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A Preliminary Investigation of Temperature Screen Design and Their Impacts on Temperature Measurements

Jane Warne
Physics Laboratory, OEB
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Authorisation

Jane Warne
Senior Physicist
Physics Laboratory

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A PRELIMINARY INVESTIGATION OF TEMPERATURE SCREEN DESIGN AND THEIR IMPACTS ON TEMPERATURE MEASUREMENTS

By Jane Warne
Bureau of Meteorology
Australia

INTRODUCTION

Current day concerns about enhanced greenhouse warming and the impact of changes in climate, has given rise to question about the accuracy of data used to identify to the expected rises in temperature. Measurements of temperature to the uncertainty required for identifying enhanced greenhouse warming is by no means simple. Aside from effects such as urbanization, the uncertainty of temperature measurements is effected by a variety of factors. These include the accuracy of the temperature sensor, the time constant of the sensor, the enclosure used to house the sensor, suitability of the sensor to the screen (Richardson and Brock 1995) and the representativeness of the site.

To measure atmospheric temperature accurately the temperature sensor must be shielded from both direct and indirect sources of radiation. To achieve this there have been many different designs of temperature screen manufactured over the past century. Designs have varied from small buildings through multi-louvered boxes to aspirated shields that draw the air over the sensing element. Most countries have for the past fifty years used a wooden screen approximately 70cm wide, 50cm deep and 70cm high with double louvered sides, a double skin top and three overlapping plates to form the base. This design is called a Stevenson Screen.

This design of screen has remained basically unchanged since the turn of the century and has provided a continuous reference in the Australian network since 1908 when it replaced the Glashier screen at most sites. It has been recognised since the early part of the century (Koppen 1913) that the Stevenson screen impacts significantly on the temperature measured. Its large thermal mass results in a large thermal lag and as a consequence underestimates the maximum and minimum temperature. Despite this it remains a useful screen. Changes to other screens have been resisted in the Australian network because of the unknown impact on the climate record.

In recent years the cost of Stevenson Screens and issues related the maintenance of them in remote locations has cause the Bureau of Meteorology to look more closely at alternate designs. However, recent screen comparison studies have predominantly been carried out in cooler climates. These studies have concentrated on the effects of reflected radiation from snow and thermal lag (Andersson 1991), (Lango, K. 1947). It is difficult to extrapolate these studies to warmer climates such as in Australia.

EXPERIMENTAL

To improve our understanding of the influence of temperature screens on temperature measurements a comparison of ten different screens was establish at the Bureau of Meteorology's field test site at Broadmeadows. The study has run continuously since December 1994. Each screen is equipped with a platinum resistance thermometer with an uncertainty of less than 0.06°C and a time constant of 18s. An Instrulab 4212 is used to measure the resistance of each temperature sensor every 12s. The average and sample standard deviation for each minute are calculated and stored. In addition to this the wind speed, wind direction, pressure and rainfall from a nearby automatic weather station and the global irradiance from a pyranometer are logged.

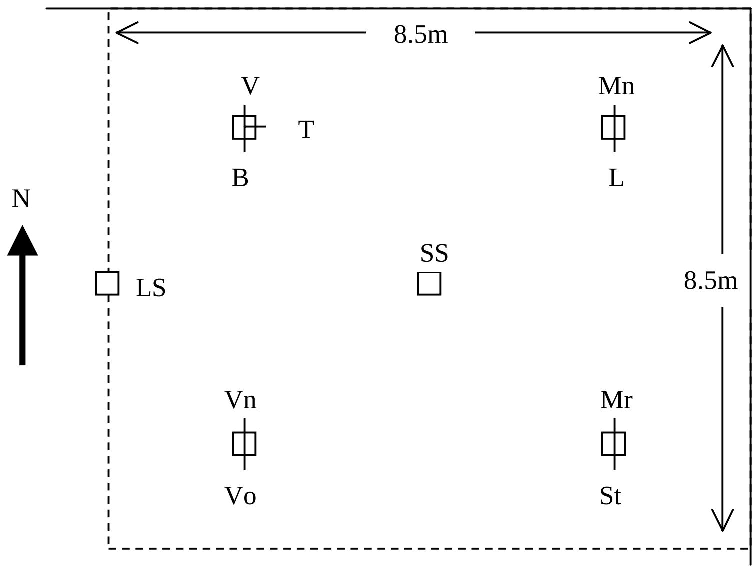
The study includes both aspirated and non-aspirated thermometer screens. Initially it consisted of a small Stevenson Screen, five beehive type screens and three aspirated screens. All except one of the aspirated screens were commercially available. Table 1 shows the types of screens used and their basic construction. In October 1995 a large Stevenson screen was added to the comparison and in December 1995 the Monitor, Steedman and Lambrecht screens were removed. They were replaced with three sensors at different locations in the small Stevenson screen. The lay out of the screens is shown in Figure 1 and the positions of the sensors in the small Stevenson screen is shown in Figure 2.

