PRODUCT REVIEW

Assessment of the Campbell Scientific 'Met 21' passive thermometer screen

By Stephen Burt MSc, PhD, FRMetS

First published online October 2010
v1.1 March 2024

A comparative assessment of the Campbell Scientific 'Met 21' passive radiation screen has been undertaken at a standard climatological observatory in Berkshire since July 2009. The trial results based upon a full 12 months' comparative observations are presented here: this paper updates and supersedes the preliminary results based upon the first four months data, written up in November 2009.

The trial period (August 2009 to July 2010) covered a wide range of weather conditions. The late summer and early autumn of 2009 were dry and a little warmer than normal, followed by a prolonged wet spell from late October to mid-December. The winter season provided four weeks of relatively severe weather, including deep snowfall and 1-in-20 year low temperatures, a useful extension of the trial into more extreme climatic conditions. Spring 2010 and early summer was predominantly dry, with above-average sunshine and solar radiation receipts, particularly in April and June and a wider than normal range of air temperatures as a result. The latter part of the summer was warm but less sunny, followed by a cloudy and wet August.

The Stevenson screen has been used as the benchmark in this comparison as it remains the UK standard instrument enclosure for air temperature sensors. Comparisons are also presented with air temperatures observed using a continuously aspirated sensor, which probably more closely represents the 'true' air temperature as it is well known that the Stevenson screen tends to overheat a little, particularly in conditions of strong insolation and light winds.

Executive summary of results

'Spot' air temperatures logged in the Campbell Scientific 'Met 21' passive radiation screen (hereafter referred to as 'Met21') compared closely to those obtained in the adjacent Stevenson screen, except where the rate of change in air temperature is significant. Where air temperatures are changing relatively rapidly, the faster response time of the Met21 screen+sensor system compared to the Stevenson screen resulted in a greater range in observed air temperatures. As a result of this differing response time, maximum and minimum air temperatures obtained from the Met21 screen usually differ somewhat from those measured in the adjacent Stevenson screen, maximum temperatures usually being slightly higher and minimum temperatures slightly lower. Occasionally the differences are substantial (> 1 degC).

Important note: this review is entirely independent. The Campbell Scientific 'Met 21' passive radiation screen was provided for this trial by Campbell Scientific, and was a standard 'off the shelf' unit without special modifications or enhancements. No incentives were offered or sought to influence this trial in any way.

Full details of the trials site and the sensors and loggers used, and their calibrations, are set out in this report. The full set of trials data referenced in this review are available on request to the author.

The CS 'Met21' screen

The CS Met21 screen (*illustrated on page 1*) is a passive (i.e. naturally ventilated) radiation screen. It is made of uPVC, white on the outside but with a black or blackened interior. It is composed of 17 stacked circular 'plates'. Its dimensions are 28 cm high (excluding the mounting bracket) by 17 cm diameter, and it is approximately twice the size of the Gill-pattern plastic automatic weather station screen also sold by Campbell Scientific. Its exterior finish is a high white gloss. With only occasional maintenance (a wipe-over with a moist cloth) the screen finish dulled only slightly over the 12 months exterior trial; there was no obvious weathering or change in the colour of the material over this period.

Results

Records from the Met21 screen commenced on 3 July 2009, and continuous records are available from that date. Spot temperatures and maximum and minimum temperatures over the 5 min sampling interval were logged every 5 min, and daily maximum and minimum records tabulated over 00-00h UTC are thus available from 4 July 2009 (see Appendix for details of the observing and logging methods employed). Records from the aspirated screen commenced on 26 July 2009. The 12 month comparative trial period used was 1 August 2009 to 31 July 2010.

1. *Spot air temperatures*

    1.1. *Versus Stevenson screen*

Hourly comparative data was available for all but 4 hours of the 12 month period (99.95% data availability).

Table 1 shows the average difference in air temperature between the Stevenson screen and the Met21 screen by month and by hour UTC, in degrees Celsius. Positive (negative) values indicate the Met21 screen warmer (colder) than the Stevenson screen; the cells are colour-coded to highlight the largest differences of either sign.

It can quickly be seen that the Met21 screen becomes slightly warmer than the Stevenson screen for about 3 hours after sunrise, and cooler than the Stevenson screen for a similar period after sunset, in all months, average differences being mostly less than 0.2 degC in midwinter but up to 0.5-0.6 degC during the summer months. Spot differences between the two screens of more than 1 degC (of either sign) occurred on only two hours each in November and December 2009 and January 2010 but on 27 hours (16 dates) during May 2010. The greatest observed positive difference at exact hours between the two screens was +2.9 degC at 0900 UTC on 2 March 2010 (Stevenson screen 1.6 °C, Met21 4.5 °C - **Figure 1, Appendix**); the greatest observed negative difference was -1.8 degC at 1900 UTC on 21 September 2009 (**Figure 2, Appendix**).

TABLE 1 Average of Met_21 temperature vs Stevenson screen, degC (+ is Met21 higher)

Hour UTC	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010	Jul 2010	Aug 2009	Sep 2009	Oct 2009	Nov 2009	Dec 2009	Hourly mean
0000	+0.02	+0.02	+0.07	-0.19	-0.22	-0.11	-0.09	-0.15	-0.05	-0.01	+0.12	+0.01	-0.05
0100	-0.05	-0.02	-0.09	-0.16	-0.16	-0.16	-0.05	-0.11	-0.03	-0.06	+0.06	-0.03	-0.07
0200	-0.01	+0.04	-0.04	-0.07	-0.15	-0.14	-0.04	-0.09	-0.01	-0.05	+0.11	-0.00	-0.04
0300	+0.01	+0.04	-0.05	-0.03	-0.10	-0.09	+0.08	-0.04	+0.02	+0.02	+0.05	+0.03	-0.01
0400	-0.02	+0.07	-0.04	-0.06	-0.06	-0.07	+0.07	-0.05	-0.01	+0.08	+0.08	-0.03	-0.00
0500	+0.05	+0.06	-0.01	-0.03	+0.11	+0.23	+0.10	+0.05	-0.04	-0.00	+0.11	-0.04	+0.05
0600	+0.07	+0.04	-0.06	+0.21	+0.38	+0.42	+0.28	+0.39	-0.01	+0.02	+0.11	-0.02	+0.15
0700	+0.02	+0.01	+0.20	+0.55	+0.53	+0.36	+0.29	+0.45	+0.44	+0.20	+0.04	+0.02	+0.26
0800	+0.04	+0.06	+0.53	+0.61	+0.44	+0.36	+0.16	+0.38	+0.55	+0.40	+0.11	+0.10	+0.31
0900	+0.13	+0.15	+0.29	+0.36	+0.08	+0.14	+0.17	+0.22	+0.23	+0.36	+0.16	+0.11	+0.20
1000	+0.21	+0.17	+0.27	+0.21	+0.07	-0.06	+0.10	+0.09	+0.13	+0.18	+0.18	+0.19	+0.14
1100	+0.17	+0.10	+0.10	-0.01	-0.03	-0.08	+0.23	-0.01	+0.10	+0.05	+0.07	+0.06	+0.06
1200	+0.04	+0.06	+0.10	-0.04	-0.03	-0.14	-0.00	-0.05	-0.05	-0.11	+0.01	-0.03	-0.02
1300	-0.04	+0.01	+0.03	-0.07	-0.01	-0.08	-0.06	-0.19	-0.09	-0.01	+0.01	-0.00	-0.04
1400	-0.01	-0.03	+0.03	-0.15	-0.19	-0.16	-0.01	-0.09	-0.16	-0.13	+0.03	-0.12	-0.08
1500	-0.11	-0.00	-0.10	-0.03	-0.04	-0.18	-0.11	-0.21	-0.17	-0.15	-0.08	-0.12	-0.11
1600	-0.14	-0.06	-0.06	-0.12	-0.03	-0.12	+0.02	-0.03	-0.03	-0.18	-0.05	-0.15	-0.08
1700	-0.06	-0.20	-0.07	+0.03	+0.02	-0.02	+0.05	-0.06	-0.08	-0.36	-0.03	-0.06	-0.07
1800	-0.06	-0.15	-0.22	-0.14	+0.09	-0.02	-0.05	-0.10	-0.37	-0.21	+0.03	-0.09	-0.11
1900	-0.04	-0.04	-0.16	-0.40	-0.25	-0.01	-0.12	-0.29	-0.30	-0.19	+0.00	-0.03	-0.15
2000	+0.03	-0.11	-0.11	-0.32	-0.49	-0.47	-0.29	-0.24	-0.16	-0.08	-0.01	+0.01	-0.19
2100	-0.02	-0.02	-0.10	-0.29	-0.35	-0.54	-0.21	-0.16	-0.16	-0.02	+0.05	-0.02	-0.15
2200	+0.07	+0.05	-0.04	-0.29	-0.25	-0.26	-0.14	-0.10	-0.10	-0.06	+0.03	-0.04	-0.09
2300	+0.02	+0.02	-0.02	-0.18	-0.18	-0.20	-0.12	+0.00	-0.06	-0.01	+0.07	-0.02	-0.06
Monthly mean	+0.01	+0.01	+0.02	-0.03	-0.03	-0.06	+0.01	-0.02	-0.02	-0.01	+0.05	-0.01	-0.01

Two conclusions can be drawn from Table 1:

- Firstly, the Met21 screen, by virtue of its smaller size and lower thermal mass (and, in this trial, a smaller and more reactive temperature sensor – see Appendix for details of sensors and logging methods used), is more responsive to changes in air temperature than the much larger Stevenson screen. This difference in response time is clearly shown in the results, with the Met21 unit typically warming more quickly during the morning and cooling more quickly during the evening than the Stevenson screen.

- The second conclusion is that the Met21 screen performance in peak solar radiation is very similar to the Stevenson screen – mean temperature differences between the two units 1100-1300 UTC being typically 0.1 degC or less (i.e. well within calibration tolerances). This latter conclusion was more surprising considering the blackened interior of the Met21 unit, but its construction does appear to offer similar resistance to solar radiation-induced heating as the conventional Stevenson screen.

There was little evidence to suggest that direct radiation penetration or warming at low solar angles (at either end of the day) resulted in any significant additional effect, although site obstructions at low elevations may obscure potential impacts for about half the year.

1.2. Versus aspirated screen

Hourly comparative data was available for all but 21 hours of the 12 month period (99.76% data availability).

Table 2 shows the average difference in air temperature between the aspirated screen and the Met21 screen by month at exact hours UTC. The same sign conventions are used as in Table 1, viz. positive (negative) values indicate the Met21 screen warmer (colder) than the aspirated screen; the cells are similarly colour-coded to indicate the highest differences.

TABLE 2 Average of Met_21 temperature vs aspirated unit, degC (+ is Met21 higher)

Hour UTC	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010	Jul 2010	Aug 2009	Sep 2009	Oct 2009	Nov 2009	Dec 2009	Hourly mean
0000	-0.11	-0.10	-0.11	-0.27	-0.26	-0.10	+0.03	-0.07	-0.07	-0.06	-0.05	-0.12	-0.11
0100	-0.11	-0.09	-0.15	-0.27	-0.22	-0.19	+0.00	-0.06	-0.11	-0.09	-0.04	-0.13	-0.12
0200	-0.11	-0.08	-0.12	-0.23	-0.19	-0.21	+0.02	-0.06	-0.11	-0.11	-0.02	-0.14	-0.11
0300	-0.11	-0.07	-0.13	-0.22	-0.19	-0.16	-0.03	-0.07	-0.10	-0.07	-0.01	-0.12	-0.11
0400	-0.12	-0.06	-0.16	-0.20	-0.21	-0.14	-0.01	-0.04	-0.10	-0.07	-0.02	-0.13	-0.11
0500	-0.11	-0.09	-0.11	-0.22	-0.17	-0.15	-0.01	-0.05	-0.13	-0.10	+0.01	-0.13	-0.10
0600	-0.08	-0.08	-0.19	-0.10	-0.07	-0.02	+0.10	+0.10	-0.11	-0.07	-0.00	-0.15	-0.06
0700	-0.06	-0.07	-0.12	+0.22	+0.33	+0.45	+0.28	+0.32	+0.17	-0.00	+0.01	-0.13	+0.12
0800	-0.07	-0.04	+0.21	+0.46	+0.50	+0.64	+0.37	+0.49	+0.35	+0.17	+0.03	-0.13	+0.25
0900	+0.02	+0.08	+0.25	+0.48	+0.42	+0.69	+0.46	+0.52	+0.38	+0.36	+0.09	-0.07	+0.31
1000	+0.07	+0.09	+0.21	+0.40	+0.42	+0.57	+0.42	+0.47	+0.38	+0.26	+0.12	+0.02	+0.29
1100	+0.23	+0.10	+0.23	+0.33	+0.40	+0.58	+0.54	+0.49	+0.43	+0.25	+0.11	+0.17	+0.32
1200	+0.21	+0.09	+0.26	+0.31	+0.44	+0.61	+0.46	+0.46	+0.43	+0.25	+0.14	+0.09	+0.31
1300	+0.20	+0.15	+0.22	+0.32	+0.47	+0.70	+0.49	+0.46	+0.44	+0.42	+0.15	+0.10	+0.34
1400	+0.23	+0.11	+0.21	+0.29	+0.43	+0.59	+0.58	+0.51	+0.43	+0.29	+0.14	+0.11	+0.33
1500	+0.16	+0.10	+0.08	+0.35	+0.40	+0.53	+0.51	+0.48	+0.36	+0.28	+0.07	+0.08	+0.28
1600	-0.01	+0.07	+0.10	+0.31	+0.35	+0.57	+0.52	+0.45	+0.39	+0.32	+0.02	-0.05	+0.26
1700	-0.10	-0.08	+0.04	+0.34	+0.38	+0.51	+0.49	+0.47	+0.29	-0.03	-0.01	-0.07	+0.19
1800	-0.10	-0.12	-0.11	+0.19	+0.39	+0.51	+0.40	+0.37	+0.08	-0.14	-0.05	-0.12	+0.11
1900	-0.12	-0.14	-0.13	-0.11	+0.15	+0.61	+0.31	+0.08	-0.07	-0.12	-0.02	-0.07	+0.03
2000	-0.12	-0.11	-0.12	-0.21	-0.12	+0.05	+0.16	+0.03	-0.11	-0.04	-0.04	-0.09	-0.06
2100	-0.12	-0.07	-0.13	-0.26	-0.15	-0.10	+0.08	+0.02	-0.07	-0.12	-0.01	-0.08	-0.09
2200	-0.08	-0.08	-0.14	-0.18	-0.18	-0.12	+0.07	-0.09	-0.04	-0.08	-0.04	-0.06	-0.09
2300	-0.12	-0.11	-0.12	-0.30	-0.21	-0.10	-0.01	-0.03	-0.07	-0.10	-0.05	-0.10	-0.11
Monthly mean	-0.02	-0.03	-0.00	+0.06	+0.13	+0.26	+0.26	+0.22	+0.13	+0.06	+0.02	-0.05	+0.09

The form of differences here are clearly very different from those shown in Table 1 and can be summarized even more simply – positive in daytime conditions (positive solar radiation receipts) and nil or slightly negative in darkness. Whilst the latter are generally small, almost all within 0.2 degC (and thus close to calibration tolerances), during daylight the differences are more significant and reach their maximum close to peak solar radiation on both hourly and monthly timescales, the largest *mean* difference noted being +0.70 degC at 1300 UTC in June. There is also a suggestion of a small asymmetrical peak, implying that the Met21 screen retains some heat into the late afternoon – most evident in midsummer. This is most likely due to thermal inertia, although there is a possibility this is as a result of the penetration of low solar-angle radiation through the screen; this was difficult to be sure of, however, as low-level obstructions block low elevation sunshine (below about 3 degrees) for about half of the year.

