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Observing an urban heat island by bicycle

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This article describes part of an investigation into the urban heat island (UHI) effect in the town of Reading, Berkshire, which was carried out by one of us (EM) in connection with an undergraduate research project. Our intention here is to demonstrate that this interesting and important meteorological phenomenon can be investigated quantitatively using rather simple (and inexpensive) technical resources. A similar investigation could be carried out by an individual amateur observer, or as a team project by students studying an environmental science at the secondary level.

The UHI effect is the tendency for the air temperature observed within a built-up area to be significantly greater than that observed in the surrounding rural environment (for comprehensive reviews see Chandler 1965; Landsberg 1981; Oke 1987). During winter, the effect is attributed mainly to the release of heat into the atmosphere from industrial and domestic sources. During summer, when the UHI is often more pronounced, the effect has more to do with differences in surface energy balance. For an urban settlement surrounded by vegetated countryside, an important effect during daytime is likely to be the difference in the partitioning of net radiation between sensible and latent heat fluxes (Oke 1987). The urban fabric can store very little water in its surface layer, so that most of the absorbed radiant energy at the surface is available to heat the overlying air and only a very small fraction goes into evaporating water from the surface. In contrast, the conversion of the absorbed solar radiation into latent heat by surface evaporation is much greater in the open countryside, where there is a more plentiful supply of surface moisture. Other significant factors may be differences in surface albedo (the urban fabric reflecting less visible radiation than the rural surface) and heat storage (the urban fabric storing more heat energy in its surface layer, which results in the upward sensible heat flux remaining positive for a longer period after sunset).

A quantitative measure of the UHI is important in relation to human comfort and energy resource management, but its actual magnitude and the way in which it varies from one place to another is actually quite difficult to measure accurately. One obvious method is to record air temperatures simultaneously at a number of sites within the urban environment and its surroundings. Such a method was used by Parry (1956) in an earlier study of the UHI in Reading. However, accurate 'mapping' of the UHI over even a small town might involve equipping and maintaining a relatively large number of sites, with obvious financial and logistical implications. It might also be difficult to establish sites which are not only accessible but also secure close to a town centre. We have, therefore, considered the possibility of measuring the UHI by sampling air temperature at a number of locations, using a single thermometer carried on a moving platform (in our case, a bicycle). This method cannot easily be used to derive a two-dimensional map of the UHI, and there are obvious problems associated with the fact that the measurements cannot be simultaneous, so that changes in air temperature with time can lead to errors in the 'spatial' interpretation of the measurements. We wanted to see if such a technique could, nevertheless, provide useful information on the magnitude and spatial variation of the UHI across a town the size of Reading.

The Reading area

Reading is a medium-size town in central Berkshire, with a mixed commercial and industrial setting, built near the confluence of the Rivers Thames and Kennet. Central Reading has a population of about 142000, but this figure increases to 232000 if the built-up areas of greater Reading are included (shown in Fig. 1). The geography is dominated by the Thames valley, with the town centre situated between the Thames and the Kennet. A series of three level terraces rises on either side of the Thames, as described by Parry (1956). Our interest is in the variation of temperature across the town centre, following mainly the course of the River Kennet. This runs from roughly south-west to north-east through the town centre, passing through about 4 km of built-up area between rural sectors comprising mainly rough grass and open woodland.

Method

The route along which the measurements were made is shown in Fig. 1. It follows mainly towpaths along the side of the Kennet and Avon Canal (south of and through the town centre) and the River Thames (north of the town centre). Measurement sites were selected to be approximately 1 km apart at the start and end of the route, but slightly less than this near the town centre.

At each site, air temperature was measured using a commercial, resistor-type thermometer providing a digital read-out with a resolution of 0.1 degC. Such an instrument is easy to use and has a relatively rapid response (lag constant about 10 s). Although its absolute accuracy is not high (typically ±0.5 degC), this was not considered important since we were mainly interested in differences rather than absolute values of observed temperature.