Two Vaisala screens were used in the study; one that was new and another that had been in use in the field for two years. The Steedman screen is similar to the Lambrecht in design except it is constructed of plastic and is smaller in diameter; 12cm compared to 16cm. The BMRC screen was designed and built in the Bureau of Meteorology Research Centre for use in the tropics. It has a double skin and two shades one just below the fan and a smaller one 20cm lower just above the intake. The intake has an inverted cone to minimise collection of water. (Keenan 1998).

Table 1 Description of the screens used in this study. The columns in order from left to right are the manufacturer or design of screen, the type of screen, size, the effective internal height of the screen, the diameter, number of louvers or plates, the approximate volume to surface area ratio for the screen, the colour and the material it is manufactured from.

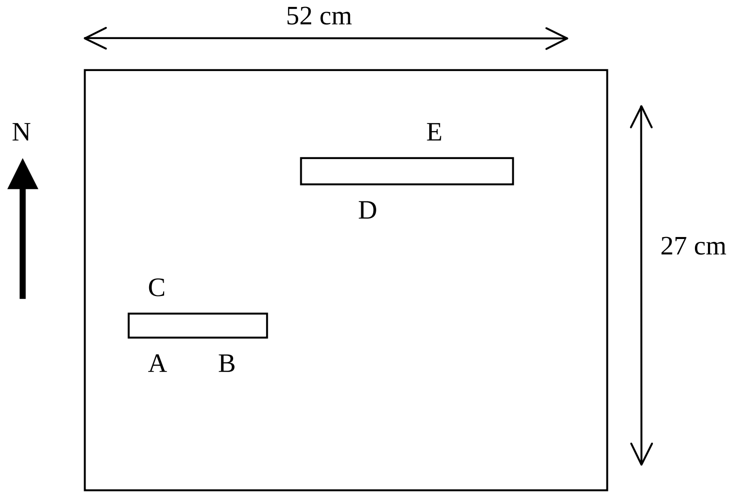
Screen	Type	Size	Effect. Height (cm)	Dia-meter (cm)	No. of Plates	Volume /Area (m)	Color	Material
Stevenson	Louvered	Medium	43	52*27	12	0.058	White	Wood
Stevenson	Louvered	Large	71	71*53	20	0.046	White	Wood
Vaisala	Beehive	Medium	26	19	12	0.038	White	Fibre Glass
Merlin	Beehive	Large	36	24	15	0.047	White	Fibre Glass
Monitor	Beehive	Large	30	26	8	0.052	White / Black	Metal
Steedman	Beehive	Small	27	12	19	0.020	White	Plastic
Lambrecht	Beehive	Small	30	16	7	0.052	Grey / Black	Metal
Teledyne	Aspirated						White	Metal/Plastic
Vector	Aspirated						White	Metal/Plastic
BMRC	Aspirated						White	Metal/Plastic

Figure 1 Layout of screens in the enclosure at Broadmeadows



SS	Small Stevenson
LS	Large Stevenson
V	Vector
T	Teledyne
B	BMRC
Mn	Monitor
L	Lambrecht
Mr	Merlin
St	Steedman
Vn	Vaisala New
Vo	Vaisala Old

Figure 2 Position of sensors in the small Stevenson screen. Note the sensor in position A is used as the reference throughout this study



RESULTS AND DISCUSSION

The Bureau of Meteorology commonly uses the average of the maximum and minimum temperatures as an estimate of the average temperature. This estimate of average temperature has been used to determine the difference in performance of the screens studied. Table 2 and Figure 3 show the difference between the average temperature as measured in the small Stevenson screen (or reference screen) and the other screens. Data collected for the period December 1994 to November 1996 was used to create the plot. From this graph it is clear that the larger fibre glass beehive screens (Vaisala and Merlin) and two of the aspirated screens (Teledyne and Vector) do not differ greatly from the reference screen. However the small beehive screens (Lambrecht and Steedman) and the larger metal beehive screen (Monitor) produced average temperatures 0.07 to 0.19°C warmer than the reference screen. The BMRC screen results in temperatures 0.08°C cooler on average.

