THE SYNOPTIC CLIMATOLOGY OF BIRMINGHAM'S URBAN HEAT ISLAND, 1965–74

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THE urban heat island, a tendency for city centres to have warmer near-surface air temperatures than their rural surroundings, is one of the best-documented local climatic effects. Because the observed temperature difference is ascribed to the effects of the urban fabric it is also one of the best-known of man's accidental modifications of climate. To date, much of the published work has been concerned to report, analyse and model individual heat island incidents using data from short-period ground or aerial traverses in conditions particularly favourable to their development (see for example Chandler, 1967; McBoyle 1970). Rather fewer studies have attempted to derive overall climatologies of heat islands, notable exceptions being the work of Eriksen (1964) at Kiel, Chandler (1965) at London, and Munn, Hirt and Findlay (1969) at Toronto. The present paper outlines the climatology of the urban heat island of Birmingham, UK as revealed by a comparison of daily maximum and minimum temperatures from Edgbaston (52°28′N 01°56′W), a city station, and Elmdon (52°27′N 01°44′W), taken as representative of green field conditions, for the period 1965–74.

THE DATA

The difference between the two stations in both the nocturnal minima and day-time maxima was taken as a measure of the magnitude of the heat island. At the outset it should be stressed that, although these differences have often been used in the literature, for a number of reasons they are a very inadequate measure of heat island effects:

(i) The stations used are at differing altitudes and with differing surrounding relief. Edgbaston is at 152 m (OD) on a broad, open ridge whilst Elmdon is at 94 m (OD) on a moderately extensive plain. It is possible to attempt a correction for altitude by considering potential temperatures, but only at risk of serious errors in surface inversion conditions, and, in view of the relatively small altitude difference involved, this was not attempted.

(ii) There is no guarantee that the compared minima and maxima are contemporaneous, so that strictly speaking like is not being compared with like. If the observations of Oke and Maxwell (1975) in two Canadian cities are of more general validity, then the differences used are likely to underestimate urban effects. Dealing with nocturnal temperature changes these authors show that a temperature difference builds up rapidly after sunset, reaches a maximum value in the late evening and then declines towards sunrise. The actual values of temperature show the usual steady fall to minimum shortly before dawn and it is at this time of reduced urban-rural contrast that the minima are recorded.

(iii) Finally, it is necessary to be careful in interpreting the results. The term 'urban heat island' is unfortunate in that it gives an impression of a monolithic feature covering the city area whereas, as Parry (1963) pointed out, we are in fact dealing with a patchwork of individual microclimates. The temperature records used are best regarded as representative of local site conditions rather than simply 'urban' or 'rural'. The Edgbaston site lies in a redevelopment area some 2 km west of the city centre where high density nineteenth century housing is being replaced by more open housing. By contrast, the Elmdon site is at a small airport about 10 km east of the city centre on the edge of the built-over area.

Despite these difficulties, the temperature data used are broadly representative of the heat island of Birmingham and three distinct approaches have been used to summarise its climatology. **The** first examines, overall, seasonal and synoptic variations in the temperature differences; the second looks at the seasonal and synoptic distributions of heat island 'events' and the third examines the various heat island types.

TABLE 1. Mean temperatures (°C), 1965–74

	Central Birmingham (Edgbaston)	Surroundings (Elmdon)	Difference T_{u-r}
Overall mean	9·49	9·22	0·27
Mean maximum	12·41	12·90	−0·49 (0·56)
Mean minimum	6·56	5·54	1·02 (1·64)

(Bracketed values are the standard deviations of the differences)

THE CLIMATOLOGY OF TEMPERATURE DIFFERENCES

(i) *Overall mean values*

The overall mean values obtained for both stations are shown in Table 1. It is clear that, on average, Edgbaston was 0·27 K warmer than Elmdon but that this difference is entirely due to the +1·02 K average difference in nocturnal minima. Indeed, the average difference in maxima, −0·49 K, is indicative of a distinct tendency for the city site to be colder by day than its rural surroundings. These differences are all statistically significant, as revealed by the usual tests, and give rise to even more pronounced possible effects on man. They give rise, for example, to a 10 per cent greater heating requirement, as measured by the accumulated degree days below 15·5°C, and a much greater risk of air frost, at the rural site. Fig. 1 shows the differences in minima as a histogram. This can be seen to be unimodal, peaking at the 'no effect' value of 0 and with a distinct positive skew, but