The absolute highest positive spot difference was +2.5 degC which occurred on the same occasion as the highest positive difference with the Stevenson screen (viz. 0900 UTC on 2 March 2010 (aspirated unit 2.0 °C, Stevenson screen 1.6 °C, Met21 4.5 °C - **Figure 1, Appendix**); the greatest observed negative difference at an exact hour was -1.3 degC following a heavy hail shower at 1500 UTC on 1 April 2010 (**Figure 3, Appendix**) – Stevenson screen 6.7 °C, aspirated 6.3 °C and Met21 5.0 °C.

This pattern of differences is very similar to the performance of the Stevenson screen when compared to the aspirated unit (**Table 3**), although the absolute values of the Stevenson screen are slightly greater.

As expected, the two main factors in the elevation of screen temperatures above true air temperature, taken here as the aspirated temperature, are (i) the intensity of solar radiation and (ii) the wind speed.

TABLE 3 Average of Stevenson screen temperature vs aspirated unit, degC (+ is SS higher)

Hour UTC	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010	Jul 2010	Aug 2009	Sep 2009	Oct 2009	Nov 2009	Dec 2009	Hourly mean
0000	-0.13	-0.12	-0.18	-0.08	-0.04	+0.01	+0.12	+0.08	-0.02	-0.05	-0.17	-0.13	-0.06
0100	-0.06	-0.07	-0.05	-0.11	-0.05	-0.03	+0.06	+0.05	-0.07	-0.03	-0.11	-0.10	-0.05
0200	-0.10	-0.12	-0.08	-0.16	-0.04	-0.07	+0.06	+0.03	-0.09	-0.06	-0.12	-0.13	-0.07
0300	-0.12	-0.12	-0.08	-0.19	-0.09	-0.07	-0.12	-0.03	-0.12	-0.09	-0.06	-0.14	-0.10
0400	-0.11	-0.13	-0.12	-0.14	-0.15	-0.07	-0.08	+0.00	-0.09	-0.15	-0.09	-0.10	-0.10
0500	-0.15	-0.15	-0.10	-0.20	-0.28	-0.37	-0.13	-0.10	-0.09	-0.10	-0.09	-0.09	-0.15
0600	-0.15	-0.13	-0.13	-0.31	-0.45	-0.44	-0.19	-0.29	-0.10	-0.09	-0.11	-0.13	-0.21
0700	-0.08	-0.08	-0.32	-0.34	-0.20	+0.10	-0.01	-0.13	-0.27	-0.20	-0.03	-0.15	-0.14
0800	-0.11	-0.11	-0.32	-0.16	+0.06	+0.28	+0.21	+0.11	-0.20	-0.22	-0.08	-0.22	-0.06
0900	-0.11	-0.08	-0.04	+0.13	+0.34	+0.55	+0.27	+0.30	+0.14	+0.00	-0.07	-0.18	+0.10
1000	-0.14	-0.08	-0.06	+0.19	+0.35	+0.63	+0.32	+0.38	+0.25	+0.08	-0.06	-0.17	+0.14
1100	+0.06	-0.01	+0.13	+0.34	+0.42	+0.67	+0.31	+0.50	+0.33	+0.20	+0.04	+0.11	+0.26
1200	+0.16	+0.03	+0.16	+0.35	+0.46	+0.74	+0.47	+0.51	+0.48	+0.35	+0.12	+0.12	+0.33
1300	+0.25	+0.14	+0.19	+0.39	+0.48	+0.78	+0.55	+0.65	+0.53	+0.42	+0.14	+0.10	+0.39
1400	+0.23	+0.13	+0.18	+0.44	+0.62	+0.74	+0.59	+0.60	+0.59	+0.42	+0.11	+0.23	+0.41
1500	+0.26	+0.10	+0.18	+0.38	+0.44	+0.71	+0.62	+0.68	+0.53	+0.43	+0.15	+0.20	+0.39
1600	+0.13	+0.14	+0.16	+0.43	+0.38	+0.70	+0.51	+0.48	+0.43	+0.49	+0.08	+0.10	+0.34
1700	-0.04	+0.13	+0.10	+0.30	+0.36	+0.53	+0.44	+0.53	+0.37	+0.33	+0.02	-0.01	+0.26
1800	-0.04	+0.03	+0.11	+0.33	+0.31	+0.53	+0.45	+0.47	+0.46	+0.07	-0.08	-0.03	+0.22
1900	-0.07	-0.10	+0.03	+0.29	+0.41	+0.63	+0.43	+0.38	+0.23	+0.07	-0.02	-0.04	+0.19
2000	-0.15	-0.00	-0.01	+0.11	+0.37	+0.53	+0.44	+0.28	+0.06	+0.04	-0.03	-0.10	+0.13
2100	-0.10	-0.06	-0.03	+0.02	+0.20	+0.44	+0.30	+0.18	+0.09	-0.10	-0.06	-0.06	+0.07
2200	-0.15	-0.13	-0.10	+0.11	+0.07	+0.14	+0.22	+0.01	+0.06	-0.02	-0.07	-0.02	+0.01
2300	-0.13	-0.13	-0.10	-0.11	-0.03	+0.10	+0.11	-0.03	-0.01	-0.09	-0.11	-0.08	-0.05
Monthly mean	-0.04	-0.04	-0.02	+0.08	+0.16	+0.32	+0.25	+0.24	+0.14	+0.07	-0.03	-0.04	+0.09

Table 4 shows the performance of the Met21 screen by month of the year (average difference in spot temperatures on the hour across all class members vs segmented classes of hourly mean global solar radiation on a horizontal surface for the immediately preceding hour, hours commencing 10-13 UTC only i.e. for the 2 hours on either side of highest solar elevation [1]). This includes all wind speed classes.

TABLE 4 Average of Met_21 temperature vs aspirated unit, degC, for different solar radiation levels (+ is Met21 higher)

	Hourly mean Global solar radiation, W/m2																					
	< 25	25-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699	700-749	750-799	800-849	850-899	900-949	> 950	Monthly mean
Jan 2010		+0.05	+0.10	+0.21	+0.26	+0.35	+0.47															+0.18
Feb 2010	+0.04	+0.02	+0.03	+0.08	+0.16	+0.13	+0.17	+0.41	+0.40	+0.09	+0.20	-0.19										+0.11
Mar 2010		+0.05	+0.05	+0.11	+0.11	+0.24	+0.15	+0.13	+0.40	+0.31	+0.44	+0.19	+0.37	+0.56								+0.23
Apr 2010			-0.02	+0.15	+0.14	-0.12	+0.14	+0.23	+0.21	+0.18	+0.51	+0.31	+0.42	+0.28	+0.52	+0.52	+0.61					+0.34
May 2010			+0.07	+0.12	+0.28	+0.15	+0.27	+0.34	+0.42	+0.43	+0.81	+0.41	+0.44	+0.45	+0.52	+0.54	+0.53	+0.75	+0.78			+0.43
Jun 2010			+0.29	+0.17	+0.23	+0.40	+0.49	+0.28	+0.52	+0.44	+0.71	+0.46	+0.56	+0.71	+0.68	+0.73	+0.76	+0.76	+0.73	+0.34		+0.61
Jul 2010				+0.17	+0.33	+0.37	+0.57	+0.43	+0.30	+0.46	+0.05	+0.58	+0.53	+0.42	+0.65	+0.67	+0.61	+0.89	+0.38	+0.39		+0.46
Aug 2009			+0.24	+0.29	+0.32	+0.30	+0.48	+0.52	+0.37	+0.46	+0.52	+0.77	+0.51	+0.58	+0.46	+0.70	+1.07					+0.47
Sep 2009		+0.12	+0.27	+0.26	+0.28	+0.36	+0.37	+0.29	+0.42	+0.50	+0.51	+0.53	+0.55	+0.36								+0.42
Oct 2009		+0.07	+0.15	+0.16	+0.29	+0.39	+0.37	+0.38	+0.64	+0.47	+0.33											+0.29
Nov 2009	+0.02	+0.07	+0.09	+0.15	+0.16	+0.21	+0.26	+0.02														+0.13
Dec 2009	-0.03	-0.01	+0.06	+0.14	+0.34																	+0.10
Mean	-0.02	+0.04	+0.09	+0.16	+0.24	+0.26	+0.31	+0.34	+0.41	+0.39	+0.46	+0.44	+0.50	+0.45	+0.55	+0.62	+0.63	+0.79	+0.69	+0.37		+0.32

[1] Note here that some cells, particularly those at the extremes of the distribution, have very small class sizes and that the results may be unduly influenced by individual days (there were only 4 hours in the year with mean hourly solar radiation above 900 W/m^2 for example).

From this analysis and **Figure 4, Appendix** (red circles) it can be seen that the 'coefficient of warming' of the Met21 screen as a function of incident global solar radiation averages 0.09 degC/100 W/m^2. This is remarkably similar to the performance of the Stevenson screen measured against the aspirated sensor (shown on **Figure 4** in blue squares). This result was unexpected (clearly the black interior of the Met21 unit does not result in additional absorption of solar radiation, except possibly at low solar elevations) but this bears out the conclusions of section 1.1 above; the mean difference from the Stevenson screen at 1200 UTC i.e. peak solar radiation averages just 0.02 degC over the year, with if anything a slight negative correlation with solar radiation levels.

The rationale for the black interior of the screen does not appear to be clearly documented: the logic for doing so is not clear, and this is a disadvantage. The purpose is *presumably* to improve performance by presenting a more impermeable barrier to incoming solar radiation than a white interior. While results show that the performance of the unit under test in conditions of strong solar radiation was similar to (no worse than) that of a Stevenson screen, it is possible that a white interior would perform differently. These tests cannot produce definitive conclusions with regard to the relative merits of black versus white interiors: the only way to say this with any certainty would be to run further tests with a second Met21 alongside, painted white inside with identical thermometers, logged at the same instant.

Wind speeds also have a significant bearing on solar radiation-induced screen warming. **Table 5** shows the mean difference between the Met21 screen and the aspirated unit under conditions of intense solar radiation (cut-off arbitrarily taken as an hourly mean of 500 W/m^2 or more[2]), by month, by various wind speed categories[3]. Under intense solar radiation the Met21 warms significantly more in light wind conditions than in stronger winds – the difference is halved with winds of Beaufort force 3 compared with Beaufort 1 (+0.41 degC vs +0.88 degC). Note, however, that some class sizes in this table are very small –those with less than 5 observations are shown in italics: the table is included to illustrate the general relationship between wind speed and screen temperature elevation; data for specific cells, particularly those with small class sizes, must therefore be regarded with caution. Note also that the row and column averages are the mean of all values, not the arithmetic mean of the row or column cells.

TABLE 5 Average of Met_21 temperature vs aspirated unit, degC, with solar radiation > 500 W/m2, by month, for different mean hourly wind speeds (+ is Met21 higher)

	Hourly mean wind speed at 11 m AGL, knots and Beaufort Force					
Month	Beaufort 0	Bft 1	Bft 2	Bft 3	Bft 4	Grand Total
	Knots <1	*1.0 to 3.5*	*3.6 to 6.5*	*6.6 to 10.5*	*>10.5*	
Jan 2010						
Feb 2010			*+0.20*		*-0.19*	+0.01
Mar 2010		+0.79	+0.28	+0.04		+0.34
Apr 2010		+0.93	+0.47	+0.29	*+0.19*	+0.53
May 2010		+0.83	+0.57	+0.36		+0.61
Jun 2010		+0.94	+0.64	+0.44		+0.70
Jul 2010		+0.73	+0.62	+0.54	+0.19	+0.57
Aug 2009		+0.90	+0.59	+0.48	*+0.53*	+0.61
Sep 2009		+0.83	+0.51	+0.31	+0.33	+0.50
Oct 2009		*+0.74*	+0.18	*+0.40*		+0.33
Nov 2009						
Dec 2009						
Average		+0.88	+0.56	+0.41	+0.24	+0.58

[2] Hourly mean radiation of 500 W/m^2 or more occurs, on average, on only about 15% of all daylight hours during the year at this site.

[3] The hourly mean wind speeds given in Table 5 are from the anemometer at 10 m above ground level; wind mean wind speeds at screen level are typically 50-70% of this value.

1.3. Conclusions

From detailed comparative analysis of hourly spot air temperatures over 12 months, it is clear that the Met21 screen performs very similarly to a Stevenson screen – it is slightly more reactive, owing to its smaller size and thus reduced thermal inertia, but it still exhibits the tendency of the latter to over-read (occasionally by 1 degC or more) compared to an aspirated sensor, particularly under conditions of high ambient solar radiation and light winds.

2. Daily maxima and minima

2.1. Versus Stevenson screen

The most common requirement for meteorological air temperature measurements is for maximum and minimum temperatures, and accordingly the performance of the Met21 unit was also assessed against both Stevenson screen and aspirated screen in this respect.

The analysis is more complicated than the straightforward comparison of hourly means of spot temperature, however, because as has been shown above the reduced thermal inertia (and thus reduced time constant) of the Met21 screen leads to a more reactive response to changes in air temperature, and this factor alone can (and does) lead to differences in observed maximum and minimum temperatures, even if all other factors are unchanged. Here a smaller screen and a smaller sensor combine to increase the effect.

Passive radiation screens of this type (such as the smaller plastic Gill-type screen also sold by Campbell Scientific) normally record maximum temperatures a little below those observed in the Stevenson screen, owing to the known tendency of the Stevenson screen to overheat a little, particularly in conditions of strong insolation and light winds (see, for example, Painter 1977, Strangeways 2009). Minimum temperatures are typically little different to those observed in the Stevenson screen except where the rate of change of temperature is high near the time of the minimum, when the shorter time-constant of the smaller screen+sensor can become significant.

The Met 21 passive screen consistently recorded slightly *higher* temperatures by day, and slightly lower by night, than those observed in the adjacent Stevenson screen. This warming is most apparent on sunny days and with high solar elevations, but was apparent even in midwinter at low solar angles.

Compared to the standard climatological measurements made by a calibrated Vaisala platinum resistance thermometer in the Stevenson screen, *mean maximum temperatures* in the Met 21 unit averaged 0.30 degC higher over the 12 months ending July 2010 (see **Table 5A** in Appendix). Mean monthly differences were strongly correlated with monthly mean solar radiation receipts - **Figure 5** shows this clearly: the correlation coefficient between the two variables is 0.82. The highest mean difference was in July 2010, +0.58 degC, the lowest in December 2009, +0.09 degC [4].

Analysis of the 12 months data 1 August 2009 to 31 July 2010 shows that the Met21 maximum was higher than the Stevenson screen on almost every day in the summer half-year (April to September), but lower on about one day in four in midwinter (December and January). The daily difference in maximum temperatures slightly exceeded +1.0 degC on nine days (largest difference +1.27 degC on

[4] Compared to the calibrated TH2500 logger also exposed in the screen, which has a faster response-time and is thus probably more directly comparable with the response characteristics of the Tinytag Plus2 thermistor/ logger combination used in the Met21 unit, the mean differences were lower, averaging just +0.05 degC over 11 months (no data for Feb 2010), with monthly extremes ranging from +0.37 degC in May 2010 to -0.19 degC in January 2010, but the relationship with monthly solar radiation receipts was very similar in form to the results from the Vaisala sensor.

