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A REVIEW OF URBAN CLIMATOLOGY

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Abstract

The review attempts to elucidate the history of interest and the developing research work done in the field of urban climatology, with special emphasis on temperature. References are made to the works of certain researchers whose publications have not yet been translated into the English language . The reference list is by no means complete but contains most of the important works in this field.

As the population of the industrial world became crowded together into urban communities during the last sixteen decades, so the effect of cities on meteorological features has slowly been recognised as a significant element in a country's climate. Some parameters have come to be dealt with more fully than others, e.g. air pollution, temperature, precipitation and wind field, whereas cloud cover, "degree days", fog and visibility have had only intermittent attention.

An overall view of the hundred or so years since the first steps were taken to study the nature of urban climate indicates that two processes have been in operation. On the one hand scientific advances have introduced new techniques giving an added impetus to research. This has occurred at three major periods; first in the years between 1800 and 1850, then in the 1930's with the introduction of the mobile traverse and the use of more than two fixed stations and finally a rebirth after World War II with a fillip in urban research culminating in the works of Sundborg and Chandler. To illustrate this development three graphs have been drawn (Figures 1, 2, and 3), two of which indicate the growth of research into temperature

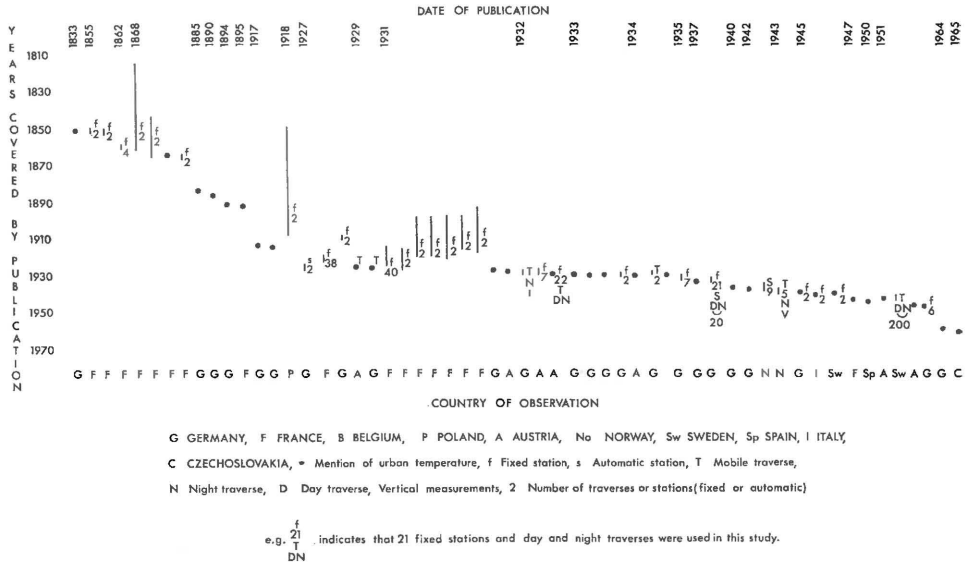
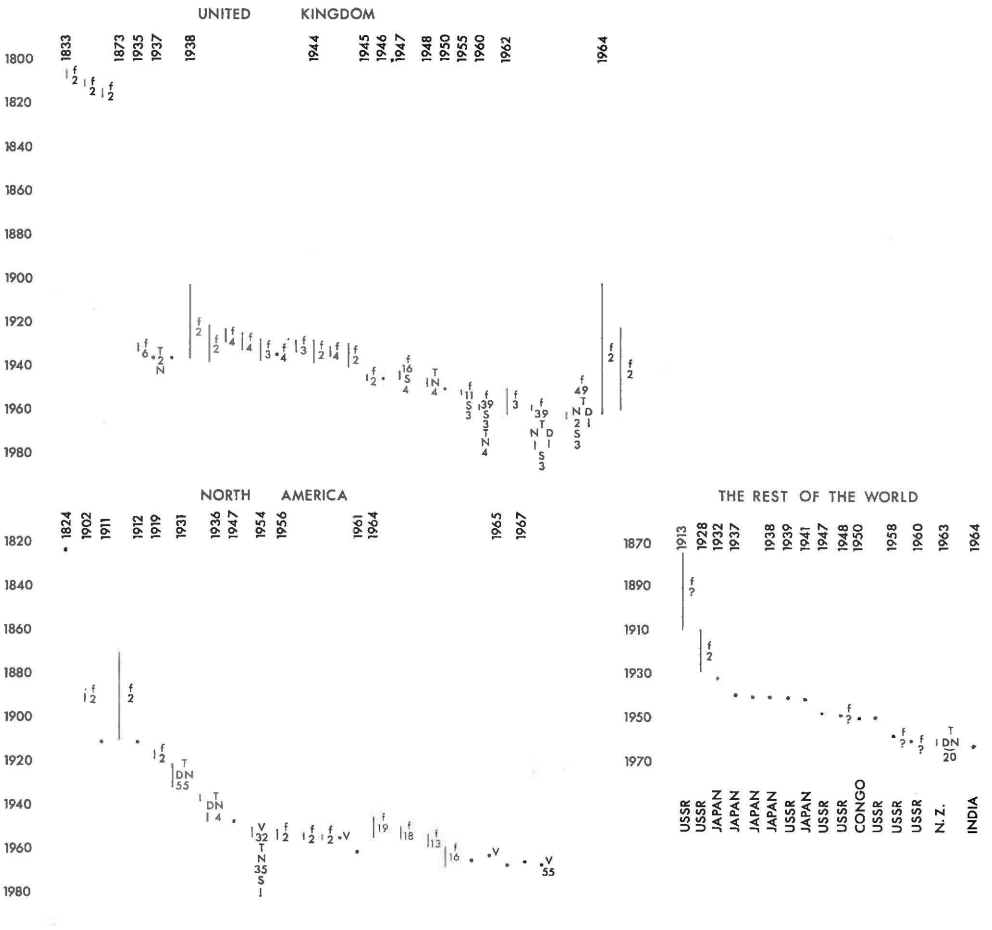