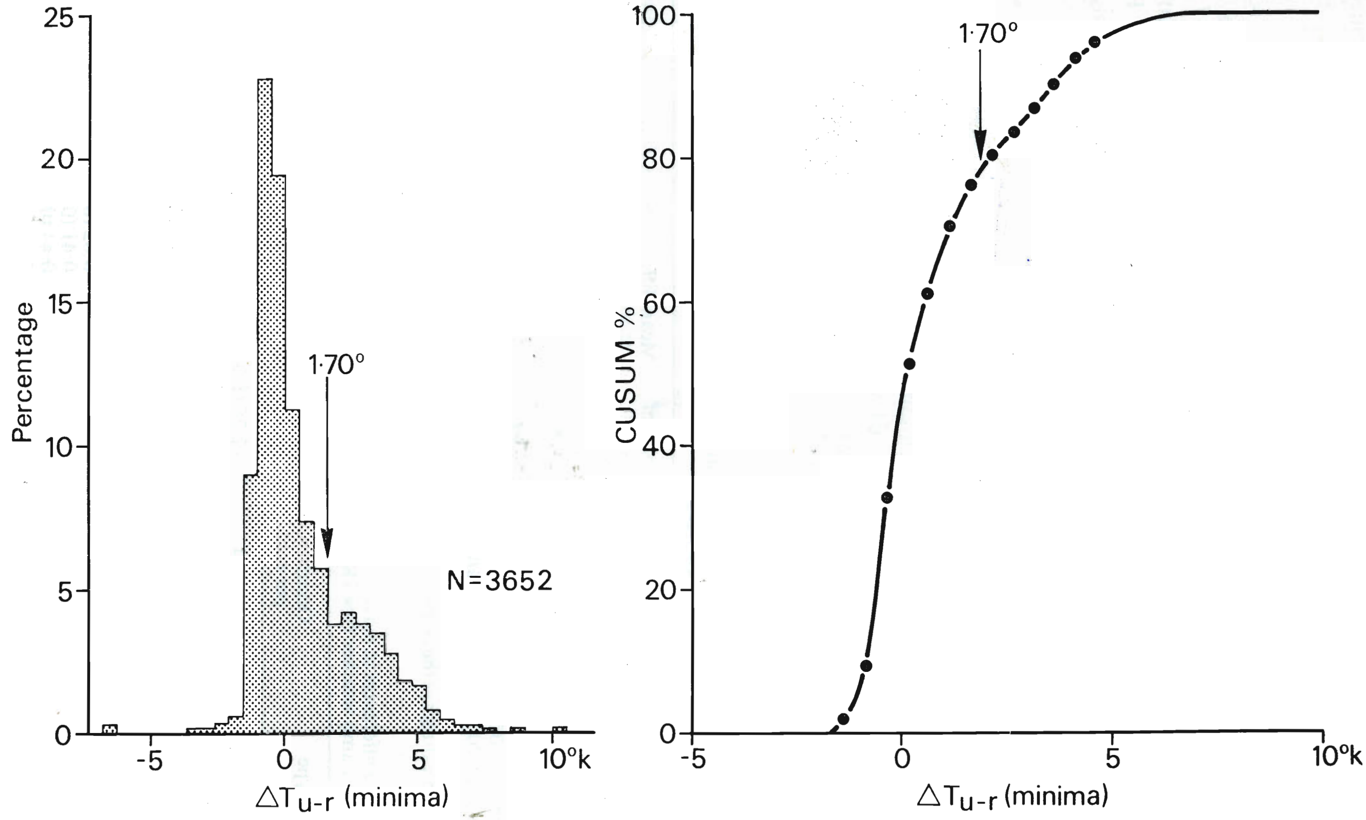

Fig. 1. Frequency distribution of urban heat island magnitude, Birmingham, 1965–74

nocturnal cold islands, when the city is colder than its surroundings, do occur. Finally, it should be noted that over the 10-years' records examined, no evidence of any secular trend in these values was detected.

