analyzed nighttime pavement temperatures as reported by RWIS sensors located in and near Des Moines and Cedar Rapids under different conditions of cloud cover. Temperatures reported in this study are given in US customer units because maintenance personnel are most likely to use these units in operation.

METHODOLOGY

Data

Des Moines and Cedar Rapids each have two RWIS sites, one located generally southwest of the highly populated urban area and the other positioned in a downtown location. The downtown Cedar Rapids site has four pavement sensors located on I-380 in the vicinity of the Cedar River. Its rural (southwest) site is located on US Highway 30 near a railroad overpass, and it also has four pavement sensors. The downtown Des Moines site has three sensors located in the vicinity of the Des Moines River on I-235. Its rural (southwest) site has four pavement sensors located on I-35 over the Raccoon River and Highway 5. Sensors at all urban and rural sites are placed on roadway approaches, bridge decks over land, and bridge decks over water (Des Moines rural site has one sensor in each of two bridges over water, BW1 and BW2). Cloud cover for Des Moines and Cedar Rapids was obtained from the January 1997 Local Climatological Data (LCD) records maintained by the National Climatic Data Center.

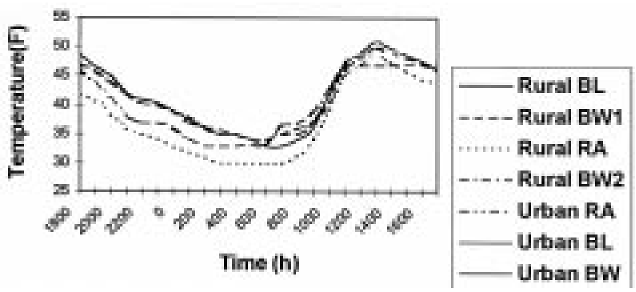

FIGURE 1 Time series of Des Moines urban and rural RWIS pavement temperatures under calm/clear skies for 01/02/97 - 01/03/97.

Procedure

RWIS pavement temperature data recorded at irregular intervals for the period 1-31 January 1997 were extracted from IDOT archives and linearly interpolated to produce an hourly temperature dataset. This dataset served as the basis for computing temperature differences, cooling rates, and lag times between urban and rural sites. Average values were stratified according to conditions of cloud cover and cloud-cover change such as clear sky/calm wind, transition from overcast to clear skies (30-50% cloud cover), transition from clear to overcast skies (75% cloud cover), and complete overcast conditions. For both cities, in general, 3-6 cases were used for each cloud-cover category.

ANALYSIS AND SUMMARY

We excluded from our analyses periods when no major changes in large-scale weather systems were the dominant influence on changes in pavement temperature.

Des Moines Pavement Temperatures

We analyzed and compared nighttime pavement temperatures for roadway approaches (RA), and bridge decks over land (BL) and water (BW) between downtown and rural Des Moines RWIS sites under different classifications of cloud cover. Figure 1 shows an example of diurnal variations in pavement temperatures for a calm/clear case.

Monotonic decrease in temperature from mid afternoon to early morning as shown in Figure 1 is a typical pattern of observed pavement temperatures, with clear skies giving the most extreme rate of temperature decrease. Under clear sky conditions, the downtown roadway approach pavement temperature exceeded the southwest site temperature by 3.9°F, the bridge deck over land downtown was warmer by 3.4°F, and the bridge deck over water downtown was warmer by 2.9°F. With complete overcast conditions, the roadway approach temperature downtown was warmer than its counterpart rural site by 1.6°F, the bridge deck over land downtown was warmer by 1.4°F and the bridge deck over water downtown was warmer by 1.2°F.

