Temperature influence on noise measurements

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ABSTRACT

International experiences indicate that the temperature is a factor which has some influence on the results of measurements of road traffic noise. The On Board Sound Intensity (OBSI) method is used by University of California Pavement Research Center (UCPRC) as well as by other researchers and consultants in USA to perform detailed measurements of tire noise emission from road pavements. In Europe the Close Proximity method (CPX) is currently used. The objective of this paper is to analyze how the temperature affects the OBSI results. The results presented here are also relevant to the CPX method because the Standard Reference Test Tire (SRTT), which is the test tire for the OBSI, is being studied as a possibility for the CPX method. The analysis is based on a unique series of detailed noise measurements performed on the California Department of Transportation (Caltrans) test sections with 5 different pavements at highway LA138 in the Mojave Desert in Southern California. The measurements were carried out in the desert within three consecutive days in the wintertime where the variation of the air temperature over the day was from to 2 to 22°C. This secures that the main variable parameter during these measurements is the temperature. Based on this project the air temperature correction factor of -0.027 dB/°C for asphalt pavements can be suggested for the SRTT tire used in the OBSI method and other noise measurement methods using this tire. The temperature mainly influences the noise at frequencies above 1000 Hz, therefore it could be relevant to apply frequency dependent correction factors.

1. INTRODUCTION

International experience indicates that the temperature is a factor which has some influence on the results of measurements of road traffic noise. The On Board Sound Intensity (OBSI) method [1] is used by University of California Pavement Research Center (UCPRC) as well as by other researchers and consultants in USA to perform detailed measurements of tire noise emission from road pavements. The OBSI method is frequently used in noise projects performed for the California Department of Transportation (Caltrans). An Expert Task Group organized by the U.S. Federal Highway Administration is currently working on a standard for the OBSI method, and a first version has been adopted by the American Association of State Highway and Transportation Officials (AASHTO) as standard AASHTO TP-76. In Europe the Close Proximity method (CPX) [2] is normally used to perform detailed measurements of tire noise emission from road pavements.

The objective of this paper is to analyze how the temperature affects the On-Board Sound Intensity (OBSI) measurements of tire/pavement noise. The results are also relevant for the Close Proximity method (CPX) if a Standard Reference Test Tire (SRTT) is utilized. It can be discussed if the temperature coefficient shall be given in relation to the air, pavement or tire temperature. There has so far been some international tendency to use the air temperature as independent variable so this will be done in the following.

2. METHOD

The work presented in this paper was done by analyzing two sets of measurement data [3]. A series of detailed OBSI noise measurements with the SRTT tire were performed on the Caltrans test sections at highway LA138 in the Mojave Desert in Southern California. The measurements were carried out in the desert in the wintertime where the variation of the air temperature over the day was from to 2 to 22°C. The noise has been measured on the same day or within a few consecutive days with the same equipment, by the same operator, and on the same pavements, at low (morning), medium (midday), and high (afternoon) temperatures. This ensures that the only main variable parameter during these measurements is the temperature. In the second measurement series a Goodyear Aquatred tire was used, which was the former standard test tire for OBSI. The variation of the pavement temperature over the day was from to 11 to 35°C.

The objective was to perform measurements where the only variable was the temperature and where the following factors were constant:

- Same measurement tire.
- Same inflation and rubber hardness of the measurement tire.
- No changes in age, tear, and wear of the measurement tire.
- Same acoustical measurement equipment.
- Measurement tire mounted on the same car.
- Same measurement operator.
- No changes in pavement conditions other than the temperature.

The noise measurements have been performed using the On Board Sound Intensity method (OBSI) [1] as it is set up in the UCPRC Dodge Stratus sedan (see Figure 1). The steel box behind the vehicle is an inertial laser profilometer that measures the pavement elevation profile on both wheel tracks. In the OBSI method the sound intensity is measured. Two sets (probes) of two microphones are in the OBSI method placed at the leading and the trailing edge of the right back tire (passenger side). The microphones (see Figure 2) are placed 3 inches (76.2 mm) over the pavement surface and 4 inches (101.6 mm) from the side of the tire. The distance between the two sets of microphones is 8.25 inches (209.6 mm). The sound intensity is measured in dB and the results are A-weighted and averaged for the front and rear position.

The OBSI measurements are performed at a speed of 60 mph (96 km/h) on a pavement section at a length of 134 m (5 seconds at 60 mph). The measurement is repeated 3 times on the same pavement section. The starting of a pavement section is marked on the road surface with reflective tape or at the road side by reflecting material mounted on a marking post. When a light ray from the vehicle is reflected by the reflecting material a photo cell triggers the noise measurements.