(ii) *Seasonal variations*

Table 2 presents the results of an analysis of the differences according to the 'natural seasons' as defined by Lamb (1950). There is evidence of a tendency for differences in the minima to be at a maximum in autumn (+1·34 K) and spring (+1·11 K) and at a minimum in fore-winter. By contrast the differences in maxima have their largest absolute value in high summer when the city is on average 0·59 K colder than its surroundings.

(iii) *Variations by airflow type*

Table 3 presents similar results for the temperature differences classified by the original eleven 'weather types' as defined by Lamb (1950, 1972). In considering these data it should be remembered that the Lamb catalogue is at best an inadequate measure of types of weather and is better regarded as a catalogue of airflow type rather than weather (Barry and Perry, 1973). Moreover, the categories are defined by each day's pressure pattern whereas the minimum temperatures relate to nocturnal conditions. Nevertheless, an

TABLE 2. Differences in maxima and minima, T_{u-r} for Edgbaston–Elmdon 1965–74 according to Lamb's 'Natural Season' (K)

Season		No. of days	Mean diff. minima	Mean diff. maxima	% nights +1·7
Late Winter	20 January–29 March	692	0·78 (1·54)	−0·49 (0·47)	21·8
Spring	30 March–17 June	800	1·11 (1·70)	−0·51 (0·55)	29·7
High Summer	18 June–9 September	840	1·08 (1·64)	−0·59 (0·67)	29·3
Autumn	10 September–19 November	710	1·34 (1·84)	−0·45 (0·49)	33·7
Fore Winter	20 November–19 January	610	0·73 (1·40)	−0·36 (0·54)	19·1

(Bracketed values are the respective standard deviations)

TABLE 3. Differences in maxima and minima, T_{u-r} for Edgbaston–Elmdon 1965–74 according to the Lamb weather type (K)

Airflow Type	Occurrence per cent	Mean diff. in minima	Mean diff. in maxima	per cent nights +1·7
Anticyclonic (A)	18·4	2·26 (1·99)	−0·23 (0·51)	55·2
Unclassified (U)	5·3	1·39 (1·86)	−0·42 (0·54)	34·9
South-east (SE)	3·1	1·32 (1·83)	−0·41 (0·36)	32·1
Southerly (S)	5·8	1·14 (1·59)	−0·44 (0·51)	31·8
Northerly (N)	8·5	0·84 (1·44)	−0·53 (0·49)	24·1
Westerly (W)	22·3	0·67 (1·32)	−0·61 (0·50)	18·1
South-west (SW)	3·9	0·67 (1·15)	−0·58 (0·51)	17·4
North-west (NW)	7·8	0·63 (1·20)	−0·62 (0·57)	18·6
Easterly (E)	7·4	0·63(1·42)	−0·41 (0·41)	18·2
North-east (NE)	2·8	0·51 (1·35)	−0·44 (0·53)	17·4
Cyclonic (C)	14·7	0·49 (1·20)	−0·61 (0·50)	15·2

(Bracketed figures are the respective standard deviations)