When complete overcast conditions gave way to clear skies (30-50% cover), the downtown roadway approach and bridge deck over land pavement temperatures were warmer than the southwest site by 2.0°F and 2.6°F respectively, and the downtown bridge deck

TABLE 1 Average Pavement Conditions Between the Des Moines Urban and Rural RWIS Sites for Different Classifications of Cloud Cover, January 1997

	Clear and Calm Skies			Overcast to Partly Cloudy Skies (30-50% cover)			Clear to Mostly Cloudy Skies (75% cover)			Complete Overcast Skies		
	RA	BL	BW	RA	BL	BW	RA	BL	BW	RA	BL	BW
Temp. Difference (°F)	3.9±1.7	3.4±2.5	2.9±2.3	2.0±1.1	2.6±1.4	1.4±1.5	2.6±1.9	1.2±0.8	1.4±1.4	1.6±1.6	1.4±1.1	1.2±1.2
Cooling Rates R:	1.1±1.0	1.3±0.9	1.2±1.0	0.9±1.3	1.0±1.3	1.0±1.1	0.9±1.3	1.0±1.4	0.9±2.6	0.3±1.0	0.2±1.0	0.2±0.8
($°Fh^{-1}$) U:	0.8±1.2	1.0±1.0	1.1±1.0	0.8±1.1	0.8±1.1	0.9±1.2	0.9±1.3	0.9±1.1	0.9±1.2	0.2±0.9	0.2±0.8	0.2±0.8
Mean Urban Lag Time (h)	4.9	3.4	2.6	2.5	3.3	1.6	2.9	1.3	1.6	8.0	7.0	6.0

R: Rural cooling rate
U: Urban cooling rate

over water pavement temperatures were 1.4°F warmer than its counterpart rural site. When skies became 75% cloud covered, the roadway approach downtown was 2.6°F and the urban bridge deck over land was 1.2°F warmer than the comparable rural site. The downtown bridge deck over water was warmer (1.4°F) than the rural bridge deck over water.

For Des Moines, a pavement temperature anomaly was observed to occur immediately preceding sunrise (0600-0730 LST). Under all classifications of cloudiness, the urban roadway approach and bridge decks downtown were warmer than the rural west site by 5-10°F. The cause for this pavement temperature anomaly is unknown and requires further study.

The rate at which the pavement cools is a significant factor in forecasting when wet surfaces might freeze. Under clear skies, cooling rates in Des Moines ranged from 0.8-1.1°F h-1 for approaches, 1.0-1.3°F h-1 for bridge decks over land, and 1.1-1.2°F h-1 for bridge decks over water. Transition to partly cloudy conditions produced cooling rates of 0.8-0.9°F h-1 for approaches, 0.8-1.0°F h-1 for bridge decks over land, and 0.9-1.0°F h-1 for bridge decks over water. The transition to mostly cloudy skies produced cooling rates of 0.9°F h-1, 0.9-1.0 °F h-1, and 0.9°F h-1, respectively. When skies were overcast the cooling rates were only 0.2-0.3°F h-1, 0.2°F h-1, and 0.2°F h-1, respectively. As a general rule, clear skies allowed fastest cooling, while completely cloudy skies suppressed the nighttime cooling rate. In addition, the approaches had the smallest cooling rates, while the bridge decks over water had the greatest cooling rates.

Maintenance personnel may be able to take advantage of the urban/rural pavement temperature difference in refining the timing of urban roadway treatments. For instance, if the time of ice formation due to pavement cooling at the rural site is noted, the urban pavement temperature and cooling rate can be used to predict time of freezing at urban sites. By dividing the urban/rural temperature difference by the urban cooling rate, we obtain an estimated lag time for the urban location to cool to the temperature of its rural counterpart. Table 1 shows the mean and standard deviation of temperature differences, cooling rates, and urban lag times for the roadways (RA), bridge decks over land (BL), and bridge decks over water (BW) for the different classifications of cloud cover.

In summary, analyses of the Des Moines January 1997 data show that the downtown pavement temperatures were consistently warmer than the rural-site temperatures, usually by 2.5°F and as much as 3-5°F under clear skies. Under clear skies, the urban time lag was largest for approaches, and least for bridge decks over water. With 30-50% cloud cover, the lag was largest for bridge decks over land, and least for bridge decks over water. When cloudiness increased to 75%, the lags were highest for roadways, and lowest for bridge decks over land. For overcast conditions, the lags were very large for all sensor locations.

