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Notes on Tyre, Pavement and Ambient Temperatures on HVS Test Section 411A4.

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Abstract:
Heavy Vehicle Simulator (HVS) testing of foam- and emulsion-treated experimental sections is currently in process on road P243-1. As part of these tests pavement, tyre and ambient temperatures where monitored. These temperatures are provided and discussed in this report.

Based on the information provided and the discussions in this Technical Note, the following conclusions are drawn:

- Pavement, ambient and tyre temperatures can be measured successfully and cost-effectively on an HVS test section;
- The pavement temperatures on the HVS section 411A4 did not differ based on location on the section, but diurnal changes existed;
- The pavement temperatures observed should not affect the pavement behaviour based on the location of a measurement, but may affect measurements based on the time of day of the measurement.

Based on the information provided and the discussions in this Technical Note, the following recommendations are made:

- Pavement, tyre and ambient temperature monitoring should be performed as normal practice on an HVS test;
- The problems associated with the weather station should be sorted out to enhance the data capturing even further;
- The data obtained and presented in this Technical Note should be used where applicable in the Level 1 and Level 2 data analyses of the HVS test section 411A4.

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EXECUTIVE SUMMARY

As part of the Gauteng Department of Public Works and Transport (Gautrans) Heavy Vehicle Simulator (HVS) testing programme on road P243-1 near Vereeniging, Gauteng, various new methods for monitoring tyre, pavement and ambient temperatures were utilised. The objective of this technical note is to summarise the methods used, data obtained and initial reduction of the data for input into the level 1 data analysis of section 411A4.

The methods used are firstly described, followed by the data that were collected. Some initial analyses of the data were performed and finally conclusions and recommendations are made concerning the technology and the data.

Based on the information provided and the discussions in this Technical Note, the following conclusions are drawn:

- Pavement, ambient and tyre temperatures can be measured successfully and cost-effectively on an HVS test section;
- The pavement temperatures on the HVS section 411A4 did not differ based on location on the section, but diurnal changes existed;

Based on the information provided and the discussions in this Technical Note, the following recommendations are made:

- Pavement, tyre and ambient temperature monitoring should be performed as normal practice on an HVS test;
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- The data obtained and presented in this Technical Note should be used where applicable in the Level 1 and Level 2 data analyses of the HVS test section 411A4.

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1. INTRODUCTION

1.1. Background

As part of the Gauteng Department of Public Works and Transport (Gautrans) Heavy Vehicle Simulator (HVS) testing programme on road P243-1 near Vereeniging, Gauteng, various new methods for monitoring tyre, pavement and ambient temperatures were utilised. The objective of this technical note is to summarise the methods used, data obtained and initial reduction of the data for input into the level 1 data analysis of section 411A4.

The methods used are firstly described, followed by the data that were collected. Some initial analyses of the data were performed and finally conclusions and recommendations are made concerning the technology and the data.

1.2. Objectives

The main objective of the work presented in this Technical Note was to evaluate the temperatures of the tyres, pavement and air, and their interrelationships. The tyre inflation pressures were also monitored and are briefly discussed.

2. METHODS

2.1. Introduction

Four methods were initially used for measuring the temperatures of the air, tyres and pavement structure. These were a dedicated weather station, thermometer buttons, a dedicated tyre temperature/inflation pressure monitoring device and thermocouples.

2.2. Methodology

The dedicated weather station was used to obtain temperature, humidity, wind speed and direction, and rainfall data. The weather station is a Davis weather station that was previously used to monitor the weather during inception testing of HVS05. Unfortunately the weather station suffered damage during a thunderstorm, and data were lost.

The thermometer buttons (i-buttons) were previously briefly used for measurement of tyre and pavement temperatures (Steyn, 2001). They were calibrated with normal thermometers and thermocouples. A full description of the devices is given in Steyn (2001). These devices were used to measure the pavement temperatures and ambient temperature. A device was originally attached to the HVS test car tyre, but this device fell off during operation and became irreparably damaged. The i-buttons were installed on two depths at four locations around the test section. The ambient temperature i-button was installed in the shade on the weather station. The data obtained from the i-buttons are temperatures at set time intervals. The time intervals can be selected between 1 minute and 240 minutes. For the HVS test, 120 minute intervals were used.

A dedicated tyre temperature / inflation pressure device was installed on the two tyres of the HVS test carriage (Smartire, 2001). The device consists of sensors that are installed on the rim and a reception unit that is in radio contact with the sensors. During normal operation the sensors are activated once the tyre starts to roll. However, with the short rolling distance of the HVS tyres this would not have been practical, and the batteries of the sensors were permanently connected to enable the sensors to provide output on a continuous basis. The sensor on the traffic side tyre failed towards the end of the test. The cause for the failure was not known at the time of writing this report, but is being investigated. The battery life for continuous operation was already in excess of 2 500 hours (104 days) at the time of writing this report. The temperatures were monitored at a two-hour interval, by noting them on a log sheet. The device does not have a memory were the data can be stored.

The thermocouples were installed as normal for HVS tests (Steyn, 1995). They were installed in the same positions and depths as the i-buttons. One thermocouple was used to monitor ambient air temperature. The data from the thermocouples provide temperatures at 2 hour intervals. Due to operator error some of the temperatures measured using the thermocouples were wrong, but these instances were easily identified and corrected.

3. TEST RESULTS AND DISCUSSION

3.1. Introduction

The data obtained from the i-buttons, the dedicated tyre temperature/inflation pressure sensor and the thermocouples are provided in this section.

3.2. Test results

The data obtained from the i-buttons are shown in Figures 1 to 8.

In Figure 1, all the pavement temperature data collected with the i-buttons are shown. The vertical gridlines indicate one-week intervals. A generally decreasing trend can be observed in the temperature data. The range of temperatures measured is between –5,5°C and 46,5°C. An area can be observed at approximately 1 300 hours where the temperatures were very closely scattered. Generally the ambient temperatures are both the higher and lower temperatures shown, with the pavement temperatures showing less scatter.

In Figure 2, the diurnal nature of the pavement temperatures is illustrated for the period between 168 hours and 336 hours (week 2). The vertical gridlines indicate the temperature at 00:00.

In Figure 3, only the pavement temperatures on the surface are shown, together with the ambient temperatures. Within the first week (0 to 168 hours) the covers on the northern side of the HVS were not installed as yet, and the relatively higher surface temperatures for the traffic side (TS) are visible. After this period the scatter in pavement surface temperatures were much lower. The range of temperatures on the pavement surface (difference between daily maximum and minimum) on a daily basis is shown in Figure 4. Although the temperatures for the caravan side (CS) are slightly lower than that for the traffic side (TS), most of the ranges for the pavement surface were between 5°C and 10°C (after the first week).

In Figure 5 only the pavement temperatures at a depth of approximately 30 mm are shown, together with the ambient temperatures. These temperatures showed a low level of scatter, with the first week's high level of scatter not visible. The daily ranges are shown in Figure 6. The range was again between 5°C and 10°C for most of the duration of the test.

In Figure 7 the differences between the pavement surface and pavement at 30 mm deep temperatures are shown. These differences ranged between -1°C and +2°C. The traffic side (TS) positions showed a slightly higher variation in temperature than the caravan side (CS) data.

In Figure 8 the difference between pavement temperatures on the traffic side and caravan side of the test section are shown for the surface and 30 mm depth. A difference of less than 5°C was obtained in most instances. The occasions where the difference exceeded 5°C are mostly where the side sun covers where not on when the specific temperatures were logged.

The data obtained from the dedicated tyre temperature/inflation pressure devices are shown in Figures 9 to 11.

In Figure 9 the tyre temperatures, tyre inflation pressures, pavement surface temperatures and the ambient temperatures are shown. The tyre temperature and tyre inflation pressures were measured with the dedicated devices. The pavement and ambient temperatures were measured with thermocouples. The increase in tyre load (from 40 kN to 80 kN) necessitated an increase in tyre inflation pressure from 620 kPa to 800 kPa. This is visible at approximately 1 775 hours. The subsequent change in tyre temperature is also visible.

In Figure 10 the diurnal pattern in both the tyre temperature and tyre inflation pressure data is shown for the period between 240 and 336 hours.

In Figure 11 the differences between temperatures and inflation pressures on the Traffic side and Caravan side tyres are shown. The traffic side tyre was mostly cooler than the caravan side tyre, although by only about 4°C. The inflation pressure of the Traffic side tyre was also higher than the Caravan side tyre by approximately 5 kPa to 20 kPa. This is negligible if the resolution of 7 kPa of the sensor is taken into account.

