A HUMAN COMFORT CLIMATOLOGY OF THE BRITISH ISLES

by

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Submitted for the degree of Ph.D. at
the University of Leicester

October 1980

"We shall never be content until
each man makes his own weather
and keeps it to himself."

Jerome K. Jerome: 'On the
Weather'. The Idle thoughts of
an Idle Fellow. (1889).

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ACKNOWLEDGEMENTS

This research has been supported financially by the Social Science Research Council and I would like to record my appreciation for this support over the three years 1977-80, and also for the Geography Department at Leicester University for having sufficient faith in me to put my name forward for their quota award.

I am indebted to many people who have helped and encouraged me during the three years of my research at Leicester University Geography Department. I am particularly grateful to David Unwin who first inspired my interest in Climatology and who as my joint supervisor has shown remarkable courage to have tolerated me for the last few years! My other supervisor Gareth Lewis also deserves considerable thanks for having ventured towards physical geography and, like David, has always been there to give encouragement and advice when needed. There are many other people on the academic and technical staff and my fellow postgraduates in the Geography Department who have all been prepared to discuss my research with me and I owe them considerable thanks.

My thanks must also be recorded to my parents who have supported me in my academic leanings and my husband, John, who has suffered much particularly during the writing up stages when he showed considerable tolerance in reading the almost-final draft of this thesis.

Finally, I would like to express my gratitude to Mr. D. Hogg, the Director of the Computer Centre at Loughborough University for allowing me time to complete my thesis since I commenced work there in May.

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Chapter One

Approaches to Comfort Climatology

1.1 Introduction

This study examines some aspects of the links between man and environment from the viewpoint of what can be called Comfort Climatology. This field is of interdisciplinary interest and to date research reflects a considerable breadth of concern by geographers, engineers, architects, physiologists and psychologists who have all considered the problem of man-climate relationships. Their work is varied and reflects different outlooks and problems with only occasional points of contact.

In considering human comfort in relationship to the ambient weather and climate, it is evident that three basic approaches have been used. The first attempts to define the weather and climate using measures that have more relevance to man's bodily comfort than the usual simple climatic elements. Such an approach is evident in studies of the Temperature Humidity Index (Thom, 1959) and indices of windchill (Siple and Passel, 1945; Steadman, 1971) and in the most recent work in this field which uses the body-environment energy balance. The second approach sets up controlled experiments in which people are subjected to a changing environment and their reactions evaluated in some way. This method has the advantage of allowing the isolation of individual environmental factors notably temperature and humidity. The third approach attempts a more direct evaluation by asking respondents to assess their real outdoor environment using psychometric techniques of measurement. This approach in effect attempts to evaluate the weather related part of Kirk's (1963) Behavioural Environment and is in contrast to the energy balance approach which is concerned with part of the Phenomenal Environment. In order to set the current work into context, this first chapter begins by reviewing previous work on human comfort climatology using these three approaches and concludes with an assessment of the problems which have emerged and an outline of the manner in which the present work attempts to overcome them.

1.2 An Energy Balance Approach

This approach is based on models of the energy balance which attempt to find meaningful elements and combinations of elements to which man reacts. The complexity of the human response to the environment was noted by Auliciems and Kalma (1979) who felt that this has resulted in the limited amount of research in the field of comfort climatology. This approach has been most successful in dealing with the thermal environment which is only a small part of man's total environmental experience.

In an attempt to evaluate the heat exchange between man and environment various comfort indices have been developed using the basic body-environment energy balance equation:

$$M \pm R \pm C - E = Q \qquad (1.1)$$

Where Q = change in the heat content of the body
R = radiative)
C = convective) heat fluxes
E = evaporative)
M = metabolic rate.

One of the first examples was the Windchill Index produced by Siple and Passel (1945) which was an empirical index designed to estimate the cooling power of temperature and wind from observations of the rate of cooling of water. It is a linear equation of the form:

$$H = (10.45 + 10\sqrt{V} - V)(33 - T) \qquad (1.2)$$

Where H = heat loss in Kcal $m^{-2}hr^{-1}$
V = windspeed in ms^{-1}
T = air temperature in deg. C..

The index has been criticised by Court (1948) who noted that it only represents the dry convective cooling power of the atmosphere and as such is unrealistic in that it only describes one of the various ways in which the human body exchanges heat with the atmosphere. Falconer (1968) felt that despite this weakness the index had value in planning outdoor activities and for military purposes. A more realistic energy balance model has been produced by Steadman (1971) based on an average, clothed, mobile human exposed to varying temperatures and windspeeds. Steadman's Windchill Index has been mapped for Lowland Britain by Smithson and Baldwin (1978) and Mumford (1979) and for Highland Britain by Baldwin and Smithson (1979). These studies are discussed further in Chapter Five.

An alternative approach to defining cold stress is to evaluate the amount of clothing required to maintain thermal comfort. As Woodcock (1964) has pointed out the study of the effects of climate on man must include a consideration of clothing. Much of the work on clothing requirements has been stimulated by the needs of the military and organisations such as the various Arctic Surveys whose personnel were being moved from temperate to more extreme climatic zones. The heat stress caused by clothing under desert conditions was discussed by Adolph (1947) whilst Brunt (1947), Siple (1949) and Lee and Lemons (1949) attempted global climatic classifications based on clothing needs for the military. An early example of using clothing requirements as an end product of an energy balance study is found in Gagge et al. (1941) who discussed the concept of a clo unit which assessed the amount of insulation provided by clothing under certain environmental conditions. This idea has been developed by Auliciems, de Freitas and Hare (1973) (see also Auliciems and de Freitas, 1976) who produced an energy balance model for the clo unit incorporating temperature, windspeed, solar angle, optical air mass, cloud and metabolic rate as its parameters. This index was mapped for Canada in their 1973 publication and the resulting distribution reflected the importance of latitude and proximity to the coast with Vancouver having the most favourable winter level of the clo unit. More recently de Freitas (1979(a); see also Fischer, 1979 and de Freitas, 1979(b)) has mapped the clo unit for Northern China and his map of the winter distribution also revealed that latitude is the major control.