6 May 2010): the largest negative differences were confined to December and January, with three days surpassing -0.5 degC (largest difference -0.66 degC on 19 December). Many of the days with relatively large positive differences in maximum temperature were showery, with short spells of intense sunshine, and response-time differences undoubtedly played a significant part. The two largest negative differences were on consecutive midwinter days with little cloud and unbroken sunshine, implying that the solar radiation shielding of the screen is perhaps more effective than that of the Stevenson screen at low solar altitudes/intensities. However, there was little correlation between absolute daily values of global solar radiation or duration of sunshine, probably because a few minutes sunshine on an otherwise cloudy day can produce larger differences in maximum temperatures than a day with long spells of unbroken sunshine.

In terms of *mean minimum temperatures,* the Met21 unit averaged 0.29 degC lower than the Stevenson screen over the year to July 2010, with much less variation by month than was the case for maximum temperatures [5]. Analysis of the year's data shows that the Met21 minimum was lower than the Stevenson screen on all but 35 nights (90%); only four of these 35 were more than 0.1 degC warmer, while three nights logged a minimum temperature in the Met21 screen 1 degC or more below the Stevenson screen. The extremes in the annual trial period were +0.79 degC (on 4 April 2010) and -1.12 degC (on 7 January 2010): most of the small tail of significant extremes appeared to be due to a relatively rapid fall in air temperature near the time of the minimum value or the terminal hour, probably as a result of the Met21 screen+sensor combination reacting more quickly than the sensor located in the Stevenson screen.

By *mean temperature*, the higher temperatures in the Met21 screen by day and the lower values at night almost cancelled each other out, and the mean temperature (the mean of all the observed samples, not the mean of max + min) was an insignificant 0.01 degC below that in the Stevenson screen over the 12 months. This is of course well within calibration allowances.

The effect of higher day maxima and lower night minima is clearly to increase the measured *daily range of air temperature*. Over the year as a whole the mean daily range in the Met21 unit averaged 0.59 degC greater than the Stevenson screen, the differences greatest in the summer months (July 2010 0.87 degC) and least in the winter months (0.35 degC in November 2009).

2.2 Versus aspirated sensor

The Met21passive screen consistently recorded considerably higher temperatures by day, and about the same by night, than those observed in the adjacent aspirated screen. Because of the forced airflow over the sensor, the aspirated unit has a very fast response time in all wind conditions, and differences due to this factor alone can probably be largely ruled out.

Compared to the aspirated sensor, *mean maximum temperatures* in the Met21 unit averaged 0.47 degC higher over the 12 month period, from 0.14 degC higher in December 2009 to 0.77 degC higher in June 2010. Analysis of the 12 months data showed that the Met21 maximum was higher than the aspirated sensor on all but 21 days (94%), with almost all of these 21 occurring in the three winter months. Differences ranged from -0.4 degC (on 6 January 2010) to +2.0 degC (on 20 May 2010).

Averaged *mean minimum temperatures* in the Met 21 screen were almost identical to those derived from the aspirated sensor, monthly mean differences being mostly less than 0.05 degC. The 12 months trial period showed that the tiny mean differences obscured a wider daily variation, with daily differences ranging from -1.8 to +1.5 degC.

By *mean temperature*, the higher temperatures in the Met21 screen by day resulted in a slightly higher mean daily temperature (annual average +0.08 degC – **Table 5A**), from -0.06 degC in December 2009 to +0.25 degC in June 2010, most of the difference as a result of higher daytime temperatures.

[5] Compared to the calibrated TH2500 logger, with its faster response-time, the mean differences in minimum temperature were very similar, averaging -0.35 degC.

In terms of daily range, the Met21 unit averaged 0.46 degC greater mean daily range than the aspirated sensor/screen combination over the 12 month period, greater in summer and least in midwinter as would be expected.

2.3. Conclusions

The Met21 screen does emulate the observed spot air temperature from a Stevenson Screen reasonably well, but observed maximum and minimum air temperatures can be significantly different, owing to reduced thermal lag of the screen combined with the faster sensor response, compared with the Stevenson screen.

(A comparative trial with an identical faster response unit mounted inside a Stevenson screen would, I suspect, not show very much difference, because here in most circumstances the response time of the screen is much greater than that of the sensor.)

3 Comparisons on individual days

Averages can only tell a part of the story. In this section the 5 minute data from individual days are examined to look in more detail at the diurnal response of each type of screen.

As expected, there is little variation between the three screens in cloudy, windy conditions (this is a useful cross-check on calibration too of course). The largest differences between that given within the Stevenson screen and 'true air temperature' tend to arise under conditions of strong solar radiation accompanied by light winds. Four dates were chosen from the available dataset as exhibiting typical characteristics of such days: 19 August 2009, 13 October 2009, 7 January 2010 and 20 May 2010.

3.1 - 19 August 2009

Sunshine was almost unbroken on this day, although hazy during the morning from extensive Ci and contrails, which largely cleared during the afternoon. Surface winds (anemometer at 11 m) were light variable or calm around dawn, freshening during the day to SSW'ly 7-8 kn (hourly means), with gusts to 18 kn, around the time of the highest temperature. **Figure 6A** plots the 5 minute spot temperatures (°C) for the three screens. **Figure 6B** shows the 5 min mean global solar radiation as measured by the Kipp & Zonen CMP3 solarimeter at the site as logged to the CR10X logger: peak values were a little over 760 W/m2 around local solar noon. The day's sunshine duration was a little over 13 hours. The time axis on both graphs is in UTC.

The night 18/19 August was clear of low cloud, with light and variable surface winds, and temperatures fell to a minimum shortly before 0500 UTC (sunrise was at 0456 UTC) on the morning of 19th. There was no great difference in the indicated minimum temperatures – see table below – although the greater sensitivity of both the Met21 record and the aspirated record in comparison to the Stevenson screen/Vaisala sensor record is immediately obvious. As temperatures rose on this sunny morning, indicated air temperatures in the aspirated and the Met21 units rose more quickly than those within the Stevenson screen, probably owing to the greater thermal lag of the latter. By mid-morning, the Met21 screen was warming much faster than both aspirated and Stevenson screens – at 0805 UTC it was 2.2 degC warmer than the Stevenson screen and 1.8 degC warmer than the aspirated sensor. (The rapid mid-morning warming of the Met21 screen was evident on many other sunny mornings, and may indicate excess sensitivity to certain angles of solar incidence. It is unlikely to be solely a simple lag effect, for the response time of the aspirated sensor is at least as good as the Met21/thermistor combination.) By around 1000 UTC the excess warming was much less apparent, and the Met21 screen indicated air temperatures very close to those logged in the Stevenson screen throughout the warmest part of the day. The mean air temperature as indicated by the sensor in the Met21 screen over the three hours 1200-1500 UTC was 0.11 degC below that of the Stevenson screen (**Table 6**), although the maximum temperature was 0.07 degC above that in the Stevenson screen. In contrast, the aspirated sensor remained on average 0.83 degC cooler than the logged Stevenson screen air temperature over the same three hour period, and the maximum temperature was 0.61 degC lower. Once again the much more sensitive nature of the aspirated and Met21 records when compared with the Stevenson screen are visually obvious.

Towards sunset both the Met21 and the aspirated sensor indicated a slightly more rapid fall in air temperature than the sensor in the Stevenson screen, again a typical feature of clear evenings, while during the late evening slight variations in surface wind speed continued to cause considerable short-term fluctuations in air temperature, well picked-up by the Met21 and aspirated records, rather smoothed in the Stevenson screen record.

Table 6 Key comparisons for each of the screen/sensor combinations, 19 August 2009. The maximum and minimum shown are the highest and lowest logged air temperatures, with the time of occurrence (in UTC): the means for 03-06h and 12-15h are three hour means of the logged 5 min spot values for the coolest and warmest part of the day, respectively. 'Diff from SS' is the difference from the Stevenson screen value, in degC.

Note that the time of extreme is available to 1 min resolution for the Vaisala and Type 107 sensors (logged to CR10X logger), but only to 5 min for the Tinytag. Temperatures are shown to 0.01 degC to aid comparison, although the accuracy is no better than ± 0.1 degC.

TABLE 6

19 Aug 2009	Minimum °C	Diff from SS	Mean 03-06h °C	Diff from SS	Maximum °C	Diff from SS	Mean 12-15h °C	Diff from SS
Stevenson screen/ Vaisala	9.95 *@ 0442*	--	10.33	--	27.66 *@ 1346*	--	27.13	--
Met 21/ Tinytag	9.69 *@ 0440*	-0.26	10.27	-0.06	27.73 *@ 1345*	+0.07	27.02	-0.11
RM Young aspirated/ Type 107	9.63 *@ 0436*	-0.32	10.47	+0.14	27.05 *@ 1329*	-0.61	26.30	-0.83

The expectation from a day of prolonged and reasonably strong sunshine was that indicated daytime air temperatures inside the Met21 screen would remain somewhat lower than those logged within the Stevenson screen. In fact, the logged results showed no significant difference between the two.

3.2 – 13 October 2009

This was another day largely free of low cloud, with only patchy contrail cover during the morning and a slow increase in high cloud during the afternoon. Sunshine duration was 9.2 hours. Surface winds (anemometer at 11 m) were light and variable throughout the day, with the highest hourly mean speed below 2 kn, the highest gust only 5 kn. **Figure 7A** plots the 5 minute spot temperatures (°C) using the same colour convention as previous graphs. **Figure 7B** shows the 5 min mean global solar radiation: peak values were just under 500 W/m^2 around local solar noon. The time axis on both graphs is in UTC.

A night free of low cloud and with only light winds resulted in a cool morning: air temperatures fell to near 0°C with a minimum a little after 0500 UTC (sunrise was at 0623 UTC). There was considerable variation in air temperature indicated by both the aspirated and Met21 records, owing to slight variations in surface wind speed, and the relative insensitivity of the Stevenson screen record is again visually obvious. There was a difference of around 0.5 degC in the indicated minimum temperatures – see table below – probably as a result of the relatively rapid fall in air temperature just after 0500 associated with a slight pickup in wind speed. As temperatures rose in the morning sunshine, indicated air temperatures in the Met21 screen again rose more quickly than those indicated by the Stevenson screen or the aspirated sensors: at 0925 UTC the Met21 screen was 1.8 degC warmer than the Stevenson screen and 1.5 degC warmer than the aspirated sensor. By around 1000 UTC the excess warming had diminished, and the Met21 screen indicated air temperatures a little below those of the Stevenson screen throughout the warmest part of the day. The mean air temperature as indicated by the sensor in the Met21 screen over the three hours 1200-1500 UTC was 0.66 degC below that of the Stevenson screen (**Table 7**), although the maximum temperature was only 0.12 degC lower. In contrast, the aspirated sensor remained on average 1.70 degC cooler than the logged Stevenson screen air temperature over the same three hour period, and the maximum temperature was 1.66 degC lower. Once again the much more sensitive nature of the aspirated and Met21 records when compared with the Stevenson screen are visually obvious. The rapid response of the Met21 screen to a late burst of stronger sunshine around 1540 UTC is very marked – this gave the highest 5 min spot temperature value (16.7 °C) although the logged maximum of 17.1 °C was recorded 2 h previously. Both aspirated and Stevenson screen temperatures were much less affected by this short spell of sunshine, and again this may be evidence of the sensitivity of the Met21 screen to direct solar radiation at particular angles of incidence.

Towards sunset both the Met21 and the aspirated sensor again indicated a more rapid fall in air temperature than the sensor in the Stevenson screen: at 1745 the Met21 screen's indicated air temperature was 2.2 degC below that in the Stevenson screen. Later in the evening slight variations in surface wind speed and cloud cover continued to cause considerable short-term fluctuations in air temperature, well picked-up by the Met21 and aspirated records, again rather smoothed in the Stevenson screen record.

Table 7 Key comparisons for each of the screen/sensor combinations, 13 October 2009. The maximum and minimum shown are the highest and lowest logged air temperatures, with the time of occurrence (in UTC): the means for 03-06h and 12-15h are three hour means of the logged 5 min spot values for the coolest and warmest part of the day, respectively. 'Diff from SS' is the difference from the Stevenson screen value, in degC.

Note that the time of extreme is available to 1 min resolution for the Vaisala and Type 107 sensors (logged to CR10X logger), but only to 5 min for the Tinytag. Temperatures are shown to 0.01 degC to aid comparison, although the accuracy is no better than ± 0.1 degC.

TABLE 7

13 Oct 2009	Minimum °C	Diff from SS	Mean 03-06h °C	Diff from SS	Maximum °C	Diff from SS	Mean 12-15h °C	Diff from SS
Stevenson screen/ Vaisala	0.51 *@ 0508*	--	1.29	--	17.23 *@ 1358*	--	16.31	--
Met 21/ Tinytag	-0.05 *@ 0505*	-0.56	1.14	-0.15	17.11 *@ 1340*	-0.12	15.65	-0.66
RM Young aspirated/ Type 107	0.02 *@ 0502*	-0.49	1.42	+0.13	15.57 *@ 1347*	-1.66	14.61	-1.70

Although solar radiation intensities were lower on this date than on 19 August, wind speeds were much lower and the warming effect of the Stevenson screen more marked as a result. On this occasion the Met21 screen remained a little cooler than the Stevenson screen during the time of highest temperatures (probably as a result of lower solar radiation levels); its indicated maximum was very close to that of the Stevenson screen but considerably higher than that indicated by the aspirated sensor.

3.3 – 7 January 2010

This was a rare opportunity to examine the relative performance of the unit under much more severe winter conditions that is normally possible in southern England. Heavy snowfall on 5/6 January was followed by clearing skies overnight 6/7 January; a steady light breeze overnight fell light around dawn allowing the Stevenson screen temperature to fall to -11.3 °C at 0707 UTC – the lowest air temperature recorded at this location since February 1986. Thereafter the air temperature rose very rapidly as cloud spread across in advance of a couple of light snow showers (the snow depth at 0900 UTC was 24 cm). After sunny spells during the morning, the cloud cleared during the afternoon to leave strong low-elevation midwinter sunshine together with intense surface reflection from the high-albedo deep snow cover; sunshine duration was 5.5 hours. Surface winds (anemometer at 11 m) showed a light but persistent NW-N breeze during the night, freshening to force 2-3 by day. **Figure 8A** plots the 5 minute spot temperatures (°C) using the same colour convention as previous Figures; **Figure 8B** shows the 5 min mean global solar radiation as measured by the Kipp & Zonen CMP3 solarimeter. The time axis on both graphs is in UTC.

The aspirated minimum was reached at 0704 UTC, the Met21 about a minute later, while the Stevenson screen minimum was delayed 3 minutes compared to the aspirated (**Table 8**). The rapid rise in temperature as cloud spread across is noticeable for the more sluggish response by the Stevenson screen, with a lag of 5-10 minutes compared to both aspirated and Met21 readings. During the afternoon's strong sunshine (and reflected solar radiation) the Met21 screen performed better than the Stevenson screen, the latter clearly considerably warmer than ambient air temperature as indicated by the aspirated unit; the Stevenson screen max was 1.41 degC above that of the aspirated, the largest difference in the 12 month trial. The Met21 max was also below that of the Stevenson screen, but only by 0.34 degC.

Table 8 Key comparisons for each of the screen/sensor combinations, 7 January 2010. The maximum and minimum shown are the highest and lowest logged air temperatures, with the time of occurrence (in UTC): the means for 03-06h and 12-15h are three hour means of the logged 5 min spot values for the coolest and warmest part of the day, respectively. 'Diff from SS' is the difference from the Stevenson screen value, in degC.

Note that the time of extreme is available to 1 min resolution for the Vaisala and Type 107 sensors (logged to CR10X logger), but only to 5 min for the Tinytag. Temperatures are shown to 0.01 degC to aid comparison, although the accuracy is no better than ± 0.1 degC.