Figure 1: The UCPRC OBSI measurement vehicle.

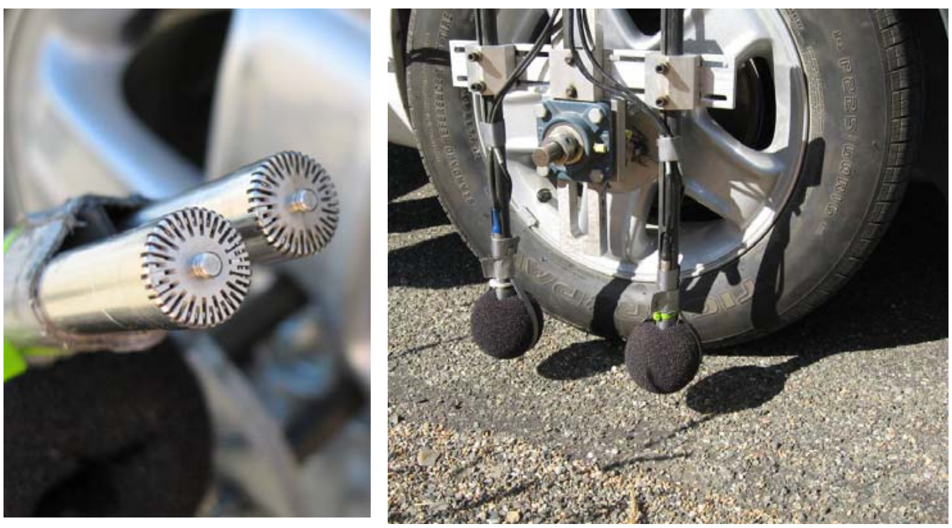

Figure 2: The microphones for the intensity probe, and the probe positions of the OBSI method.

In the CPX method used in Europe and other countries [2] the sound pressure level is measured. The sound pressure level is measured in dB and the results are A-weighted and averaged for the front and rear position. The position of the two microphones in the CPX method are 100 mm (4 inches) over the pavement surface and 75 mm (3 inches) from the side of the tire. The distance between the two sets of microphones is 400 mm (15.75 inches). The distance from the tire to the microphones is twice as long in the CPX method as in the OBSI method.

In different measurement series it has been found that OBSI levels normally are 2 to 4 dB higher than CPX levels measured on the same pavement depending on which test tires are used [4, 5]. The higher OBSI levels can partly be explained by the microphone positions where the OBSI microphones are placed much closer to the noise source (tire and pavement) than the CPX microphones. The different types of tires used in the CPX and the OBSI methods are also an explanation for the difference. It must be expected that the two methods will rank pavements in the same way in relation to noise.

A pocket weather station was used to measure air temperature. The measurements were taken on the tested traffic lane at 1.2 to 1.5 meters over the pavement surface (measurements out the car's window). A piece of paper/cardboard was held over the pocket weather station in order to provide shielding from direct sun rays. The pavement temperature is measured using a thermal infra-red gun, and is the average of 3 to 5 readings taken on the right wheel path. Air and pavement temperature are measured immediately before and immediately after the OBSI testing. The devices for air and pavement temperature are shown in Figure 3. The pocket weather station provides, in addition to air temperature, the air relative humidity and the barometric pressure.

Figure 3: Pocket weather station and thermal infrared gun used to measure respectively air and pavement temperature.

3. THE TEST PAVEMENTS

Figure 4: The LA138 test road on Highway 138 in the Mojave Desert.

The LA138 test sections were constructed on State Highway 138 in the Mojave Desert west of Lancaster in 2001. The purpose was to develop and test different types of noise reducing pavements [6]. A total of 5 different pavements were constructed including a Dense Graded Asphalt Concrete (DGAC) used as a reference. The OBSI measurements were performed both in the eastbound and the westbound directions in February 2008 when the pavements were 8 years old. The DGAC was for practical reasons only measured in one direction. Therefore a total of 9 datasets are included in this survey. The following pavements were constructed on the test road:

- A Dense Graded Asphalt Concrete (DGAC) with a specified thickness of 30 mm used as a noise reference pavement.
- An Open Graded Asphalt Concrete (OGAC 30) with a specified thickness of 30 mm.
- An Open Graded Asphalt Concrete (OGAC 75) with a specified thickness of 75 mm.
- An Open Graded Asphalt Concrete with rubber powder added to the bitumen (RAC-O) and a specified thickness of 30 mm.
- A Bonded Wearing Course (BWC). A propriety product used in California.