Each 'experiment' consisted of taking measurements at the selected sites during consecutive outward and return journeys, starting from the extreme north-east end of the route. Six temperature observations were recorded at each site over a period of a minute or so, in order to derive a representative mean value for the site and avoid the inclusion of misread data. In addition, the observer recorded cloud type and cover (in eighths) and approximate wind speed and direction (with reference to Beaufort scale and compass). The total time required to carry out a complete traverse (outward and

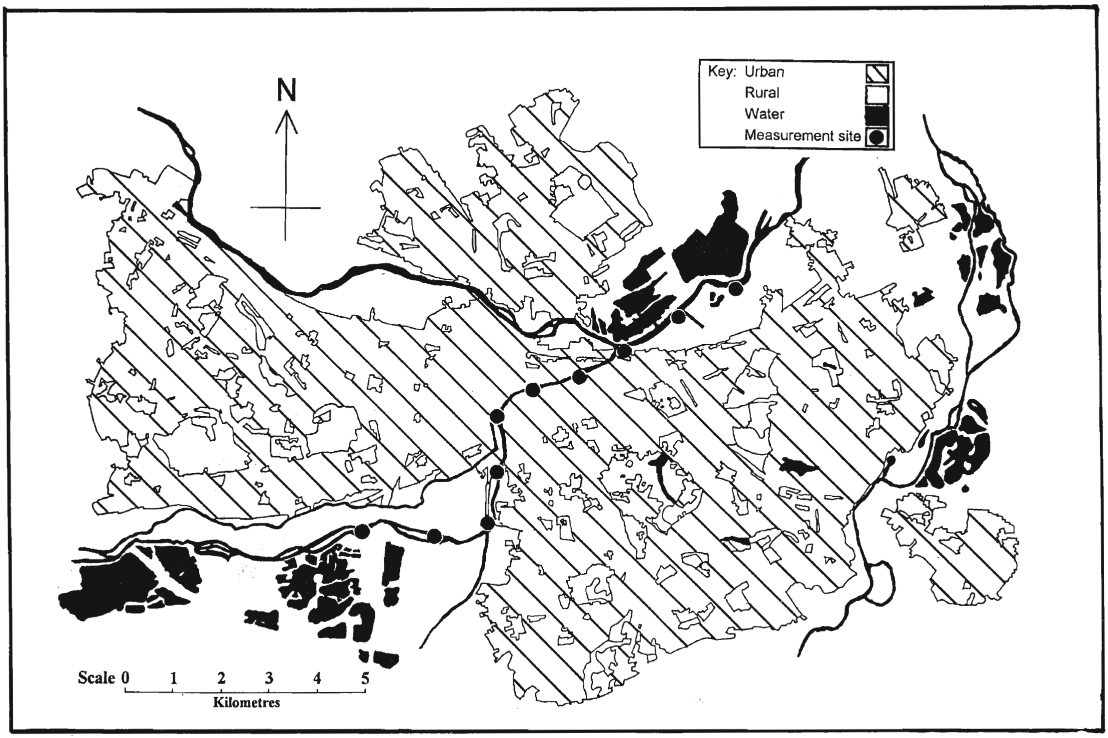

Fig. 1 Map of the greater Reading area showing the distribution of urban, rural and water surfaces. Also shown are the locations of measurement sites along a route following canal and river towpaths.

return journeys) was around 1.5 hours.

The results reported here are from experiments conducted around dusk on days during July and August 1996. The elevation of surface temperature due to the UHI effect should be near its maximum around sunset (Oke 1987). On the other hand, it might not be the best time of day to observe UHI by this method because of the relatively rapid decrease of temperature at that time. However, the choice of sampling period had to correspond to 'free' time available to the observer (outside normal working hours). Similarly, the number of days on which experiments could be conducted had to be selected on the basis of opportunity. Choice was also limited by considerations of safety; it was not considered wise to attempt an experiment during wet conditions or after dark!

Results

A total of 15 successful traverses were completed between 13 July and 30 August 1996. Figure 2 shows four examples of temperature profiles recorded along outward and return legs of a traverse. It is obvious that these are affected by a general cooling over the period of the experiment. The difference between the first and last observations (at the extreme north-east site) was as large as 4 degC on some occasions, corresponding to a cooling rate of about 3 degC per hour. If it is assumed that the cooling rate at all sites is constant throughout the duration of an experiment, then taking the mean of the two measurements at each site should eliminate the time dependence. The result is shown by the continuous line profiles in Fig. 2.

