

# The application of locally developed pavement temperature prediction algorithms in Performance Grade (PG) binder selection

Prepared for SATC 2007

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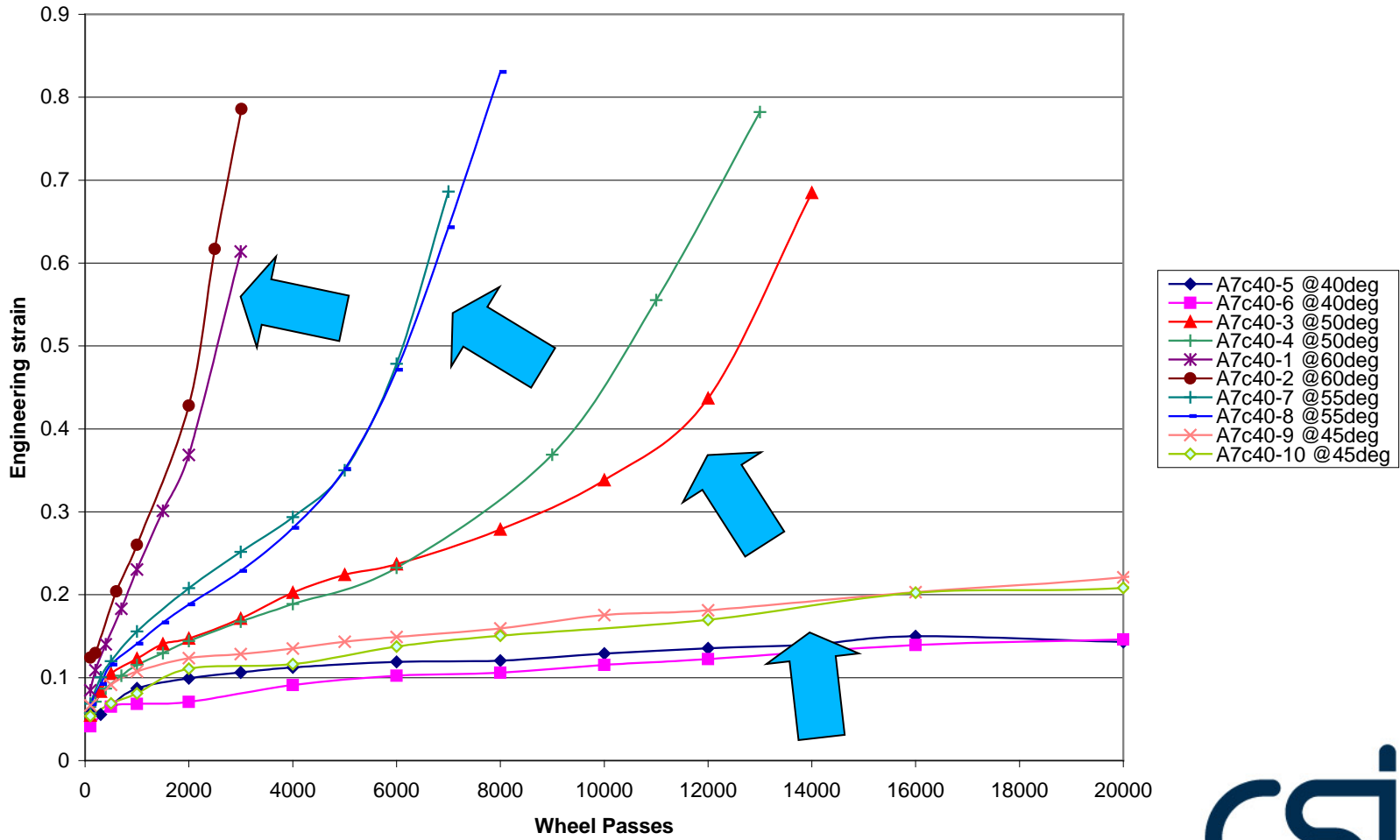
# Presentation structure

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- Temperature susceptibility of HMA
- Pavement temperature prediction equations,
- Validation of prediction models,
- Performance Grade (PG) binder specification,
- Binder selection using CSIR ThermalPADS,
- Future direction.