TABLE 8

7 January 2010	Minimum °C	Diff from SS	Mean 03-06h °C	Diff from SS	Maximum °C	Diff from SS	Mean 12-15h °C	Diff from SS
Stevenson screen/ Vaisala	-11.34 *@ 0707*	--	-7.43	--	-0.02 *@ 1416*	--	-0.64	--
Met 21/ Tinytag	-12.15 *@ 0705*	-0.34	-7.74	-0.31	-0.36 *@ 1405*	-0.34	-1.39	-0.75
RM Young aspirated/ Type 107	-12.42 *@ 0704*	-1.08	-7.12	+0.31	-1.41 *@ 1307*	-1.39	-1.82	-1.18

3.4 – 20 May 2010

This date illustrates well the effects of both cloudy and sunny conditions within a day. The morning of 20 May began clear, then clouded up after 02h, remaining cloudy throughout the morning and early afternoon. The cloud began to break around 1400 and the day was mostly sunny and warm thereafter. Sunshine duration was only 3.6 hours. Surface winds (anemometer at 11 m) were light and variable throughout the day, with the highest hourly mean speed barely 2 kn, the highest gust only 5 kn. With clear skies during the early evening the temperature fell quickly. **Figure 9A** plots the 5 minute spot temperatures (°C) using the same colour convention as previous Figures. **Figure 9B** shows the 5 min mean global solar radiation. A short but intense burst of sunshine at 1424 UTC gave a 1 sec peak solar radiation value of 1095 W/m2, although the highest 5 min mean was only 663 W/m2. The time axis on both graphs is in UTC.

The aspirated minimum was reached at 0204 UTC, the Met21 about a minute later, while the Stevenson screen minimum was delayed 17 minutes on the aspirated (**Table 9**). Under cloudy skies during the morning the Stevenson screen and Met21 temperatures remained fairly similar, the Met21 screen being noticeably faster in its response to short-term fluctuations in insolation, while both warmed a little relative to the aspirated temperature under relatively high diffuse solar radiation in cloudy skies. As the sun appeared during the afternoon, the difference between the Stevenson screen and Met21 screens and the aspirated increased: with very light winds and strong sunshine late afternoon the Met21 temperature response is noticeably spikier and the day's maximum in the Met21 screen, recorded at 1640, was 1.22 degC above the Stevenson screen value (the second-largest difference during the 12 month trial) and 2.00 degC above the aspirated value. There is little evidence of much impact on any of the screens of the intense burst of sunshine at 1424 however – perhaps because the sun was at a relatively high elevation and the spike was very short-lived; the later spikes in temperature 16-18h are closely associated with variations in both wind speed and solar radiation.

As the temperature fell quickly during the early evening, the faster response of both Met21 and the aspirated unit is clear; the Stevenson screen is lagging here by 35-40 minutes.

Table 9 Key comparisons for each of the screen/sensor combinations, 20 May 2010. The maximum and minimum shown are the highest and lowest logged air temperatures, with the time of occurrence (in UTC): the means for 03-06h and 12-15h are three hour means of the logged 5 min spot values for the coolest and warmest part of the day, respectively. 'Diff from SS' is the difference from the Stevenson screen value, in degC.

Note that the time of extreme is available to 1 min resolution for the Vaisala and Type 107 sensors (logged to CR10X logger), but only to 5 min for the Tinytag. Temperatures are shown to 0.01 degC to aid comparison, although the accuracy is no better than ± 0.1 degC.

TABLE 9

20 May 2010	Minimum °C	Diff from SS	Mean 03-06h °C	Diff from SS	Maximum °C	Diff from SS	Mean 12-15h °C	Diff from SS
Stevenson screen/ Vaisala	6.92 *@ 0221*	--	9.74	--	21.91 *@ 1639*	--	19.45	--
Met 21/ Tinytag	6.58 *@ 0205*	-0.34	9.99	+0.25	23.13 *@ 1640*	+1.22	19.27	-0.18
RM Young aspirated/ Type 107	6.57 *@ 0204*	-0.49	10.00	+0.20	21.13 *@ 1636*	-0.78	18.70	-0.75

Summary conclusions

'Spot' air temperatures logged in the Campbell Scientific Met 21 passive radiation screen compared closely to those obtained in the adjacent Stevenson screen, except where the rate of change in air temperature was significant. Where air temperatures were changing relatively rapidly, the faster response time of the Met21 screen+sensor system compared to the Stevenson screen resulted in a greater range in observed air temperatures. As a result of this differing response time, maximum and minimum air temperatures obtained from the Met21 screen usually differ somewhat from those measured in the adjacent Stevenson screen, maximum temperatures usually being slightly higher and minimum temperatures slightly lower. Occasionally the differences are substantial (> 1 degC).

The rationale for the black interior of the screen does not appear to be clearly documented: the logic for doing so is not clear, and this is a disadvantage. The purpose is *presumably* to improve performance by presenting a more impermeable barrier to incoming solar radiation than a white interior. While results show that the performance of the unit under test in conditions of strong solar radiation was similar to (no worse than) that of a Stevenson screen, it is possible that a white interior would perform differently. These tests cannot produce definitive conclusions with regard to the relative merits of black versus white interiors: the only way to say this with any certainty would be to run further tests with a second Met21 alongside, painted white inside with identical thermometers, logged at the same instant.

Whilst these trials show that the Met21 screen can be used as a substitute for a Stevenson screen where spot air temperatures are required, homogeneity with regard to maximum and minimum air temperatures is considerably harder to attain owing partly to its significantly more reactive performance, and partly because the smaller size of the screen permits the use of smaller (and thus faster response) temperature sensors. Replacing an existing Stevenson screen-based climatological measurement system with one based upon the smaller Met21 screen (for instance where an existing Stevenson screen-based site was to be automated) would therefore be likely to introduce significant inhomogeneities into the climatological record. Any such planned replacements should therefore be carefully planned to allow for at least a 12 month overlap period to identify site- and instrument-specific inhomogeneities, to avoid destroying the continuity and homogeneity of existing records. Where a new site is being considered, it is likely that an aspirated thermometer exposure would provide significantly more accurate and reproducible climatological data and should be the exposure of choice where continuity or comparison with Stevenson screen-based records is not required (and where a suitable power supply is available).

APPENDIX – TRIAL DETAILS

Details of instruments, their calibration and the trial site

1. Location and period of comparison trial

The Campbell Scientific Met21 screen is exposed alongside existing climatological equipment at the Stratfield Mortimer Climatological Observatory in Berkshire (**Figure A1**). Details of the sensors and loggers used for each screen are given below. The site in central southern England (51.4°N, 1.0°W, altitude 60 m AMSL) is rural and well-exposed, particularly between east and west through south: the instruments are located in a fenced enclosure located in a paddock. The observing location is an official Met Office and Environment Agency rainfall site, and is regularly inspected by representatives from both organisations: it is also graded 'A' under the Climatological Observers Link (COL) station grading scheme.

Most of the equipment on site is automated, (cabled) sensors being connected to a Campbell Scientific CR10X datalogger which samples most of the sensors every second, logging data every minute, every 5 minutes and every hour. Daily summary totals, means and extremes are also generated at midnight UTC. All major meteorological parameters are measured, including solar radiation and wind speed/direction at 10 m. The datalogging system and sensors closely resemble the Met Office Climat Data Logger system in use at many Met Office and co-operating authority climatological sites throughout the UK.

Figure A1 *– the trials site in central southern Berkshire, looking south-west. Left to right are four screens - the Davis VP2 is located to the left of the Stevenson screen, the Met21 a similar distance to the right (NW of the screen) while the aspirated screen is mounted on the instrument tower north of the Stevenson screen. This photograph was taken on 30 July 2009, during the evaluation period.*

2. The measurement or air temperatures

2.1 Stevenson screen

Standard measurements of air temperature in the UK and Ireland, and in many other countries around the world, are made in Stevenson screens, white-painted wood or (more recently) white plastic double-louvred shelters which permit relatively free ventilation of the contents whilst protecting the instruments inside from both direct and reflected solar and long-wave radiation and from precipitation (Knowles Middleton 1966, Strangeways 2003).

Although the Stevenson screen has been the standard method of housing air temperature sensors in the UK for 125 years, it is not perfect: shelters of this design are known to overheat slightly in strong sunshine, particularly with light winds (see, for example, Painter 1977, Strangeways 2009). However, it remains the 'national standard' to the present day, and that is why it was used as the comparative benchmark.

For many years liquid-in-glass thermometers located in Stevenson screens have been used to measure both current and maximum and minimum air temperatures, and while these are still in use today (**Figure A2**), the records of air temperature used for comparison with the Met21 were taken from a calibrated Vaisala HMP45C platinum resistance temperature and capactitative humidity probe co-located within the Stevenson screen, sampled every second; maximum and minimum air temperatures are taken as the highest and lowest, respectively, of 30 second running mean air temperatures.

Accurate calibrations (to within 0.1 degC) of the Vaisala platinum resistance thermometer (PRT) were obtained by comparison with a portable calibrated reference source, a Tinytag TH-2500 thermohygrometer (Burt 2008).

Figure A2 *– Conventional Stevenson screen layout, showing maximum and minimum sheathed liquid-in-glass thermometers (mounted horizontally) together with the Vaisala HMP45C temperature and humidity sensor used in this comparison (grey cylinder, left of screen). This photograph was taken on 14 June 2009.*

The maximum and minimum temperatures are taken as the highest and lowest respectively of 30 second running mean air temperatures for two reasons: firstly, to dampen slight electrical noise present in the system (in a cable run of almost 50 m) and secondly to emulate more closely the time constant of a liquid-in-glass thermometer (all other conditions, primarily ventilation, being equal). This does mean that very short-period changes in temperature are damped somewhat. These short-period fluctuations, typical of short bursts of sunshine on a day of broken cloud but also occurring occasionally during short clear spells at night, can result in maxima and minima being slightly under-estimated. In order to provide a comparable response-time to the sensors used in the aspirated and Met 21 screens, the calibrated Tinytag TH2500 logger was also exposed in the Stevenson screen throughout the trial, with sampling interval 2 seconds and logging interval 5 minutes. Both TH2500 and Vaisala maximum and minimum temperatures are quoted – the Vaisala ones being the official 'climatological' value which would typically be reported from a Stevenson screen/sensor combination.

2.2 Campbell Scientific Met21 screen

The CS Met21 screen (*illustrated on front page*) is a passive (i.e. naturally ventilated) radiation screen. It is made of uPVC, white on the outside but with a black or blackened interior. It is composed of 17 stacked circular 'plates'. Its dimensions are 28 cm high (excluding the mounting bracket) by 17 cm diameter, and it is approximately twice the size of the Gill-pattern plastic automatic weather station screen also sold by Campbell Scientific.

The Met21 screen was installed on 3 July 2009. Logged records began immediately; the first complete date of record is 4 July.

Air temperatures were measured using a small Tinytag TGP-4020 logger mated with a fast-response PB-5009 thermistor on a short flying lead [6]. Details and specifications are at http://www.geminidataloggers.com/data-loggers/tinytag-plus-2/tgp-4020. The logger itself was mounted underneath the Met21 screen, so that its small thermal bulk did not affect the screen in any way (and it was also shaded from direct sunshine and rainfall by the screen's mounting bracket). Apart from a few very short periods of record loss during logger changeover, the record is complete for the entire 12 month period.

The thermistor is less than 10 mm long and 3 mm in diameter and has a quoted 10 s response time (in water). The sensor was exposed as close to the middle of the Met21 screen as possible by being affixed to, but not touching, a short metal pole of about 2 mm diameter and then clamped into position using the provided fixing at the base of the screen.

The Tinytag logger is sampled once per minute and spot, minimum and maximum temperatures are logged every 5 minutes. The logger/thermistor combination was calibrated alongside the portable standard reference TH-2500 Tinytag logger in the Stevenson screen by long-period logged data comparisons over several months, usually in cloudy, breezy conditions when temperatures were changing only slowly; the calibration is accurate to within 0.1 degC.

The Tinytag fast-response sensor mated with the Met21 screen certainly provides a fast-response record of air temperatures; perhaps too fast, because the response time is noticeably faster than that of a standard Stevenson screen/sensor combination such as the Vaisala HMP45C unit compared here. It also probably slightly overestimates the daily range in temperature, especially in conditions where the air temperature is changing quickly. For this reason, the records of both the Stevenson screen sensors, the fast-response TH2500 unit and the 'standard' Vaisala HMP45C unit, are compared with the Met21 results in an attempt to shed light on differences that are clearly down to response time rather than genuine variations in air temperature resulting from differences in screen type or construction.

2.3 Aspirated screen

Records of aspirated (i.e. forced ventilation) air temperature were made using the RM Young 43502 Aspirated Radiation Shield (**Figure A3**). This unit employs concentric downward-facing intake tubes and a small canopy shade to isolate the temperature probe from direct and indirect radiation, while a 12 V DC blower motor pulls ambient air into the shield and across the probe to reduce radiation errors. From the manufacturer's specification, this permits air temperature to be measured with an RMS error of less than ±0.2°C at 1000 W/m^2 solar radiation intensity (a value rarely attained for any length of time in southern England). In this installation a Campbell Scientific Type 107 thermistor is used to measure air temperature, and the constant airflow over the sensor is around 10 m/s. As a result of the

[6] Ideally, a Vaisala HMP45C unit identical to the one used in the Stevenson screen would have also been housed in the Met21 screen, but owing both to the high cost of such sensors to a privately-funded observatory and the unavailability of spare channels on the CR10X logger a separate and independent datalogging system was mandated.

forced ventilation, the response time is very fast indeed, while measured air temperatures are probably very close to the true undisturbed air temperature under almost any conditions (for discussion of air temperature measurement methods, including aspirated sensors, see Strangeways 2003, Chapter 3, and Knowles Middleton 1969, Chapter II: for more discussion on the evolution and principles of thermometer screens, see Knowles Middleton 1966, Chapter X).

Figure A3 *– RM Young Type 43502 aspirated radiation shield in use at the trials site. This photograph was taken on 30 July 2009.*

The Type 107 thermistor is sampled once per second and 10 s running means logged every minute using the CR10X logger. Daily maximum and minimum air temperatures are taken as the highest and lowest, respectively, of 30 s running means, for direct comparison with the logged output from the Vaisala sensor in the Stevenson screen. The sensor calibration was checked by comparison of long-period logged outputs against the calibrated TH2500 unit in the Stevenson screen during cloudy, breezy nights over a six month period in 2008; the calibration is accurate within 0.1 degC over the normal range of observed air temperatures. During cloudy, breezy conditions at night it is normal for the Stevenson screen, aspirated and Met21 temperatures to be within < 0.1 degC of each other.

Records from this screen/sensor combination commenced on 27 July 2009, replacing a Gill-pattern screen which had been in use for a little over 3 years.

2.4 Terminal hours used

All 'daily' values quoted here relate to the civil day i.e. 00-00h UTC for ease of tabulation; this also avoids any 'observer proximity' terminal hour effects with the Stevenson screen dataset as can happen with comparisons made using 09-09h UTC data. Throughout, a positive (negative) difference is taken to mean that the screen/sensor combination under comparison was warmer (colder) than the Stevenson screen.

References

Burt, Stephen (2008) Calibration of air temperature sensors. *Climatological Observer's Link Bulletin* No. 460, August 2008, pp 30-32

Knowles Middleton, W E (1966) *A history of the thermometer and its use in meteorology*. Chapter X, The exposure of thermometers. Johns Hopkins Press, Baltimore

Knowles Middleton, W E (1969) *Invention of the meteorological instruments*. Chapter II, The thermometer. Johns Hopkins Press, Baltimore

Painter, H E (1977) *An analysis of the difference between dry-bulb temperatures obtained from an aspirated psychrometer and those from a naturally ventilated large thermometer [Stevenson] screen at Kew Observatory.* Met Office unpublished report, available from the National Meteorological Library, Exeter

Strangeways, Ian (2003) *Measuring the natural environment.* Cambridge University Press. Chapter 3, temperature.