Another set of test pavements are included in this temperature project. These pavements are part of a UCPRC project on noise emission from typical pavements used in California [7]. Three types of pavements were included:

- Dense Graded Asphalt Concrete (DGAC). 4 different pavements.
- Open Graded Asphalt Concrete (OGAC). 3 different pavements.
- Gap-graded rubberized asphalt concrete (RAC-G). 3 different pavements.

4. AIR TEMPERATURE AND NOISE

The results of some of the measurements of noise and air temperature are shown in the following figures [3] (temperature at the surface of the pavement was analyzed too and showed similar trends). The figures to the left show the normalized results of each of all the OBSI runs (three per pavement per temperature). A linear regression analysis is included. The figure to the right shows the 1/3 octave band spectra at different temperatures as average spectra for the three OBSI runs per pavement at approximately the same temperature.

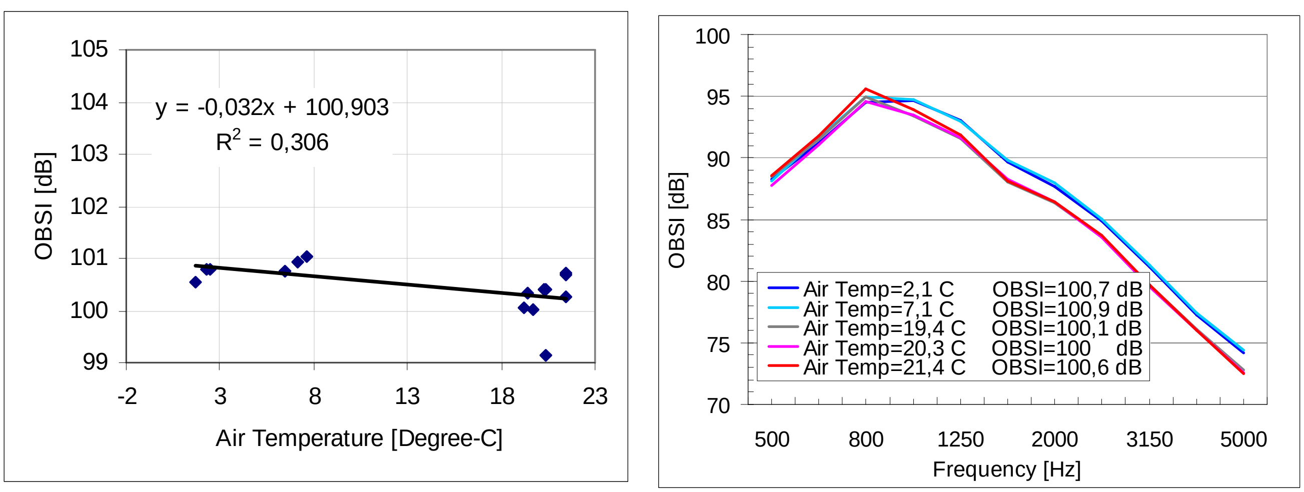

Figure 5: OGAC 75 pavement eastbound. Normalized OBSI noise measurement results with SRTT tire versus air temperature to the left and average spectra at the different temperatures to the right [3].

The results from the OGAC 75 pavement in east- and westbound directions can be seen in Figure 5 and 6. The air temperature coefficients are -0.032 dB/°C in both directions. Below 800 Hz the frequency spectra are quite alike - independent of the temperature. At the frequencies above 1000 Hz the level is around 1 dB higher at 2°C than at 20°C.