# Temperature susceptibility of HMA

Hamburg Rut Test (Field mix with different Temperatures) @ 40mm



# Pavement temperature prediction

- Maximum daily surface temperature
- $Q_s + Q_a - Q_c - Q_k - Q_r = 0$
- $Q_s$  = Energy absorbed at the asphalt surface from direct solar radiation.
- $Q_a$  = Energy absorbed at the asphalt surface from atmospheric radiation.
- $Q_c$  = Energy transferred from the asphalt surface to the surrounding atmosphere by convection.
- $Q_k$  = Energy transferred from the asphalt surface into the asphalt layer.
- $Q_r$  = Radiation energy emitted from the asphalt surface.

# Pavement temperature prediction

- Maximum surface temperature SUPERPAVE (Huber)

$$T_{s(max)} = T_{air(max)} - 0.00618 \times \text{altitude}^2 + 0.2289 \times \text{altitude} + 24.4$$

- Maximum surface temperature Vilioen

$$T_{s(max)} = T_{air(max)} + 24.5(\cos Z_n)^2 \times C$$

# Pavement temperature prediction

- Minimum surface temperature SUPERPAVE

$$T_{s(min)} = 0.859T_{air(min)} + 1.7$$

- Minimum surface temperature Viljoen

$$T_{s(min)} = 0.89T_{air(min)} + 5.2$$

# Pavement temperature prediction

- Maximum temperature at depth

- SUPERPAVE

$$T_{d(max)} = (T_{s(max)} + 17.8)(1 - 2.48 \cdot 10^{-3} d + 1.085 \cdot 10^{-5} d^2 - 2.441 \cdot 10^{-8} d^3) - 17.8$$

- Viljoen

$$T_{d(max)} = T_{s(max)} (1 - 4.237 \cdot 10^{-3} d + 2.95 \cdot 10^{-5} d^2 - 8.53 \cdot 10^{-8} d^3)$$