The indices described so far are mainly concerned with cold stress, however the energy balance approach has also been applied in studies of comfort in hot environments which were summarised by Givoni (1976) who described the five major thermal indices which are listed below.

(i) Effective Temperature. This index, which incorporates temperature, humidity and windspeed, was first proposed by Houghten and Yagloglou (1923) and later developed by Smith (1955) to predict sweat rate as a function of the original Effective Temperature. Yagloglou (1947) noted that the index overemphasised the effect of humidity whilst Smith (1955) found that different windspeeds had varying and unreliable effects on the index. Givoni (1963(a)) also found discrepancies in the weightings of air velocity and humidity around a mean value of 32 degrees Effective Temperature.

(ii) The Resultant Temperature. This index was developed by Missenard (1948) also using temperature, humidity and windspeed as parameters. Although Givoni (1976) discovered discrepancies in relation to physiological responses he found this second index more reliable than the Effective Temperature Index and he suggested that the Resultant Temperature Index is more satisfactory in predicting the response of people at rest or engaged in sedentary activity.

(iii) The Predicted Four Hour Sweat Rate Index. The index takes account of metabolic rate and clothing as well as climatic factors and finds the sweat rate resulting from four hours exposure to certain conditions. Smith (1955) suggested that it is more reliable than the Effective Temperature Index, which is in agreement with the comments of Macpherson (1963) who used both indices in his work in Singapore.

(iv) Heat Stress Index. This index was developed by Belding and Hatch (1955) using the same parameters as used in the Effective Temperature Index. It seems suitable for analysing the relative contribution of the various factors resulting in thermal stress but not for predicting quantitative physiological responses to the stress (Givoni, 1976).

(v) Index of Thermal Stress. The inadequacies of the four indices discussed above led Givoni (1963(a)) and Givoni and Berner Nir (1967(a)) to propose this fifth index which incorporated a consideration of the environmental conditions, clothing, metabolic rate, and the physiological strain as manifest by the sweat rate. Givoni (1976) found this index useful in studying the range of conditions between comfort and severe stress, provided that thermal equilibrium was maintained.

In addition to these five indices another heat stress index is the Discomfort Index or Temperature Humidity Index (THI) developed by Thom (1959) who used the linear combination of the wet and dry bulb temperatures:

$$THI = 0.4\ (Td + Tw) + 15 \qquad (1.3)$$

Where Td = dry bulb temperature deg. F.
Tw = wet bulb temperature deg. F..

Thom found that this gave a reliable indication of the degree of discomfort and suggested that it would be useful to use it for a cooling-degree-days system with 60^{o} THI as a possible base level. At the time of Thom's paper the index had been adopted by the Washington Metropolitan

Area where the government regulations allowed supervisors to give consideration to the mass dismissal of employees when the THI in their offices reached 86° THI or higher. Thom initiated an experimental period in which the predicted THI was given as part of the weather forecast in the United States of America and Hare and Thomas (1974) noted that it was a part of the normal weather forecast in Canada at the time of writing.

There are a number of other studies which have developed indices using an energy balance approach; these include the work of Gates (1972) whose comfort index included a consideration of body and air temperature and metabolic rate, and the less general humiture index which was designed by Winterling (1979) for use in Jacksonville, U.S.A.. A 'physiological strain' index was developed by Hounam (1970) who produced maps for Australia showing the distribution of the frequency of days on which a critical value of this index was exceeded. This paper is unusual in two respects: first, this is one of the few papers in the field which produces maps of the chosen comfort index; and second, Hounam made use of meteorological data from standard stations. Studies of the distribution of the indices of comfort are unusual and Edholm (1966) noted the importance of such studies but emphasised the difficulty of obtaining suitable meteorological data. This problem was also found in the study being described in this thesis.

Specialised studies which adopt the energy balance approach have been carried out in the indoor working environment attempting to assess the maximum comfort conditions for particular activities. To do this Bedford (1936) adopted a new approach by developing a seven point rating scale for assessing people's attitudes towards their working environment comparing the results with physical environmental criteria.

This scale has been used in various working environments by Bedford (1936) and by Hickish (1955). Some further examples of attempts to define working comfort conditions include Angus and Brown (1957) who studied comfort in lecture theatres; Hardy (1963) in industry and Fanger (1972) who considered thermal comfort and working capacity. Research on the relationship between work and comfort has tended to concentrate on physical labour although Givoni and Rim (1962) considered mental activity and Auliciems (1978) in his work on moods and their relationship with weather found that there were indications that more energetic mood states were related to increased intensities in weather elements, while thermal neutrality outdoors seemed to be more conducive to learning.

Man not only spends a large part of his life in indoor environments, which has resulted in the research described above, but he also spends a considerable time outdoors in urban areas and this fact has generated several papers on the theme of climate-man relationships in urban areas at a conference on the 'Metropolitan Physical Environment' (1975). Various energy balance approaches for the assessment of comfort at particular urban sites were described, Herrington and Vittum (1975), for example, adopted the Relative Strain Index proposed by Belding and Hatch (1955) whilst Plumley (1975) used Fanger's (1970) model. The major climatic considerations in all the relevant papers presented were temperature, humidity, windspeed and solar radiation. The models revealed that comfort levels varied considerably between sites and Arens and Ballanti (1975) felt that designers should attempt to evaluate the potential comfort climatology of proposed built environments in advance of finalising any plans. Stark and Miller (1975) suggested a method of making such an evaluation and their model incorporated both climatic factors and a consideration of the proposed relative amounts of vegetation and synthetic surfaces at sites. These papers presented fairly comprehensive energy balance studies of the outdoor built environment but Arens and Ballanti (1975) considered that there is a need for studies not just of the physiological strain imposed by particular climatic conditions but also of the associated psychological strain. They note, for example, the discomfort caused by wind which can result in both physical and mental stress (also, Arens and Ballanti, 1977).