Obviously, the assumption of constant cooling rate is unlikely to be valid in reality, and this could lead to errors in interpreting the profile of the means as a true measure of the spatial distribution of temperature at a particular time. Nevertheless, the mean profiles do exhibit a structure consistent with the UHI effect, with a clear temperature maximum located at a distance of about 4 km from the north-east origin, coinciding roughly with the town centre. The

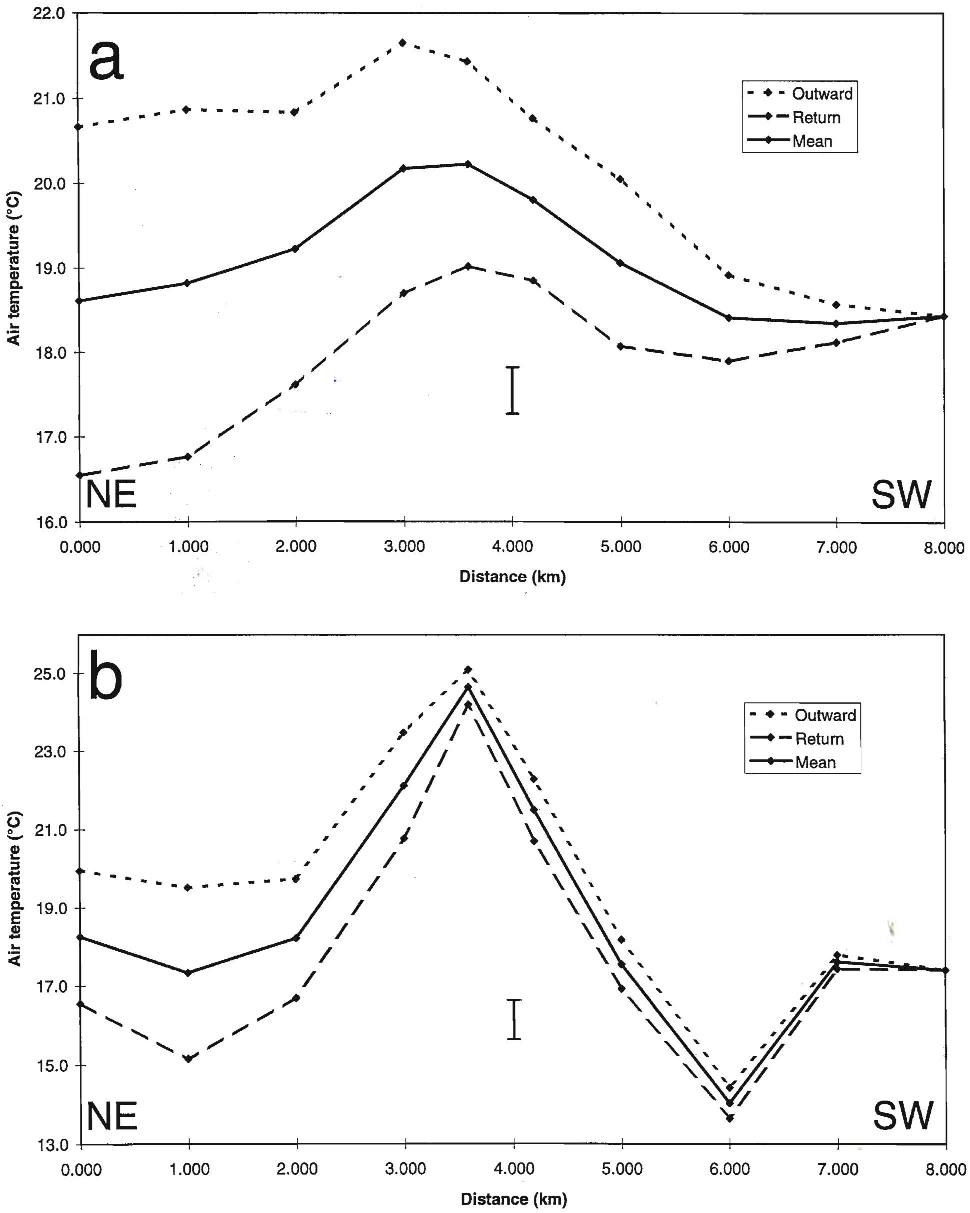

Fig. 2 Temperature profiles measured during four experiments carried out on (a) 13 July 1996, (b) 22 July 1996, (c) 23 July 1996 and (d) 19 August 1996. Distance is measured along the selected route, starting from the extreme north-east measurement site (see Fig. 1). On each panel the vertical bar indicates the average range of uncertainty on individual measurements associated with sampling fluctuations in observed temperature.

profiles for 22 July and 19 August (Figs. 2 (b) and (d)) represent rather extreme examples of the effect, recorded during spells of very warm, anticyclonic weather. In both cases the wind direction was mainly south-easterly and the wind speed during the experiment less than 4 kn. Cloud cover was also recorded as being less than three oktas. On these days, intense solar heating during the day, together with near-stagnant conditions within the urban area, has led to relatively large differences in temperature between the centre and the outskirts of the town. A maximum heat island intensity can be defined as the largest observed difference between the urban air temperature and the air temperature representative of the sur-