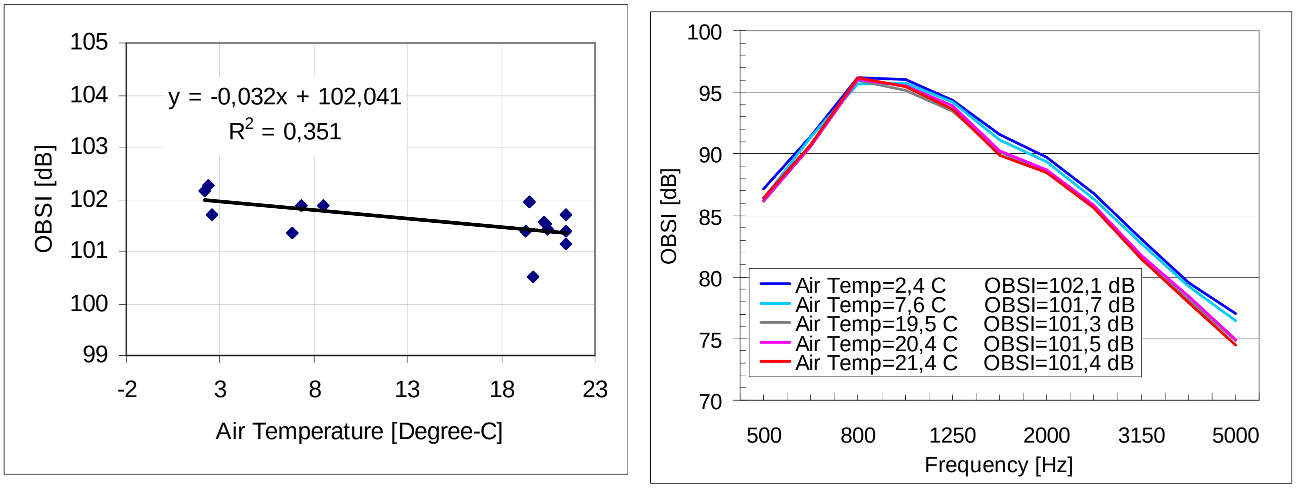

Figure 6: OGAC 75 pavement westbound. Normalized OBSI noise measurement results with SRTT tire versus air temperature to the left and average spectra at the different temperatures to the right [3].

The noise levels in the westbound direction are around 1 dB higher than in the eastbound direction on the same pavement. This general tendency is seen for all the 4 pavements for which measurements have been carried out in both directions. In Table 1 it can be seen that the Medium Profile Depth (MPD) is lower in the west direction than in the east direction indicating that the pavements are denser in the surface structure in the west direction and this can effect the noise generation. Differences in construction conditions and/or tear and wear by the traffic might be an explanation for the difference at the same pavement between the east- and westbound directions. This east/-west phenomenon has no influence on the temperature dependency of the measurement results.

Table 1: Medium Profile Depth (MPD) in Microns of the LA138 pavements east-/ westbound direction [3].

Direction	OGAC 75	OGAC 30	RAC-O	BWC	DGAC
East	1054	997	815	726	-
West	967	887	686	714	745

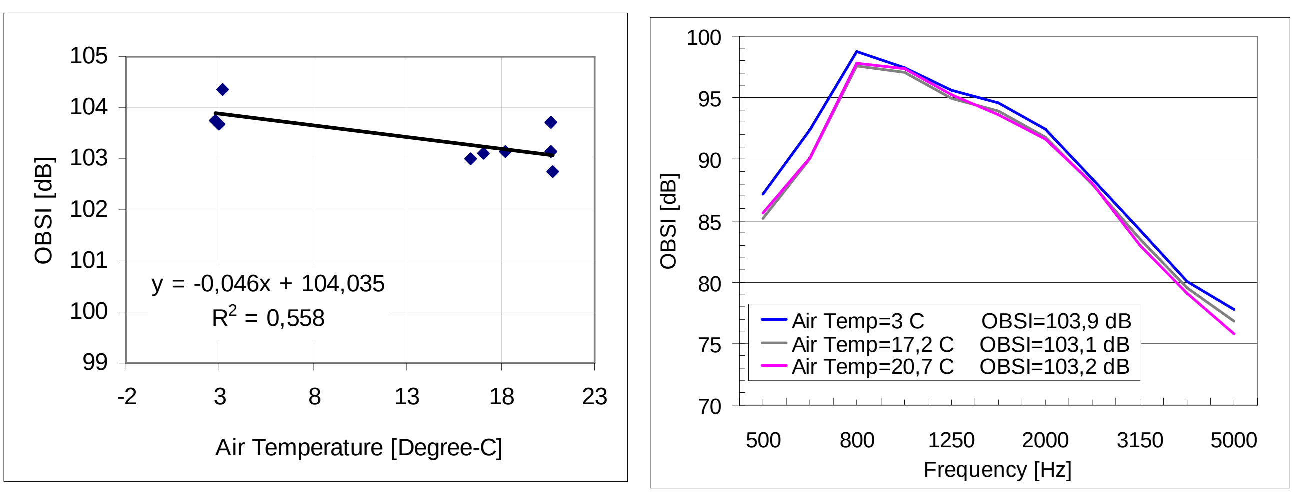

Figure 7: DGAC pavement westbound. Normalized OBSI noise measurement results with SRTT tire versus air temperature to the left and average spectra at the different temperatures to the right [3].