The problems of acclimatisation have been studied for military purposes and present a further example of specialised energy balance studies. The body needs to change its thermal exchanges with the environment when moved from, say, a temperate climate to a tropical one; the extent of these changes and the speed with which they occur have been studied by a number of researchers. Both Ellis (1953) and Pepler (1958) have looked at work performance in Singapore but found little difference between acclimatised and unacclimatised subjects. Givoni and Goldman (1973(a), 1973(b)) produced a dynamic formula for heart rate response of 'reasonably fit' young men to the combined effects of the environmental conditions in which work load was expressed by the metabolic rate and the thermal properties of clothing. They looked at heart rate and inner body temperature as a function of the number of days of exposure to work in the tropical heat for any temperature and humidity combinations for acclimatised and non-acclimatised subjects. A number of studies have found the Effective Temperature to be a useful measure when studying acclimatisation and the need for building ventilation in the tropics; Stephenson (1963) in Singapore, McCleod (1965) in Gan, and Watt (1967) in Bahrain, for example, all found it a useful index in studies relating heat and humidity with acclimatisation.

Many of the energy balance studies discussed so far have a wide application for many situations. In contrast Tuller (1980) pointed out the need for a consideration of the effects of some of the individual weather types or events which are deemed to have a particularly important influence for man's comfort. The example Tuller used was the 'Canterbury Nor'wester' which is a warm, dry, foehn wind. His consideration of the thermal exchanges resulted in the conclusion that during most situations the Nor'wester can be considered favourable for human comfort. This is particularly true in winter with heat strain only occurring in summer especially for people who are exercising and those in the urban environment. Although he saw the importance of this examination Tuller appreciated that thermal exchange is only one part of the total effect of the weather on human beings and there is therefore much work to be done in assessing the total effect.

Obviously energy balance studies can yield useful objective measures of the ambient weather from the point of view of human comfort. From the geographical point of view, a weakness is that very few of the examples cited examine the spatial distribution of 'comfort' as defined by the various indices.

Much of the pioneer geographical work has been undertaken by Terjung (1966, 1967) who attempted to produce a 'human classification of climate'. In his 1966 paper he used relative humidity, windchill and solar radiation as the parameters of his index of human comfort. He mapped the Windchill index and the Effective Temperature Index for the U.S.A. for day and night averages in January and July using 300 stations. The results of the two maps were combined to produce a human comfort classification for the U.S.A. and the resulting distributions reveal that the major control is latitude with modifications due to altitude and to the tempering influence of the Pacific in the northwest. His results reveal that 35% of the area of the U.S.A. can be classified as being 'oppressive' on an average July day and only 10% as being 'comfortable'; on an average January day only 6% of the area can be identified as being 'comfortable' with the rest of the area varying from 'cool' in the south to 'very cold' in the north. In a later paper (Terjung, 1967) these general patterns were converted into six physioclimatic regions. Terjung felt that his work could have wide implications in terms of retirement climates, clothing requirements, military geography, housing and building requirements and as a tool for climatic education. However, as Mather (1974) notes:

> "Terjung's work is preliminary. Little is really known about the factors that influence human comfort and the complex physiological, psychological and cultural factors within man that influence perception of comfort. His efforts are to be commended in view of the difficulties in applying climatic data to such a problem. It is to be hoped that he, or others following his lead, will continue to develop this important aspect of applied climatology."

As will be seen later the work described in this thesis develops such a line of research as one of its major themes.

A similar study to Terjung's, by Tuller (1977), examined the human climate of New Zealand using a range of energy balance indices such as windchill, clo units and effective temperature and found that no matter which index was used the same regional patterns were revealed with latitude, elevation and exposure to the moderating influence of the sea being the major controls. He found that air temperature appeared to be the most important single element in determining the regional pattern.

A third geographical contribution is that by Auliciems and Kalma (1979) who found that one of the main problems with work using energy balance equations is to obtain a single index relating to man's response above and below the threshold of active sweating. Their study area was

Australia where they note there have been few studies of climatic stress. In their paper they attempted to assess the human stress found under different thermal regimes in Australia and made an assessment of both heat and cold stress using climatic elements such as temperature, wind and solar radiation together with a number of physiological factors. Both types of stress were calculated for daytime in January and July and the resulting distributions revealed that latitude was the major determining factor in July with some modifications along the east coast but in January proximity to the coast was the major determinant of heat stress.

A major problem in all this work is that the calculated energy balance is only valid instantaneously, yet convenient climatic data suitable for regional mapping are only readily available as time averaged means or as maxima and minima. The three pieces of work described above used mean data in the mapping process. It will be shown later that more realistic results can be obtained if, and only if, instantaneous data are used.

The energy balance approach has been widely used in different fields in an attempt to study man's relationship with his thermal environment. This relationship is complex and most studies have concentrated on small parts of the whole, for example studies of either heat or cold stress. It is to be hoped that Auliciems and Kalma (1979) point the way to future holistic studies of the energy balance of man.

1.3 Laboratory Experiments

A second broad approach in the study of human comfort climates uses laboratory experiments often making use of psychometric techniques in controlled environments. The majority of experiments using this approach have been carried out by psychologists such as Craik (1966, 1968) who was concerned with attempting to assess people's comprehension of the physical environment but Canter (1975), a leading environmental psychologist, has argued that the physical environment has little relevance in the explanation of behaviour when compared to the social and cultural environments. Environmental psychologists have, however, concentrated on the indoor environment rather than the outdoor physical environment which may have important effects on behaviour which have not yet been isolated. Research in this field also tends to be univariate in design and related to a single point in space yet experience of the environment is notably temporal and sequential.

Despite early recognitions of the value of links between psychologists and geographers by Macleod (1947) and Kirk (1963), by 1973 Craik (1973) and Milgram (1973) both noted that very few links had been developed between the two disciplines. Milgram (1973) felt that psychologists could learn a great deal from geographers in terms of applying problems to the real world and although Ittelson et al. (1974) realised this need for environmental psychologists to move into the real world they referred to laboratory experiments of a very artificial kind. Much of the work conducted by environmental psychologists is based in laboratories and tends to consider just temperature and humidity variations.