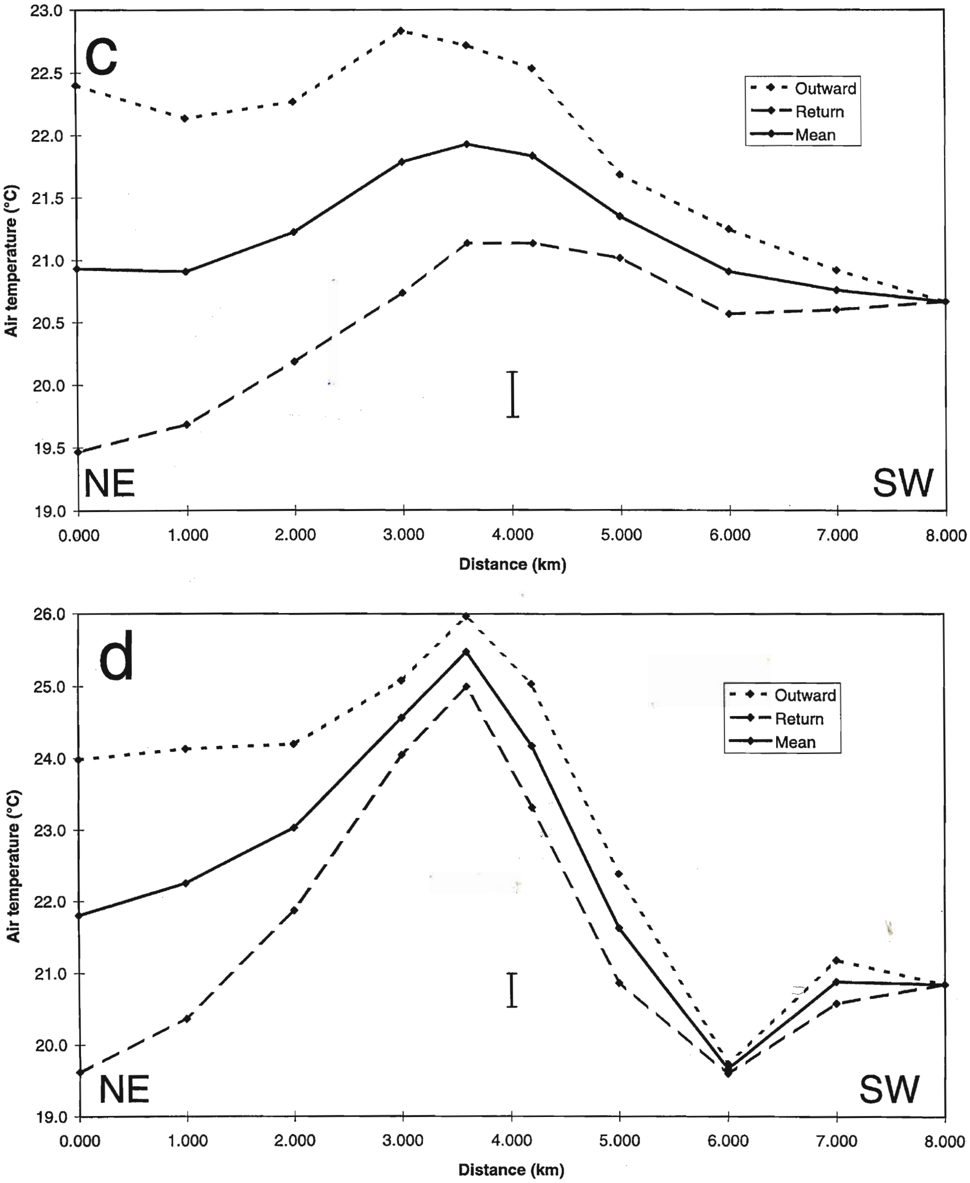

Fig. 2 Continued

rounding rural environment (Oke 1987). Unfortunately, our experimental procedure did not allow us to obtain reliable measurements of the latter. However, if we assume that the lowest observed temperature is close to a representative rural value, then the traverses of 22 July and 19 August indicate a maximum intensity in the range 6–9 degC.

The profiles for 13 and 23 July (Figs. 2 (a) and (c)) are much less extreme and less sharply peaked around the town centre. On these occasions the reduced UHI intensity was probably due mainly to the influence of horizontal advection. The mean wind speed observed during both experiments was around 10 kn (from the north-west on 13 July and from the west on 23 July). An increase in the strength of the wind means not only that individual air parcels undergo less total heating as they move across the urban area, but also that there is more turbulence in the airflow leading to greater mixing between the surface air and air at higher alti-