Further investigation of the difference in the monthly average temperatures showed distinct annual cycles for all of the screens except the Teledyne and the large Stevenson screen (See Figure 4, 5, 6 and 7). The uncertainty for the monthly averages shown in the figures is less than 0.1°C for all the non-aspirated screens, 0.15°C for the Vector and BMRC screens and between 0.1 and 0.45°C for the Teledyne. Typically the cycle is a refection of the difference in the maximum temperatures. There was little or no cycle in the minimum temperatures. Typically the cycle resulted in the greatest difference between to the small Stevenson screen in the summer and the least in the winter.

Beehive Screens

Of the beehive screens the Vaisala and Merlin screens behaved the most like the reference (see Figure 4). This is due to their relatively high volume to surface area ratio (Table 1) and low thermal conductivity. The Monitor screen's high thermal conductivity results in the screen heating up quicker and therefore generating warmer maximums as the air flows over the plates. A similar problem in the Lambrecht screen is compounded by its colour; the gray metal results in greater heating of the screens surface and an additional 0.25°C of warming in the maximums throughout the year (see Figure 5).

Louvered Screens

The differences between the small and large Stevenson screen were very small and there was no seasonality to them, (Figure 6). Typically the large screen was within ±0.06°C of the small screen for the average temperatures and less than ±0.1°C for the maximums and minimums. On average the large screen was 0.006°C cooler than the reference. (See Table 2) This is of the same order as the variation within the small Stevenson screen. The two sensors facing the north, (C) and (E) in Figure 1, were slightly warmer than the reference and the other (D) was the same.

Table 2 The difference in the average temperature as estimated from the average monthly maximum and minimum temperatures compared to a small Stevenson screen with the sensing element in position A in the screen.

	Average Max Diff (°C)	Average Min Diff (°C)	Average Ave Diff (°C)	U_{95} Ave (°C)	Skew	# of Months	Range of Ave. (°C)
Aspirated							
Teledyne	-0.250	0.236	-0.007	0.028	-1.011	24	-0.316
Vector	-0.095	0.098	0.002	0.039	-0.300	24	-0.407
BMRC	-0.052	0.204	0.076	0.041	-0.672	24	-0.372
Beehive							
Monitor	-0.209	0.068	-0.070	0.029	-1.237	13	-0.180
Lambrecht	-0.537	0.150	-0.194	0.034	-0.179	13	-0.173
Vaisala New	-0.081	0.064	-0.009	0.018	-0.196	24	-0.185
Vaisala Old	-0.083	0.066	-0.009	0.017	-0.777	24	-0.177
Merlin	-0.020	0.041	0.011	0.020	-0.135	24	-0.188
Steedman	-0.295	0.042	-0.127	0.043	-1.343	13	-0.254
Louvered							
Large Stev's	0.094	-0.082	0.006	0.015	-0.632	14	-0.105
Small Stev's C	-0.015	-0.003	-0.009	0.009	-1.983	11	-0.048
Small Stev's D	0.018	-0.016	0.001	0.014	-0.469	11	-0.075
Small Stev's E	-0.014	0.002	-0.006	0.018	-0.520	11	-0.091
Small Stev's B (Ord)	0.101	-0.054	0.024	0.017	2.246	24	-0.194
Small Stev's A							

Figure 3 The average difference between the temperature in the small Stevenson screen at position A and all other measurements of temperature. (See Table 2)