The major difficulty confronting psychologists using a controlled environment is to develop a reliable method of assessing the perceived human comfort. The most popular techniques have involved the use of psychological rating scales and the work of Rohles (1965, 1967) is a typical example of this kind of study. In 1965 he attempted a classification of the various factors which he felt were of interest to environmental psychologists and in a later paper (Rohles, 1967) he examined the reactions of college students exposed to various temperatures and humidities by asking his subjects to grade the conditions along a seven point rating scale but did not find any clearly defined comfort range and concluded that this failure might be a problem of the semantics of his questionnaire. Rohles also described work in schools on academic achievement and found little variation according to whether or not the school was air-conditioned. Similar work by Griffiths and McIntyre (1974) assessed people's response to various controlled temperature conditions using both a Bedford seven point scale (Bedford, 1936, 1961) and a series of eleven semantic differential scales. They concluded that both scales were useful in assessing the attitudes of the respondents to differing temperature conditions. Using the Bedford Scale as a reference, McIntyre (1976) conducted a comparative study in which he asked the respondents to grip a dynamometer so that the strength of the grip was equal to the thermal sensation and found that this method was as reliable as the Bedford Scale.

Some of the most interesting work in this field has been produced by Fanger (1967, 1970) who was concerned with the analysis of thermal comfort. A part of his work dealt with inter-group differences in comfort levels and he found little variation in preferred temperature between respondents despite their age, sex or nationality. These conclusions supported the work of Edholm and Bacharah (1965) who concluded that no definite evidence could be presented of an ethnic or racial difference in response to cold exposure and were in turn supported by the work of McIntyre (1972).

A major problem in using controlled environments is that the responses obtained relate only to changes in one isolated factor, whereas outside in the real world these factors are not usually independent. The need for work of a multivariate nature was appreciated by Griffiths (1975) who noted that most studies concentrate on the single thermal sensation of warmth. Griffiths appreciated that there are problems of control outside the laboratory and concluded that the research of the psychologist in this field had only just begun.

Auliciems (1969, 1972) presented a study which was concerned with a multi-variate problem. His work was involved in assessing children's working capacity, found by a number of tests, as a function of the climate of the room and the outdoor weather. The schoolroom was therefore his laboratory giving him a quasi-controlled environment. The schoolchildren were also asked to scale the outside weather on a seven point Bedford scale. It is difficult to assess the value of the tests he chose because the children used may not have been accustomed to intensive testing and levels of concentration may well have varied independently of the outdoor weather. Auliciems concluded that the indoor comfort was related to the outdoor weather and that working efficiency was related to indoor thermal comfort.

Work in the field of thermal comfort has advanced considerably in this century (Macpherson, 1962) and although many indices have been devised to measure the thermal environment most of these have been concerned with the indoor climate, and very little with the real outdoor environment of relevance to outdoor workers. Sargent (1964) points out that the central problem is to find out how weather influences relate to the impact of the total environment on man; the two main aspects being the spatial and temporal. Going from a laboratory, where great control can be made over variables, to the real world where little control can be exerted is a step that psychologists and physiologists seem unwilling to make. There is obviously much to be gained from inter-disciplinary co-operation in the advancement of this field of research.

1.4 Weather Perception Studies

The third research avenue is that of weather perception studies which have been the main geographical contribution to the field of human comfort climatology. Even so, the number of geographical studies has never been large and has fluctuated through this century as a result of changing philosophies within the subject. Geographers have seldom been interested in artificially controlled situations so it was inevitable that all research has been concerned with the outdoor weather. It is perhaps appropriate to note that in this thesis the term 'perception' is used very broadly to refer to cognition of, attitudes towards, and knowledge of the environment in which man lives, and not in the specialist sense as used in behavioural geography (Gold, 1980).

In the first half of this century geographers showed an interest in the relationship between man and his environment. Huntington (1915, 1945) suggested that climate was fundamental to the development of civilisations. In this philosophy of climatic determinism climate was felt to be important for four major reasons:

(i) as a physical factor in determining the habitability, occupations and mode of life in different parts of the world.

(ii) variability from one time period to another and from place to place is manifestly 'geographic'.

(iii) in its influence on health and vigour.

and (iv) based on work in the U.S.A. and elsewhere Huntington felt that climate seemed to set the basic pattern of civilisation upon which other factors impose variations with all degrees of magnitude. Despite its deterministic overtones Huntington's ideas have been taken up by a number of writers, for example, Markham (1947) in his book Climate and the Energy of Nations attempted to determine whether or not climate influences civilisation and Mills (1944) in his book of the same name concluded that Climate makes the Man. Like Huntington and Markham, Mills attempted to relate climate and weather to world dominance, a theme taken up by the historian Toynbee (1946). There were many valid ideas in this early work and further research could have advanced the field of human climatology. This was not the case however because this early work was discredited as a reaction against all environmental determinism set in.

Probably as a result of this discrediting of man-climate studies, one of the most forward-looking pieces of research in this field was ignored. This work was by Winslow and Herrington (1935) who compared the daily response to the weather of between 40 and 100 people with standard meteorological records, concluding that sunshine, relative humidity and the total ions in the atmosphere were the three most important variables in explaining the variance in response. This is one of the few studies which links man's reaction to the total real weather and it is unfortunate that recent studies have not taken this very early work as an example.

Another important piece of human climatology produced during this dormant period was Brooks' (1950) book on Climate in Everyday Life. Brooks considered the effects of the weather as felt by various economic activities, upon the siting and design of factories and houses; and at ideal conditions for working. He made many suggestions for future work including human comfort climatology and Hendrick (1959) produced a rare paper for the decade on this theme. Hendrick attempted to produce an index of the effect of the outdoor weather on man, including temperature, relative humidity, windspeed and solar radiation as the parameters.

Lee (1954) urged that the work of the environmental determinists should be considered in the light of newly acquired knowledge within geography and the related fields, such as physiology where research was being carried out on the relationship between man and thermal conditions. Lee's ideas were not followed by climatologists at the time but during this period there were developing interests in geography which were to lead eventually to the study of man-climate relationships being a more respected form of geographical research. It is worth noting these developments at this stage.