Strangeways, Ian (2009) *Measuring global temperatures.* Cambridge University Press. Chapter 3, Screens, stands and shelters.

TABLE 5A *Monthly means of maximum and minimum temperature, and differences, between various screen types: Berkshire, 2009-10*

Screen comparisons

Summary tables

All values are in °C/degC. Terminal hours 00-00h UTC

CSMet21 records commenced 4 July 2009
Aspirated screen records commenced 27 July 2009
Davis VP2 instrument replaced with another VP2 unit 9 December 2009

MEAN MAXIMUM AIR TEMPERATURE °C

Date/s	Stevenson screen Vaisala	Stevenson screen TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	21.82	22.12	22.24	n/a	21.58
August	22.48	22.72	22.81	22.16	22.31
September	20.05	20.29	20.38	19.74	19.88
October	16.13	16.34	16.28	15.76	15.90
November	11.99	12.22	12.12	11.92	12.00
December	6.10	6.36	6.19	6.05	6.12
2010 January	4.24	4.56	4.36	4.04	4.13
February	6.66	n/a	6.87	6.65	6.46
March	10.87	11.27	11.19	10.90	10.56
April	15.40	15.58	15.79	15.23	15.06
May	17.01	17.17	17.54	16.91	16.62
June	22.79	23.00	23.19	22.42	22.27
July	23.94	24.32	24.52	23.87	23.35
Averages *12 months ending July 2010*	14.80	n/a	15.10	14.64	14.55

DIFF FROM **VAISALA/STEVENSON SCREEN** MEAN *degC*; DIFF FROM **TH2500/STEVENSON SCREEN** MEAN *degC*; DIFFERENCE FROM **ASPIRATED** MEAN *degC*

Date/s	Vaisala/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	TH2500/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	Aspirated: Vaisala	TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	--	+0.30	+0.42	n/a	-0.25	-0.30	--	+0.12	n/a	-0.55					
August	--	+0.25	+0.33	-0.32	-0.17	-0.25	--	+0.09	-0.57	-0.42	+0.32	+0.57	+0.66	--	+0.15
September	--	+0.25	+0.33	-0.30	-0.16	-0.25	--	+0.08	-0.55	-0.41	+0.30	+0.55	+0.63	--	+0.14
October	--	+0.21	+0.15	-0.37	-0.23	-0.21	--	-0.05	-0.57	-0.44	+0.37	+0.57	+0.52	--	+0.13
November	--	+0.24	+0.14	-0.06	+0.01	-0.24	--	-0.10	-0.30	-0.23	+0.06	+0.30	+0.20	--	+0.07
December	--	+0.25	+0.09	-0.05	+0.02	-0.25	--	-0.17	-0.31	-0.24	+0.05	+0.31	+0.14	--	+0.07
2010 January	--	+0.32	+0.12	-0.20	-0.11	-0.32	--	-0.19	-0.52	-0.43	+0.20	+0.52	+0.32	--	+0.09
February	--	n/a	+0.22	-0.01	-0.20	n/a	--	n/a	n/a	n/a	+0.01	n/a	+0.23	--	-0.18
March	--	+0.40	+0.32	+0.03	-0.31	-0.40	--	-0.08	-0.37	-0.71	-0.03	+0.37	+0.30	--	-0.34
April	--	+0.18	+0.39	-0.17	-0.34	-0.18	--	+0.21	-0.35	-0.52	+0.17	+0.35	+0.56	--	-0.17
May	--	+0.16	+0.53	-0.10	-0.40	-0.16	--	+0.37	-0.26	-0.56	+0.10	+0.26	+0.63	--	-0.30
June	--	+0.21	+0.40	-0.37	-0.52	-0.21	--	+0.19	-0.58	-0.73	+0.37	+0.58	+0.77	--	-0.15
July	--	+0.38	+0.58	-0.07	-0.58	-0.38	--	+0.20	-0.45	-0.97	+0.07	+0.45	+0.65	--	-0.52
Averages *12 months ending July 2010*	--	n/a	+0.30	-0.17	-0.25	-0.26		+0.05	-0.44	-0.51	+0.17	n/a	+0.47	--	-0.08

MEAN MINIMUM AIR TEMPERATURE °C

Date/s	Stevenson screen Vaisala	Stevenson screen TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	11.21	11.23	10.92	n/a	11.41
August	11.41	11.46	11.08	11.06	11.58
September	8.83	8.86	8.52	8.54	9.10
October	6.76	6.81	6.51	6.47	7.05
November	5.53	5.78	5.32	5.29	5.82
December	-0.55	-0.28	-0.92	-0.93	-0.30
2010 January	-1.71	-1.53	-2.02	-2.01	-1.61
February	0.33	n/a	0.07	0.10	0.36
March	1.49	1.55	1.25	1.31	1.52
April	2.59	2.54	2.25	2.23	2.61
May	4.44	4.30	4.16	4.20	4.41
June	8.89	8.80	8.56	8.54	8.76
July	12.01	11.97	11.72	11.58	11.85
Averages *12 months ending July 2010*	5.00	n/a	4.71	4.70	5.10

DIFF FROM **VAISALA/STEVENSON SCREEN** MEAN *degC*; DIFF FROM **TH2500/STEVENSON SCREEN** MEAN *degC*; DIFFERENCE FROM **ASPIRATED** MEAN *degC*

Date/s	Vaisala/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	TH2500/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	Aspirated: Vaisala	TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	--	+0.02	-0.29	n/a	+0.20	-0.02	--	-0.31	n/a	+0.18					
August	--	+0.05	-0.33	-0.35	+0.17	-0.05	--	-0.37	-0.40	+0.13	+0.35	+0.40	+0.03	--	+0.53
September	--	+0.04	-0.30	-0.29	+0.28	-0.04	--	-0.34	-0.32	+0.24	+0.29	+0.32	-0.02	--	+0.56
October	--	+0.05	-0.25	-0.29	+0.30	-0.05	--	-0.30	-0.34	+0.24	+0.29	+0.34	+0.04	--	+0.58
November	--	+0.25	-0.22	-0.25	+0.28	-0.25	--	-0.46	-0.49	+0.04	+0.25	+0.49	+0.03	--	+0.53
December	--	+0.28	-0.37	-0.37	+0.25	-0.28	--	-0.64	-0.65	-0.02	+0.37	+0.65	+0.01	--	+0.62
2010 January	--	+0.18	-0.31	-0.30	+0.10	-0.18	--	-0.49	-0.48	-0.08	+0.30	+0.48	-0.01	--	+0.40
February	--	n/a	-0.26	-0.22	+0.04	n/a	--	n/a	n/a	n/a	+0.22	n/a	-0.04	--	+0.26
March	--	+0.06	-0.24	-0.18	+0.02	-0.06	--	-0.30	-0.24	-0.04	+0.18	+0.24	-0.06	--	+0.21
April	--	-0.05	-0.34	-0.36	+0.02	+0.05	--	-0.29	-0.31	+0.07	+0.36	+0.31	+0.02	--	+0.37
May	--	-0.13	-0.28	-0.24	-0.02	+0.13	--	-0.14	-0.10	+0.11	+0.24	+0.10	-0.04	--	+0.21
June	--	-0.08	-0.32	-0.35	-0.13	+0.08	--	-0.24	-0.26	-0.04	+0.35	+0.26	+0.02	--	+0.22
July	--	-0.04	-0.29	-0.43	-0.17	+0.04	--	-0.25	-0.39	-0.13	+0.43	+0.39	+0.14	--	+0.26
Averages *12 months ending July 2010*	--	n/a	-0.29	-0.30	+0.10	-0.05	--	-0.35	-0.36	+0.06	+0.30	n/a	+0.01	--	+0.40

MEAN AIR TEMPERATURE °C *(mean of all 5 min samples, not 1/2 max+ min)*

Date/s	Stevenson screen Vaisala	Stevenson screen TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	15.86	15.87	15.84	n/a	15.89
August	16.77	16.80	16.75	16.54	16.83
September	14.33	14.38	14.30	14.18	14.46
October	11.34	11.41	11.32	11.26	11.48
November	8.86	9.00	8.91	8.89	9.09
December	3.06	3.24	3.05	3.11	3.21
2010 January	1.32	1.54	1.34	1.36	1.38
February	3.41	n/a	3.42	3.45	3.40
March	6.11	6.13	6.11	6.12	6.05
April	9.10	9.06	9.07	9.02	8.98
May	11.08	10.99	11.03	10.92	10.89
June	16.07	16.00	16.00	15.75	15.79
July	17.99	17.97	17.98	17.74	17.64
Averages *12 months ending July 2010*	9.95	n/a	9.94	9.86	9.93

DIFF FROM **VAISALA/STEVENSON SCREEN** MEAN *degC*; DIFF FROM **TH2500/STEVENSON SCREEN** MEAN *degC*; DIFFERENCE FROM **ASPIRATED** MEAN *degC*

Date/s	Vaisala/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	TH2500/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	Aspirated: Vaisala	TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	--	+0.01	-0.02	n/a	+0.03	-0.01	--	-0.03	n/a	+0.02					
August	--	+0.03	-0.02	-0.24	+0.05	-0.03	--	-0.05	-0.27	+0.02	+0.24	+0.27	+0.21	--	+0.29
September	--	+0.06	-0.02	-0.14	+0.14	-0.06	--	-0.08	-0.20	+0.08	+0.14	+0.20	+0.12	--	+0.28
October	--	+0.08	-0.02	-0.07	+0.15	-0.08	--	-0.10	-0.15	+0.07	+0.07	+0.15	+0.05	--	+0.22
November	--	+0.14	+0.05	+0.02	+0.23	-0.14	--	-0.09	-0.11	+0.09	-0.02	+0.11	+0.02	--	+0.20
December	--	+0.18	-0.01	+0.05	+0.15	-0.18	--	-0.18	-0.13	-0.03	-0.05	+0.13	-0.06	--	+0.10
2010 January	--	+0.22	+0.02	+0.04	+0.06	-0.22	--	-0.20	-0.18	-0.16	-0.04	+0.18	-0.02	--	+0.02
February	--	n/a	+0.02	+0.04	-0.01	n/a	--	n/a	n/a	n/a	-0.04	n/a	-0.02	--	-0.05
March	--	+0.02	+0.01	+0.02	-0.06	-0.02	--	-0.01	-0.00	-0.08	-0.02	+0.00	-0.01	--	-0.08
April	--	-0.04	-0.03	-0.08	-0.12	+0.04	--	+0.01	-0.04	-0.08	+0.08	+0.04	+0.05	--	-0.04
May	--	-0.10	-0.05	-0.16	-0.19	+0.10	--	+0.05	-0.07	-0.09	+0.16	+0.07	+0.11	--	-0.03
June	--	-0.07	-0.07	-0.32	-0.28	+0.07	--	-0.00	-0.25	-0.22	+0.32	+0.25	+0.25	--	+0.03
July	--	-0.02	-0.01	-0.25	-0.35	+0.02	--	+0.01	-0.23	-0.33	+0.25	+0.23	+0.24	--	-0.10
Averages *12 months ending July 2010*	--	n/a	-0.01	-0.09	-0.02	-0.05		-0.06	-0.15	-0.07	+0.09	n/a	+0.08	--	+0.07

MEAN DAILY RANGE, degC

Date/s	Stevenson screen Vaisala	Stevenson screen TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	10.61	10.89	11.32	n/a	10.17
August	11.07	11.27	11.73	11.10	10.72
September	11.22	11.43	11.85	11.20	10.78
October	9.37	9.53	9.77	9.29	8.84
November	6.45	6.44	6.81	6.64	6.18
December	6.66	6.64	7.11	6.98	6.43
2010 January	5.95	6.09	6.38	6.05	5.74
February	6.33	n/a	6.81	6.54	6.10
March	9.38	9.72	9.94	9.59	9.04
April	12.81	13.04	13.54	13.00	12.46
May	12.58	12.87	13.39	12.71	12.20
June	13.90	14.20	14.63	13.88	13.51
July	11.92	12.34	12.79	12.29	11.51
Averages *12 months ending July 2010*	9.80	n/a	10.40	9.94	9.46

DIFF FROM **VAISALA/STEVENSON SCREEN** *degC*; DIFF FROM **TH2500/STEVENSON SCREEN** *degC*; DIFFERENCE FROM **ASPIRATED** *degC*

Date/s	Vaisala/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	TH2500/Stevenson: Vaisala	TH2500	Met21	Aspirated	Davis VP2	Aspirated: Vaisala	TH2500	Met21	Aspirated	Davis VP2
2009 July *(4-31st only)*	--	+0.28	+0.71	n/a	-0.45	-0.28	--	+0.43	n/a	-0.72					
August	--	+0.20	+0.66	+0.03	-0.35	-0.20	--	+0.46	-0.17	-0.55	-0.03	+0.17	+0.63	--	-0.38
September	--	+0.21	+0.63	-0.01	-0.44	-0.21	--	+0.42	-0.23	-0.66	+0.01	+0.23	+0.65	--	-0.43
October	--	+0.15	+0.40	-0.08	-0.53	-0.15	--	+0.25	-0.23	-0.68	+0.08	+0.23	+0.48	--	-0.45
November	--	-0.01	+0.35	+0.18	-0.27	+0.01	--	+0.36	+0.20	-0.26	-0.18	-0.20	+0.17	--	-0.46
December	--	-0.02	+0.45	+0.32	-0.23	+0.02	--	+0.47	+0.34	-0.21	-0.32	-0.34	+0.13	--	-0.55
2010 January	--	+0.14	+0.43	+0.10	-0.21	-0.14	--	+0.29	-0.04	-0.35	-0.10	+0.04	+0.33	--	-0.31
February	--	n/a	+0.47	+0.21	-0.24	n/a	--	n/a	n/a	n/a	-0.21	n/a	+0.27	--	-0.44
March	--	+0.34	+0.57	+0.21	-0.33	-0.34	--	+0.23	-0.13	-0.67	-0.21	+0.13	+0.36	--	-0.55
April	--	+0.23	+0.73	+0.19	-0.35	-0.23	--	+0.50	-0.04	-0.59	-0.19	+0.04	+0.54	--	-0.55
May	--	+0.29	+0.81	+0.14	-0.37	-0.29	--	+0.52	-0.16	-0.67	-0.14	+0.16	+0.67	--	-0.51
June	--	+0.30	+0.73	-0.02	-0.39	-0.30	--	+0.43	-0.32	-0.69	+0.02	+0.32	+0.75	--	-0.37
July	--	+0.42	+0.87	+0.36	-0.42	-0.42	--	+0.45	-0.06	-0.84	-0.36	+0.06	+0.51	--	-0.78
Averages *12 months ending July 2010*	--	n/a	+0.59	+0.14	-0.35	-0.21		+0.40	-0.08	-0.56	-0.14	n/a	+0.46	--	-0.48

Figure 1 Air temperatures from the three screens on 2 March 2010, a day of almost unbroken sunshine following a heavy frost, with increasing wind speeds afternoon and evg. The largest differences between the Met21 screen and the Stevenson screen and aspirated sensors during the 12 month trial period occurred on the morning of this date.