Cedar Rapids Pavement Temperatures

We evaluated and compared nighttime pavement temperatures for roadway approaches, bridge decks over land, and bridge decks over water for Cedar Rapids downtown and southwest (rural) RWIS sites for different classifications of cloudiness for the same period covered by the Des Moines analysis.

Data available for Cedar Rapids, although fewer than Des Moines, offer an independent comparison of urban/rural temperature differences and cooling rates. Under clear skies, the roadway approach temperature downtown typically was warmer than the southwest site by 1.6°F although differences as large as 3°F were recorded. The downtown bridge deck over land was approximately 1.8°F warmer than the rural site. For overcast conditions the downtown roadway approach pavement temperature exceeded the rural site temperature by 0.4°F, and the bridge deck over land was warmer by 0.7°F. For partly cloudy skies with 30-50% cloud cover, downtown pavement temperatures for both roadway approach and bridge deck over land were modestly warmer (0.4°F for approaches and 0.8°F for decks over land). When skies became approximately 75% cloud covered, the downtown roadway approach was consistently 1.5°F warmer than the comparable location outside the city. The urban bridge deck over land also was warmer (2.5°F) than the rural deck over land.

Downtown Cedar Rapids cooling rates generally were greater than rural-site rates. Under clear skies cooling rates ranged from 0.8-0.9°F h-1 for approaches and were 1.0°F h-1 for bridge decks over land. When skies were overcast cooling rates were only 0.2°F h-1 for approaches and bridge decks. Transition to partly cloudy conditions (30-50% cloud cover) and transition to mostly cloudy conditions (75% cloud cover) produced cooling rates of 0.4-0.6°F h-1 for approaches and 0.6-0.7°F h-1 for bridge decks. As a general rule, clear skies allowed fastest cooling, while completely cloudy skies suppressed the nighttime cooling rate.

In summary, the Cedar Rapids data show that urban pavement temperatures can be expected to exceed rural pavement temperatures, with a difference of 1.6°F being typical under clear conditions. Urban temperature lags typically were 1.8-2.0 h for clear skies, 1.0 h for roadways and 1.3 h for bridge decks under partly cloudy skies, and 3.0 h for roadways and 4.2 h for bridge decks under mostly cloudy conditions. For overcast conditions, the lags were 2.0 h and 3.5 h for roadways and bridge decks, respectively.

CONCLUSION AND DISCUSSION

In conclusion, we have seen that RWIS pavement temperatures can differ significantly between urban and rural locations and that cloud cover can have a significant influence on cooling rates at all locations.

Data for Des Moines show that downtown pavement temperatures were consistently warmer than the rural-site temperatures, usually by 2.5°F for cloudy conditions and as much as 3-5°F under clear skies and calm conditions. Cedar Rapids data confirmed the urban heat island effect although the magnitude of the difference was consistently less. Des Moines area cooling rates were the greatest with clear skies during the nighttime hours and the rates for bridge decks over land (1.0-1.3°F h-1) exceeded its rates for approaches and bridge decks over water. Cedar Rapids cooling rates were of comparable magnitude. For clear sky conditions, the urban time lags ranged from 2.6-4.9 h in Des Moines where the approaches had the greatest values and bridge decks over water had the lowest values. Cedar Rapids lag times were about half as large. When skies were overcast the cooling rates were greatest (0.2-0.3°F h-1) for approaches at both cities. For complete overcast conditions, the urban lags ranged from 6.0-8.0 h in Des Moines and about half as much in Cedar Rapids.

We emphasize that these results are preliminary since they cover only January and not other winter months which may experience different patterns of temperature cooling. Also, other January months may give patterns that depart from the limited period studied herein. Despite these limitations, we conclude that pavement temperatures offer roadway maintenance personnel guidance for treating roadways for frost, snow, and ice conditions.

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