EVALUATION OF A LOW-COST TEMPERATURE MEASUREMENT SYSTEM FOR THE INVESTIGATION OF THE CHARACTERISTICS OF THE URBAN CANOPY HEAT ISLAND IN KANO CITY, NIGERIA

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ABSTRACT

This paper present result of preliminary evaluation of the performance of a small size and relatively inexpensive self-contained temperature sensor and data logger, the Thermochron iButton within a simple design radiation shield. Thirteen iButtons and their respective shields were divided into two groups of five (facing up and eight facing down) and exposed for a 24 h period under similar conditions to assess the precision of the sensors and efficacy of the designed solar radiation shields. Significant differences ($p < 0.05$) were detected between the two groups. The highest mean daily temperatures recorded by the iButtons shielded from the sun and facing down are lower and less variable than those exposed to the sun and facing up, with values of 31.6 °C and 34 °C respectively. However, the shielded iButtons facing up recorded the lowest mean and minimum daily temperatures of 23.7 °C and 19.7 compared to 24.2 °C and 20 recorded by the iButtons facing down. The mean precision of the two groups (facing up and facing down) were ±0.41 and ±0.62 respectively at the 95% confidence interval. In both groups the uncertainty was consistently low (< 0.5 °C) at night but increased with solar heating. It was however significantly lower for the systems facing down. The precision observed in this study for the systems facing down is in close agreement with values reported in the literature for similar iButtons. Our preliminary evaluation has been positive and has given us an insight into the performance of the sensors and the limitations of our present radiation shield design. Improvements to be evaluated on the current design will include a white plastic disc or another funnel at the bottom to shield the iButtons from reflected and longwave radiation. The iButtons have provided us with a robust and affordable tool for monitoring the urban canopy heat island in Kano city.

Keywords: Thermochron iButton, temperature measurements, urban heat island, Kano, Nigeria

1. INTRODUCTION

More and more people are moving from rural areas of the developing world in the tropics to huge cities like Kano, the capital of Kano state in northern Nigeria. This rural-urban migration is increasing environmental problems, many of which are climate related. One such local climate effect is the urban canopy heat island (UCHI); the characteristic warmer urban core compared to its rural surroundings and data on its variability in sub-Saharan Africa are few. Air temperature is the traditional and most frequently measured variable in efforts to recognize and understand the characteristics of this human impact on climate from local to global scales. However, the lacks of funding and research resources are some of the major limitations to urban climate research in developing countries. Advancements in electronics technology have recently resulted in the production of lower-cost, miniaturized, robust and reliable temperature data loggers (e.g. Hobo, Stowaway Tidbit, Optic Tinytalk, Thermochron iButton, etc). The DS1921 series Thermochron iButton is a miniature, rugged and self-sufficient temperature sensor and data logger system. It has been reported that the iButton is an accurate, durable and low-cost alternative to more expensive temperature data logging systems, and is well suited for obtaining quality spatially distributed data for environmental investigations (Hubbart et al. 2005, Johnson et al. 2005).
This study presents a preliminary evaluation of the performance of the thermochron iButton (DS1921G-F52) within a simple design solar radiation shield.

2. MATERIALS AND METHODOLOGY

The Maxim-ic, Dallas, TX, thermochron iButton is a 17.35mm diameter by 6 mm-thick instrument that costs $25 per iButton, but can be < $15 when ordered in large quantity. Fig. 1a shows the thirteen DS1921G-F52 iButtons used in this study and accessories (USB adapter and reader), its software is downloadable from Maxim-ic’s website. The iButton has a specified temperature range of -40 to +85 °C at 0.5 °C resolution, with a manufacturer’s stated accuracy of ±1 °C. Each iButton has a unique digital identification code and can store up to 2048 data points configurable from 1 to 255 min time intervals. The iButton's expected life is 10 years or one million temperature conversions at 50 °C or less, whichever comes first. The internal clock measures seconds to years accurately to within ±2 minutes per month from 0 °C to 45° C. Most commonly they are used in monitoring shipping of food and pharmaceutical products, but have now been used in hydro climatic investigations (Hubbard et al. 2005, Johnson et al. 2005, and Weiler et al. 2005). When sensors are used to measure air temperature, radiation shields are also required to minimise sensor heating by solar and terrestrial radiative exchange; however, the performance of both the sensors and radiation shields must be evaluated to assure data quality and interpretation (Hubbart et al. 2005, Nakamura and Mahrt, 2005). To shelter the Buttons from overheating by radiative exchange when measuring air temperature, Weiler et al. 2005 used a radiation shield made out of ordinary kitchen funnels. We adopted this simple design (Fig. 1b). 3 cm x 4 mm slits were machined on opposite sides, just below the rim of a white small 8.50 cm diameter funnel. This slit held a 10.5 cm x 2.5 cm x 3mm white PVC strip that was also machined in the center to hold the iButton snug and can be removed/replaced with the thumb and index finger. The strip is secured by tiny 2 mm bolts and screws (Fig. 1b).