In 1945 Gilbert White published a paper concerned with human adjustments to floods. This work was produced at the University of Chicago which was to become synonymous with the study of hazards and hazard perception. In the 1960s and 1970s under White's influence, a number of hazard perception studies were undertaken, for example Burton and Kates (1964) considered flood perception, Saarinen (1966) drought, Rooney (1967) snow and Saarinen and Cooke (1970) general environmental hazards in cities. More recent work includes Auliciems and Dick's (1976) work on the pollution problem in Brisbane. Inevitably this work has confronted a need to use psychometric techniques in geographic investigation (Saarinen and Sims, 1969); Golant and Burton (1969) and Burton and Golant (1970), for example, adopted a semantic differential test from psychology and found it a useful technique.

Hazard perception is only one example of the growing interest among geographers during the 1960s in the behavioural approach. As Goodey (1971) pointed out, behaviouralism gave geographers the possibility of studying the environment as a monistic whole which most geographers aimed for but in practice could not attain. Lowenthal (1961) proposed a framework for studying behavioural problems but Kirk (1963) was more successful in geography in uniting physical and human geography with his concept of the 'behavioural environment', that is the part of the real, or 'phenomenal', environment which is perceived by man. Various approaches to studying the behavioural environment have been adopted, many of them being stimulated by a growing interest in decision making. Sonnenfield (1969, 1972) was concerned with the way social and cultural differences influenced respondents' perception of the environment, Lynch (1960) was interested in urban images whilst Lowenthal and Riel (1972(a) and (b)) were concerned with urban landscape perception.

The growing interest in behavioural geography through the 1960s resulted in a number of publications concerned with man-climate relationships and these tended to be related to man in general and not to the links between man as an individual and the weather. The weather has an important effect on many aspects of man's activities and this is reflected in the few papers which appeared during this period. The influence of climate on man has been discussed for industry by Von Bichert and Browne (1966) and Maunder (1970), and for agriculture by Landsberg (1968) and Smith (1975), whilst Crowther (1977) and Page (1976) noted the need for architects to take considerable account of the weather in urban design. People's enjoyment during leisure time and holidays may be affected by the weather and Clawson (1966), Foord (1973) and Crowe (1975) concerned themselves with this possibility. All these studies advanced the field of human climatology and reflected a growing geographical interest in the relationship between man and climate.

Most of the man-climate studies discussed above have been concerned with groups of people who are influenced by the weather and climate. Some climatologists have also looked at the relationship between man as an individual and his personal climate by concerning themselves with man's physiological and psychological reactions to the weather and climate.

A series of optimum weather indices have been developed which their authors often used to analyse past records and to predict future weather if a trend was observed. These tended to be subjective and based neither on physiological fact, nor on a perceptual basis, unless it was the perception of the author. Instead they were based on an examination of the range of possible conditions at certain weather stations. The indices tended to be very general and used average values such as monthly or maximum mean values, mean sun hours and total summer rain. On the whole they say very little about the extremes which are the situations where discomfort is felt. Using average figures the results, even if the indices are valid, could only show relative variations in comfort and did not show discomfort, which may only occur for short periods in this country. The indices, which are discussed below can be summarised as the expression:

$$\text{COMFORT} = f\,(W_i X_i + \ldots,\ W_n X_n) \qquad (1.4)$$

where X_i = weather variables
W_i = a weight for the i th variable.

Usually the function 'f' is a linear combination of weighted elements and presents two major problems: first, linearity does not allow for interactions or take account of collinearity between elements and second, the weights chosen are often arbitrary and based on the author's feel for the problem rather than on objective observation.

One of the first of this series of indices was presented by Poulter (1962) who aimed to develop an index of summer weather which would be useful for predictive work on the weather of London. This index presents a typical example of those which followed, many of the other authors developing a modified Poulter index, and is given by the equation:

$$\text{INDEX} = 10T + S/6 - R/5 \qquad (1.5)$$

where T = mean temperature (deg. F.) for June, July and August
S = total sun hours for June, July and August
R = total mm. rain for June, July and August.

With hindsight Sutton (1966) and Booth (1966) criticised these predictions for their inaccuracy. Similarly Fergusson (1964) was interested in summer weather at the seaside and used a modified Poulter index which increased the importance of sunshine, which he considered to be an important psychological variable for the holidaymaker. Rackliffe (1965) modified Poulter's index for summer and winter at Armagh and Hughes (1967) for summers in Manchester. None of these authors made any attempt to produce a climatology of their index unlike Davis (1968) who mapped an index based on the standard deviation of the mean Poulter index. Davis found that his maps of Britain provided a useful starting point for a consideration of the relationship between climate and horticulture.

Another subjective index was produced by Maunder (1962) who attempted to define an index of the overall human climate of New Zealand throughout the year. The breadth of his study is unsurpassed in that he considered features of temperature, rainfall, sunshine, humidity and wind; he weighted his elements - thirteen in all - in relation to the expected conditions in New Zealand and summed them. Despite the number of elements included his index included no combinations of variables which was a major weakness.

A further subjective index was developed by Bailey (1964) who looked at departures of temperature from his optimum yearly average of 14° C.. By using a log term he compressed the range of moments from the mean into a zero to 100 scale and believed that the resulting empirical expression may have value. The use of yearly averages, however, means that his work is very general.

An alternative approach is to actually ask people their views of the weather. This contrasts with the indices already discussed which are based on the author's view of the weather. Work of this nature involves adopting techniques for examining attitudes which have been developed by psychologists. Very little work has been done in this field particularly in relation to the outdoor weather.

The only paper to date which directly used this approach is by Auliciems (1976) who carried out an attitude test on students in Queensland. He used a seven point Likert-type rating scale (Likert, 1932) which asked the respondents to assess the extent to which they agreed or disagreed with the statement 'Today's weather is pleasant'. The responses were related to measurements of the actual weather conditions at the time of the questionnaire by a stepwise multiple regression. Auliciems concluded that the weather was judged as being more pleasant with increased amounts of sunshine and higher values of temperature with increased cloudiness, humidity and windspeed resulting in lower values of the perceived degree of pleasantness. Auliciems' work is the only use of attitude scales in the context of linking the individual response to the weather but there are a number of problems in his work which will be examined later in this chapter.