Figure 1. The course of research into urban climate in Europe.



SEE FIGURE 1 FOR THE LEGEND AND AN EXPLANATION OF THE DIAGRAMS.

Figure 2 (above). The course of international research into urban climate.

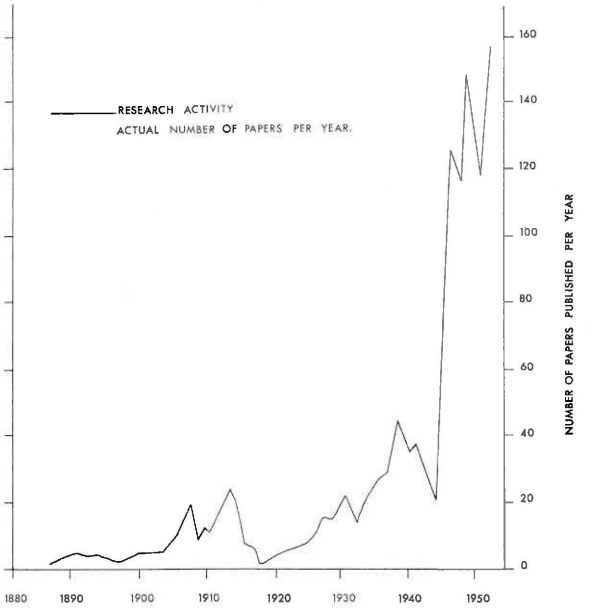


Figure 3 (right). Progress of research activity into atmospheric pollution (after Halliday, 1961).

and one the work in the field of atmospheric pollution. From these graphs it can be seen that research activity has been adversely affected both by periods of war and by economic depressions. On the other hand, as more and more people became urbanised the need for research into urban climate became realised and provided the incentive for study into factors not so popular or evident, e.g. the relationship between visibility, sunshine and pollution, and the interconnection between temperature, pressure, cloud cover and wind field.

Since temperature by itself is a regularly forecast element of wide interest to the public its unique pattern in and around a city deserves careful study. This it has received. With the exception of air pollution it was the first element to attract the interest of climatologists in their studies measuring and interpreting the effect of a city on the regional climatic pattern. The history of research into air pollution is ably summarised by Halliday in "Air Pollution" published in 1961 by the World Health Organisation. There he describes the dawning realisation of its existence and danger, and gives account of the progress made in collating measurements of pollutants and the subsequent development of methods of ameliorating atmospheric pollution in the major industrial countries.