- Minimum temperature at depth

- SUPERPAVE

$$T_{d(min)} = T_{s(min)} + 5.1 \cdot 10^{-2} d - 6.3 \cdot 10^{-5} d^2$$

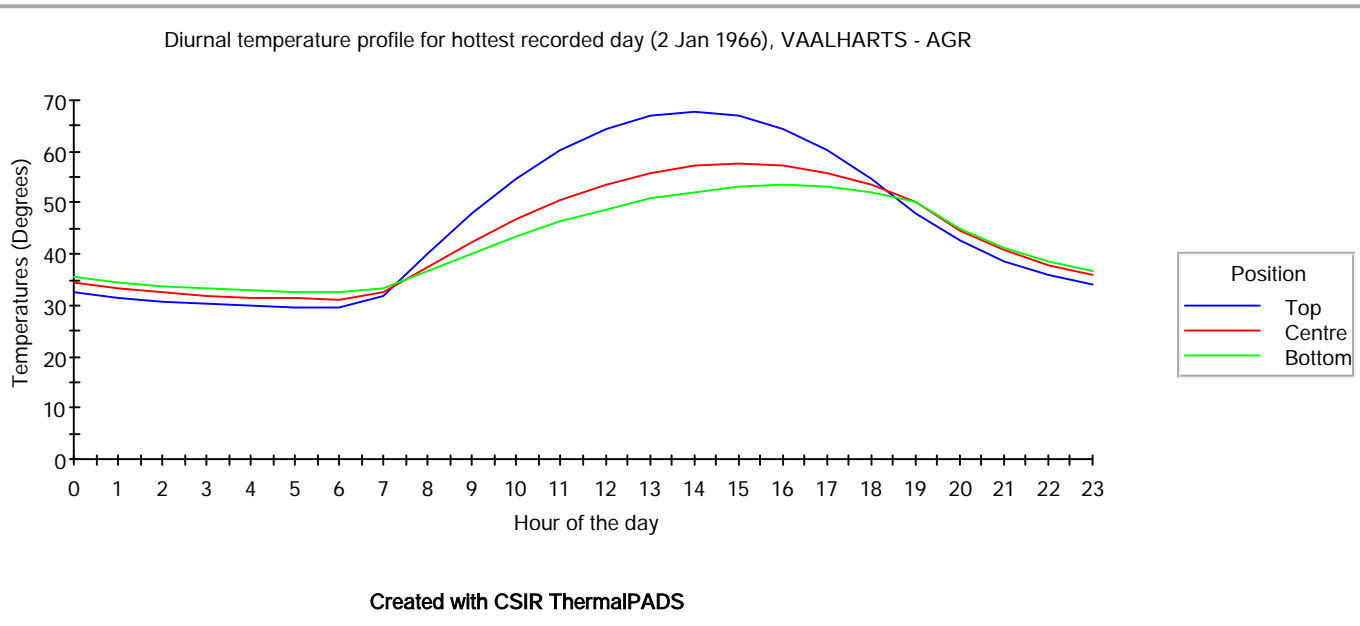
- Viljoen

$$T_{d(min)} = T_{s(min)} + 3.7 \cdot 10^{-2} d - 6.29 \cdot 10^{-5} d^2$$

# Pavement temperature prediction

- Diurnal temperature profile (Viljoen only)

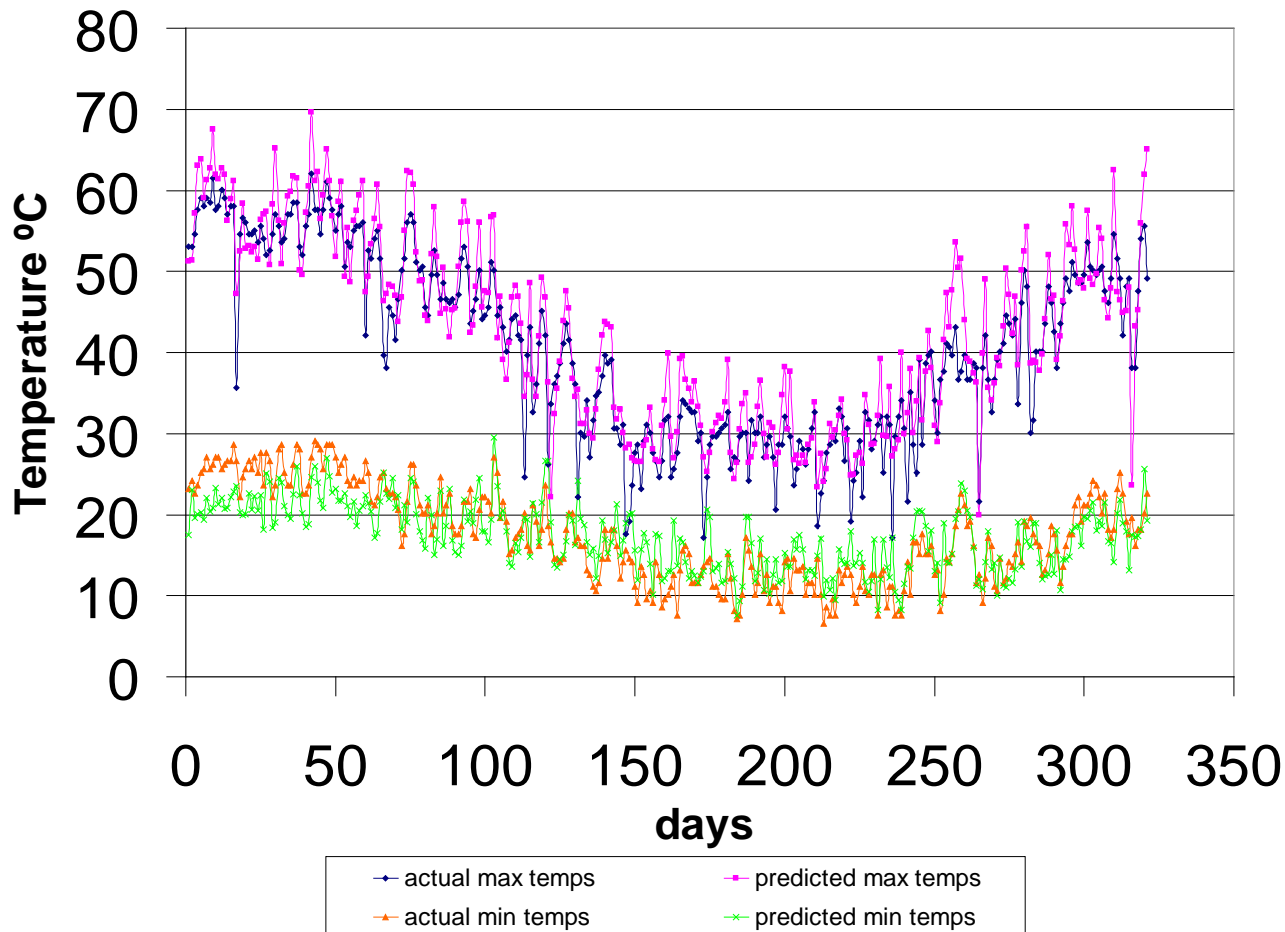
$$T_{d(t)} = T_{d(min)} + [T_{d(max)} - T_{d(min)}] \sin \frac{\pi}{DL + 2(\alpha - \beta)} (t - t_r - \beta)$$