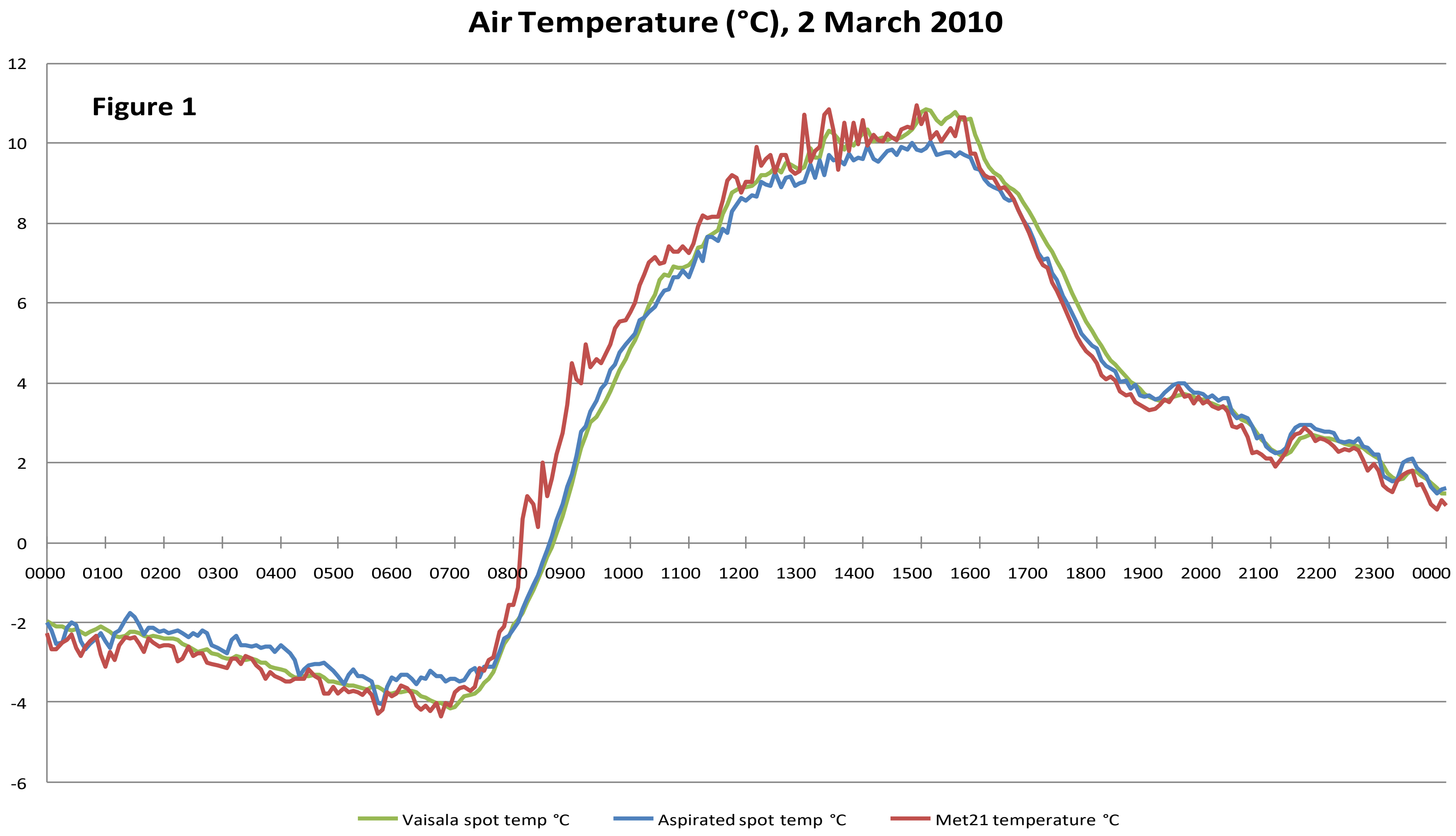

Figure 2 Air temperatures from the three screens on 21 September 2009. A short-lived clear spell during the early evening gave the largest negative differences between the Met21 screen and the Stevenson screen during the 12 month trial period, viz. 1.8 degC at 1900 UTC

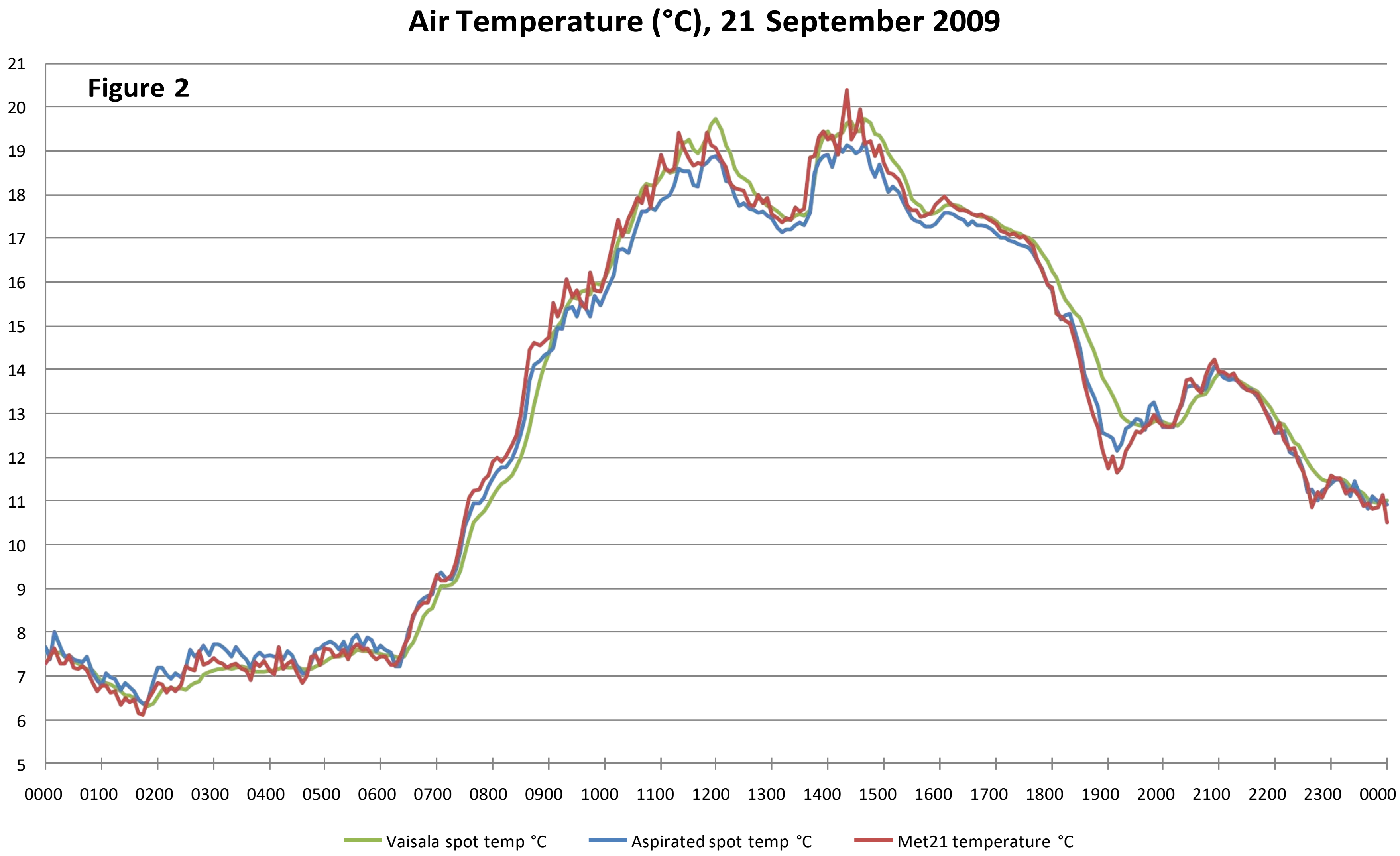

Figure 3 Air temperatures from the three screens on 1 April 2010. Heavy rain and hail showers during the afternoon caused brief rapid falls in air temperature, leading to the greatest negative difference between the Met21 screen and the aspirated sensor during the 12 month trial period, viz. briefly 1.3 degC at 1500 UTC

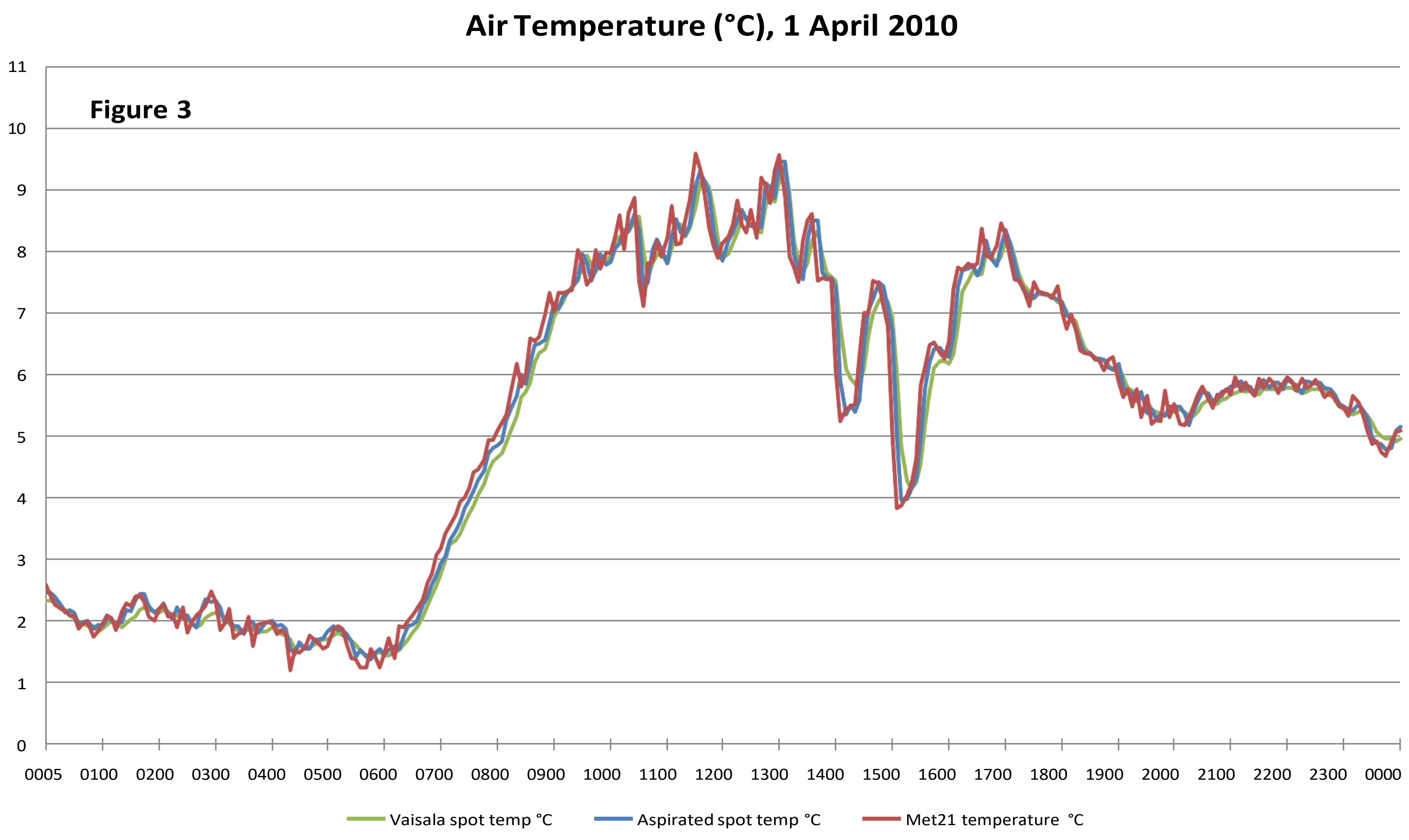

Figure 4 Annual mean temperature differences from aspirated temperature (average of all months) of the Met21 screen (red circles) and the Stevenson screen (blue squares) for increasing levels of near-noon solar radiation (1000-1300 UTC), averaged for all class members. Units are W/m^2 for global solar radiation (x axis) and degC for temperature differences (y axis). The red and blue lines are least-squares trendlines for the Met21 and Stevenson screen data, respectively. See note in text re small sample sizes at the extremities of the distribution.

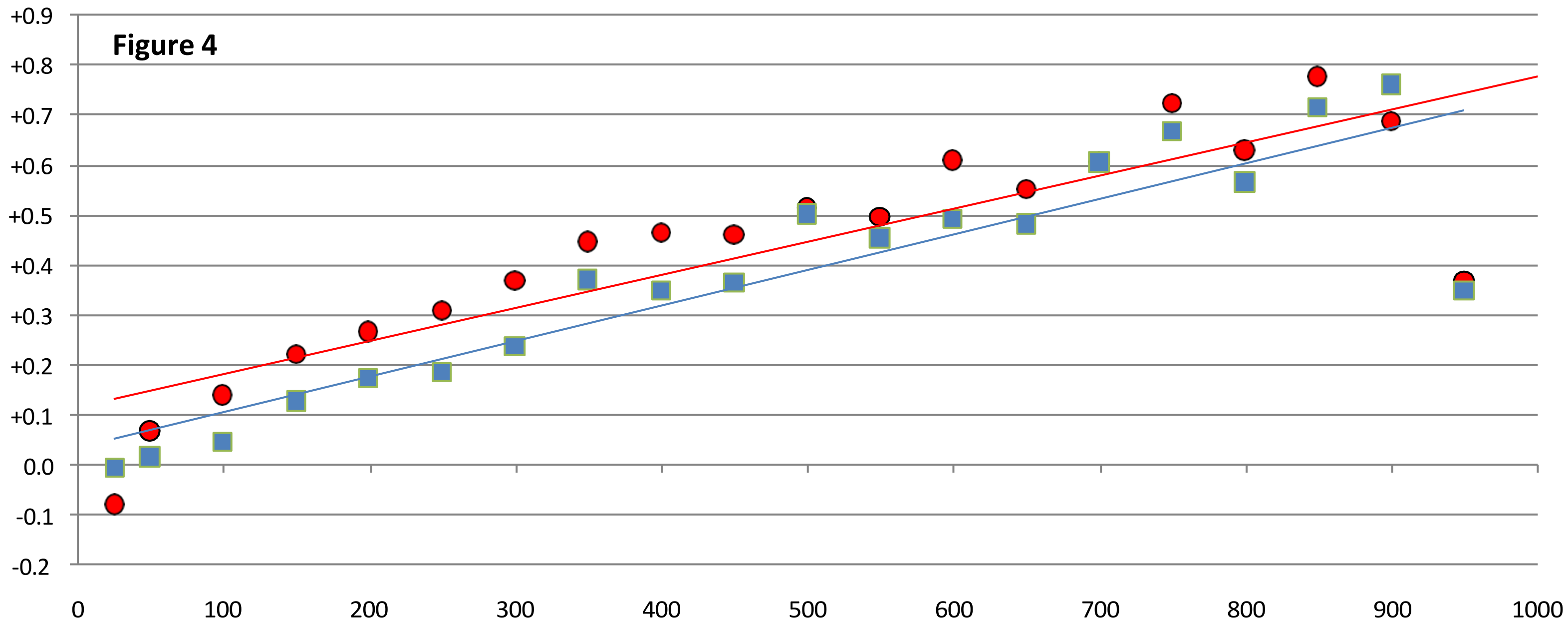

Figure 5: Scatterplot of monthly mean difference in Met21 maximum temperature compared with the Stevenson screen versus monthly mean global solar radiation on a horizontal surface, with derived least-squares linear trendline: at the trials site in Berkshire, for the 12 months ended July 2010