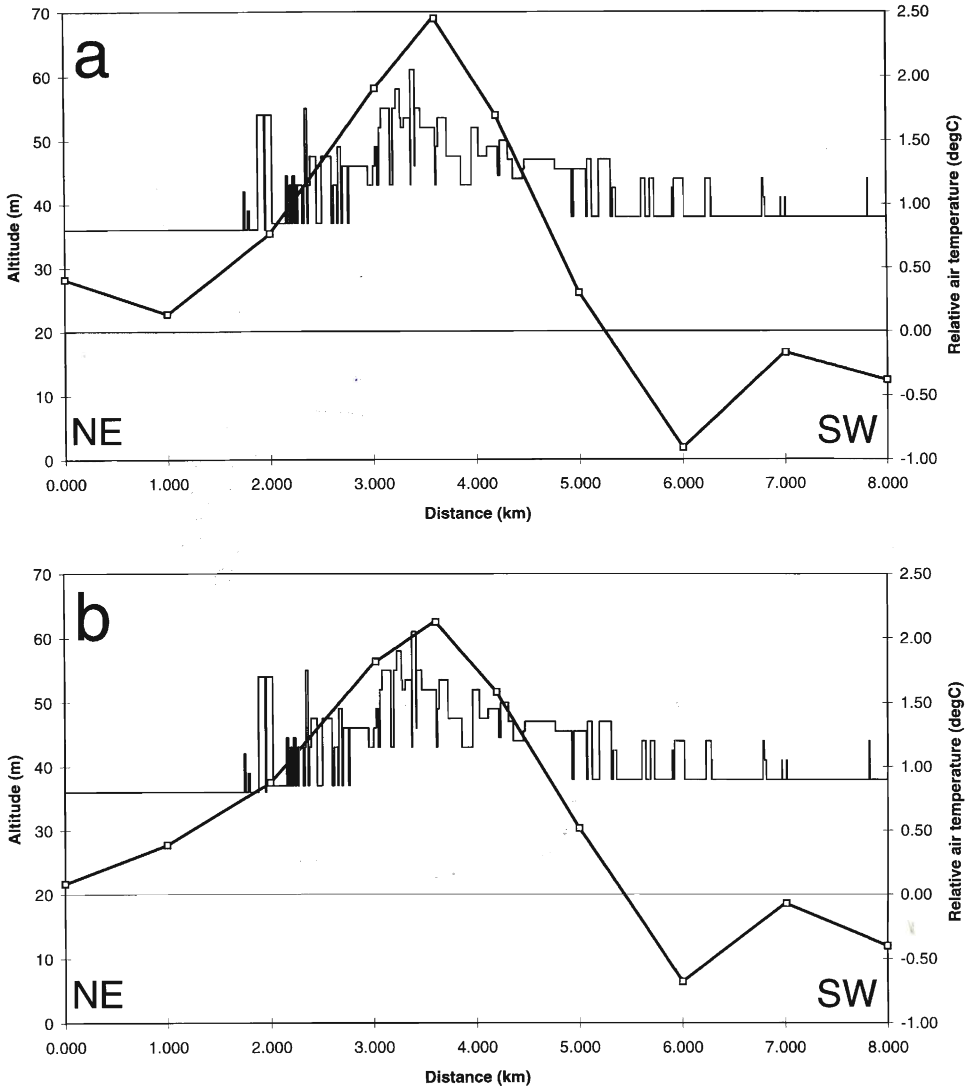

Fig. 3 Averaged profiles of UHI *temperature anomaly derived from (a) 6 experiments in July 1996, (b) 9 experiments in August 1996 and (c) all 15 experiments. Also shown is a profile of urban topography measured along the traverse (see text for details).*

tudes, thus spreading the effect of the surface heating over a greater depth. (According to Oke (1973), the intensity of the UHI is inversely proportional to the square root of the wind speed, and is negligible for wind speeds averaging more than about 9 $m\,s^{-1}$.)

As is clear from the examples shown in Fig. 2, the actual magnitude and shape of the observed profiles varied from one experiment to another. We could arrive at some 'mean UHI' profile by subtracting a representative value of rural air temperature from each observation before averaging values from a number of experiments. Since we did not have reliable measurements of rural air temperature, we instead chose a reference temperature for each experiment defined arbitrarily as