# Validation of prediction models

**Actual vs predicted surface temperatures  
Lamberts bay 2006 (Vredendal station)**



# Validation prediction models

## Maximum surface temperature (actual - predicted)

Location	Number of days data	Viljoen equation		Superpave	
		Mean error [°C]	Standard deviation of error [°C]	Mean error [°C]	Standard deviation of error [°C]
Cullinan (R238)	93	1.72	2.59	-4.32	-3.29
Vereniging (P234/1)	92	0.31	2.48	-2.03	2.83
Cape Town (N7)	332	-3.40	2.92	1.82	6.66
Lamberts Bay (R365)	320	-2.05	3.68	3.46	7.11

## Minimum surface temperature (actual - predicted)

Location	Number of days data	Viljoen equation		Superpave	
		Mean error [°C]	Standard deviation of error [°C]	Mean error [°C]	Standard deviation of error [°C]
Cullinan (R238)	93	-2.73	2.23	2.67	2.13
Vereniging (P234/1)	92	1.01	2.44	5.39	2.20
Cape Town (N7)	332	-2.80	2.85	3.23	2.28
Lamberts Bay (R365)	320	0.19	3.17	6.17	3.37

# Performance Grade (PG) binder specification

- Applicable to modified and unmodified bituminous binders,
- Based on the stiffness of the aged binder,
- Takes into account traffic load and environmental condition,
- Specification for high and low temperature
  - PG x-y with x is high temperature y is low temperature
- Spec based on 100 km/hr and  $10^7$  E80s max.

## **SA bitumen (source SABITA)**

Pen grade	40/50	60/70	80/100	150/200
Refinery I	X	PG 64-16	PG 58-22	X
Refinery II	PG 64-16	PG58-22	PG 58-22	X
Refinery III	PG 64-16	PG64-22	PG 58-16	PG 52-22
Refinery IV	PG 70-20	PG 64-16	PG 58-22	PG 52-22

# Binder selection using ThermalPADS

- Details on CSIR ThermalPADS
  - Based on Viljoen asphalt pavement temperature prediction equations,
  - Uses daily maximum and minimum air temperature to calculate:
    - Maximum and minimum surface temperature,
    - Temperature at depth,
    - Diurnal temperature profile
  - Currently contains weather data from 65 SA weather stations
  - Can be used to select Performance Grade (PG) binder,
  - Software available from [www.prac.co.za](http://www.prac.co.za)



# Binder selection using ThermalPADS

- **Case I**
  - Freeway near Darling in Western Cape
  - Latitude  $-33.3^{\circ}$
  - Expected E80s on HMA overlay: 12E06
  - No intersections
  - Required design reliability: high
- **Case II**
  - Provincial road in Midrand (Gauteng)
  - Latitude  $-26.0^{\circ}$
  - Expected E80s on HMA overlay: 6E06
  - Intersections
  - Required design reliability: medium

# Step 1: select nearby weather station

- Confirm climate on site is similar to weather station,
- Stations selected: Langgewens (WC) & Irene (Gauteng)