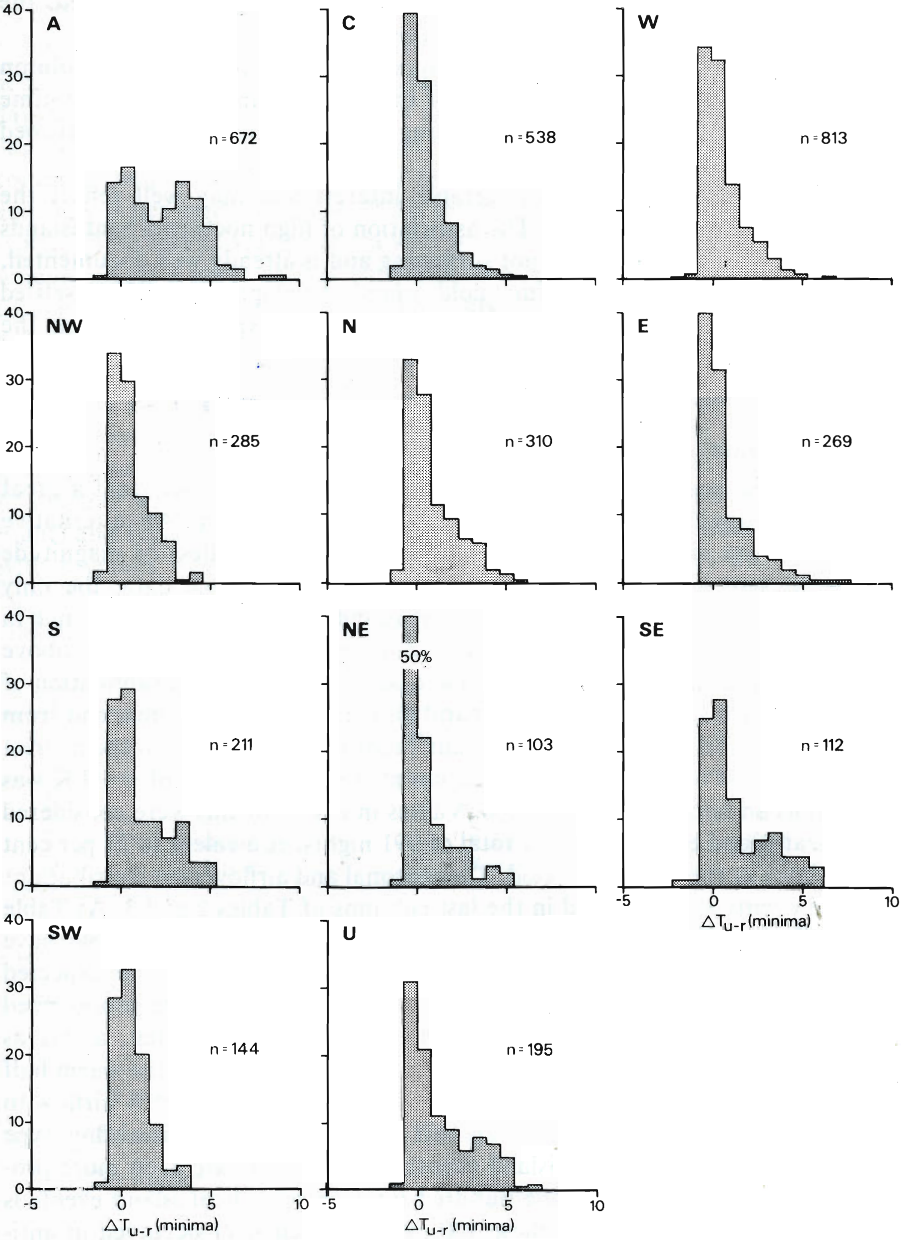

Fig. 2. Frequency distributions of urban heat island magnitude by weather type, Birmingham, 1965–74

examination of the records for the differences in minima, also shown graphically in Fig. 2, emphasises the importance of anticyclonic circulation with a mean difference in minima of +2·26 K, some 0·9 K greater than the next most important type, the unclassified 'U'. As might be expected, the nocturnal effect is least in cyclonic conditions (C).

The results for the differences in maxima, shown in the fourth column of Table 3 are almost a mirror image of those for the minima. The day-time city-centre cold island effect is on average most in the generally disturbed types westerly (W) and cyclonic (C).

This relationship is of considerable interest and may well reflect the operation of differing controls. The association of high nocturnal heat islands with anticyclonic conditions is not surprising and is already well documented, but that of maximum day-time cold island development with unsettled westerly and cyclonic conditions is not. A possible explanation is that the increased turbulence during stronger winds over city areas results in greater mixing of cold air brought downwards.