In Figure 12 the differences between the temperatures measured using the thermocouples and the i-buttons are shown. Initially the operators had some problems when measuring the thermocouple temperatures (i.e. ambient temperatures were measured in the caravan and the sensor was plugged in the wrong way round). This explains some of the variability in the data during this period. However, after the initial period the differences in pavement temperatures were on average less than ± 5°C. The ambient temperature measured using the i-button where up to 20°C higher than those measured using the thermocouple. This is mainly due to the position of the i-button on the weather station pole. The pole was in the sun for most of the day. In Figure 13 this effect can be clearly seen where the differences in ambient temperature in the afternoons is the largest (the vertical gridlines are at 00:00.

Figure 14 shows the results of a Power Spectral Density (PSD) analysis performed on the ambient and pavement temperature data to determine dominant frequencies / wavelengths in the temperature data. Only these two data sets are shown, as similar trends were obtained for all the temperature data sets. The objective of this analysis was to determine mathematically whether a diurnal pattern does exist in the data. The figure indicates that dominant frequencies occurred at 24 hours, 12 hours and 6 hours. Some lesser frequencies were also observed for various multiples of 2 hours, which was caused by the intervals between data points. The 24 hour frequency indicate the diurnal pattern, while the 12 hour frequency indicate the day / night pattern. The 6 hour frequency is caused by maxima and minima that occurs every 6 hours.

3.3. Discussion

Temperature and inflation pressure data were presented as measured using the different sensors. In Figures 1 to 14 various sets of temperature data are shown. The objective of the various figures is mainly to highlight some trends observed in the temperatures data sets.

The following main trends are visible from the data:

1. A strong diurnal pattern exists in all the data sets (Figure 14).
2. A strong relationship appears to exist between the tyre temperature and tyre inflation pressure data (Figure 9).
3. The change from summer to winter is observable in the overall data (i.e. Figure 1), where minimum temperatures decreased steadily as the test progressed.
4. The effect of the covers that were installed on the side of the HVS to prevent uneven heating of the HVS test section is visible (Figures 3 and 8). Very small differences were observed between the Traffic side and Caravan side data when the covers where used.
5. The daily range of temperatures (difference between daily maximum and daily minimum) was also positively affected by the use of the shade covers (Figure 4).

6. It appears as if the difference in pavement temperature at the surface and a depth of 30 mm was negligible for the specific test (Figure 7). This may be attributable to the use of the shade covers.
7. It appears as if the increased tyre inflation pressure towards the end of the test (where the load was increased from 40 kN to 80 kN) was less than optimal, as the tyre temperatures increased even after the increased tyre inflation pressure (800 kPa as opposed to the original 620 kPa).
8. A negligible difference was observed between the tyre inflation pressures and tyre temperatures for the two tyres (Figure 11). This may again be attributable to the shade covers used for the test.
9. The differences between the different temperature devices appear negligible after initial problems were resolved (Figures 12 and 13).

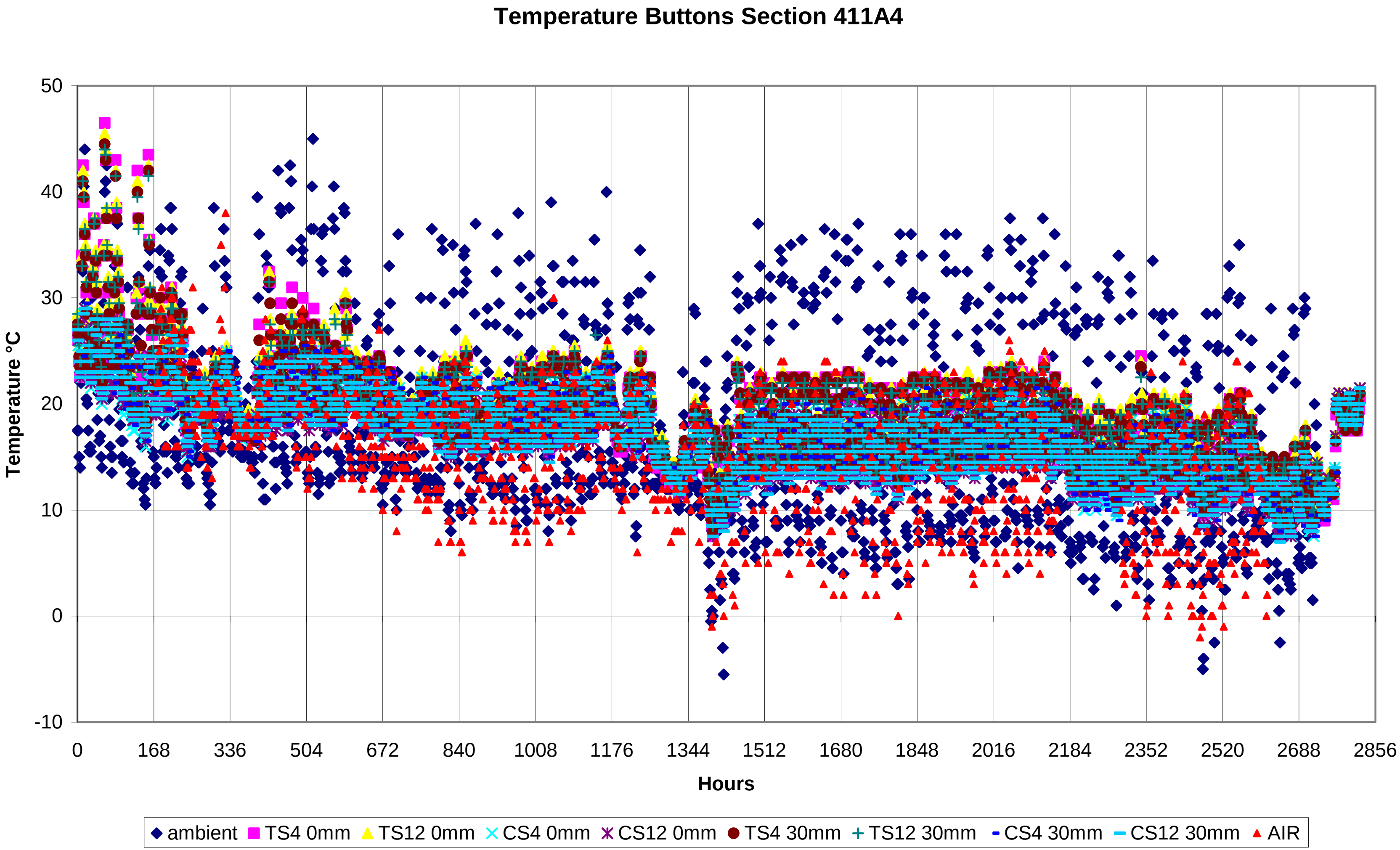

Figure 1: Full set of temperature data as collected using i-buttons.

