ORIGINAL ARTICLE

Assessing a population's exposure to heat and humidity: an empirical approach

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Background: It is widely accepted that assessing the impact of heat on populations is an important aspect of climate change research. However, this raises questions about how best to measure people's exposure to heat under everyday living conditions in more detail than is possible by relying on nearby sources of meteorological data.

Objective: This study aimed to investigate practical and viable approaches to measuring air temperature and humidity within a population, making comparisons with contemporaneous external data sources. This was done in a rural South African population during the subtropical summer season.

Results: Air temperature and humidity were measured indoors and outdoors at three locations over 10 days and the datalogger technology proved reliable and easy to use. There was little variation in measurements over distances of 10 km.

Conclusions: Small battery-powered automatic dataloggers proved to be a feasible option for collecting weather data among a rural South African population. These data were consistent with external sources but offered more local detail. Detailed local contemporary data may also allow post hoc modelling of previously unmeasured local weather data in conjunction with global gridded climate models.

Keywords: *climate*; *weather*; *population measurement*; *temperature*; *humidity*; *heat stress*

Access the supplementary material to this article: a User Guide and Data File (see Supplementary files under Reading Tools online).

Received: 28 June 2010; Revised: 8 August 2010; Accepted: 23 August 2010; Published: 17 September 2010

One of the possible effects of changes in climate is that people may be exposed to more stressful combinations of heat and humidity and this may occur more often than previously (1). This is particularly likely to be the case in the hotter regions of the world, and may be associated with excessive outdoor temperatures or, with increasing industrialisation, very hot and/or poorly ventilated indoor work environments (2).

The livelihoods of many people who live in the hottest places depend at least partly on subsistence farming rather than paid employment, but this too should be regarded as a kind of occupational exposure even if it does not strictly fall within the remit of conventional occupational health (3). In communities with relatively simple housing, many people spend a large proportion of daylight hours outside. School buildings in many hot settings may also be poorly designed and ventilated in these hotter environments. Transport often involves walking or cycling in full sunshine.

[#]The Deputy Editor Peter Byass has had no part in the review and decision process for this paper.

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Citation: Global Health Action 2010, **3**: 5421 - DOI: 10.3402/gha.v3i0.5421
(page number not for citation purpose)

Heat exposure for typical individuals in some of the world's hottest communities is therefore likely to be represented by an amalgam of outdoor conditions, workplace or school circumstances, and indoor conditions at home. The associated health risks and impacts on work and daily activities are clearly linked to the physiological limits of the human body (4).

When considering the effects of heat stress on population health, the ideal situation would be to know the amount of time people spend in different situations and to measure air temperature and humidity in each of those places. This is clearly impossible on a large scale, but conceptually desirable, for example, in prospectively assessing heat stress exposure as a risk factor for human performance, morbidity, and mortality at the population level. Less ideal but more practical solutions therefore have to be found which give sufficient detail on the exposure patterns of a local population without involving unreasonable intrusion, cost, or effort. At the same time, there is a need for appropriate solutions that offer more detailed and localised exposure data – for example, indoor–outdoor differentials – than are available from the nearest official weather station or computer models of gridded climate data (5).

Firstly, we present a pre-pilot study concerned with practical issues of measuring air temperature and humidity within a population, and secondly the results of an empirical pilot study in rural South Africa that set out to measure small-scale differentials in air temperature and humidity within a local population, including characterising indoor–outdoor differentials in typical houses. Although this small study cannot enable wide-reaching conclusions to be made, it provides a methodological template that could very well be used and developed further in other settings. We also compared our local measurements with data from the nearest weather station and a gridded weather data model.

Methods

Lascar EL-USB-2-LCD automatic air temperature and humidity loggers (http://www.lascarelectronics.com) were used to measure air temperature (°C) and humidity in these pilot studies. Relative humidity (%) and absolute humidity (dew point, °C) are recorded by these instruments. The accompanying document 'Assessing a population's exposure to heat and humidity: a practical guide' gives practical details on the use and deployment of these instruments. These loggers cost approximately US$80 each, and are small battery-powered devices that can be preprogrammed via a USB port to record data at specified times that can later be downloaded for analysis. In all of these pilot studies, the loggers were programmed to record every 30 min, on the hour and half hour.