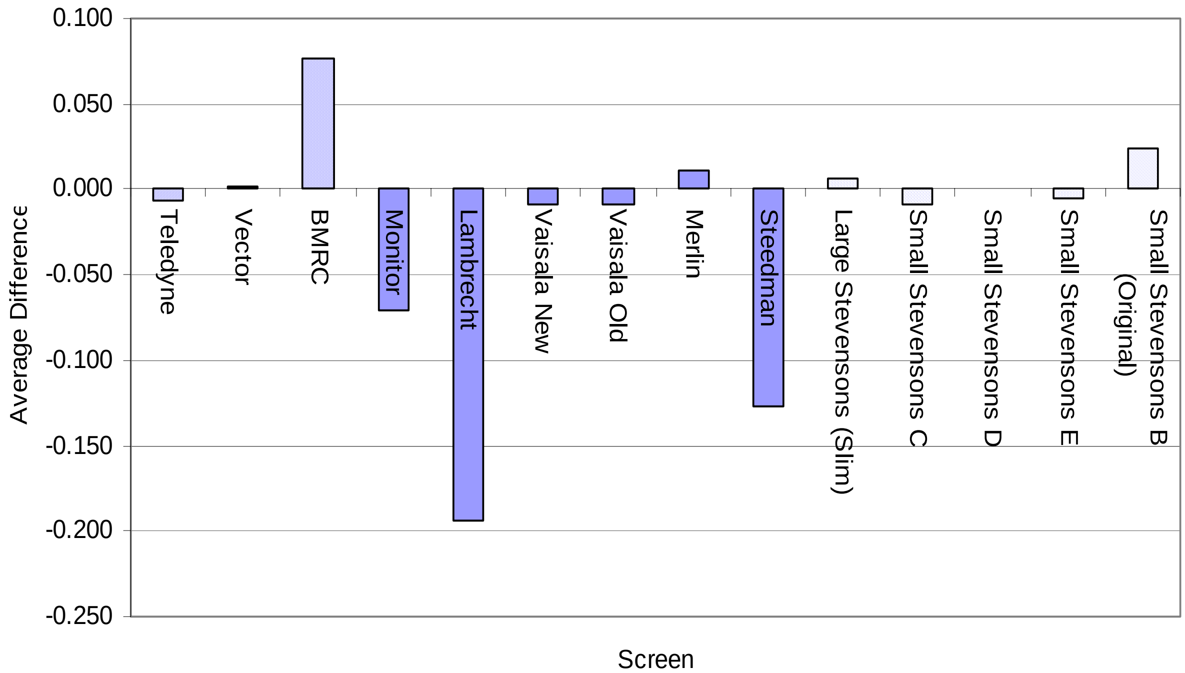


Figure 4 The difference in the monthly average temperatures for the beehive screens

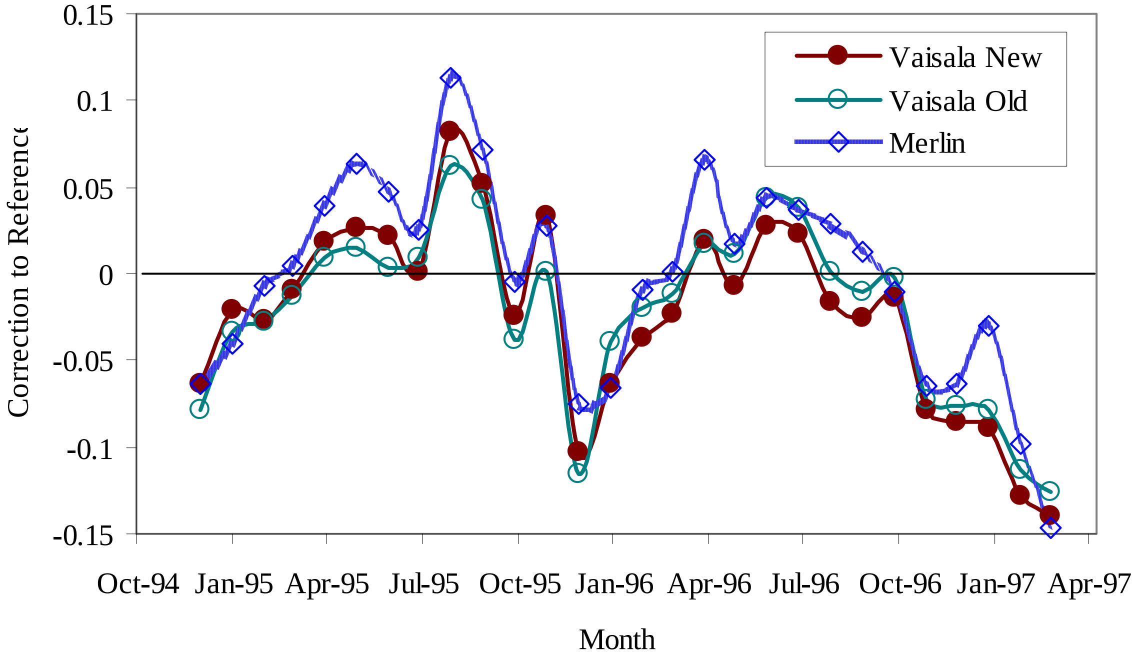


Figure 5 The difference in the monthly average temperatures for the beehive screens