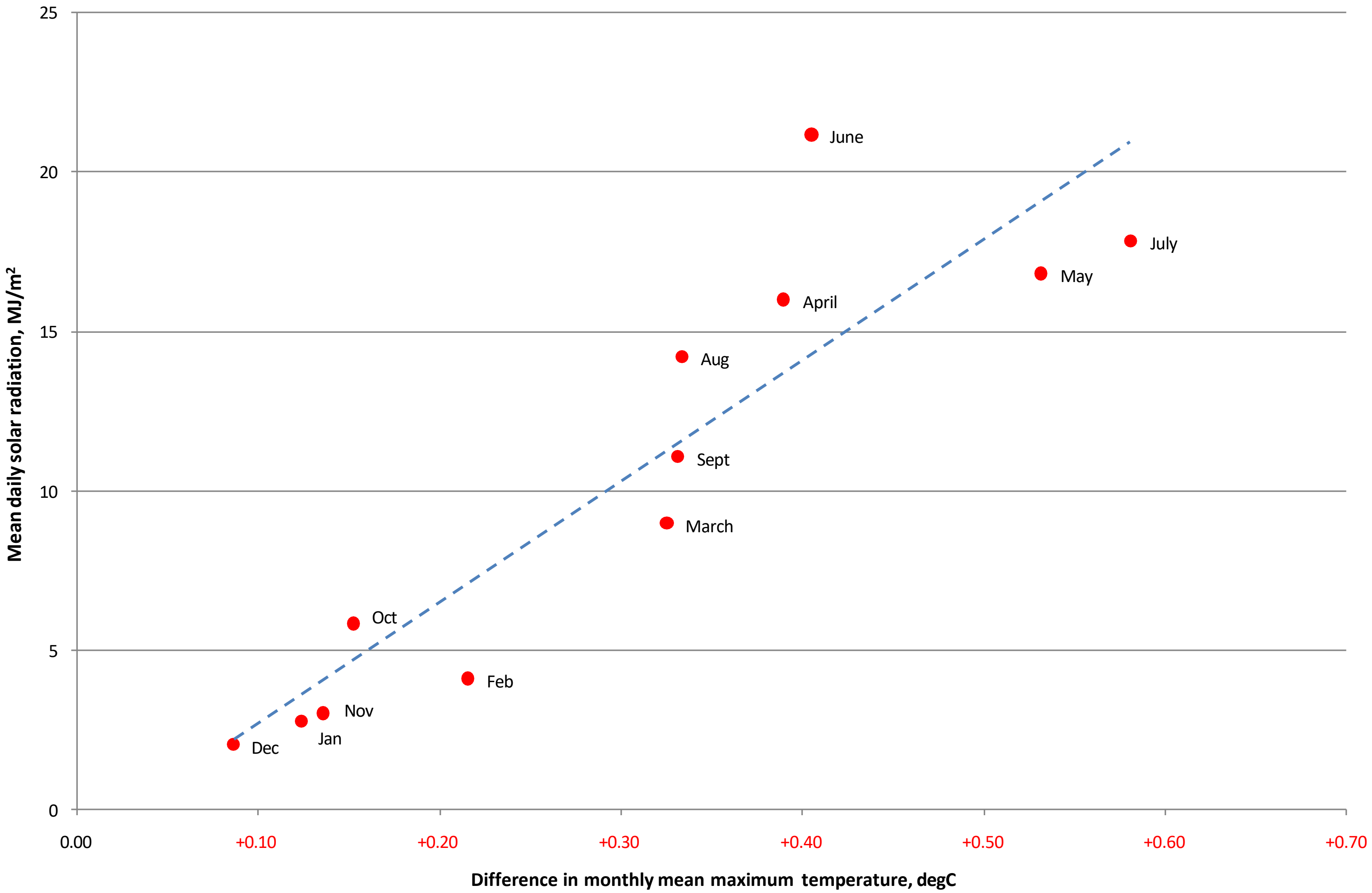

Figure 6A: Air temperature measurements (5 min spot values), 19 August 2009. See text for descriptive analysis.

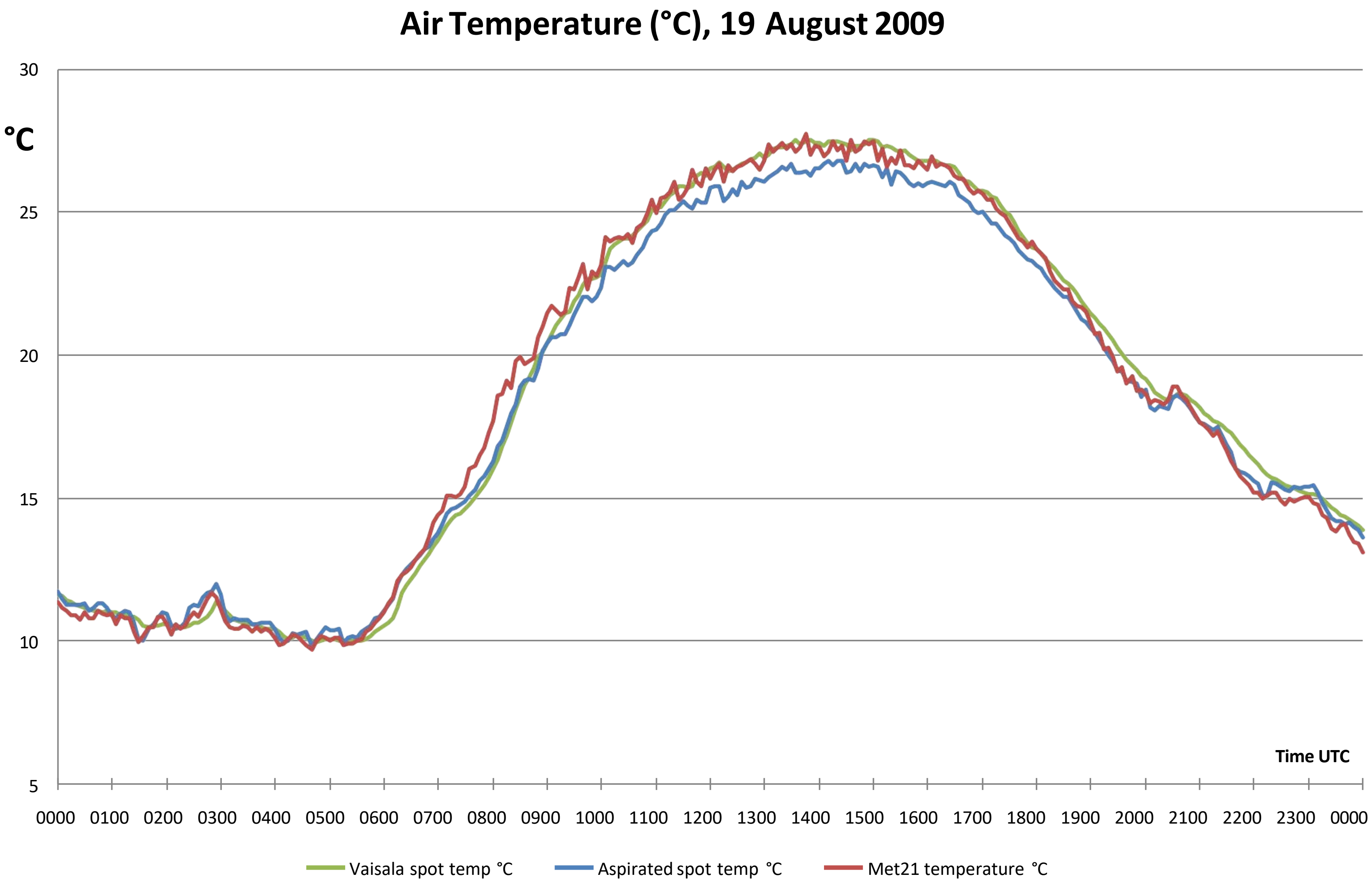

Figure 6B: Solar radiation levels (5 min averages), 19 August 2009

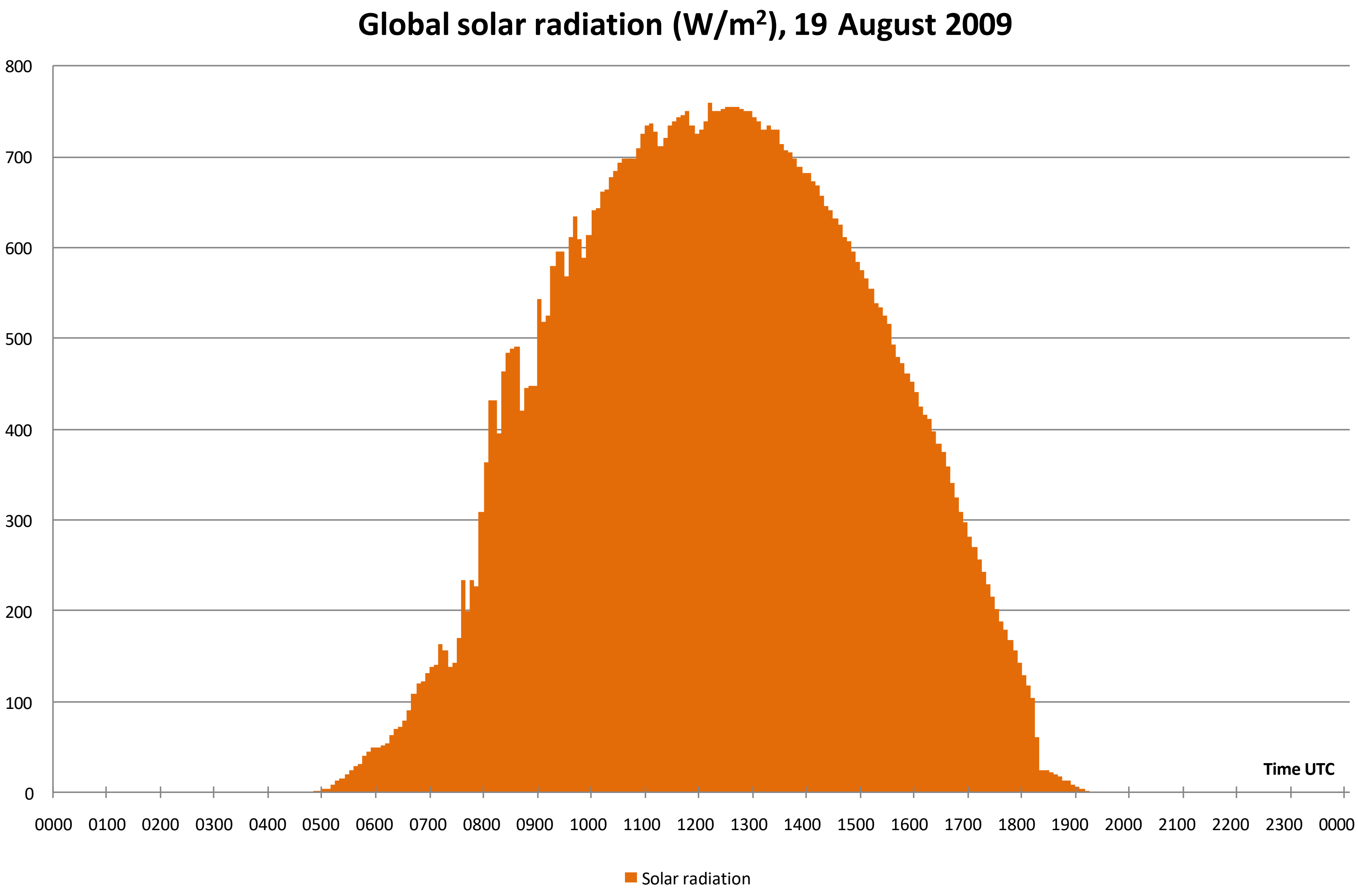

Figure 7A: Air temperature measurements (5 min spot values), 13 October 2009. See text for descriptive analysis.