Humphreys (1974) also used an attitude scale to measure the weather but in a different context. He was concerned with the effect of the weather on children's behaviour at school. He gave the teachers fifteen bipolar semantic differentials to mark on a seven point scale for an assessment of the weather conditions. He then asked the teachers to report on how their lesson had progressed. He found that the teachers' assessment of the weather correlated significantly with the children's behaviour, although the relationship was not very strong.

Any comprehensive study of the effects of the weather on human comfort must of course include many factors not assessed in the majority of the indices discussed thus far particularly instantaneous measurements. In any new field of research it is inevitable that criticisms are levelled at the work but it is important that work continues in the light of these criticisms. Bates (1966) commented that he:

> "ends up more impressed with our ignorance than with our knowledge on the subject of the effects of the weather on human behaviour."

Munn (1970) felt that:

> "research is needed into the question of population response to multiple environmental stresses. To reduce the number of variables in an ecosystem there is a need for simple atmospheric indicators that integrate the effects of several environmental stresses. Undoubtedly separate indices are required for separate ecosystems but this should not deter the investigator in his research."

The academic atmosphere in geography, in terms of the interest in perception studies and behavioural geography makes this an ideal time for detailed work into the relationship between man and climate. Terjung (1976) noted the lack of geographical climatology and urged further work in this field. Weather perception studies seem an ideal point for the geographer to start his research.

1.5 Problems of Studying Human Comfort Climatology

There are numerous problems in any work in human comfort climatology and these can be illustrated by looking at some of the literature described above.

An initial problem is that the physiology of the human being reacts to the instantaneous weather and not to climatic averages: man may have some idea of the expected seasonal weather but he will adjust his behaviour according to his perception of the individual day's weather. Also most of the indices of thermal comfort (for example, Thom, 1959) and windchill (Siple and Passel, 1945; Steadman, 1971) are defined for more-or-less instantaneous conditions; this is implicit in the energy balance approach, since the equations used are only instantaneously valid.

Another related problem is that the human being reacts to combinations of weather elements as well as to individual elements and this is also recognised in indices such as the THI and the indices of windchill which use the combined effects of two or more weather variables. It follows that any study which uses these indices must use data which reflect the covariance of the elements used. This covariance is not necessarily captured in mean data.

Recent papers by Smithson and Baldwin (1978) and Baldwin and Smithson (1979) on windchill in Lowland and Highland Britain respectively illustrate these problems and have been discussed by Mumford (1979). The data used in the calculation of lowland windchill were monthly means; such mean values have only very general relevance to public perception of the weather and their resulting behaviour because they remove the covariance of wind and temperature which is used to define the windchill index. For example, in Lowland Britain low windspeeds often occur with low temperatures in so-called 'radiation nights' whereas high wind speeds and relatively high temperatures are associated with disturbed westerly conditions and these relationships will be obscured by the use of mean data. In their paper on windchill in Highland Britain Baldwin and Smithson (1979) had instantaneous data, which are ideal for calculating this index, but they then converted these to mean data before carrying out their analysis. The present author (Mumford, 1979) has re-calculated the windchill index for the synoptic stations of the British Isles; this is discussed in Chapter Five. Further examples of authors who used mean data in their analysis of comfort levels include Maunder (1962), Terjung (1966, 1967) and Auliciems and Kalma (1979). A second problem with mean data is in its relationship to public perception. People do not perceive the average but they perceive and react to the weather, or the forecast weather, at any particular time.

The weather, as perceived by people, is necessarily multivariate in nature and thus it is important to include all weather elements in any analysis.

There appears to be only one example which attempts to tackle the problem of using averaged weather data. Auliciems (1976) asked a large sample of students to complete an attitude scale measuring their perception of that day's weather. He then carried out a multiple regression which postulated that the measure of perception was a function of the real weather. Unfortunately at best he only explained 23% of the variance using a combination of the temperature and sunshine parameters. A major drawback is that he asked the respondents to answer the questionnaire whilst sitting at their desks and thus depending on recall as to the state of the weather outside. There were other problems with this piece of research including the invalidity of his attitude scale (which will be discussed in the next chapter); a lack of variation in weather on his sample days; a point of sampling technique on which he does not elaborate; and a lack of consideration of the joint effects of weather variables.

There is however currently a large gap in the research field between the valid use of psychometric techniques in controlled environments by the psychologist who knows exactly which variables he is trying to measure and the problems which occur when these techniques are applied to the outdoor weather. These problems are directly related to the multivariate nature of the real world environment. It is only by conducting more research that the important variables in controlling attitudes to the real world environment can be identified. Auliciems' (1976) attempt to bridge this gap failed for the reasons outlined above, but this failure has led to the identification of some of the problems involved in work in human comfort studies and his paper is therefore a useful starting point for further work.

The literature review has shown that there is often a failure to map the results of studies in human comfort. This could be for two major reasons. First, many of the indices were designed by engineers, psychologists and other workers who were concerned primarily with indoor climates and not with spatial variations in the outdoor weather. Second, data for mapping indices are difficult to obtain and studies which have mapped the results have often been forced to use the available data which may not be ideal. A good example of this is de Freitas' (1979) work in Northern China in which mean minimum monthly temperatures, lowest possible solar radiation and an assumed wind velocity were input into the clo unit equation (Auliciems, de Freitas and Hare, 1973). In an answer to criticism by Fischer (1979), de Freitas (1979(b)) replied that although he appreciated the inadequacies of the data he felt that it was useful to offer a general indication of comfort variation within the constraints of these data. This is a very valid point and it is regrettable that more researchers in this field did not map their results even if the distributions were only valid in a very general sense. In spite of all the foregoing work we still know very little about spatial and temporal variations in comfort.