the average of the observations at the extreme north-east and south-west ends of the traverse. This reference value was then subtracted from individual site means to produce a profile of temperature anomalies. The anomaly profiles could, in turn, be averaged over a chosen set of experiments in order to define an average UHI profile. Figure 3

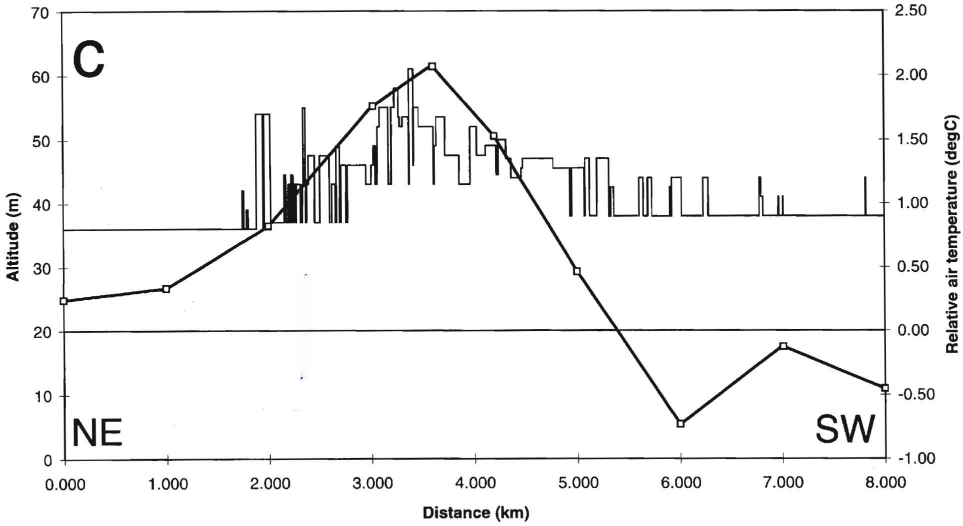

Fig. 3 Continued

shows the result of applying this analysis to (a) 6 experiments conducted in July 1996, (b) 9 experiments in August 1996, and (c) all 15 experiments carried out in July and August. Also shown is a representation of the urban topography, measured by the variation in height and distribution of buildings observed along the traverse relative to ground level (which itself varies between 36 and 39 m above mean sea-level). The urban topography was estimated somewhat subjectively by counting the number of storeys typical of buildings 'within sight' along the traverse and converting to an equivalent height based on an assumed 2.5 m per storey.