As early as 1818 and 1833 Luke Howard wrote on the systematic investigations which he had made over a number of years at various positions in what is now North-east London, and at Somerset House. He dealt mainly with temperature but at the same time measured wind speed, wind direction, precipitation and relative humidity. "Apart from the drawback that the instrument at Plaistow (1806-09) was hung from a laurel bush, and at Tottenham (1813-16) the thermometer was 10 feet above the ground on a north facing wall, his work was monumental in this field" (Chandler 1962b). Indeed his work was the first of its kind.

Between 1855 and 1868 several articles by M. E. Renou were published following observations made at four stations in and around Paris. Renou's investigations were tackled in a similar manner to those of Howard in that he measured most climatic factors although his main aim was to find the town-country temperature difference which he called the "error in the temperature caused by the town". Measurements of other meteorological factors were made simply in order to supplement his investigations into temperature characteristics. It was not until a much later date that other factors were considered for their own importance and not simply in the significance of their interconnection with temperature.

In Germany, Dove in the 1850's made mention of the town-country relationship, an observation which was pursued no further until 1885 when Hann published his work on the temperature variations of Berlin.

Although North America was not to begin its industrial programme until the 1840's (James 1965) the indication that man's activities were likely to cause changes in climate was not overlooked. Thomas Jefferson made mention of this in a letter to Dr Lewis C. Beck of Albany, New York, when in 1824 he wrote "climatic surveys should be repeated once or twice in a century to shew the effect of clearing and culture towards the changes of climate" (Landsberg 1956). However this continent had to wait until 1891 for concrete evidence of a change in climate caused by man for it was in that year that Hammon and Duenchel (1902) compared temperatures between a "downtown" station in a smoky factory area of St Louis and an outlying station on a smoke-free hill in Forest Park. Theirs was one of the earliest attempts to correlate temperature effects with air pollution.

These, then, formed the fundamental works upon which later research in the 20th century was to be based.

The century following 1820 saw climatological studies content to illustrate by case studies the differences existing between two fixed stations. A masterpiece of

the era, in addition to that of Howard, was the work done by Kremser (1908) in which he emphasised the significance of relative humidity and wind in addition to temperature. This was a break away from the tradition of temperature studies as was Russell's article on fog (1892). Palmer (1911) and Kassner (1917) both mention precipitation, while Kremser in 1909 had written on wind field.

The only exception to the trend of using two fixed stations was carried out by Renou (1862, 1868) who compared the variations in temperature between four stations over the 10-year period 1858-68. This was a minor breakthrough advancing what in fact would logically have occurred in time but it was an innovation which was, incredibly, ignored. Not until 1927 when Louis Besson published his early work in temperature variations was mention made of this technique again. By 1931, using data from 38 stations in Paris, Besson produced a monumental piece of work. Insufficient attention has been paid to his classic papers — a sad oversight, for he studied every aspect of the climate of Paris not excluding temperature isotherms which today would delineate what is known as a city's "heat island" and knew of the latter's movement relative to differing wind directions. His research into the cloud cover and its variations over a city remains as one of the most scientific studies for this parameter. Strangely, Besson's results differ widely from those obtained by Chandler (1962b) in his London Survey.

Altogether Besson covered the aspects of cloud cover, insolation, transparency of air, relative humidity, wind, temperature and to some degree, air pollution. However before the idea of using many fixed observation stations could disseminate, Schmauss in 1925 employed a thermograph and a hygrograph to study temperature and humidity variations respectively and Schmidt used a motor car for the first mobile temperature traverse ever undertaken, carried out in Vienna in 1927. So it was that Besson's work was overlooked in favour of these innovations. It was during this period too that Ashworth (1929) published a paper on the variation of precipitation and air pollution in Lancashire cities, a paper, incidentally, which has stood up well to the test of time.

This, then, was an era of rapid developments, a result of intuitive inspiration and technological advancement. The novelty of mobile traverses caught the imagination of climatologists and consequently many studies followed similar to the original of Schmidt, e.g. Peppler in Germany (1929), Brooks in U.S.A. (1936), Middleton and Millar in Canada (1936) and Matthews in England (1937). It is interesting here to note the time-lag in the diffusion of this idea from Austria to other parts of the world.

Advances in urban climatology from the temperature point of view came at different times in different parts of the world because of this time-lag, in itself mainly due to the delay in works being translated into the respective languages of individual countries. However as ideas did diffuse they became refined to include new concepts. In Europe the period of greatest interest in the subject of urban climate, in as far as can be assessed from the number of publications, would seem to be between 1929 and 1935. For the British Isles the corresponding period would be 1935 to 1947, in America 1954 to 1964 and for the rest of the world in general and Japan in particular, 1932 to 1941 (Figures 1 and 2). It is significant to note that, although the use of the mobile traverse stimulated interest in the subject, yet during each of the respective periods referred to above a much greater reliance was placed on the use of results from fixed observation stations.