There are therefore a number of problems and deficiencies which need to be overcome in the field of human comfort climatology. First, there is a need to use instantaneous rather than averaged data which are truly almost 'meaningless' means except in very general terms. Second, to obtain a realistic measure of the stress caused by the multivariate weather all weather elements must be included in the analysis using instantaneous data. Third, in any measurement of human comfort the respondents must be experiencing the weather which they are being asked to respond to. Fourth, there is a need for a consideration of the spatial and temporal aspects of human comfort. The aim of the research described in this thesis was to overcome some of these problems.

1.6 The Current Work

The research builds upon the literature described in this chapter and was carried out in the light of the problems and deficiencies outlined above. The organisation of the chapters is shown diagrammatically in Figure 1.1. The research was concerned with an attempt to assess people's attitudes to the weather. This involved the use of a questionnaire which incorporated an attitude scale to obtain an indication of the respondents' perception of the weather which is discussed in Chapter 2. Preliminary results are presented in Chapter 3 whilst Chapter 4 reviews the results of a Multiple Regression Analysis which was used to compare the response with the weather as measured simultaneously resulting in the production of an Index of Human Comfort. The significant variables and the Index of Human Comfort were then mapped in Chapters 5 and 6 by season to give an indication of the spatial and temporal variations in comfort. In Chapter 7 the thesis finally considers the lessons learned from the research and examines the possibilities for future research.

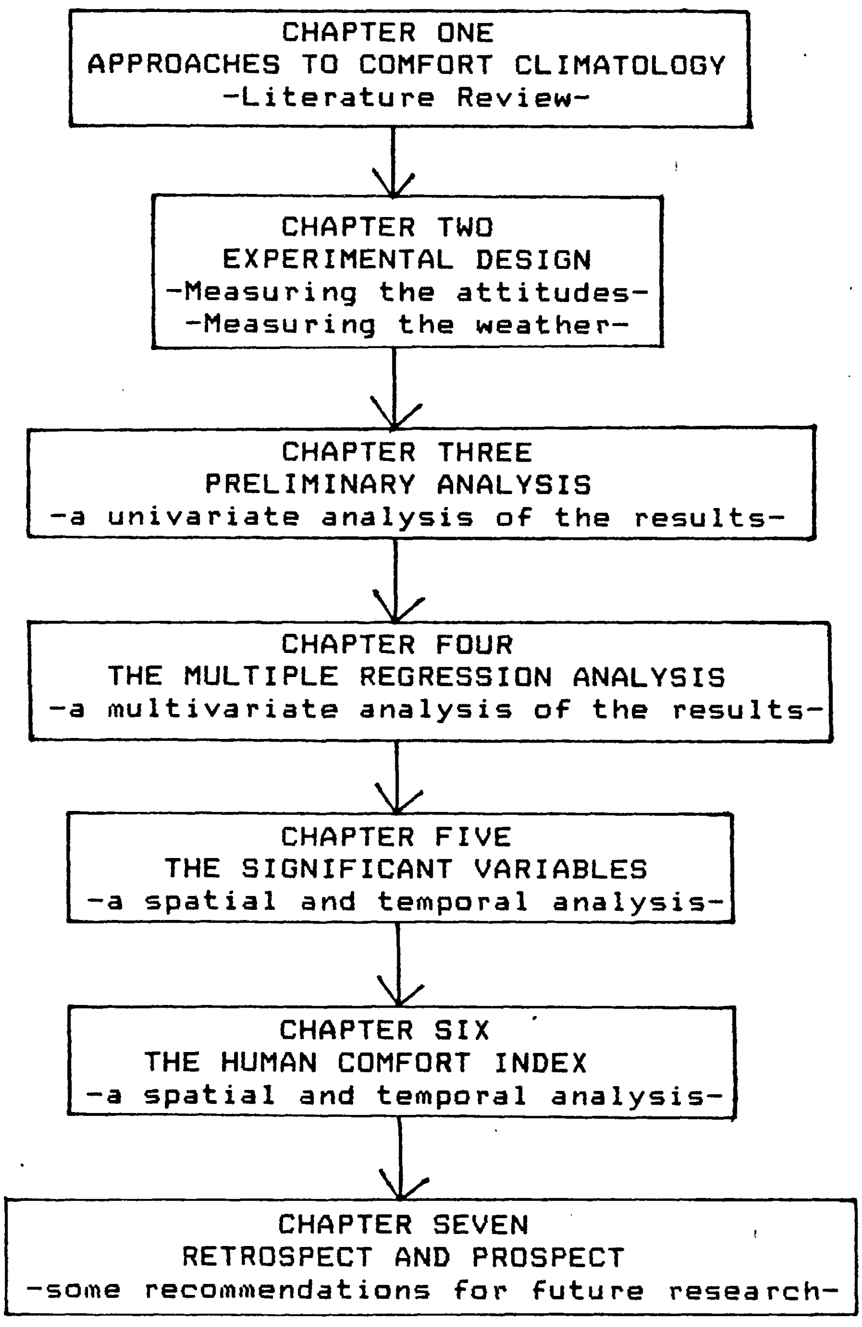


FIGURE I.I. The organisation of the chapters.

Chapter Two

The Experimental Design

2.1 Introduction

This chapter discusses the design of the experiment which was outlined in the previous chapter. This experiment tests the hypothesis that there is a relationship between the weather as measured objectively and man's perception of it and further assumes that this relationship can be calibrated. Similar hypotheses were used - and often confirmed - by psychologists using laboratory conditions to assess perception of the thermal environment (Fanger, 1970; McIntyre, 1972) but Auliciems (1972) provides the only example of this hypothesis being applied to the outdoor weather. Research suggests that there is some relationship but there is a lack of precise quantitative measurements and a true indication of the variables involved. The experiment which is set up in this chapter aims to discover which weather variables are important in controlling man's perception of the weather and exactly how important each variable is in relation to the others.

At this design stage it is worth emphasising two of the four problems outlined in the previous chapter which this experiment aimed to overcome and which played a major part in determining the overall experimental design used:

(i) in any measurement of human comfort the respondents must be experiencing the weather which they are being asked to respond to; recall is inadequate.

(ii) to obtain a realistic measure of man's attitudes to the weather all weather elements, or as many as possible, must be included in both the attitude measurement and the objective measurement of the weather.