The screenshot displays the ThermalPADS software interface. The window title is 'ThermalPADS'. The top menu bar includes 'Output', 'Graphs', 'Monthly Temps', and 'Stations'. Below the menu bar, there is a 'Stations List' button and a dropdown menu for 'Station Name' with 'LANGGEWENS' selected. The main area is split into two maps. The left map is a detailed view of the Western Cape region, showing the location of Langgewens (marked with a red dot) and surrounding areas like Cape Town and the Groot Waterpoort Wilderness Area. The right map is a national overview of South Africa, showing the location of Langgewens in the Western Cape province. The software interface also includes zoom controls (Zoom Out, Last Zoom, Back Zoom) and a 'Stations List' button. The bottom status bar shows the current time as 11:51 and the active project as 'LANGGEWENS'.

# Step 2: Input latitude of road

**LANGGEWENS - ThermalPADS**

File Calculate! Help

Input | Solar Declination | Zenith Angle | Surface Temperatures | Output | Graphs | Monthly Temps | Stations

Station Name: LANGGEWENS    Latitude: **-33.3**    Thickness: 100

Total number of years: 47    Display data for year: 1960     Use data for this year

Monthly mean air temperatures    Maximum Air Temperature for year 1960    Minimum Air T Temperature for year 1960

	Temp °C
Jan	23.3163
Feb	23.7197
Mar	22.2832
Apr	19.5689
May	16.1656
Jun	13.575
Jul	12.5923
Aug	11.4736
Sep	14.7053
Oct	17.6667
Nov	20.3229
Dec	22.1602

Calculate Mean

Evaluation Depths

#	Depth
1	
2	
3	
4	
5	

**Calculate**

Day	Jan	Feb	Mar	Apr	May	Jun
1	38.800	33.000	33.500	25.000	25.000	23.500
2	30.600	29.000	29.400	21.500	27.500	25.500
3	22.000	32.000	33.500	17.500	30.400	25.000
4	20.000	35.500	27.000	21.500	25.400	27.600
5	25.000	37.000	22.500	17.500	25.500	14.800
6	32.500	28.000	25.900	18.000	20.300	14.000
7	33.000	24.000	28.400	20.000	22.000	12.700
8	35.500	24.500	32.900	20.400	16.000	14.400
9	40.200	25.000	32.900	19.000	16.800	15.500
10	30.400	27.000	30.000	24.000	16.600	17.000
11	25.000	33.000	25.000	29.000	22.200	19.000
12	27.200	40.000	30.000	30.000	13.400	16.500
13	31.500	32.000	35.500	22.200	13.500	16.700
14	36.700	38.000	33.000	25.300	15.600	25.000
15	34.500	35.500	32.500	26.700	18.400	25.500
16	34.500	26.000	30.500	29.600	21.500	25.400
17	31.000	25.000	27.600	31.400	23.000	21.600
18	28.700	24.000	30.000	29.000	20.000	15.000
19	30.500	24.800	29.500	29.000	18.500	16.700
20	32.000	33.800	25.000	23.200	18.500	14.000
21	30.000	35.800	24.500	22.500	16.500	15.000
22	31.000	36.500	28.500	24.000	16.000	14.000
23	37.600	39.500	28.500	25.500	16.500	17.500
24	29.000	35.000	27.200	26.600	15.900	14.900
25	26.500	35.500	29.000	27.200	18.200	15.500
26	32.700	31.500	17.500	29.400	19.500	17.500
27	31.500	36.600	21.200	30.800	25.900	18.400
28	28.500	39.700	30.500	27.000	18.500	19.500
29	21.200	28.500	20.500	25.000	18.500	18.500