These studies were carried out in rural north-eastern South Africa (as shown in Fig. 1) in the lowveld area during the subtropical summer season. Our first consideration, which was addressed in a pre-pilot study, was how to house the loggers either outdoors or indoors in such a way that they would not be exposed to direct sunshine or rainfall, be in well-ventilated locations, and protected from interference by humans, monkeys, and so on. Our aim was to approximate the measurement conditions afforded by a Stevenson screen, while preserving the portability, security, and convenience of the loggers.

We found that the loggers conveniently fitted into electrical conduit boxes that were easily available, white, with secure lids, and prepunched with holes on all sides for conduit fixings. The pre-pilot study involved strapping an unprotected logger and one in a conduit box to the shaded underside of a tree branch approximately 2 m above the ground (Fig. 2), and recording data for a 48-h period on

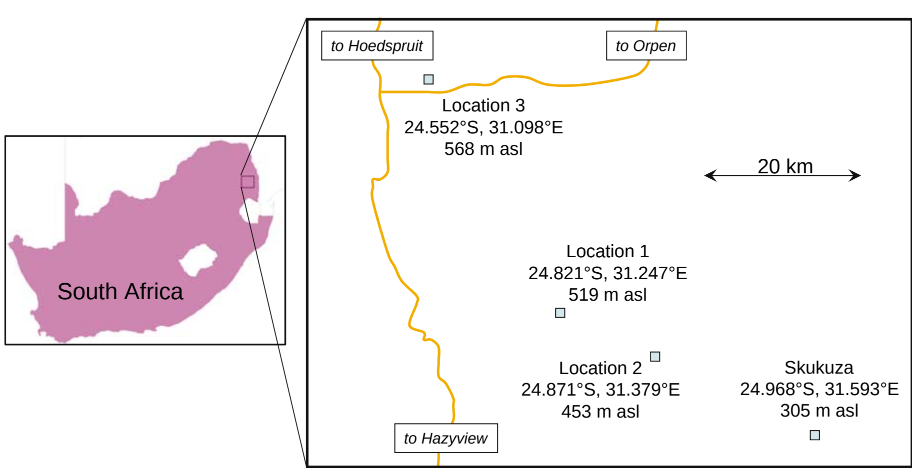

Fig. 1. Map of the area used for the study, showing the three locations of the loggers, their altitudes, and location within South Africa. Locations 1 and 2 were compounds in the Agincourt subdistrict; location 3 was at the University of Witwatersrand's Rural Facility and Skukuza is the nearest official weather station at an airport on the edge of the Kruger National Park.

Citation: Global Health Action 2010, **3**: 5421 - DOI: 10.3402/gha.v3i0.5421

Fig. 2. Unprotected and protected loggers during the pre-pilot study.

25–26 January 2010 to assess comparability between the results from the protected and unprotected loggers.

For the pilot study, we located two pairs of loggers inside and outside two houses in the Agincourt field study area, plus one logger outside at the University of Witwatersrand's rural facility as a slightly more distant reference point, all approximately 2 m above ground level and all situated in identical conduit boxes. The outside loggers were strapped to the underside of convenient tree branches, and the inside ones were attached to convenient fixing points that were not near windows, nor in kitchens, and so on. Both of the houses involved were constructed with cement walls and corrugated metal roofs. These three locations, in South Africa's lowveld, are shown on a map in Fig. 1. The straight-line distance from location 1 to location 2 is 13.6 km, from location 1 to location 3 is 33.8 km, and from location 2 to location 3 is 45.3 km. The five loggers all recorded data synchronously every 30 min over a 9-day period from 30 January to 7 February 2010 inclusive.

Data from the loggers were downloaded into Microsoft FoxPro and subsequently Stata 10 was used for analyses. The complete dataset in Excel format (pilot.xls) is available as a supplementary file.