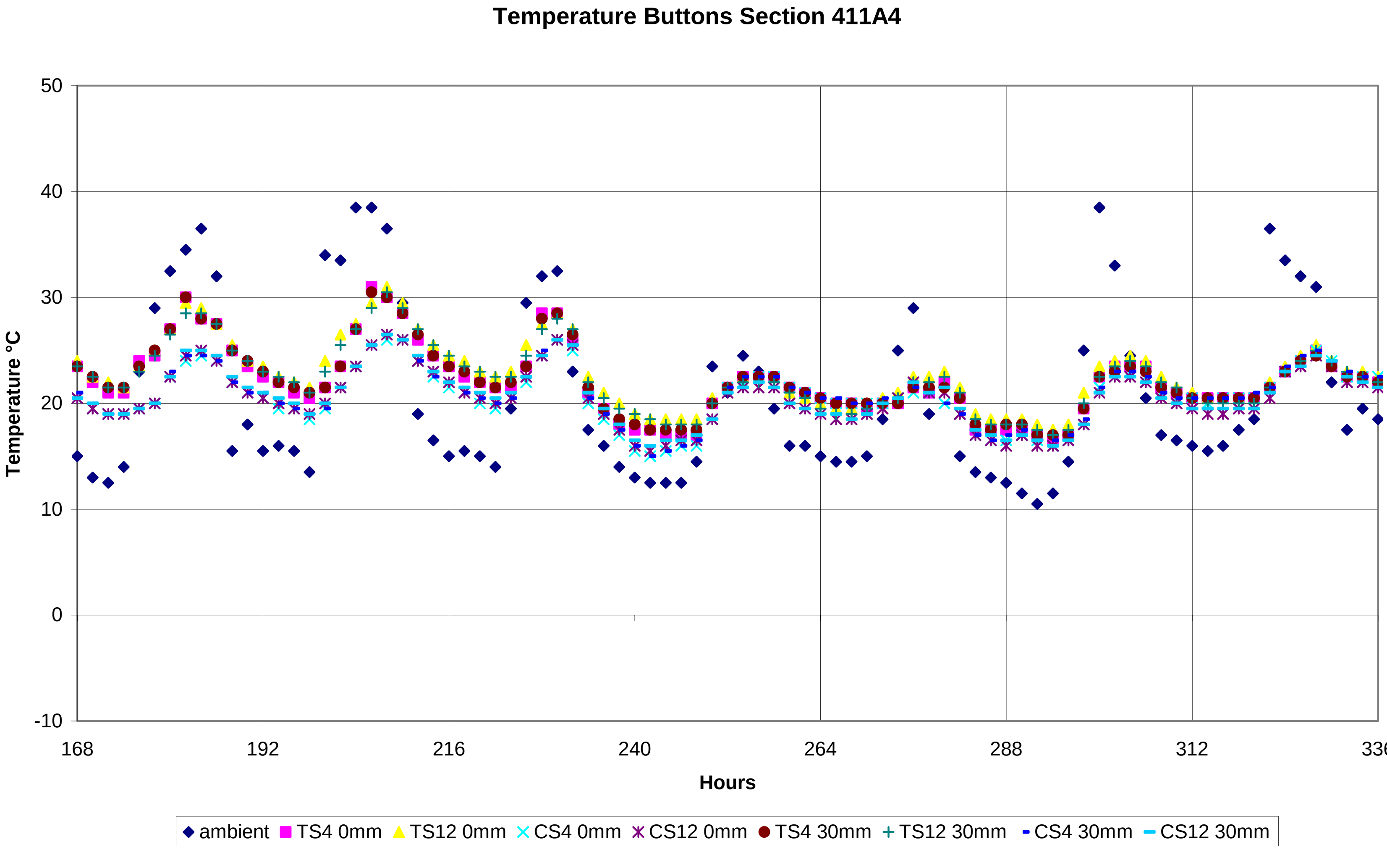

Figure 2: Diurnal temperatures as measured using i-buttons (week 2).

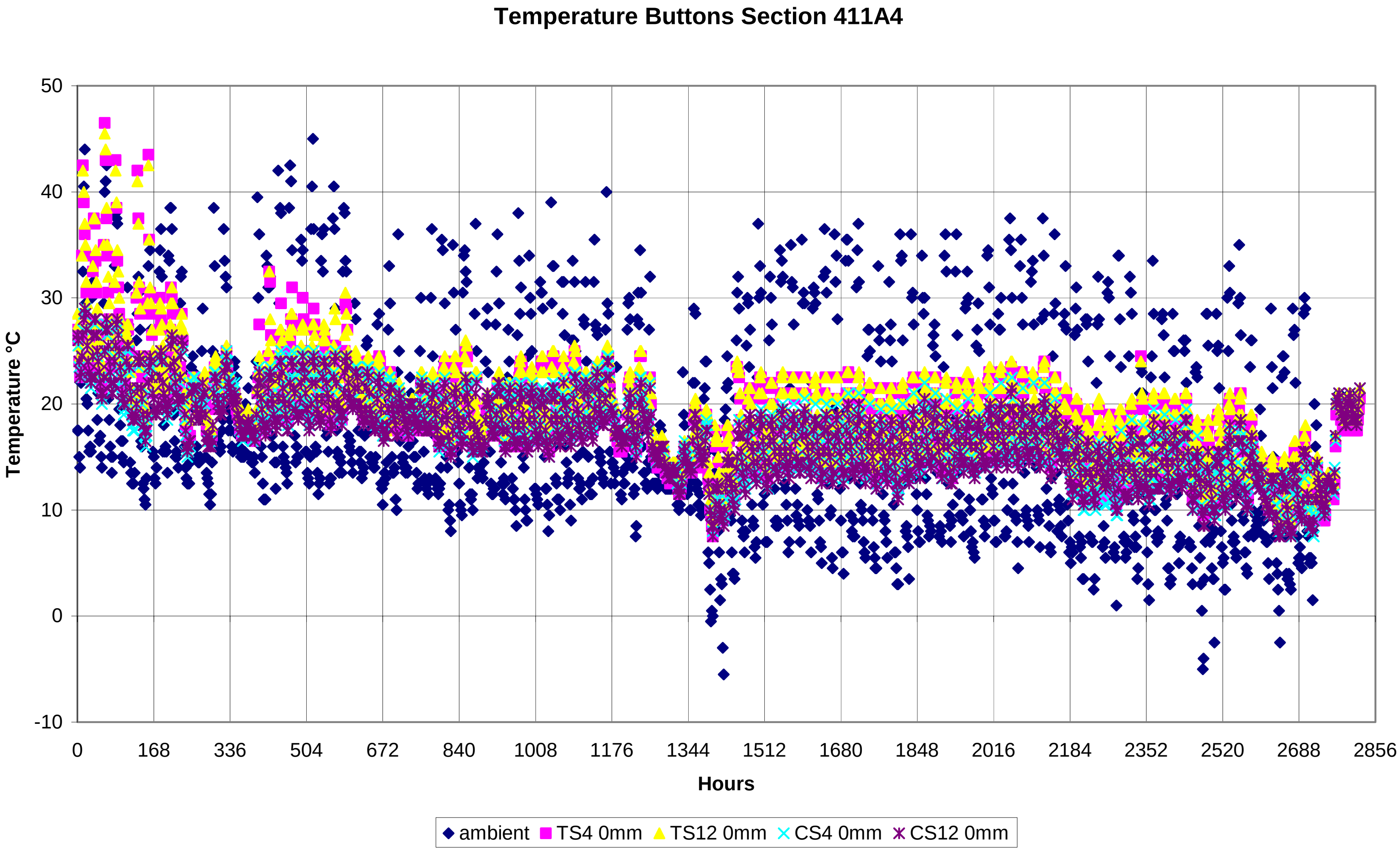

Figure 3: Pavement surface temperatures as measured using i-buttons.