The DGAC pavement was only measured in the westbound direction. The air temperature coefficient is -0.046 dB/°C and higher than for the other pavements.

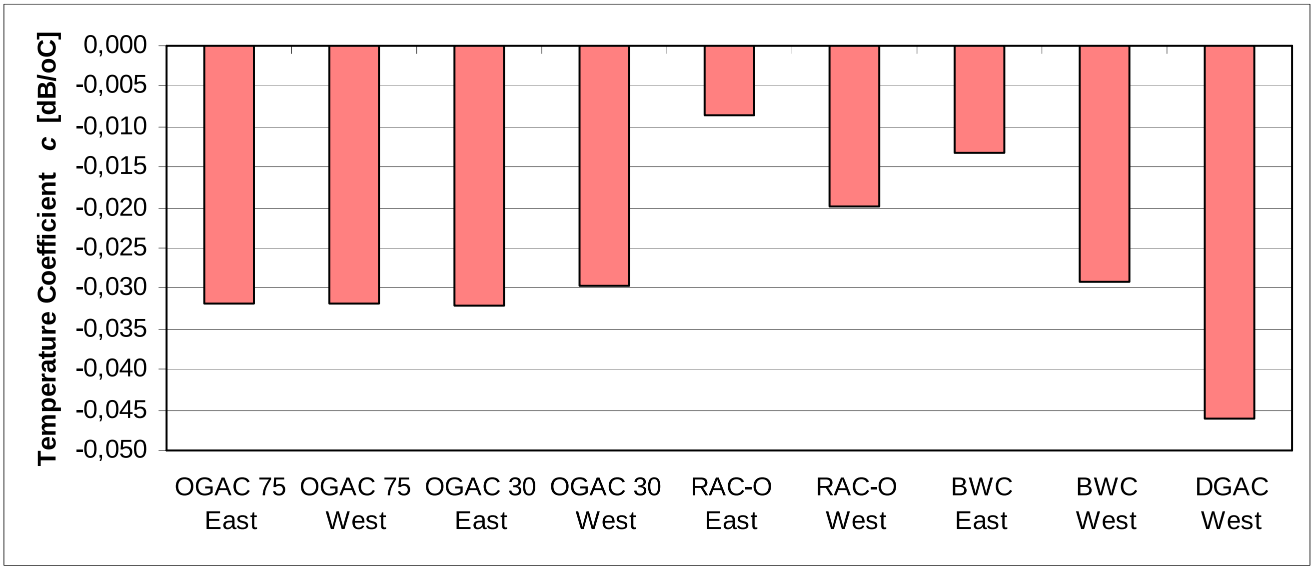

Figure 8: Air temperature coefficients in dB/°C measured in the range 2 – 22 °C at LA138 using the OBSI method and the SRTT tire [3].

The air temperature coefficients for all the nine measurements ranges between -0.009 dB/°C and -0.046 dB/°C (see Figure 8). For the different pavement types the results are the following:

- The average air temperature coefficient is -0.027 dB/°C (or -0.015 dB/°F) for all 9 measurements.
- For the dense pavements (DGAC and BWC with air void respectively 7 and 5 %) the average is -0.029 dB/°C (-0.016 dB/°F)
- For the open graded pavements (OGAC 30, OGAC 75 and RAC-O all with an air void of 10 to 11 %) the average is -0.026 dB/°C (-0.014 dB/°F).