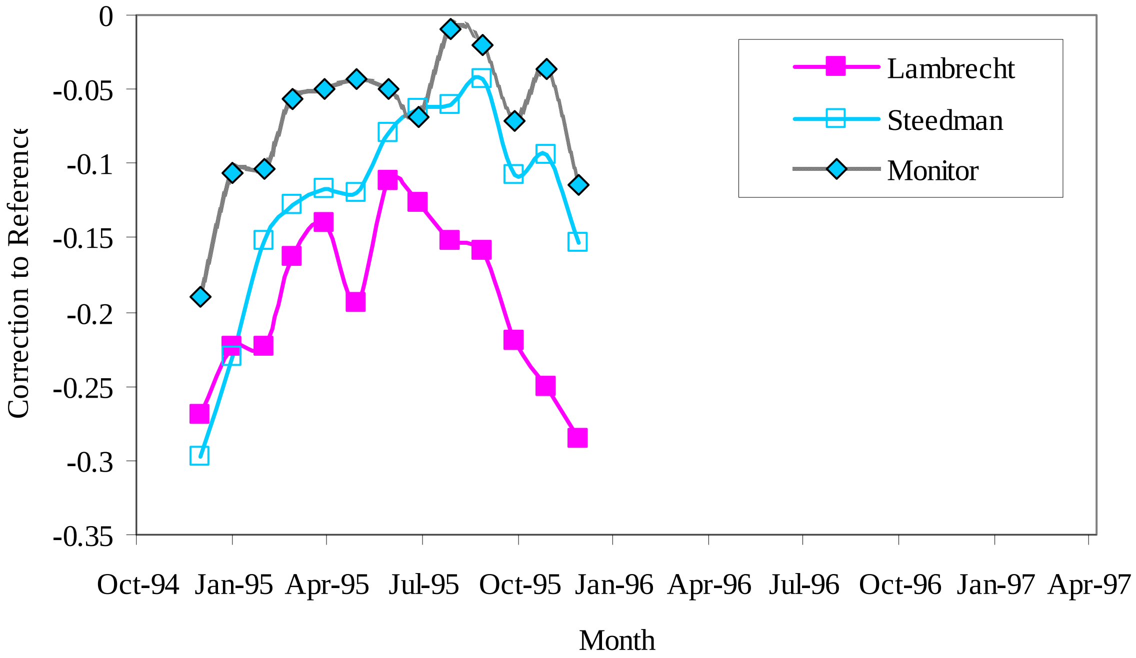


Figure 6 The difference in the monthly average temperatures for the louvered screens.