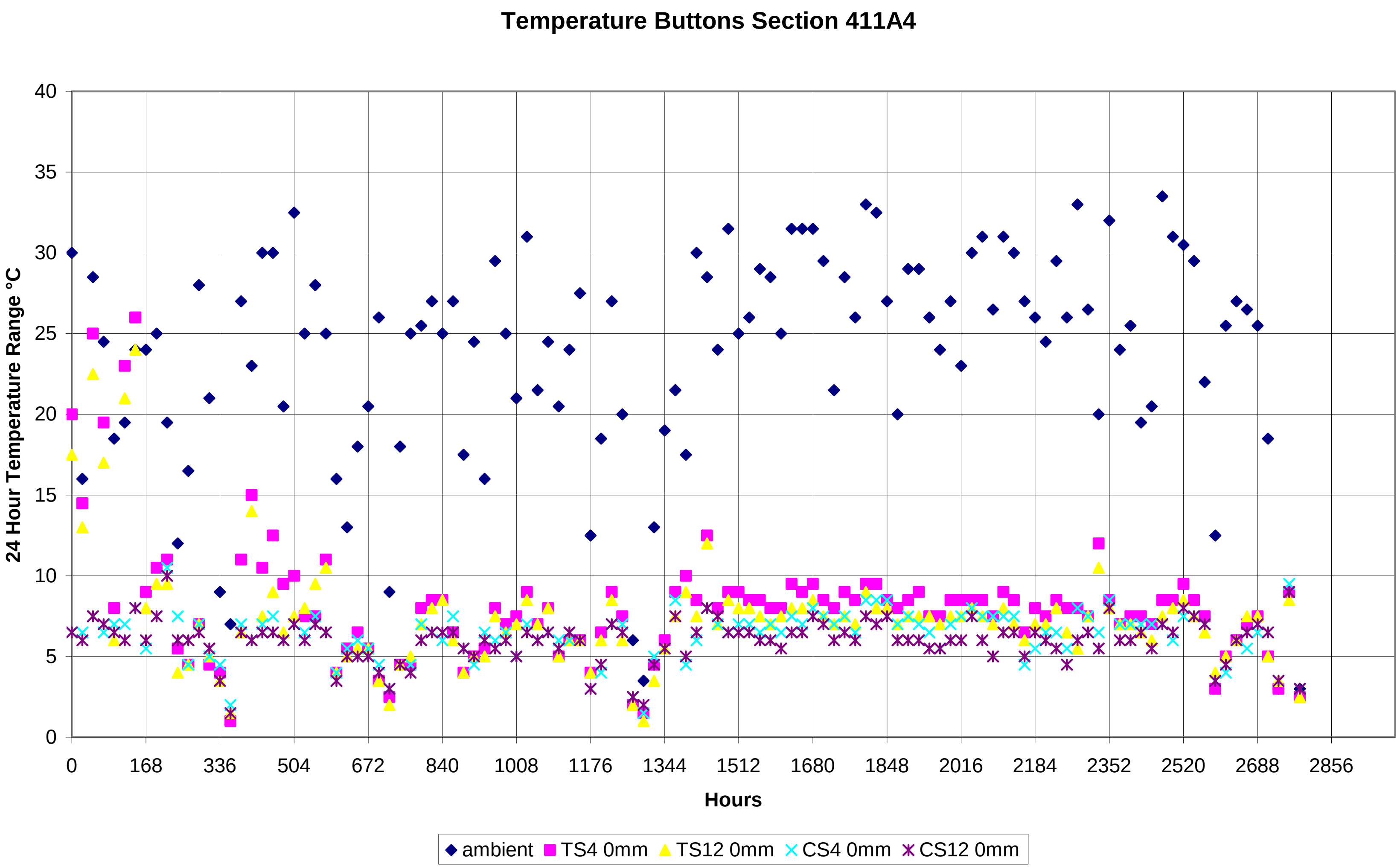

Figure 4: Daily range of pavement and ambient temperatures as measured using i-buttons.

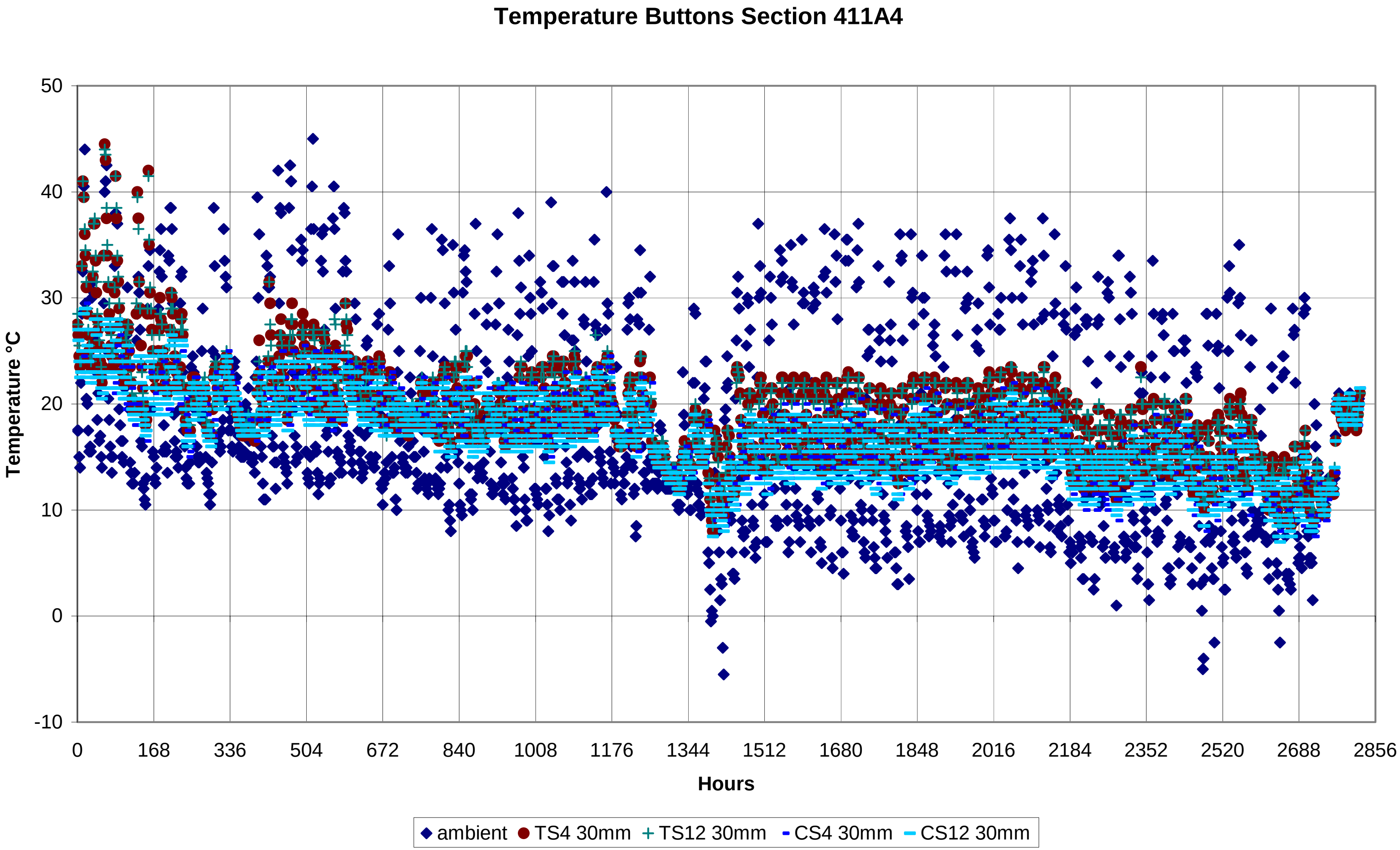

Figure 5: Pavement (30 mm depth) and ambient temperatures measured using i-buttons.

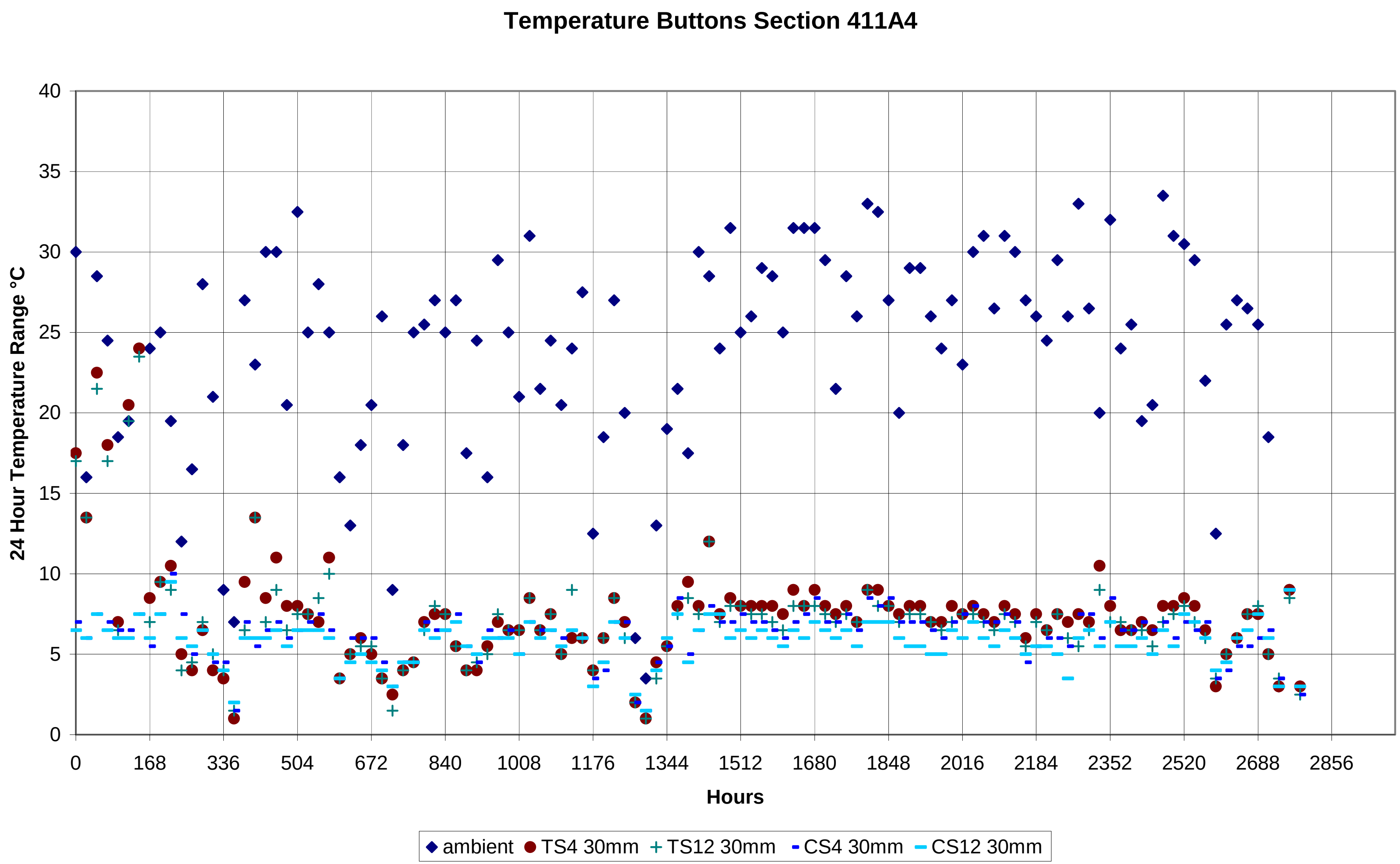

Figure 6: Daily ranges of ambient and pavement temperatures (at 30 mm depth) measured using i-buttons.