The mobile traverse, however, did constitute something of a break-through but with the perhaps unfortunate result that its supporters tended to concentrate research into temperature alone and not until Balchin and Pye (1947), Landsberg (1947) and Sundborg (1951) did a return to the complete climatology occur. However, this is not to say that work in other elements was entirely neglected. Papers published in the 1930's and early 1940's dealt with other parameters, but often

individually. Here can be cited Albrecht and Grunow (1935) — wind field; Bilham (1938) — insolation and precipitation; Garnett (1939) — insolation and shadow; and Tinn (1939) precipitation and thunderstorms.

With this background in mind one would perhaps expect that the development of investigation techniques would have pursued the following pattern: the first step (1) from using two fixed stations to (2) more than two, then (3) self-recording instruments followed by (4) mobile traverses. The next step in fact was the use of an upward traverse (5) to discover the effect of height on different parameters, while finally came the realisation of the value of using a combination of techniques (6). Figures 1 and 4 indicate how this pattern applies to Europe with regard to temperature. Although research into other parameters is now tending towards this pattern, most of the work being published remains reliant on stages (2) and (3) with the exception of recent research into relative humidity. The innovators of these different methods were: (1) Howard (1813), (2) Renou (1862), (3) Schmauss (1925), (4) Schmidt (1927), (5) Spence (1935), (6) Balchin and Pye (1947).

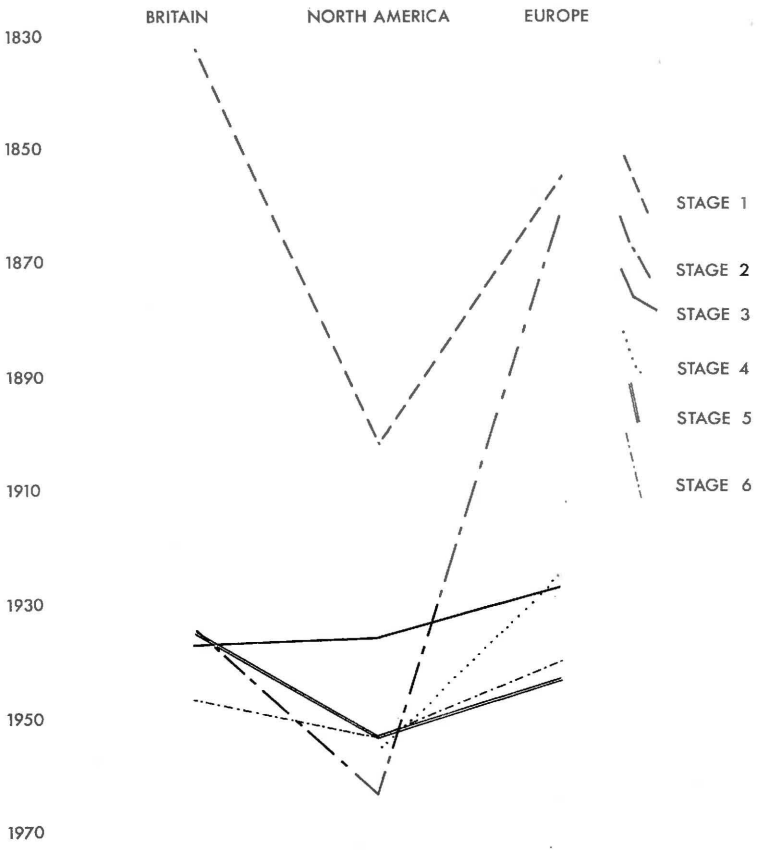


Figure 4. The major steps in the development of research techniques for urban climatology.

Both Britain and North America had different developments from those of Europe, especially since the 1930's, a fact attributable partly to the differing degrees of interest shown in these techniques and partly to the differing speeds of their diffusion. The notion of using more than two fixed stations did not reach the

American continent until Woollum's survey of temperature and precipitation in Washington carried out over the years 1946-64 and published in 1964, whereas the mobile traverse was being practised by Brooks in 1930, several years earlier, to assist his investigations into relative humidity, fog and temperature variations in Springfield, Massachussetts. In the case of Britain the mobile traverse was introduced in 1937 with Matthews' work but thereafter interest waned. The method lost popularity to the use of several fixed stations which Spence had advocated in 1935, and which was later employed by Bilham (1938) in London (insolation), Tinn (1939) in Nottingham (precipitation) and Manley (1944) in Durham and Manchester (frost). Not until Chandler's work on London in 1960 did the mobile traverse make its reappearance when he carried out a survey using a combination of fixed stations, self-recording instruments and mobile traverses, the first of its kind.