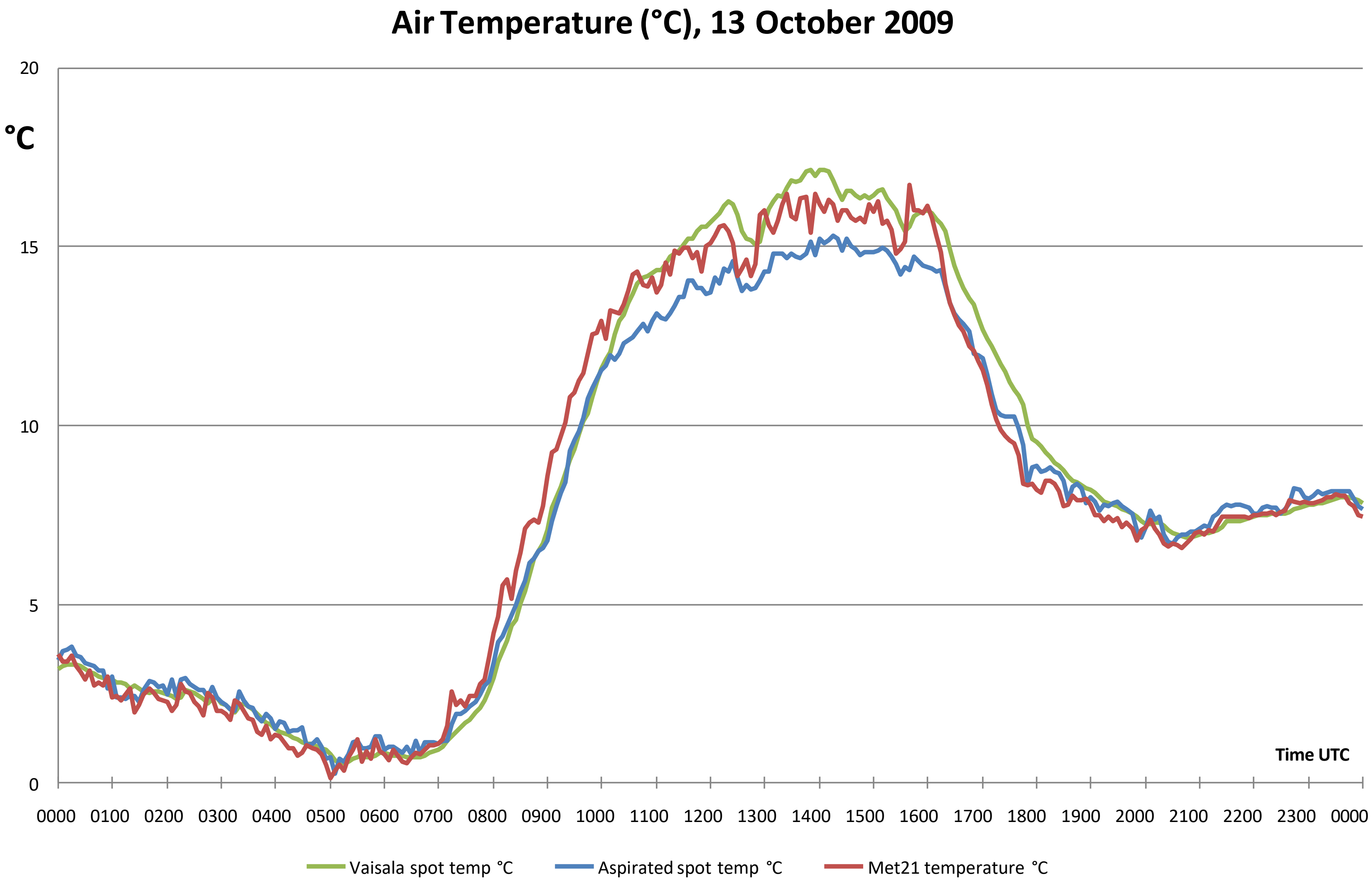

Figure 7B: Solar radiation levels (5 min averages), 13 October 2009

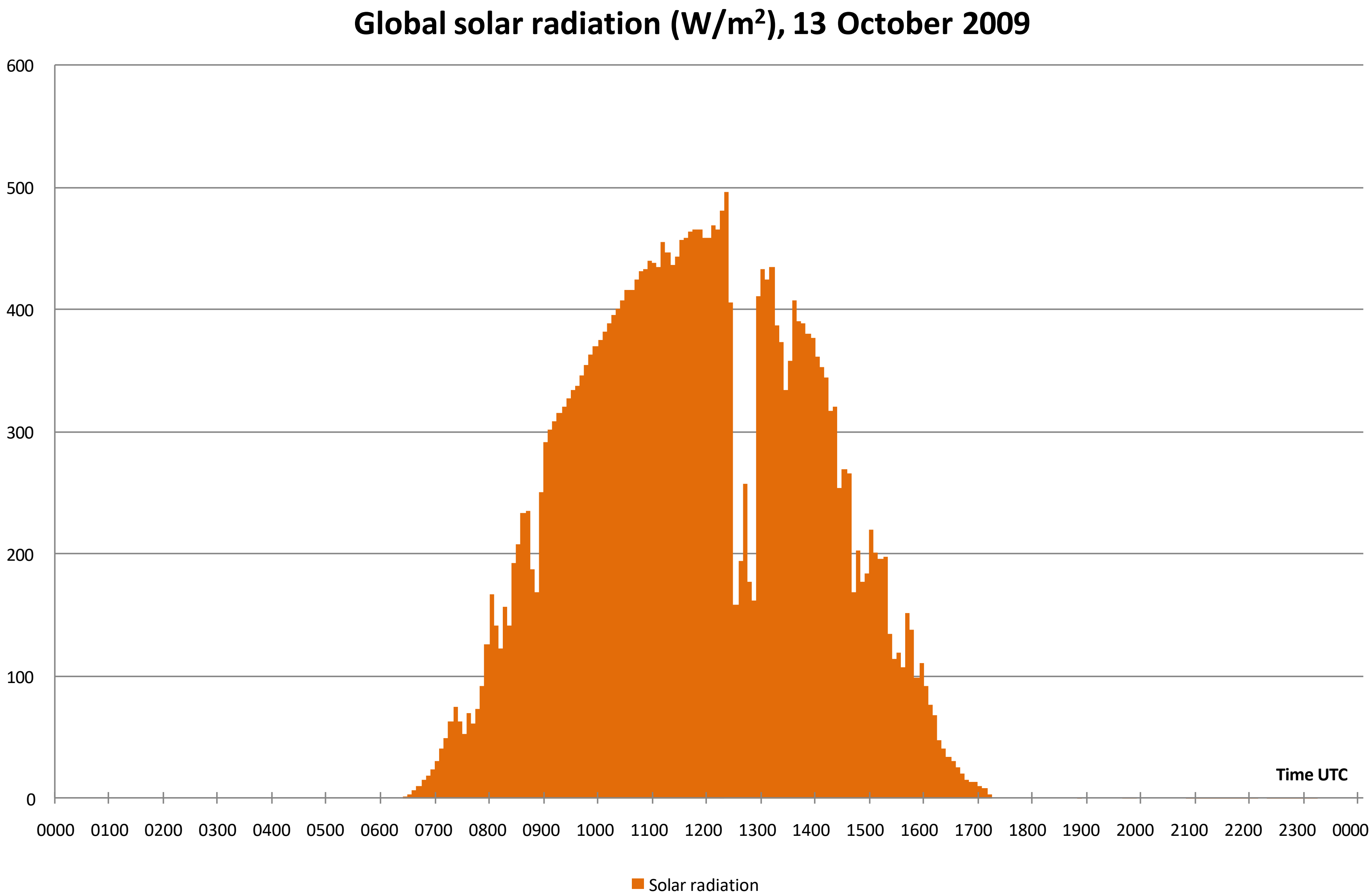

Figure 8A: Air temperature measurements (5 min spot values), 7 January 2010. See text for descriptive analysis.

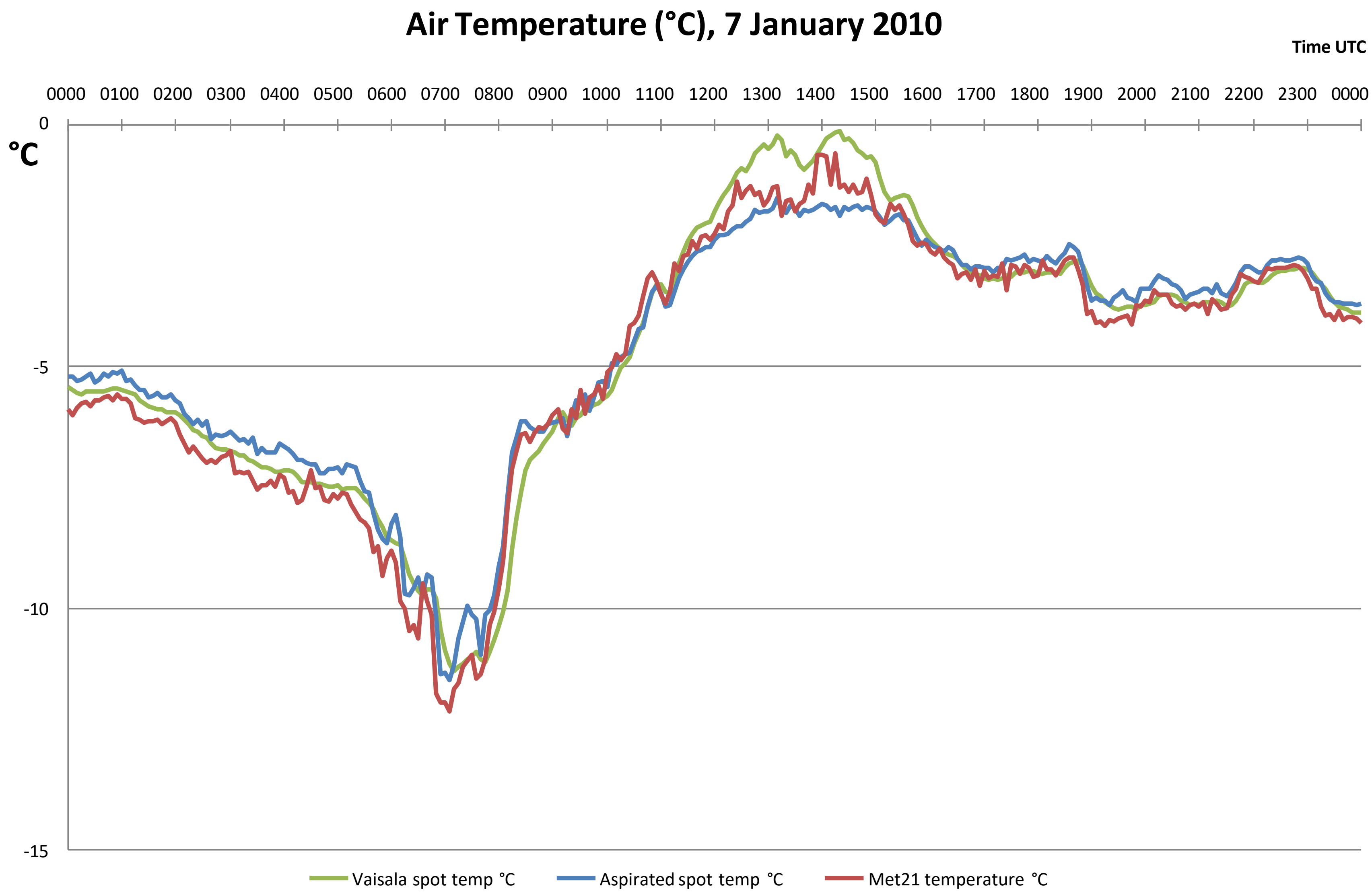

Figure 8B: Solar radiation levels (5 min averages), 7 January 2010

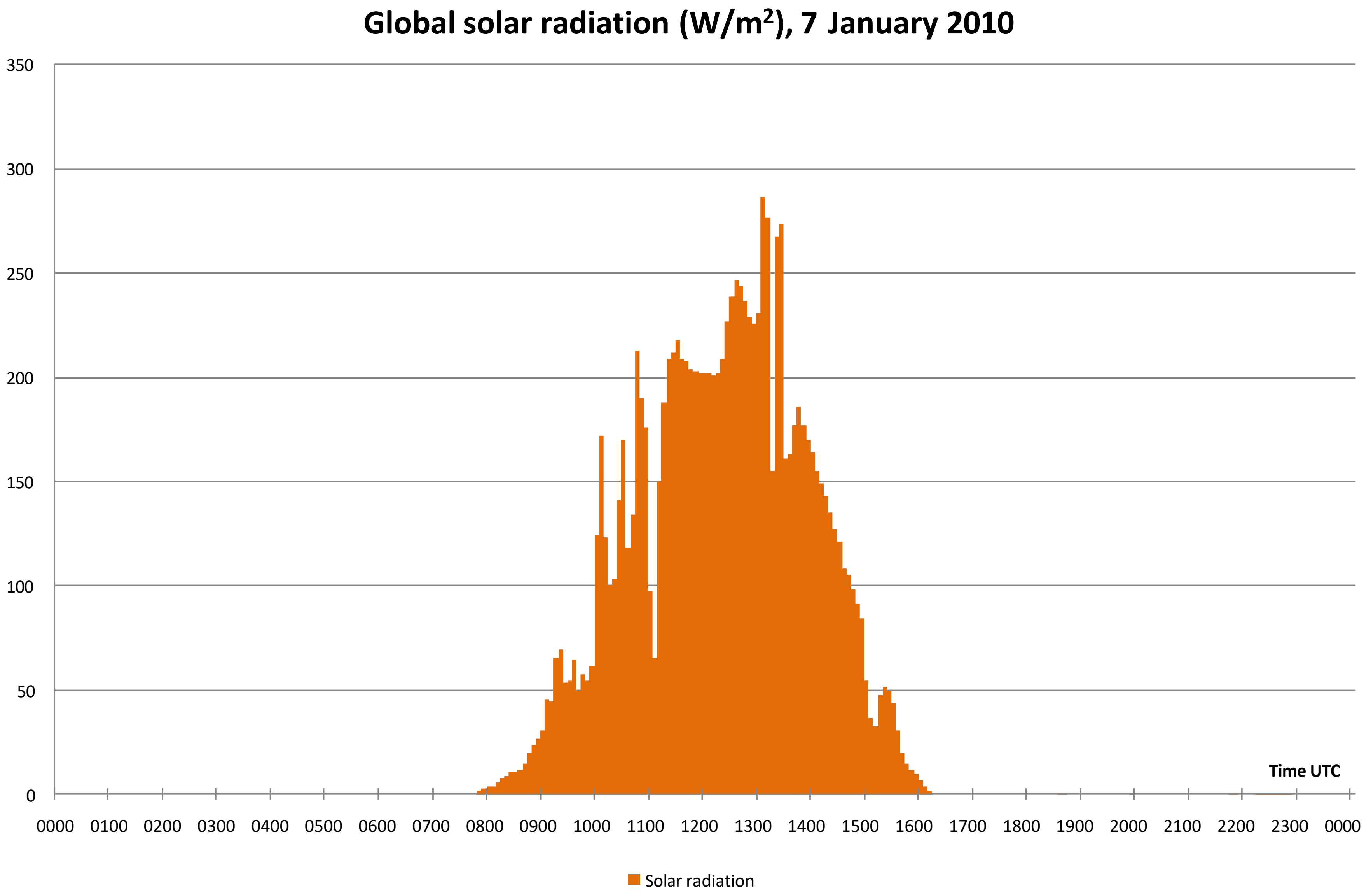

Figure 9A: Air temperature measurements (5 min spot values), 20 May 2010. See text for descriptive analysis.

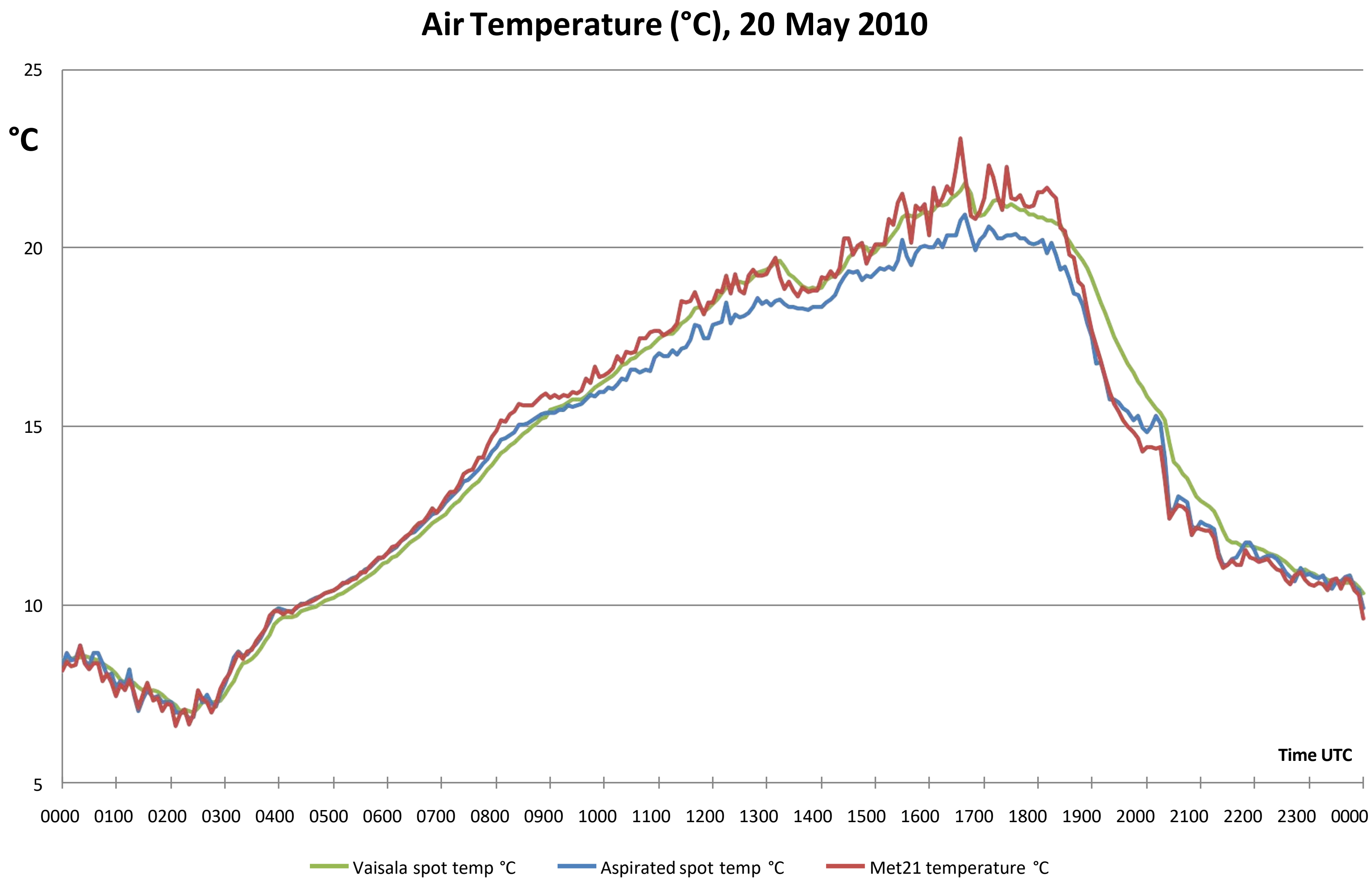

Figure 9B: Solar radiation levels (5 min averages), 20 May 2010