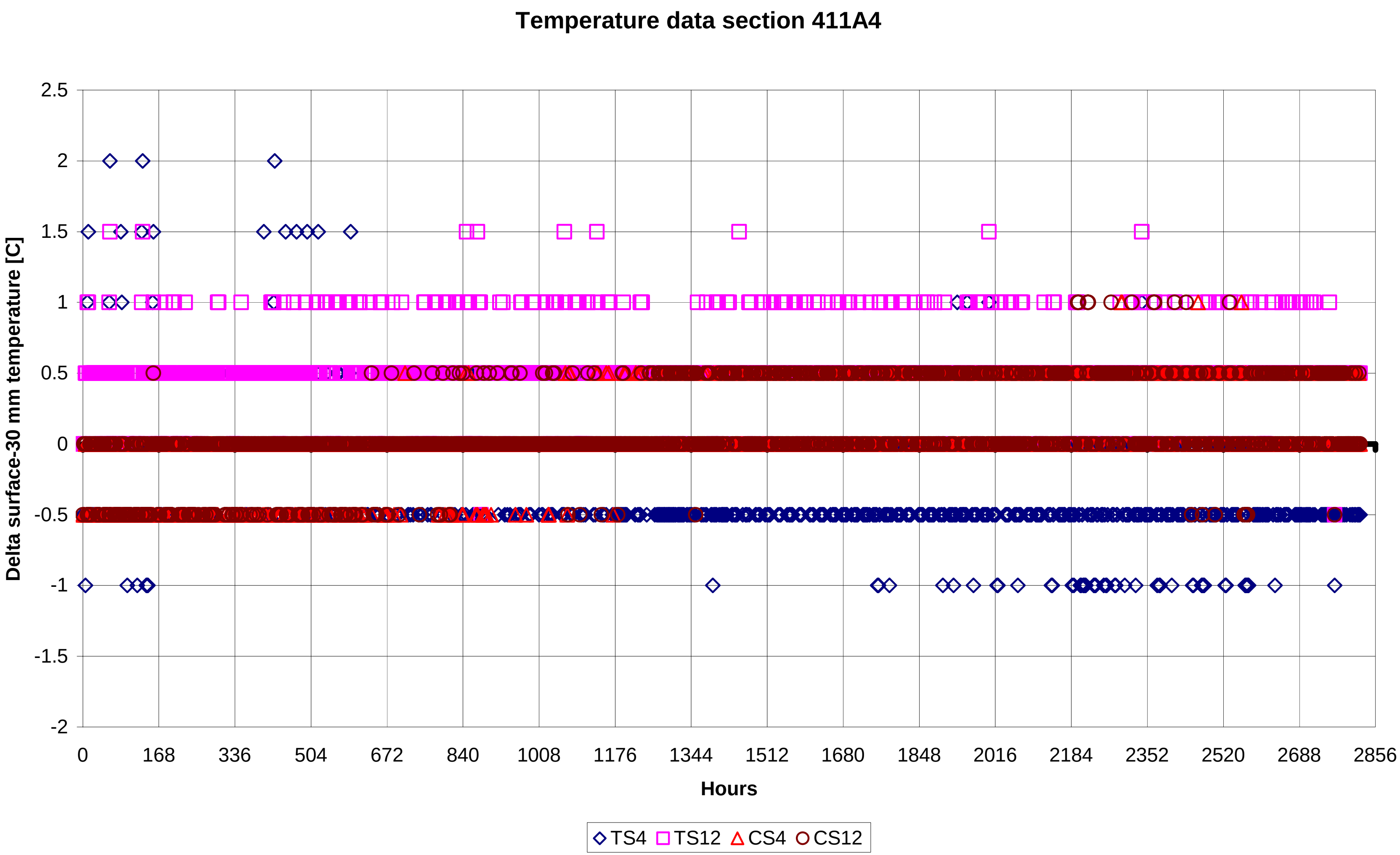

Figure 7: Differences between pavement surface and pavement depth (30 mm) temperatures as measured using i-buttons.

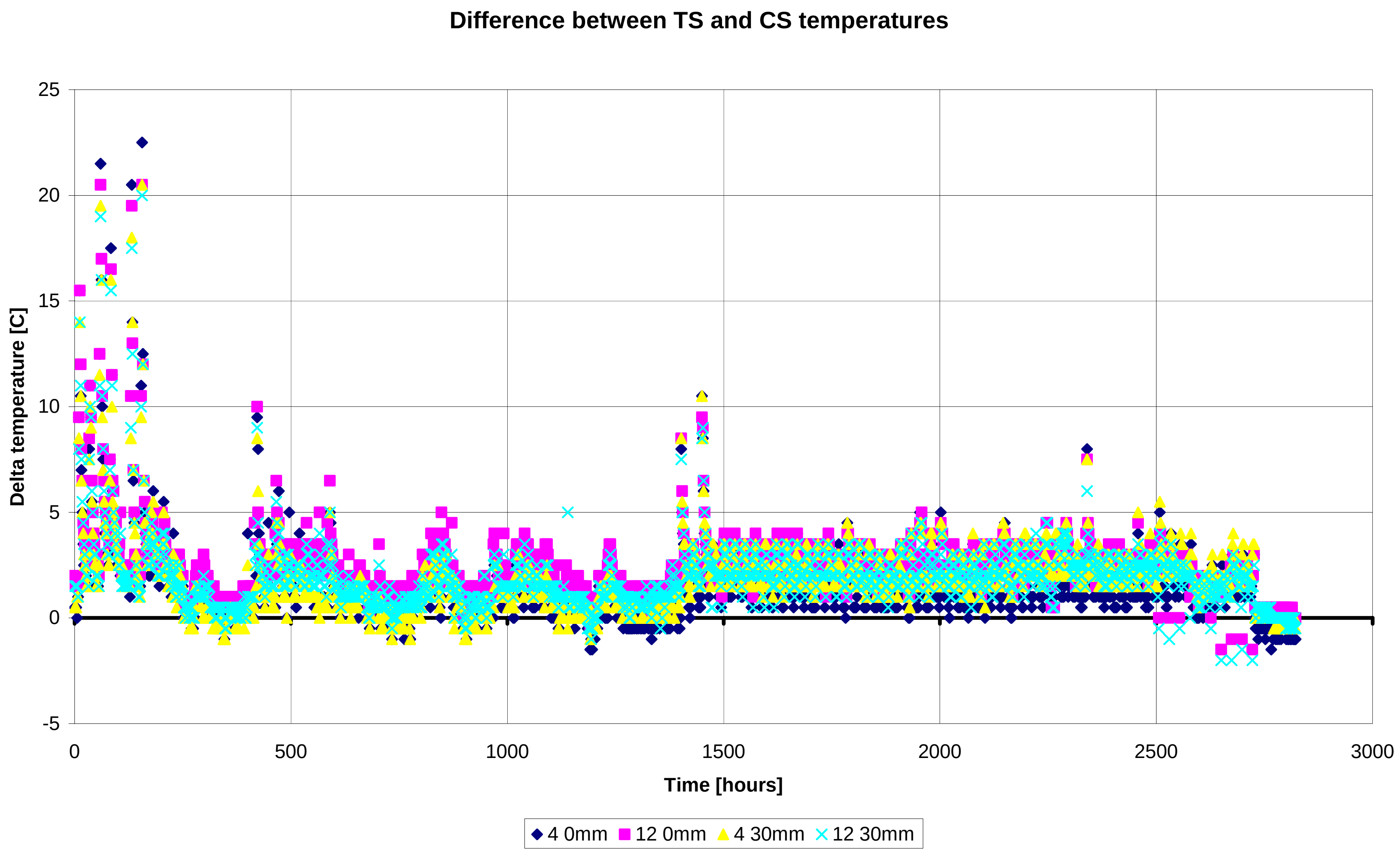

Figure 8: Difference between Traffic side and Caravan side pavement temperatures as measured using i-buttons.