THE DISTRIBUTION OF HEAT ISLAND EVENTS

Analyses, such as those above, which use mean values conceal a great deal of the reality of nocturnal heat island development. An alternative treatment is to isolate specific heat island 'events', regardless of magnitude and to present a climatology of these. Given the available data, the only criterion of presence or absence of a heat island is the observed difference in minima. The problem is to use this to develop a sensible threshold above which an event can be considered to have occurred. From an examination of the frequency distribution of urban-rural differences in the minima, and from the consideration that it is the first value recorded (records are to the nearest 0·1 K) in excess of one standard deviation above zero, a value of +1·7 K was selected as an appropriate threshold. Values in excess of this were considered to be heat island events, giving a total of 991 nights, equivalent to 27 per cent of all nights in the ten-year period. The seasonal and airflow type distributions of these events are presented in the last columns of Tables 2 and 3. As Table 2 shows, it is only the spring, high summer and autumn seasons that have occurrences in excess of the 27·1 per cent of nights that would be expected were events equally distributed over all seasons and there are pronounced deficits in both winter seasons confirming the earlier result that, as far as Birmingham is concerned, heat island formation is a feature of the warm half of the year. Table 3 serves to emphasise the importance of type A airflow to heat island development: more than half of all nights with this airflow type can be expected to give heat island events. These results are even more pronounced if the frequency of the hundred most extreme heat island events is considered, as in Table 4. Of these 100 extreme events, 71 occurred in anticyclonic conditions.

TABLE 4. Monthly frequency of the 100 greatest heat island events (+5·0 K), Edgbaston–Elmdon 1965–74

Month	J	F	M	A	M	J	J	A	S	O	N	D
Number	2	5	15	6	8	9	2	6	18	17	6	6

HEAT ISLAND TYPES

Recently, Atwater (1977) has recognised four distinct heat island types according to the relative temperatures of the city and its surroundings by day and night. Table 5 summarises the relevant criteria and the number of days of each type in the Birmingham record. Type 1 heat islands are the most common (54 per cent), followed by type 3 (29 per cent), type 2 (14 per cent) and only 3 per cent in type 4. With the exception of the high frequency of type 3, these results are in accord with previous work. The basic classification scheme places a great deal of emphasis on a zero threshold in assigning days to a particular heat island type. To overcome this, the data have been re-analysed inserting a neutral category in both the maximum and minimum criteria, with the results shown in Table 6. It can be seen that, when both maximum and minimum are taken into consideration, 87 per cent of days fall into one or other of the five 'neutral' categories. Of the remainder, the great majority (404 days) fall unequivocally into type 1 with the city colder by day and warmer at night. Only 49 are type 2 (city warmer by both day and night) and types 3 and 4 are hardly represented at all. This result is in accord with previous work in mid-latitude cities by Mitchell (1961) who showed a type 1 heat island in summer in Vienna and Hage (1972) who showed a similar result for Edmonton, Alberta.

TABLE 5. Temperature difference between urban and rural areas for each heat island type

Type	Higher daytime temperature	Higher nocturnal temperature	No. in Birmingham record
1	Rural	Urban	1964
2	Urban	Urban	507
3	Rural	Rural	1054
4	Urban	Rural	123

TABLE 6. Heat island types for Birmingham, 1965–74 (no. of occurrences, n = 3652)

		NIGHT		
		City colder	City neutral (−0·8 K to +0·8 K)	City warmer
DAY	City colder	18	860	404
	−0·6 K			
	City neutral	23	1318	957
	+0·6 K			
	City warmer	1	22	49

CONCLUSIONS

In so far as it is revealed by an urban rural comparison of nocturnal minima, heat island development is a fairly frequent feature at Birmingham, especially during spring and autumn in settled anticyclonic conditions when city temperatures can be as much as 5 K greater than those in the rural surroundings. During the day-time there is a less well marked tendency for the city to be colder than its surroundings, especially in spring and high summer. These negative temperature anomalies are associated with disturbed airflow types, suggesting that vertical mixing is an important factor in their development. In common with summer heat islands reported from other mid-latitude cities, Birmingham's heat island is predominantly of type 1, that is the city to be colder than its surroundings, especially in spring and high surroundings.

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