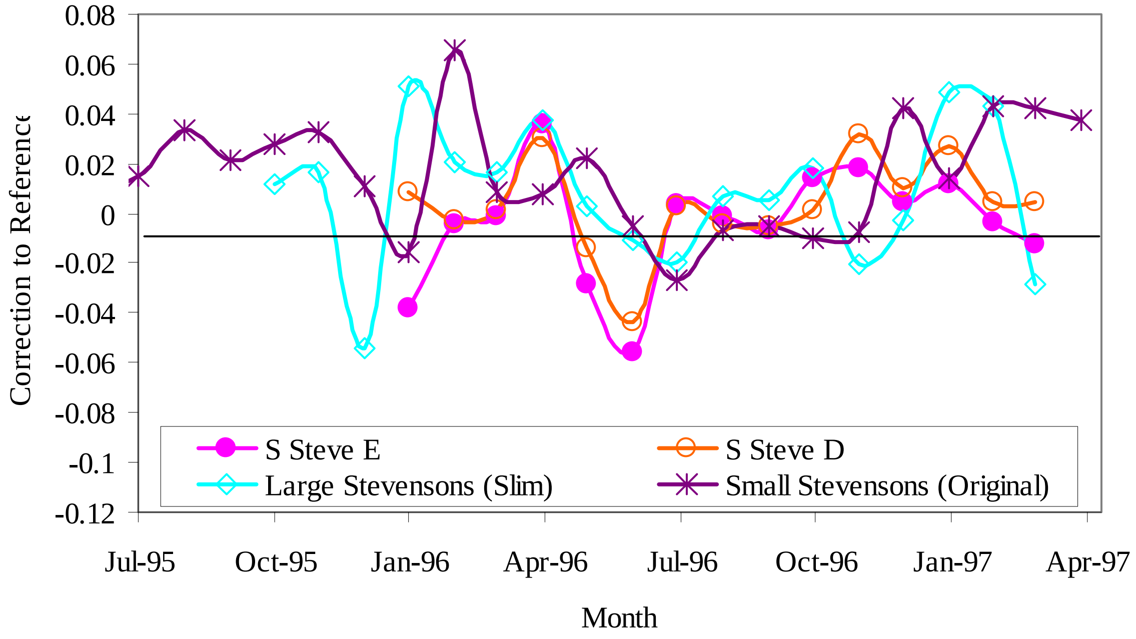
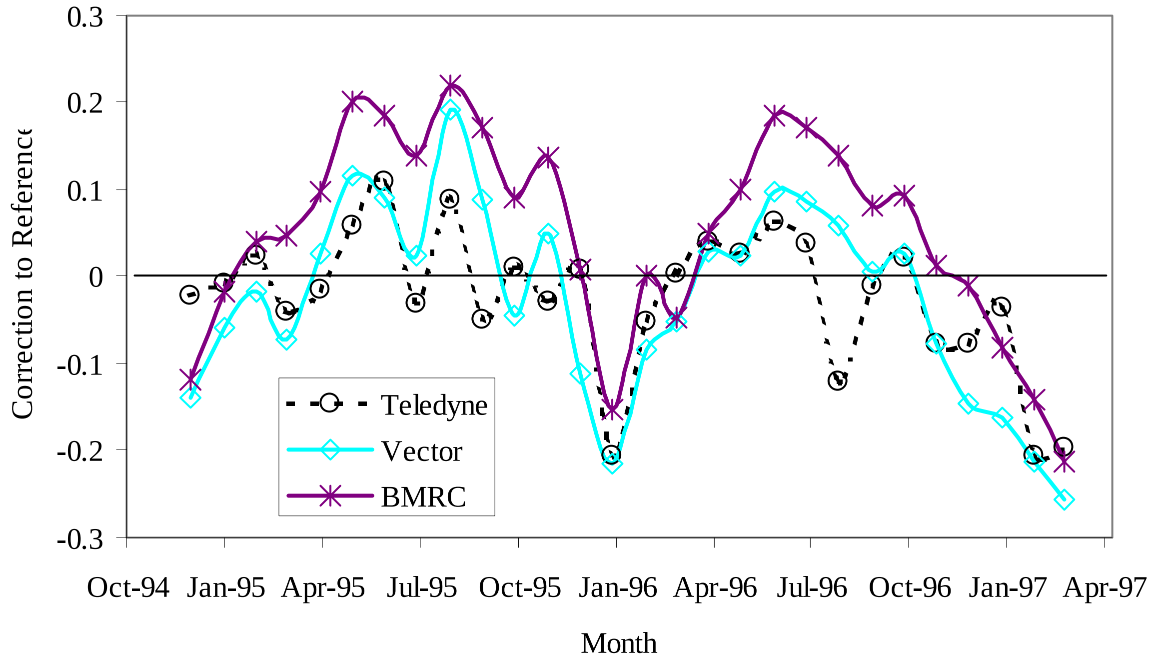


Figure 7 The difference in the monthly average temperatures for the aspirated screens.