Routinely recorded weather data from the nearest official weather station at Skukuza airport (24.968°S, 31.593 °E, 305 m above sea level) were obtained for the same time period (http://www.wunderground.com). Gridded global temperature data were obtained from the NOAA NCEP/NCAR dataset (6) (http://www.esrl.noaa.gov/psd) for the cell 22.5 to 25.0°S, 30.0 to 32.5°E for the same period.

Results

In the pre-pilot study, both loggers recorded data every 30 min for 48 h (i.e. 96 data points each). Fig. 3 shows the air temperature and humidity data as recorded by both loggers. The pairs of daily maximum temperatures were 32.5, 33.5°C and 27.5, 28.0°C; minima 24.5, 24.5°C and 22.0, 22.0°C for the protected and unprotected loggers, respectively. Similarly the daily maximum relative humidities were 78.5, 81.0% and 92.5, 95.5%; minima 55.0, 55.0% and 77.0, 71.5%. The mean difference in temperature between the two loggers over the whole period was 0.3°C and in relative humidity 0.8%, both of which are within the manufacturer's stated measurement accuracy for the instrument (±0.5°C and ±3%, respectively). The 48-h period of observation happened to include times of sunshine and rainfall as is typical of the summer season in this subtropical area.

In the pilot study, five loggers recorded data every 30 min for 9 days (i.e. 432 data points each) during a period that included some cloudy, wet weather and some hot, dry days. Fig. 4 shows the outside air temperature and relative humidity for the three locations over the whole

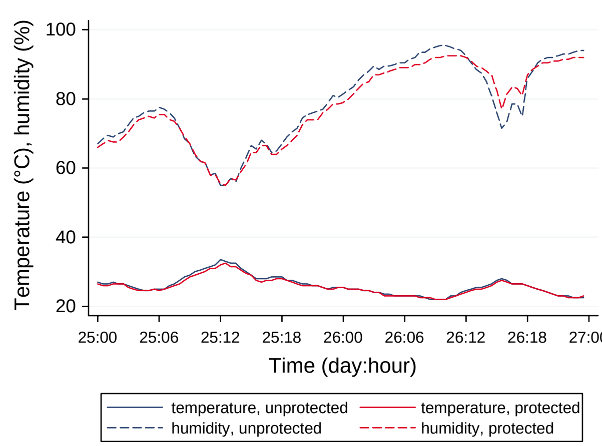

Fig. 3. Air temperature and relative humidity data as recorded by unprotected and protected dataloggers (see Fig. 2) over a 2-day period, 25–26 January 2010.

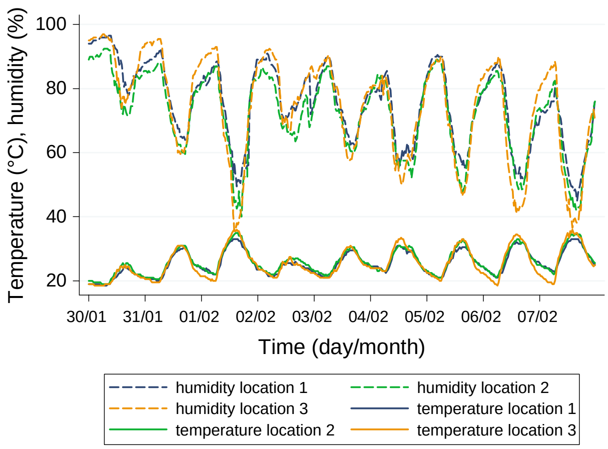

Fig. 4. Outside air temperature and relative humidity data recorded every 30 min for three locations (see Fig. 1) over a period of 9 days, 30 January to 7 February 2010.

period. Overall mean outside air temperatures by location were 25.4°C at location 1, 26.0°C at location 2, and 25.5°C at location 3. Corresponding dew points were 20.4°C, 20.4°C, and 20.3°C. Mean outside relative humidities were 75.2%, 72.1%, and 74.3%, respectively.

The mean inside–outside air temperature difference at location 1 was +4.0°C (inside warmer than outside) and location 2 was +2.9°C. The corresponding differences in dew point were −1.8°C and +1.3°C. The mean humidity differences were 22.4% less humid inside at location 1 and 7.0% at location 2. Fig. 5 shows the inside–outside differences in air temperature and relative humidity for locations 1 and 2 over the whole period.