Independent assessment of the accuracy and precision of thermochron iButton have been reported, the study of Johnson et al. (2005) revealed a precision of ±0.4 °C and an accuracy of ±0.5 °C for 201 iButtons, while Hubbart et al. (2005) reported the accuracy of the sensors to be well within the manufacturer’s stated specification of ±1-0 °C, with a collective temperature variance of ±0-21 °C for 61 iButtons. Our preliminary performance evaluation of the ibutton is based on the assessment of the precision and variability between individual devices and the efficacy of the designed solar radiation shield as we have no standard or control to compare them with at the time of writing. The thirteen iButtons and their respective shields were divided into two groups and exposed for a 24 h period under similar conditions. The sensors and shields were installed at 3 m height and held in a nearly concentric ring around a telecom pole with clear view of the sky (Fig. 1b). In group1 were five sensor and shield units installed facing up, with the iButtons exposed to direct solar radiation, but screened from reflected and longwave radiation. While in group 2 were eight units facing down and shielded from direct solar radiation, but exposed to reflected and longwave radiation from the surface. The radiation shield experiment was designed to subject the sensors to prevailing environmental conditions, to gain an appreciation of the temperature response of the sensors in the shields under varying conditions. All units were sampled at 15 minutes interval. Descriptive statistics were applied with one-way analysis of variance (ANOVA) to detect significant differences (95% confidence interval) in mean values between the two groups.
3. RESULTS AND DISCUSSION

Fig. 2 show that the highest mean daily temperatures recorded by the thermochron iButtons shielded from the sun and facing down are lower and less variable than those exposed to the sun and facing up (Figs. 2a and 2b), with values of 31.6 °C and 34 °C respectively. However, the shielded iButtons facing up recorded the lowest mean and minimum daily temperatures of 23.7 °C and 19.7 compared to 24.2 °C and 20 recorded by the iButtons facing down. Fig. 2c shows the difference between the two groups. The mean precision of the two groups (facing down and facing up) were ±0.41 and ±0.62 respectively at the 95% confidence interval. In both groups the uncertainty was consistently low (< 0.5 °C) at night but increased with solar heating, indicating that the influence of direct solar radiation is the major source of errors. It was however significantly lower for the systems facing down. (Figs. 2a and 2b). The precision observed in this study for systems facing down is close to the ±0.4 reported by Johnson et al. (2005). It may be possible that occasional shadows from the telecom pole may also have contributed to the higher uncertainty of the systems facing up. One-way ANOVA also indicated that, there was a significant difference (p < 0.05) between the daily temperature means of the two groups.

![Fig. 2: Temperature responses of Thermochron iButtons within a designed solar radiation shield (a) shields facing up, (b) shields facing down and (c) difference between shields facing up and facing down on 9/5/2009. Although all iButtons responded to solar diurnal cycle, temperature response means between shields facing up and facing down varied significantly (p < 0.05).](image)

The higher diurnal mean and minimum temperatures recorded by the systems facing down is not surprising and indicate that while the influence of direct solar radiation may have been greatly reduced by the shield, the iButtons were still influenced by reflected solar radiation during the day and longwave radiation at night, leading to the observed higher diurnal mean and minimum temperatures recorded. These results calls for an improvement to the current design of the shield and underpin the importance of the need to assess the performance of both the sensors and radiation shields for data quality assurance and interpretation. Improvements to the current design will include a white PVC plastic disc or another funnel at the bottom to shield the iButtons from reflected and longwave radiation. A re-assessment of the accuracy and precision of the iButtons and efficacy of the improved shield design will be conducted with a certified standard thermometer and an aspirated system as control. The influence of solar and terrestrial radiation as well as ventilation to assess correction needs will also be evaluated.
This re-evaluation will be conducted in a flat open field far away from any obstruction that can cast shadows on the systems. The pilot measurements of urban canopy air temperatures in Kano city to investigate the variability of the UCHI will commence fully after the re-evaluation of the performance of the iButtons and efficacy of the improved shield design have been completed.

4 CONCLUSIONS

Thermochron iButtons exhibit many advantages over other temperature data-logging systems, the primary one being their cost, other benefits include their being wireless, small size, self-sufficient (sensor, logger and power unit), long life span and applicability to a vast range of environmental research needs. Though more accurate loggers may be required for sites where thermal variations are very small, higher performance iButtons (not reviewed here), are available with improved resolution and accuracy (read to 0.0625 °C and 0.5 °C respectively), greater recording interval range (1 s to 273 h), and greater storage capacity (8192 data points), however with greater cost (http://www.maxim-ic.com/products/ibutton/ibuttons/thermochron.cfm). The objective of this study was to assess their performance within a simple design radiation shield. Thirteen iButtons and their respective shields were divided into two groups of five (facing up and eight (facing down) and exposed for a 24 h period under similar conditions to assess the precision of the sensors and efficacy of the designed solar radiation shields. Significant differences ($p < 0.05$) were detected between the two groups. The highest mean daily temperatures recorded by the thermochron iButtons shielded from the sun and facing down are lower and less variable than those exposed to the sun and facing up, with values of 31.6 °C and 34 °C respectively. However, the shielded iButtons facing up recorded the lowest mean and minimum daily temperatures of 23.7 °C and 19.7 compared to 24.2 °C and 20 recorded by the iButtons facing down. The mean precision of the two groups (facing down and facing up) were ±0.41 and ±0.62 respectively at the 95% confidence interval. In both groups the uncertainty was consistent at night but increased with solar heating. It was however significantly lower for the systems facing down. The precision observed in this study for the systems facing down is in close agreement with values reported in the literature for similar iButtons. Our preliminary evaluation has been positive and has given us an insight into the performance of the sensors and the limitations of our present radiation shield design. Improvements to be evaluated on the current design will include a white plastic disc or another funnel at the bottom to shield the iButtons from reflected and longwave radiation. The iButtons have provided us with a robust and affordable tool for monitoring the urban canopy heat island in Kano city.

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REFERENCES