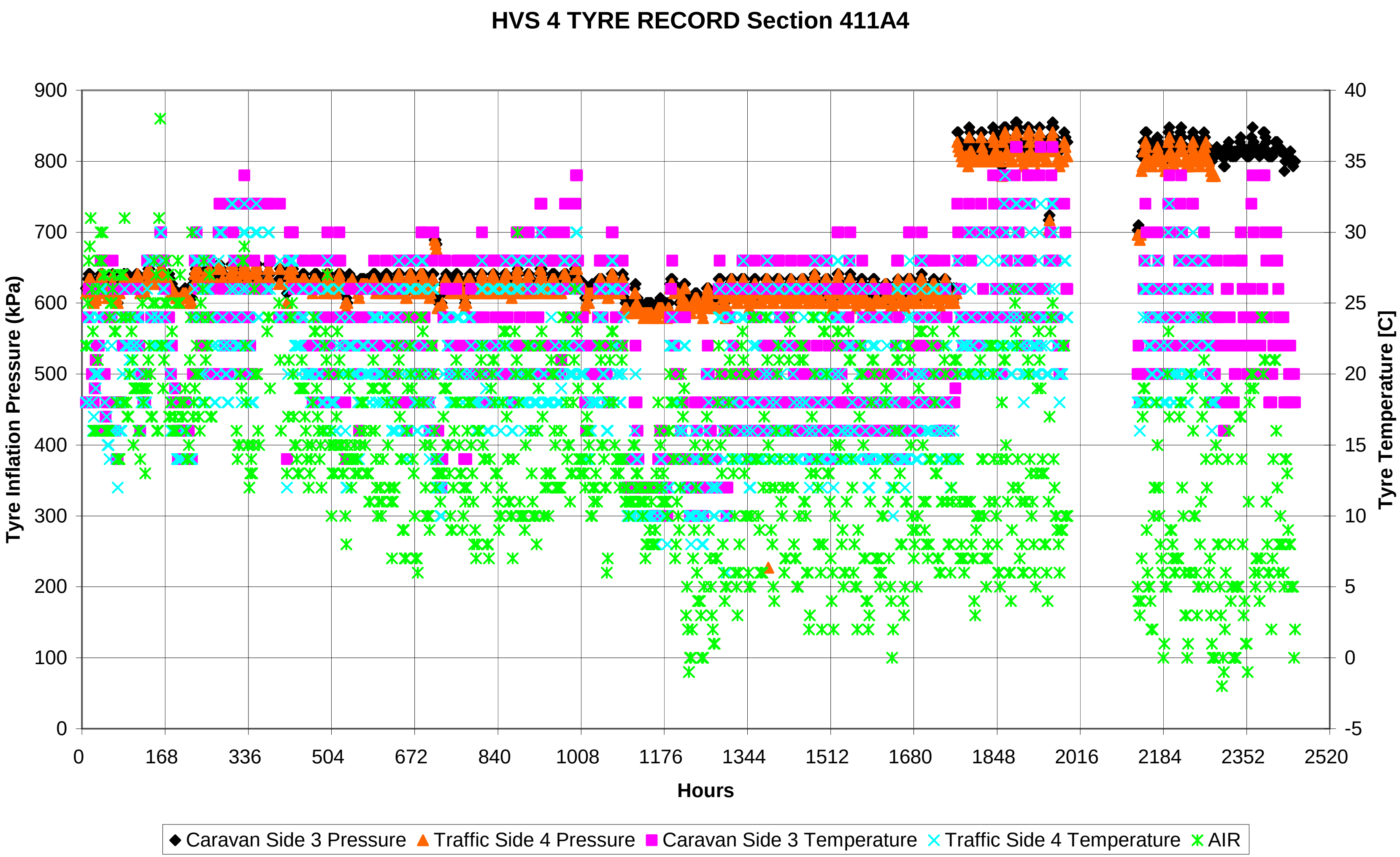

Figure 9: Tyre temperature and pavement temperatures as measured using dedicated sensors.

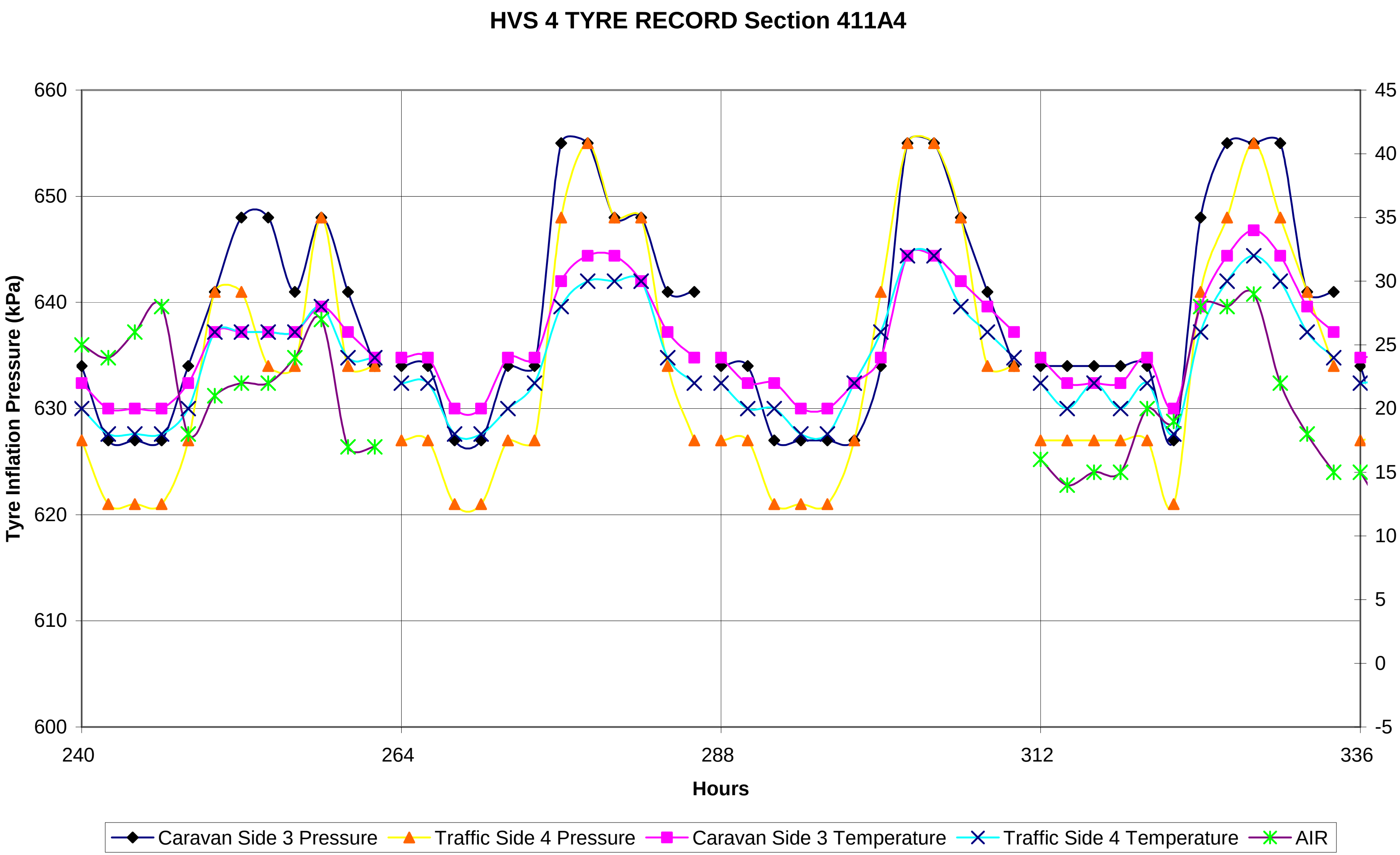

Figure 10: Diurnal cycle in pavement and tyre temperatures.