Temperature data from the Skukuza weather station, recorded at 0800, 1400, and 2000 each day were obtained for the period of the pilot study and are shown in Fig. 6.

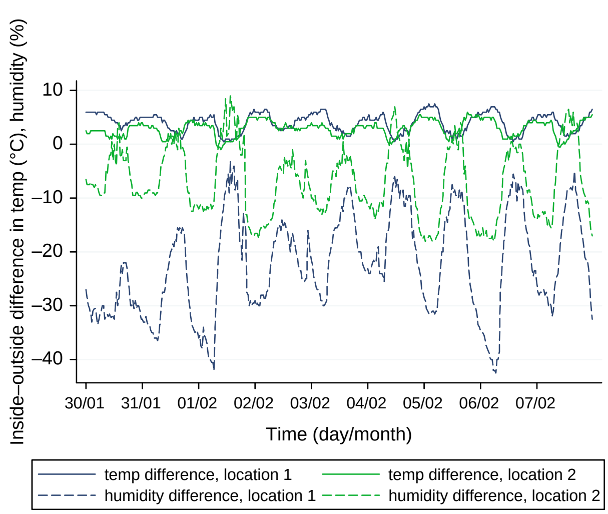

Fig. 5. Differences between inside and outside air temperature and relative humidity data recorded every 30 min for two locations (see Fig. 1) over a period of 9 days, 30 January to 7 February 2010.

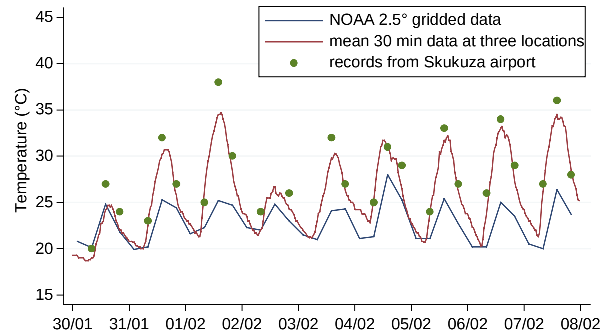

Fig. 6. Mean outside air temperature as recorded by dataloggers every 30 min at locations 1, 2, and 3 together with 6-h temperature data from the NOAA 2.5° global gridded model and records from Skukuza airport (0800, 1400, and 2000 daily).

In the same figure, the average temperatures every 30 min from the outside dataloggers at locations 1, 2, and 3 are shown for comparison, together with the 6-h temperature data from the NOAA NCEP/NCAR reanalysis 2.5° gridded temperature data for the cell 22.5 to 25°S, 30 to 32.5°E.

Discussion

Although this pilot study did not set out to establish any connections between air temperature and humidity measurements and the population in which the measurements were made, it revealed a number of practical considerations associated with making such measurements at the population level. The pre-pilot study results confirmed the feasibility of using easily sourced boxes to secure the dataloggers, without materially affecting the data collected, both during wet and fine conditions. Although minor differences were observed between the two loggers, these were within the stated accuracy of the instruments and too small to substantially affect considerations of human heat exposure.

In the pilot study, the relatively close agreement in air temperature and humidity between the three outside dataloggers (Fig. 4) suggests that distancing measurements by some tens of kilometres results in rather small differences, and for most purposes it is probably unnecessary to make measurements at closer intervals than 10 km. However, in this example the altitudinal differences between the three datalogger sites were fairly small (115 m). In places with larger differences in altitude or including coastal areas, local topography needs to be considered in locating measurement sites. When it comes to measuring air temperature and humidity inside houses, however, it seems from Fig. 5 that there may be appreciable variation between houses (although only two houses were sampled here). The difference between exterior and interior humidities (measured both as dew point and relative humidity) varied substantially, possibly

Citation: Global Health Action 2010, **3**: 5421 - DOI: 10.3402/gha.v3i0.5421

reflecting differences in the ventilation between houses. Characterising peoples' exposure to heat indoors, therefore, may be more challenging than measuring outdoor exposure.