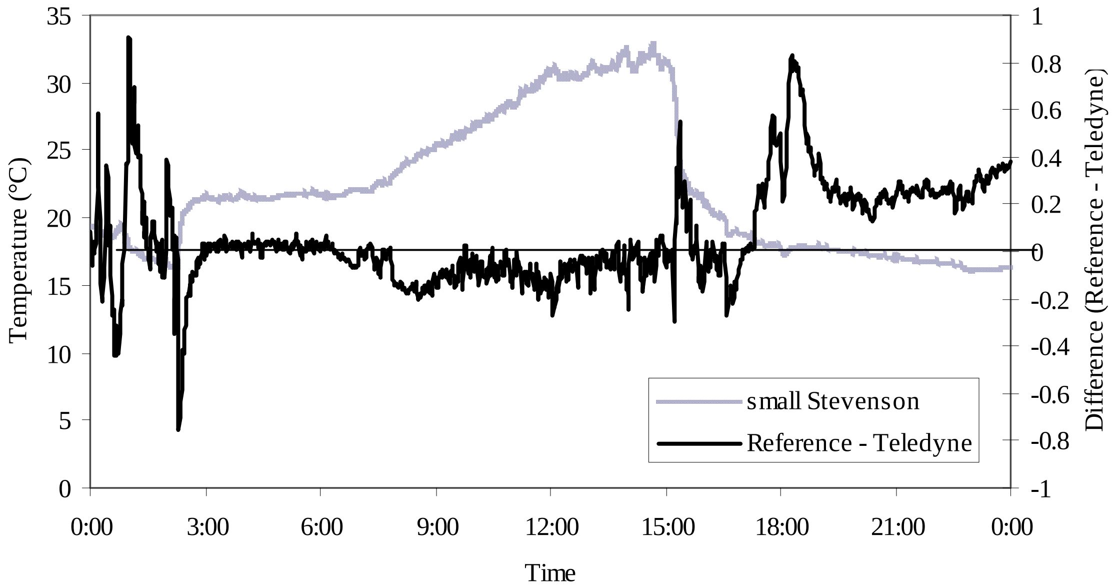
Sensor (B) was of a different and older design to the other sensor used sensor used in this study. The new sensors have a response constant of 18s while the older ones had a response time 80s. The consequence is that the old sensor measures maximum temperatures 0.1°C cooler and minimum temperatures 0.05°C warmer than the new sensor. The overall average temperature is therefore 0.024°C cooler (see Figure 6). This is 2 to 3 times the variability of temperature within the screen or between the small and large Stevenson screens.

Aspirated Screens

The monthly data for the aspirated screens shows some of the greatest differences to the reference screen, (see Figure 7). The range of the monthly differences for these screens is approximately twice that of the beehive screens and three to four times the range of the large Stevensons screen (see Table 2). The Vector and BMRC screens displayed the same seasonal cycle in the differences as seen in the beehive screens however the Teledyne did not.

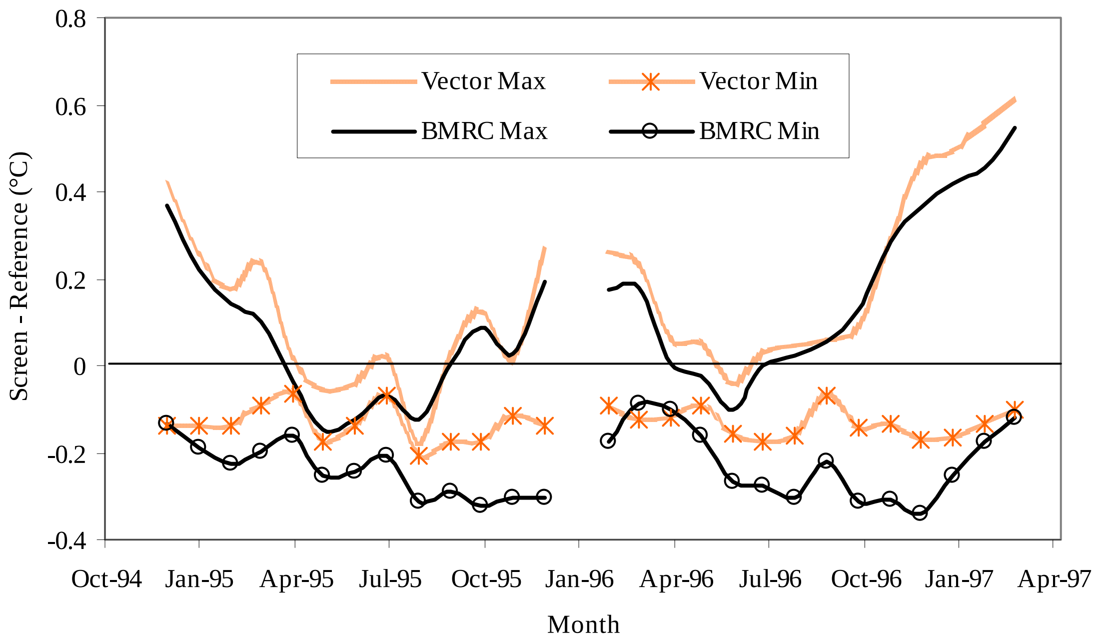
This lack of cycle is not entirely a result of the Teledyne responding to the environment in the same way as the reference screen. Examination of the daily data shows that approximately 5 to 10% of the days per month show gross differences in the average temperature to all other screens. These differences are of the order 0.3°C for the average of all minute data for a day. Thus far all days where a discrepancy has been identified have resulted in the Teledyne measuring the temperature cooler than all the other screens and occured on day when it has rained. It is suspected that water can pool at the air intake and as a consequence the sensor measures a lower temperature. An example of one of these events is given in Figure 8. It is a plot of the reference temperature and the difference between the reference and the Teledyne for the 26 February 1996. On this day a change in the weather occurred at approximately 15:00, at this time the wind direction changed from northerly to a southerly and was followed by 4.6mm of rain over the period 17:00 to 20:00. A little after 17:00 the Teledyne screen started to report temperatures between 0.2 and 0.8°C cooler than the small Stevenson screen. This correlates well with the occurrence of rain. The Teledyne continued to report cooler temperatures until approximately 9:00 the following day. These events appear to be biasing the monthly data for the Teledyne and masking any seasonal differences to the Stevenson screen.