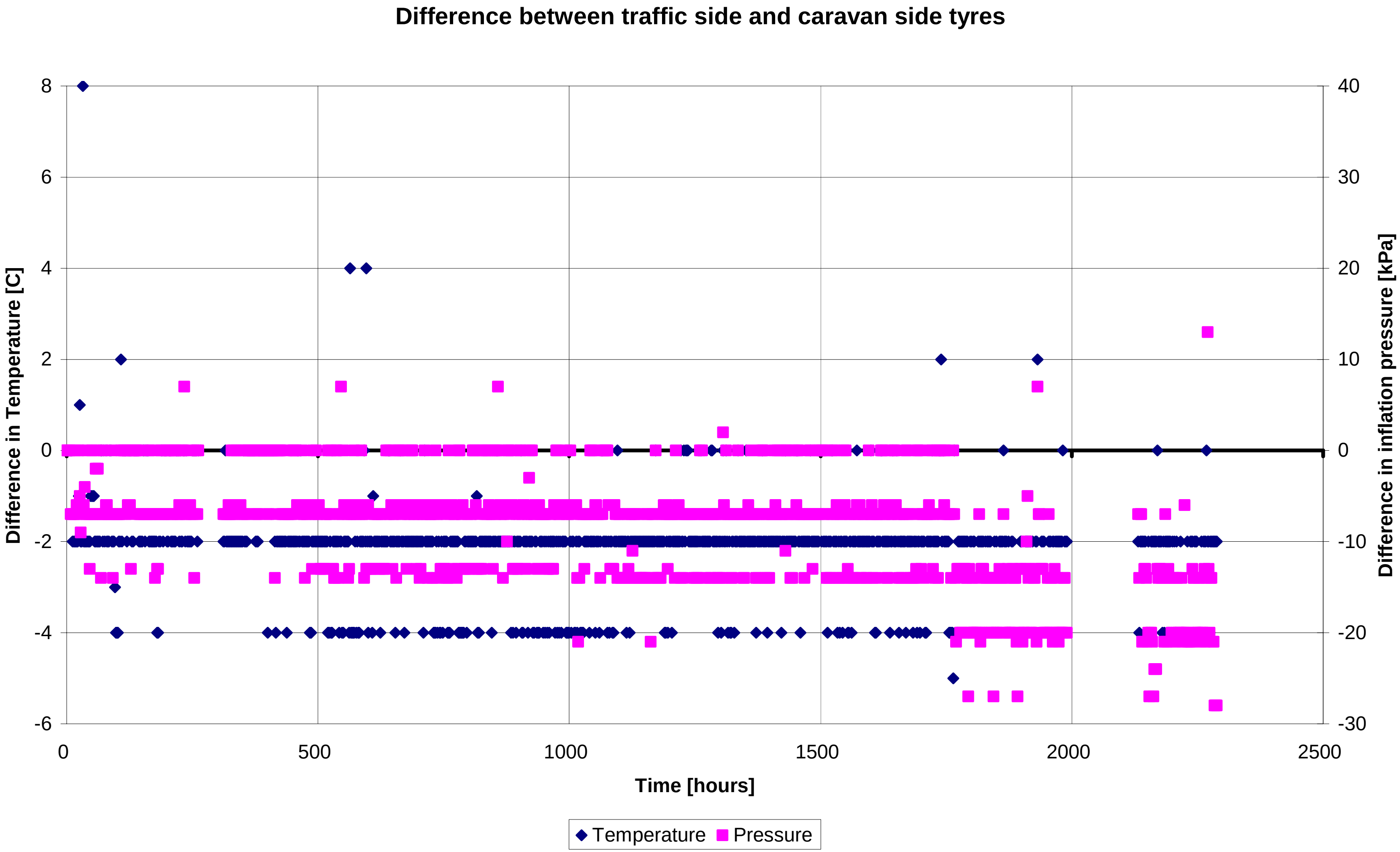

Figure 11: Difference between Traffic side and Caravan side tyre inflation pressures and temperatures as measured using dedicated sensors.

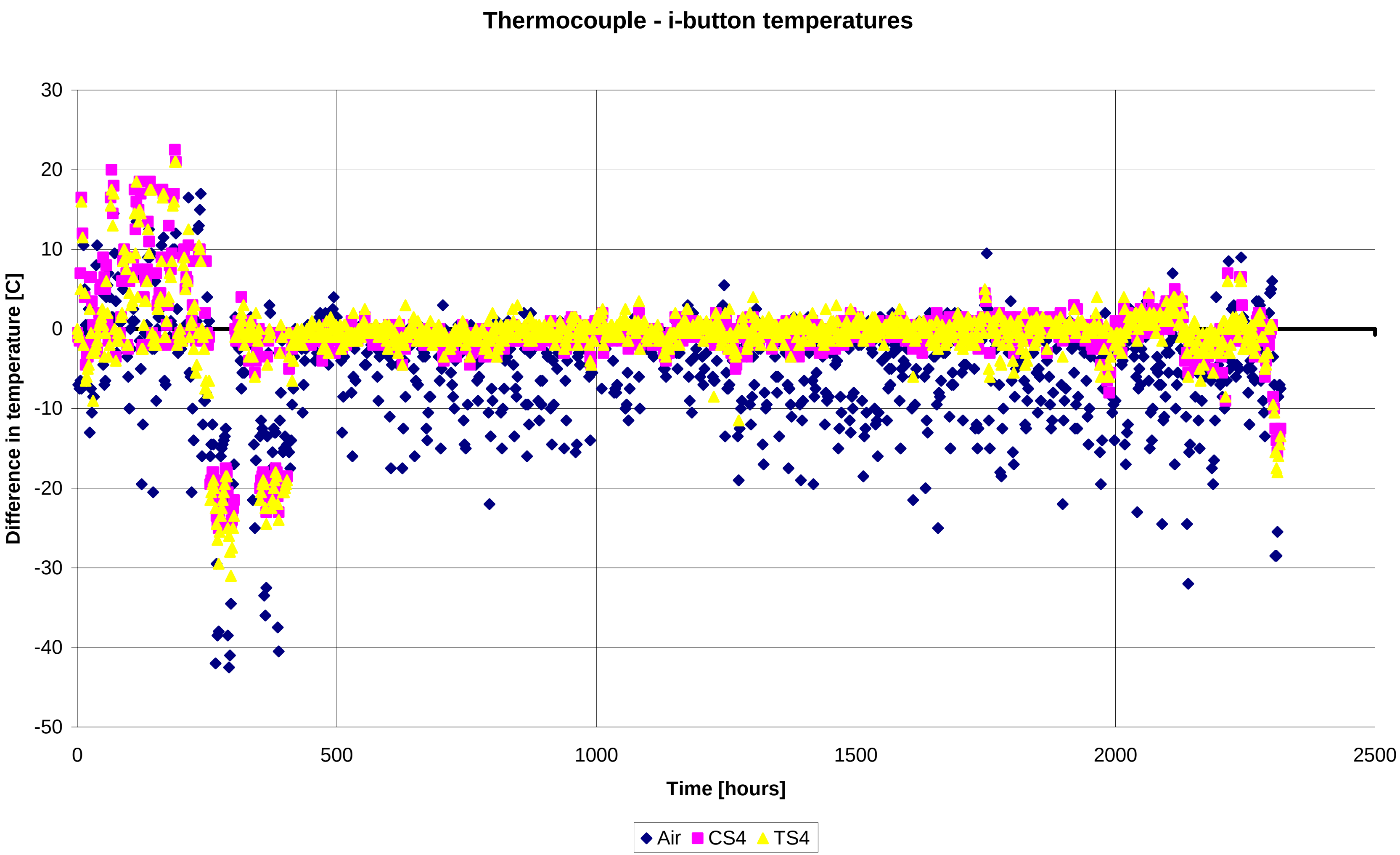

Figure 12: Differences between temperatures measured using thermocouples and i-buttons.