In view of the considerable variation between individual profiles and the relatively small sample size, the mean profiles for July and August are remarkably similar. Both indicate a maximum UHI anomaly of the order of 2 degC located at the same site (3.6 km from the north-east origin), and both reveal a similar asymmetry in the profile, with lower but more variable temperatures in the south-west sector than in the north-east. Not surprisingly, the same features appear on the overall mean profile (Fig. 3 (c)). The average maximum measured anomaly is 2.1 degC (standard error 0.4 degC) and the interpolation suggests that the average anomaly exceeds 1 degC for a distance of about 1 km either side of Reading town centre. A distinct minimum near the south-west end of the average profile was also observed in the majority of individual samples. The reason for this feature is not clear, but may be related to variations in surface type within that sector. Its presence points to the difficulty of obtaining representative measures of the overall UHI trend from a small number of fixed-site observations. Another less marked feature is the tendency for the temperature to be slightly greater (by about 0.5 degC) at the north-east extreme of the profile than at the south-west extreme. The majority of experiments took place when the prevailing wind direction was between south-west and south-east. Under such conditions, we might expect a site at the extreme north-east end to be influenced by air advected from off the extensive urban area within a sector between south-west and south-east of the site, thus leading to some asymmetry in the observed profile. However, it is again important to note that even the average profile may be influenced by errors of representativity, and that choosing a slightly different route or a different set of observing sites could have resulted in a significantly different profile of observed temperature anomalies.

Conclusions

Our sampling method does appear to provide a convincing measure of the shape and magnitude of the UHI temperature profile across an urban area the size of Reading. The scale of the region within which a significant UHI impact can be detected was found to be roughly comparable with the size of the urban development itself. In the case of Reading, early-evening air temperatures observed near the town centre were on average about 2.5 degC above the lowest values observed around the outskirts during fair-weather conditions in summer. However, under anticyclonic conditions of strong daytime insolation and light winds, the maximum UHI intensity over Reading has been observed to be greater than 5 degC and in one case as large as 9 degC. These values are consistent with those presented by Oke (1973) for European settlements with populations comparable with Reading's.

There are obvious ways in which the experimental method could be improved, especially if more than one observer were available. For example, measurements recorded by two observers cycling reciprocal routes could be used to reduce the uncertainty due to the time variation of temperature at individual sites, as well as reduce the time taken to complete a traverse. With several observers, it might even be possible to derive a two-dimensional map of the UHI over a small town within which there were a suitable network of safe cycle paths.

Acknowledgement

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Pen portraits of Presidents – Edward Mawley

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Edward Mawley was born at Blackheath, Kent, on 14 May 1842, the second of the three children of Robert Thomas and Marian Mawley. His father was briefly an officer on one of the East India Company ships, but retired early, married, and, shortly after Edward's birth, moved to Fairford, Gloucestershire, to indulge his love of gardening and country life. Edward Mawley trained as an architect at the South Kensington School of Art where he gained a medal, and practised for several years. When he and his elder brother were both working in London, their father moved to Richmond, Surrey, to keep the family together; following his death in 1870, the family, now including Edward's mother and sister, and his elder brother and his wife, moved to Lucknow House, Addiscombe, Surrey, where a garden was laid out on virgin ground. Here Edward's interest in meteorology seems also to have taken root and flourished.

In 1874/75 Mawley and a friend made a round trip to Australia on board SS *Sobraon*, during which voyage he made careful thermometrical observations, noting how far exposure affected the readings. On his return he joined the Royal Meteorological Society, being elected on 16 February 1876. His interest now centred on the growing of roses and the meteorology of his garden and the surrounding district, to the extent of equipping a complete second-order station, the Robinson anemometer being affixed to his chimney. Following his experience on board ship, Mawley was concerned to find the best exposure for his thermometers. Originally he employed a Glaisher stand, but in 1877 he added a Stevenson screen and for five years compared the two sets of