The need to conduct recordings upwards through the atmosphere was first recognised by Spence in 1935 and was followed by Godske (1943) and Balchin and Pye (1947) when they studied temperature measurements taken at various heights above sea level. The results when processed gave temperature curves which Spence entitled "lapse rates" and Godske called "vertical cross-sections". However the first temperatures actually recorded at varying heights *in a vertical plane* were those of Duckworth and Sandberg (1954) when they analysed the characteristics of urban gradients determined from vertical data in order to find out their relationship with city size. At selected locations in California balloons carrying "wiresonde"* equipment were released simultaneously from a town and a country site for this purpose. Further work has been done in this subject by Demarrais who in July 1957 took temperature measurements as recorded at the 60-, 170-, and 524-foot levels on a town television station aerial in Louisville. His results indicate that vertical temperature variations at night are greatly affected by the urban area. Latterly Summer's (1965) work in Montreal in the same field prompted his urban heat island model, a theory which should provide a stimulus for further research in this field. In addition, in their analysis of the data obtained from the "tetroon transponder system"† applied to New York City in 1965, Hass, Hoecker, Pack and Angell (1967) commented on the possible use of this system to determine the rate of vertical diffusion of air over cities.

It is surely axiomatic to suggest that to conduct a competent urban study requires more than one method alone. To rely solely on self-recording instruments is unwise since they record changes in temperature and humidity more reliably than actual readings. However, it was a method used widely by earlier climatologists: Schmauss (1925) for relative humidity and temperature analyses, and Spinnangr (1942) for temperature studies. The method can be successfully employed when used in combination with another, e.g. Balchin and Pye's (1947) examination of temperature, relative humidity and rain for Bath when they made use of sixteen fixed stations in addition to four self-recording instruments, producing the most comprehensive urban climatography since Besson in 1931. The trend was then set and there ensued the classic works of Sundborg (1951) at Uppsala, Landsberg (1947 and 1956) in the U.S.A., Parry (1956) at Reading, and Chandler (1960's) in London. In Europe the "combination" technique has not caught the interest of urban climatologists to nearly the same extent as in Britain and North America both of which countries employ a variety of combinations in present research programmes. For example, Duckworth and Sandberg (1954) used mobile traverses, self-recording instruments and vertical ascents in

* *Wiresonde equipment* — an unaspirated thermistor is carried aloft by a balloon cluster. A conducting cable tethers the balloon and transmits the electrical impulses to a temperature indicating unit on the ground.

† *Tetroon transponder system* — a system of constant volume balloons (tetroons) which have a radar beacon installed in them allowing their path to be tracked by weather radar systems.

order to examine climatic elements in three dimensions. In Britain the epitome of investigations undertaken so far is that of Chandler (1960's) who has over the last eight years made a detailed study of London's climate using 49 fixed stations, at least three self-recording units along with numerous mobile traverses undertaken both by day and by night. This has enabled him to examine temperature variations, relative humidity, insolation, fog, visibility and wind movements. Chandler's work into the latter has produced his account of the "land and sea breeze" effect occurring at the junction of city and rural areas.

The latest innovations on the research scene are the use of helicopters to measure temperature changes in the vertical along with tracker ballons traced by means of radar and employed for the purpose of discovering air currents within a city which are so significant in the movement (or lack of it) of air pollution (Hass, Hoecker, Pack and Angell, 1967). However, for reasons of limited finance or otherwise, most of the recent and, indeed, present research into the climate of cities must be content to rely on a selection of the six methods described earlier.

Today no climatic element is left unchanged in an urban environment. The work which has already been done in this field, discussed incompletely in this review, in fact provides only a backcloth on which future studies will be performed in the essential search for a fuller understanding of urban climate. The dangers of air pollution have become all too evident. What must be discovered now is whether changes in other elements, however slight at present, will become sufficiently large in future for man to regret his ignorance of them; and whether the knowledge of these processes can enable man to alter the weather to suit his own needs.

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