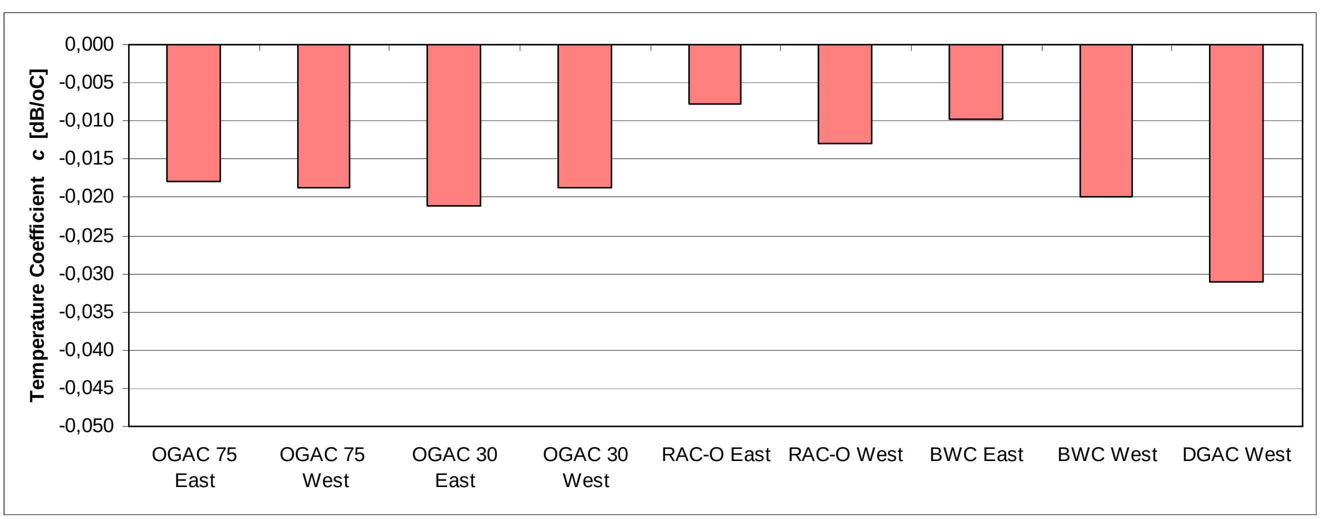

Figure 9: Pavement temperature coefficients in dB/°C measured in the range -2 – 33 °C at LA138 using the OBSI method and the SRTT tire [3].

Figure 9 shows the pavement temperature coefficients in dB/°C.

The results of the noise measurements performed on ten different Californian pavements at different temperatures can be seen in Figure 10. The OBSI measurements were performed using a Goodyear Aquatred tire which was the previous standard for OBSI before the SRTT tire was adopted. The measurements were performed June-July 2007. Due to practical reasons, only the pavement temperature data are available for reporting. In order to investigate the influence of temperature, noise measurements were carried out on the same pavement on the same day at 3 different temperatures (targeted air temperatures 15, 25, and 35°C).

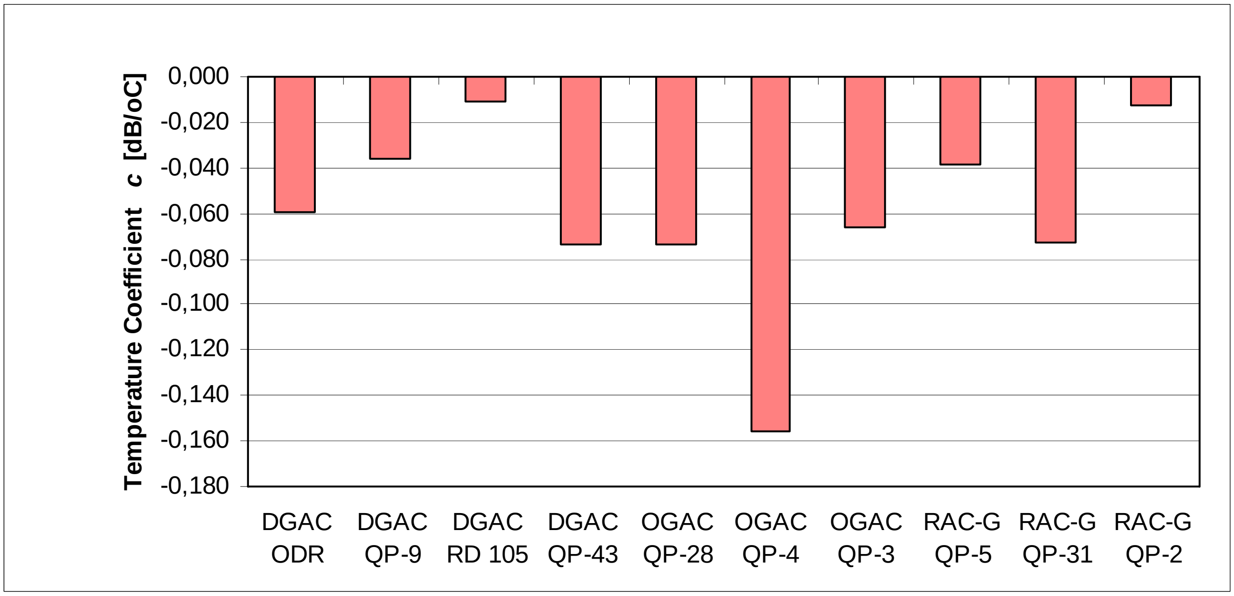

Figure 10: Pavement temperature coefficients in dB/°C measured in the range 11 – 34 °C at the Californian pavements using the OBSI method and the Aquatred tire [3].