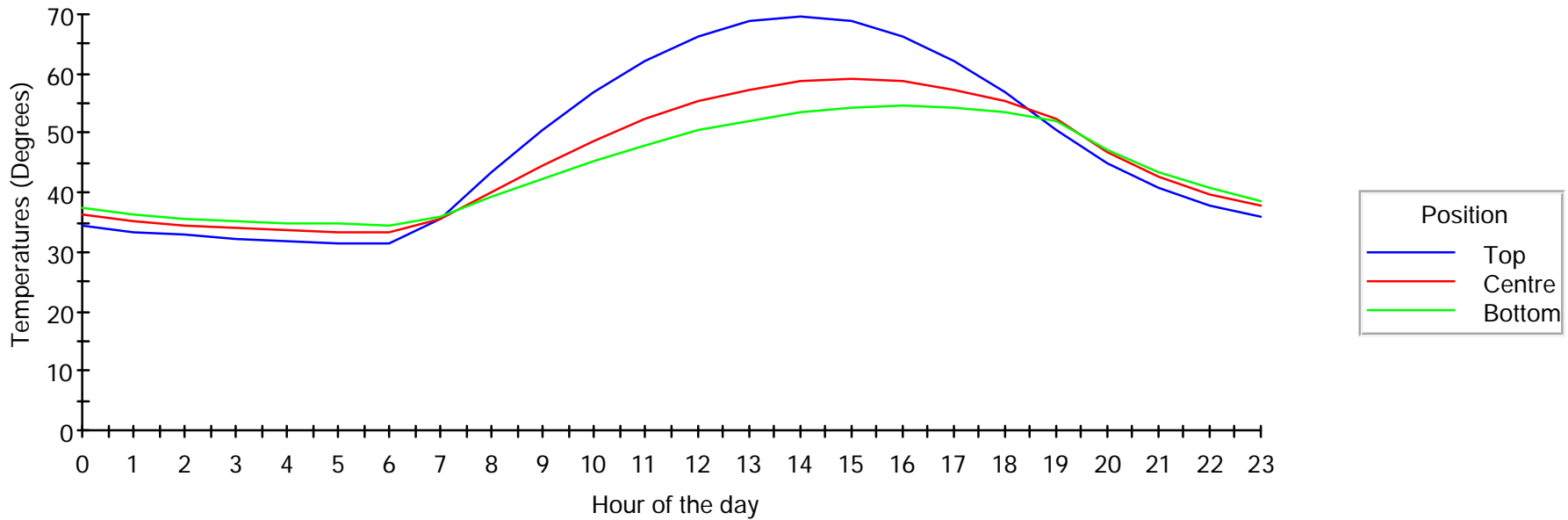
Day	Jan	Feb	Mar	Apr	May	Jun
1	21.000	15.100	15.500	10.100	10.500	14.000
2	17.200	16.000	15.900	10.000	9.700	13.000
3	13.000	16.500	18.500	9.000	11.200	13.000
4	10.000	20.500	16.000	8.000	10.500	14.800
5	9.400	18.000	14.400	9.400	11.000	10.900
6	11.900	14.500	12.700	11.500	14.500	7.800
7	17.000	15.000	13.400	11.800	13.500	8.000
8	15.400	11.600	15.500	12.500	9.500	10.500
9	20.500	14.500	18.000	10.400	10.500	5.800
10	17.500	14.000	14.000	8.500	11.500	5.500
11	14.500	12.800	14.500	10.000	8.700	6.100
12	16.500	20.500	13.800	12.600	8.500	7.600
13	14.600	18.500	15.000	12.400	8.500	9.500
14	17.000	17.000	17.400	13.000	10.000	10.200
15	17.400	19.000	20.100	14.900	10.500	14.300
16	17.200	16.200	16.900	15.000	10.500	15.000
17	16.000	13.000	16.400	16.300	11.000	14.800
18	15.600	15.000	15.000	16.600	10.600	12.500
19	15.700	13.000	14.000	17.300	12.000	11.500
20	16.300	13.000	13.000	15.000	9.700	11.000
21	18.300	17.500	14.000	14.400	10.000	7.000
22	14.500	20.500	13.400	15.000	11.500	7.700
23	20.500	23.000	14.000	15.500	11.500	10.400
24	17.400	17.500	12.200	16.000	11.500	9.800
25	14.200	18.000	12.000	17.000	6.500	7.000
26	18.000	17.000	14.900	15.000	7.600	7.900
27	18.000	16.000	8.900	16.000	8.100	8.000
28	15.500	20.000	11.000	14.000	9.200	8.500
29	14.500	19.000	16.500	11.000	10.000	9.500