Figure 8 Plot of the minute data for the 26 Feb 1996 of the difference between the reference small Stevenson and the Teledyne screens.



The BMRC on average measures the monthly average temperatures between 0.05 and 0.1°C cooler than the other two aspirated screens. Typically the maximum temperature are similar to the Vector however the minimums are considerably lower, see Figure 9. The BMRC screen was the only screen to display any seasonal cycle in the minimum temperatures. Potentially indicating a problem with either condensation on the intake or radiative cooling of the screen's outer casing. This problem and the gross difference detected for the Teledyne will require further investigation.

Figure 9 Monthly maximums and minimums for the Vector and BMRC screens.



Screen Lag

The seasonal cycle mentioned earlier is a primarily a consequence of the lag in response of the small Stevenson screen. The large thermal mass of the wooden screens slows their response to changes in temperature. Table 3 is an estimate of the response time of some of the sensor screens combinations used in this study. They were determined by examining the change in temperature over a short period during passage of a cold front. The temperature dropped from a high of 36.7 to a low of 21.7°C in a matter of a few minutes. For the sake of this exercise it was assumed that the drop in temperature was more rapid than the response of the screens. The uncertainty of the relative response times is ± 0.5s. From this data it can be seen that all screens excepting the large Stevenson and Teledyne had response times significantly less than the small Stevenson screen. This correlates well with the observation that only the large Stevenson and Teledyne showed little or no seasonal cycle. A regression of the response time verses the seasonal cycle in average temperature gave a correlation coefficient of 0.828 with a significance of greater than 99%.

Table 3 Response time of screens to a 25°C step change in temperature.

	Response Time (hh:mm:ss)
Small Stevenson	00:03.5
Small Stevenson (Old)	00:04.1
Large Stevenson	00:03.7
Vaisala New	00:02.8
Vaisala Old	00:02.6
Merlin	00:02.7
Teledyne	00:03.5
Vector	00:02.8
BMRC	00:02.4

CONCLUSIONS

Determination of a screen that allows accurate measurement of temperature is very difficult. All screens by their very presence impact on the measurement of temperature. Of the screens looked at in this study the Vector aspirated screen appears to have the least overall impact. However it needs to be born in mind that an aspirated screen measures an integrated vertical column of air while a non aspirated screen measure a horizontal slice of the air. In the situation where a strong vertical gradient of temperature exists this can result in large discrepancies. These conditions could not be tested in this study. Also the difference of an aspirated screen to the small Stevenson screen will be greatest at low wind speed.

The Teledyne and BMRC aspirated screens require further study to identify the reasons for their different responses. The Lambrecht, Monitor and Steedman screens are unsuitable for use in Australian conditions. Of the screens studied the Vaisala screen behaves most like the Stevenson Screen. Use of these in a climatic network would result in a maximum increase in the average climatic temperature of 0.1°C and average increase of 0.02°C. As yet no investigation into the difference under particular climatic conditions have been carried out. This will be necessary to determine the ultimate impact of the different screens on the climate record.

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