The average coefficients for the different pavement types can be seen in Table 2 together with average for all the 10 pavements. The two dense pavement types (DGAC and RAC-G) have nearly the same coefficient -0.045 dB/°C and -0.041 dB/°C with an average of -0.043 dB/°C. For the open graded pavement type (OGAC) the coefficient is -0.099 dB/°C, which is twice as much. But the higher average for the open graded pavements is caused by the OGAC QP-4 with a very high coefficient. If this pavement is not considered the difference between the open and the dense pavements is reduced to -0.043 dB/°C versus -0.070 dB/°C.

Table 2: Average pavement temperature coefficients for the three pavement types using the OBSI method and the Aquatred tire [3].

Pavement type	Pavement temperature coefficient in Celsius	Pavement temperature coefficient in Fahrenheit
DGAC	-0.045 dB/°C	-0.025 dB/°F
RAC-G	-0.041 dB/°C	-0.023 dB/°F
Average dense (DGAC and RAC-G)	-0.043 dB/°C	-0.024 dB/°F
OGAC	-0.099 dB/°C	-0.055 dB/°F
Average all 10 pavements	-0.060 dB/°C	-0.033 dB/°F

5. DISCUSSION AND CONCLUSION

Table 3 shows a comparison of the results of the two measurement series. The coefficients of noise vs. temperature measured with the SRTT tire and the Aquatred tire are significantly different. The average air temperature coefficient for the Aquatred tire is 3 times higher than for the SRTT tire depending on the pavement type. This means that the Aquatred tire is much more sensitive to temperature than the SRTT tire.

Table 3: Average temperature coefficients for the SRTT and the Aquatred tire on different asphalt pavement types.The air temperature coefficient for the Aquatred tire is predicted based on the ratio between air and pavement temperature coefficients for the SRTT tire [3].

Tire	**Dense asphalt pavements (DGAC)**	**Open graded asphalt pavements (OGAC and RAC-O)**	**Average all asphalt pavements**
SRTT air temperature	-0.029 dB/°C	-0.026 dB/°C	-0.027 dB/°C
Aquatred air temperature (predicted)	-0.062 dB/°C	-0.160 dB/°C	-0.090 dB/°C
SRTT pavement temperature	-0.020 dB/°C	-0.016 dB/°C	-0.018 dB/°C
Aquatred pavement temperature	-0.043 dB/°C	-0.099 dB/°C	-0.060 dB/°C

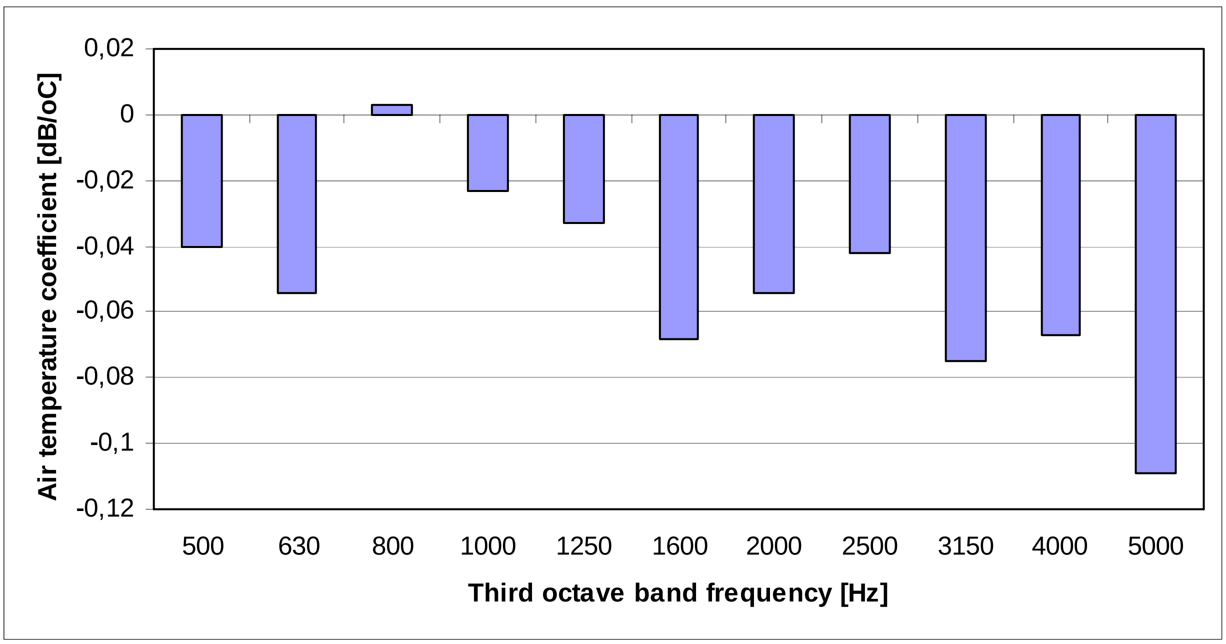

Figure 11: Suggestion for third octave band air temperature correction factors in dB per degree Celsius for the SRTT tire used at asphalt pavements in the OBSI method [3].