The comparisons with the local weather station and gridded climate data (Fig. 6) are important and interesting, since these sources represent the main alternatives to actual measurement of air temperature and humidity in the field. Both sources have much less frequent data than the 30 min data from the dataloggers. The Skukuza airport data were available for 0800, 1400, and 2000, and Fig. 6 shows reasonably good agreement between the 0800 and 2000 Skukuza data and the average readings of the three outdoor dataloggers. Skukuza, although not far away, lies at a substantially lower altitude than the datalogger sites, and this may be the reason for the substantially higher air temperatures recorded at 1400. In other settings, both distance and altitude may need to be taken into account in determining locations for a group of dataloggers.

The comparison with the NOAA NCEP/NCAR data for the same time period, also shown in Fig. 6, is interesting. These gridded data are available every 6 h (0200, 0800, 1400, and 2000 local time) with the data points at 1400 roughly coinciding with daily observed maxima in this location. In addition, the relatively large size of the 2.5° grid (in this case the cell 22.5 to 25°S, 30 to 32.5°E covers an approximate rectangle of 250 km west-to-east and 380 km north-to-south, with an altitudinal range from 1,810 m above sea level at the south-western corner to 115 m in the Limpopo river valley to the north-east) can be problematic. As it happens, we are dealing with a relatively heterogeneous grid cell covering the escarpment between the highveld and lowveld areas here, and so inevitably the gridded data reflect some kind of average over this area that needs interpreting with care in terms of local air temperature and humidity.

Nevertheless, there are obvious relationships between the gridded data and the other sources shown in Fig. 6, which may be of epidemiological value. If one had a longer series of contemporary local records, for example over a 1-year period, then one might start to model the relationship between the gridded and observed data. The potential value in doing so could be huge in populations where demographic and epidemiological archives have been accumulated over many years but without local weather data. If it is possible to assume that modelled relationships between current gridded and locally observed data are fairly consistent, it would then be possible to apply such models to construct post hoc local data from gridded data for past years for analyses against population data archives.

Overall, we conclude that a relatively small number of automatic air temperature and humidity loggers located within a population represent an effective and cost-effective means of gathering weather data at the local level, on a current and prospective basis. We would recommend population surveillance sites to adopt this strategy as a matter of routine to enable prospective enquiries into associations between heat exposure, changes in climate, and human health, performance, and productivity (7). It may also be the case that a reasonable series of contemporary weather data in a particular location will enable local estimates of past weather to be made in a relatively precise manner.

Acknowledgements

We are grateful to Andreas Béguin for comments on the manuscript. NCEP reanalysis data was provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA from their website at http://www.esrl.noaa.gov/psd/

Conflict of interest and funding

The Umeå Centre for Global Health Research is supported by FAS, the Swedish Council for Working Life and Social Research (Grant No. 2006-1512). The MRC/Wits Agincourt health and sociodemographic surveillance system is funded by The Wellcome Trust, UK (Grant Nos. 058893/Z/99/A and 069683/Z/02/Z) and the University of the Witwatersrand and Medical Research Council, South Africa.

References

1. Sherwood SC, Huber M. An adaptability limit to climate change due to heat stress. Proc Nat Acad Sci 2010; 107: 9552–5.
2. Kjellstrom T, Holmer B, Lemke B. Workplace heat stress, health and productivity – an increasing challenge for low and middle income countries during climate change. Glob Health Action 2009; 2. DOI: 10.3402/gha.v2i0.2047.
3. Morton JF. The impact of climate change on small holder and subsistence agriculture. Proc Nat Acad Sci 2007; 104: 19680–5.
4. Parsons K. Human thermal environments: the effects of hot, moderate and cold environments on human health, comfort and performance. 2nd ed. New York: CRC Press; 2002.
5. Verdin J, Funk C, Senay G, Choularton R. Climate science and famine early warning. Philos Trans R Soc Lond B Biol Sci 2005; 360: 2155–68.
6. Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, et al. The NCEP/NCAR 40-year reanalysis project. Bull Amer Meteor Soc 1996; 77: 437–70.
7. Kjellstrom T, Gabrysch S, Lemke B, Dear K. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. Glob Health Action 2009; 2. DOI: 10.3402/gha.v2i0.2082.

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