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# Typical output: Diurnal temperature profile

Diurnal temperature profile for hottest recorded day (4 Jan 1993), LANGGEWENS



Created with CSIR ThermalPADS



# Step 3: Interpret temperature statistics

LANGGEWENS - ThermalPADS

File Calculate! Help

Input | Solar Declination | Zenith Angle | Surface Temperatures | **Output** | Graphs | Monthly Temps | Stations

Extreme surface temperatures (days per year)

Year	Average	Year 1960	Year 1961	Year 1962	Year 1963	Year 1964	Year 1965	Year 1966	Year 1967	Year 1968	Year 1969	Year 1970	Year 1971	Year 1972	Year
>40°C	184	193	177	179	196	181	177	189	190	174	180	177	178	196	
>45°C	148	156	146	149	162	139	139	149	156	145	144	144	150	156	
>50°C	96	107	100	91	116	85	70	102	105	81	94	84	90	105	
>55°C	55	75	60	57	80	56	33	64	75	45	49	41	52	63	
>60°C	16	26	17	15	20	17	12	15	21	8	11	12	17	19	
>65°C	1	3	0	1	4	0	2	1	1	0	0	0	0	5	
<5°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<0°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<-5°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Mean Standard deviation 98% Percentile

Hottest 55.83 1.74 59.31

Coldest 9.01 1.23 6.55

Extreme pavement temperatures (at 20mm depth) for data set

Temp	Day	Month	Year
Hottest 7day	58.8	17	Dec 1979
Hottest day	64.4	4	Jan 1993
Coldest day	4.9	1	Dec 1977

Extreme pavement temperatures (at 20mm depth) per year

Temp	Day	Month	Year
Hottest 7day	56.7	9	Dec 1960
Hottest day	63.3	13	Dec 1960
Coldest day	8.6	19	Jul 1960
Hottest 7day	54.5	20	Jan 1961
Hottest day	60.0	24	Jan 1961
Coldest day	9.3	6	Aug 1961
Hottest 7day	54.0	1	Jan 1962
Hottest day	61.7	2	Jan 1962
Coldest day	8.4	14	Jun 1962
Hottest 7day	58.4	13	Jan 1963

Print Graph Copy Graph Plot: PavementTemperatures

Pavement Temperatures (at 20mm depth), LANGGEWENS

Created with CSIR ThermalPADS



## Step 4: Determine PG grade

Road section	Darling	Midrand
Seven day average maximum temperature (20 mm depth) [Median / 98 <sup>th</sup> percentily value]	55.8 ° C / 59.31 ° C	52.3 ° C / 56.1 ° C
Minimum surface temperature [Median / 98 <sup>th</sup> percentily value]	9.0 ° C / 6.6 ° C	4.1 ° C / -2.1 ° C
Required design reliability	High (Use 98 <sup>th</sup> percentile)	Medium
Expected traffic [E80s]	> 10E06 (increase PG)	< 10 E06
Slow moving or stationary loads (intersections)	no	Yes (increase PG)
Selected PG grade	PG 64 - 16 or PG 70 - 20	PG 58 - 16

# Available PG binders in SA (source: SABITA)

Pen grade	40/50	60/70	80/100	150/200
Refinery I	X	PG 64-16	PG 58-22	X
Refinery II	PG 64-16	PG58-22	PG 58-22	X
Refinery III	PG 64-16	PG64-22	PG 58-16	PG 52-22
Refinery IV	PG 70-20	PG 64-16	PG 58-22	PG 52-22

# Conclusions

- The temperature algorithms developed by Viljoen (2001) provide an acceptable prediction of extreme surface temperatures of four LTPP sections in Gauteng and the Western Cape.
- The model yields acceptable results to start implementing and validating PG binder selection in South Africa

# Future direction

- Further validation required for outlying areas,
- Increase the number of weather stations from 65 to 500+,
- Link temperature prediction to HMA stiffness and rutting models,
- Take into account the effect of binder ageing,
- Include temperature prediction algorithms for other materials (concrete pavements, granular base layers).

**End, thank you!**