The results from different international measurement series are also summarized in [3]. The SRTT tire has significantly lower temperature correction factors than the other tires and tire populations included in the comparison. This shows that the SRTT tire is not very sensitive to temperature variations. The average air temperature coefficient for the SRTT tire on asphalt concrete pavements is -0.027 dB/°C. There is no big difference between dense and open graded pavements: -0.029 dB/°C versus -0.026 dB/°C. Therefore it is suggested that -0.027 dB/°C be used as the air temperature correction factor for the SRTT tire used on asphalt pavements. This is practically the same found by Donavan/Lodico (-0.026 dB/°C) [8]. Third octave band correction factors have also been determined (see Figure 11). There has not been any data available to evaluate the temperature correction coefficient for the SRTT tire used on concrete surfaced pavements. The following general conclusions can be drawn regarding temperature corrections to tire/road noise measurements [3]:

- The air temperature has an important influence on the tire/road noise measurements results.

- The sensitivity of tire/road noise to temperature can be approximated by a linear relation.
- The temperature correction coefficient varies significantly for different tire types.
- At the low frequencies the temperature coefficient is low. At the frequencies over 1000 Hz the temperature coefficient is higher.
- The temperature coefficient varies for different pavement types.
- The temperature coefficient seems to be higher for dense asphalt concrete than open/porous asphalt pavement.
- Temperature correction factors have to be determined specifically for each measurement method (OBSI, CPX, Controlled Pass By, Statistical Pass By) taking into consideration the specific test tire(s) or the tire population included in the measurements.

Some other conclusions obtained from this study [3] but not discussed in this paper include:

- The temperature correction coefficient is generally less for truck tires than for passenger tires.
- The difference in temperature correction for different pavement types almost vanishes when many different tires are included.
- The temperature coefficient seems to be lower for cement concrete pavements than for asphalt concrete pavements.

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REFERENCES

1. Further Development of the Sound Intensity Method of Measuring Tire Noise Performance of In-Situ Pavements. Illingworht & Rodkin, Inc. Report prepared for the California Department of Transportation January 4, 2006. See: http://www.i80.dot.ca.gov/hq/env/noise/pub/2_Probe_SI_Report_04Jan06.pdf
2. ISO/CD 11819-2: 2000. "Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2: The close-proximity method." 2000.
3. H. Bendtsen et. al. Temperature influence on road traffic noise. Californian OBSI measurement study. Danish Road Institute/Road Directorate, Report 169, 2009. See: www.roadinstitute.dk
4. Comparative Measurements of Tire/Pavement Noise in Europe and the United States. Noise Intensity Testing in Europe (NITE) Study. State of California Department of Transportation. Paul R. Donavan, Illingworht & Rodkin, Inc. July 26, 2006. A summary can be found at: http://www.dot.ca.gov/hq/env/noise/pub/NITE_Article_for_Caltrans.pdf
5. Measuring Tire-Pavement Noise at the Source. Paul Donavan and Dana M. Lodico. NCHRP Report 630. National Cooperative Highway Research Program. Transportation Research Board. Washington 2009.
6. April 2007 Status Report: Caltrans Thin Lift Study: LA138 Tire/Pavement Noise Study. Judith Rochat. Volpe Center Acoustics Facility (VCAF). April 30, 2007.
7. Investigation of Noise, Durability, Permeability and Friction Performance Trends for Asphalt Surface Types First and Second year Results. Research report UCPRC-RR-2007-03, University of California Pavement research Center, Davis and Berkeley, CA, February 2008.
8. Effect of Test Parameters on OBSI Measurements. Paul R. Donavan, Illingworht & Rodkin, Inc and Dana M. Lodico, ICF Jones & Stokes. Presentation at TRB ADC40 Summer Meeting Key West, Florida. July 2008. See: http://www.adc40.org/summer2008/LodicoTRB08.pdf