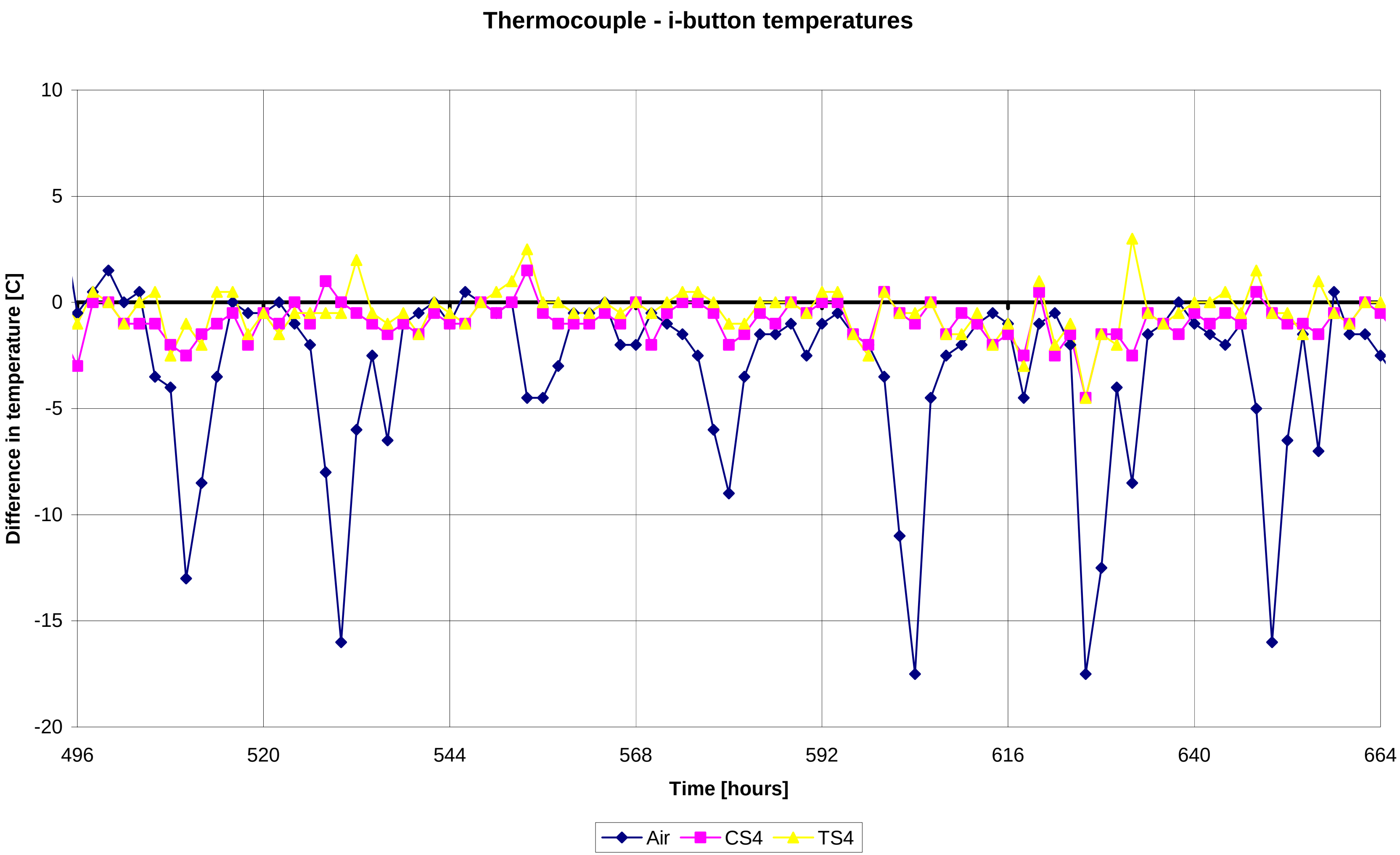

Figure 13: Diurnal pattern in differences between thermocouple- and i-button-measured temperatures.

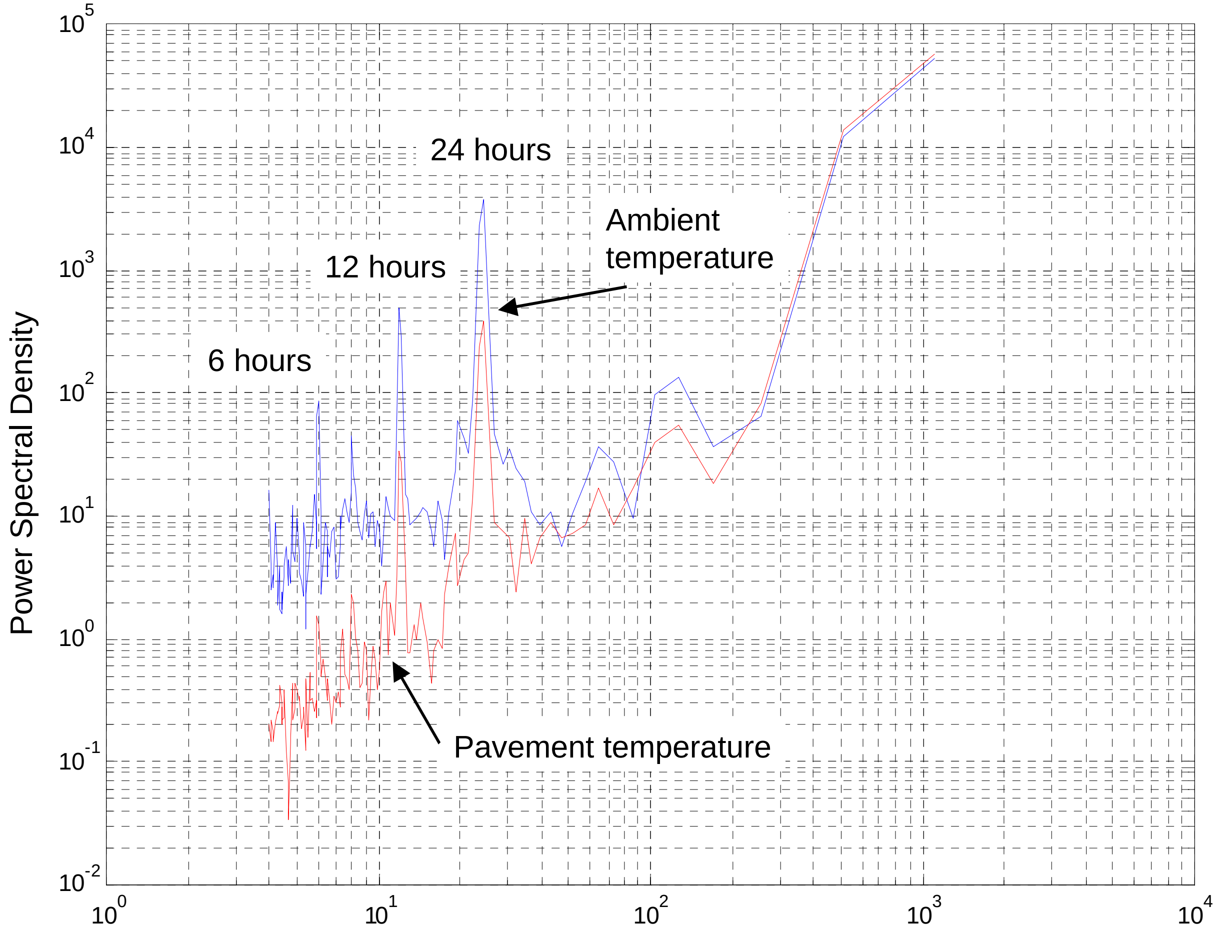

Figure 14: Power Spectral Density (PSD) analysis indicating dominant frequencies in temperature data.

3.4. Effects on pavement parameters

The data discussed above are mainly of value if the effects on the pavement behaviour and performance can be determined and quantified. It falls outside the scope of this Technical Note to perform such an analysis, but some guidelines as to the possible effects are provided for further use in the Level 1 and 2 analyses of the HVS results.

The temperature of the pavement mainly affects the behaviour and performance of the asphalt surfacing because of the temperature-dependent stiffness of this layer. The data indicates that the temperatures of the various locations around and inside the pavement where temperatures were measured did not differ significantly. It can thus be assumed that the response of the pavement at a specific time of day was not highly influenced by the position at which pavement response measurements are taken.

However, the diurnal effect of temperature on asphalt surfacing stiffness may have an influence on the performance of the pavement structure, as the stiffness at night and during the day differs due to temperature differences. The effect of these changes on the asphalt surfacing stiffness should be investigated to determine whether or not it is significant. This should be done for both the diurnal cycles and the longer term (seasonal) cycles.

The combined effects of diurnal tyre inflation pressure (and therefore tyre-pavement contact stress) cycles and asphalt stiffness cycles on the behaviour and performance of the pavement should be investigated as a separate project, as this probably falls outside the scope of the current HVS test.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the information provided and the discussions in this Technical Note, the following conclusions are drawn:

- Pavement, ambient and tyre temperatures can be measured successfully and cost-effectively on an HVS test section;
- The pavement temperatures on the HVS section 411A4 did not differ based on the measurement location, but diurnal changes existed;
- The pavement temperatures observed should not affect the pavement behaviour based on the location of a measurement, but may affect measurements based on the time of day of the measurement.

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5. REFERENCES

i-Button, 2001. http://www.ibutton.com

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STEYN, WJvdM. 2001. **A preliminary investigation into tyre and pavement temperatures.** Pretoria: CSIR Transportek (STEP Report TR-2001/4).