It can be seen that both involve problems of mensuration, on the one hand of developing measures of human response to the instantaneous state of the atmosphere or 'weather', and, on the other, of finding appropriate ways of measuring this weather. The evaluation of methods of measuring both facets played a major part in the design of the experiment reported here. Further problems were presented when the questions of where, when and who to question were considered.

2.2 Evaluating the Response to the Weather

A major problem in the research design was to find an appropriate way of quantifying people's response to the outside weather. Psychological literature presents a number of scaling methods which have been used to measure respondents' attitudes to a wide variety of stimuli and which initially appeared to be potentially suitable for this study. Not all of these scales are appropriate for research in comfort climatology, and not all are appropriate for this particular study. In evaluating their suitability, four major criteria were identified:

(i) the chosen scale should incorporate a number of weather elements;

(ii) to simplify analysis the chosen scale should have as its end product a single score implying that the scale needed to be additive;

(iii) the chosen scale should be able to produce the same score from different weather conditions because different values of, for example, temperature and wind could produce the same level of comfort; this meant that the feature of reproducibility, where a particular score could only be produced from one particular set of weather variables, was not required;

(iv) the chosen scale should be relatively simple to operate in order to make the questionnaire quick to ask if people were to answer it while experiencing the weather.

With an awareness of these four requirements the six major types of attitude scale can be examined to find the most suitable.

(i) Rating Scales. The simplest type of scale is the so-called Rating Scale on which the respondent is asked to place his attitude along a spectrum, usually with five or seven categories. These scales are simple to operate in the field and are more sensitive than a simple yes/no answer but only measure a single item and therefore tend to be unreliable (Moser and Kalton, 1971) and are particularly unsuited to responses involving complex or emotional topics.

Rating scales have been much used in comfort climatology. Bedford (1936) introduced a seven point scale for thermal comfort ranging from 'much too warm' to 'much too cool' which has been adopted subsequently by a number of workers such as Hickish (1955), McIntyre (1976) and Black (1954) although the latter reduced the scale to five categories.

Although this scale has been of much value in studies of physiological reaction to working conditions it only considers the thermal environment. In this study other elements such as humidity, precipitation and sunshine needed to be considered and because of this a single rating scale with no additive properties was inappropriate.

(ii) Likert Scales (Likert, 1932). In a Likert scale the respondent is asked to state his attitude to a series of statements usually along a five point scale ranging from 'strongly agree' to 'strongly disagree'. In some studies seven categories have been used but Oppenheim (1966) noted that this larger division has shown little benefit.

A Likert scale is additive in that it is scored by adding the response scores on the component items. One feature of Likert scales is that they lack reproducibility, that is one cannot tell from the total score what the individual responses to each statement were. This feature is important when studying man's response to the weather in that physiological research such as that by Steadman (1971) suggested that it is the combination of weather elements which cause a person to feel comfortable or uncomfortable; the individual elements may in themselves mean very little. Moser and Kalton (1971) noted that Likert scales give a reasonable ordinal scale and point out that they are easier to construct than the Thurstone scale discussed below and in his work on medical care Phillips (1979) found it to be robust and practical.

A Likert scale appeared to fulfill the requirements of the study of weather perception and an example of its use can be found in Auliciems (1976) who used a seven point scale to assess people's attitudes to the statement 'Today's Weather is Pleasant'. He only used this one statement and thus did not use the additive property of a Likert scale. The reliability and validity of a single question is doubtful and cannot be tested. Used correctly, a Likert scale seems an appropriate scaling technique for the analysis of human comfort.

(iii) Thurstone Scaling (Thurstone, 1928). This scaling method involves the use of a large number of attitude statements which relate to the problem being studied and which vary from one extreme of favourableness to another. The statements are written onto cards and given to a panel of judges who are asked to group the statement cards into piles according to the neutrality or extremeness of each attitude expressed. The number of piles usually varies between seven and eleven. The statements which have a high scatter between the judges are discarded and those to be used in the questionnaire are selected from the remainder by choosing statements in which the pertinent attitude statement cards cover the entire range of attitudes and which appear to be about equally spaced along the scale. The respondents in the questionnaire are then asked to respond to the selected statements which are positioned in random order in the questionnaire.

This method is very laborious and the panel of judges may view things differently from the respondents used in the main survey. It is inappropriate for this study because very few people would know the relative merit of a temperature, humidity or wind velocity if it was presented to them on a card to rank. To use this method people would need to experience the elements of the weather under controlled laboratory conditions, a method which is impracticable, and in any case not ideal, for the reasons discussed in the last chapter, for this study.

(iv) Guttman Scales (Guttman, 1950). This scaling method is based on the assumption that a set of items can be ordered along a continuum of difficulty, the order being reflected by the relative infrequency with which each item is endorsed. This method is cumulative in that acceptance of one item implies acceptance of all other items of lesser magnitude. A simple example of this is a series of mathematical problems of increasing difficulty; as the difficulty increases fewer and fewer respondents will be able to successfully complete the problems. This scaling method involves the concept of reproducibility, that is the individual responses to each statement or problem can be inferred from the total score.

Guttman scaling can be criticised because of its analytical complexity and its deterministic nature. It is unsuitable for this study because of the property of reproducibility which is not required in a study of human comfort where the weather elements cannot be laid out on a continuum of comfort levels.

(v) Semantic Differentials (Osgood, 1957). Like the Likert scale this scaling method is an additive one. It consists of a number of bi-polar rating scales with each extreme defined by an adjective such as hot/cold or wet/dry. The respondent has to consider each set of adjectives and place his position on the scale between the two extremes; the scale is conventionally divided into seven. The response is scored between one and seven depending on the placing of the respondent's attitude and the scores are then added to give a total score. In an attempt to avoid bias due to the placing of the scale in the questionnaire the position of the positive end is randomised. This technique has not been used within the field of human comfort climatology but has been usefully adopted by Burton and Golant (1970) in a classification study of environmental hazards, by Sonnenfield (1969) in a study of the sensitivity of a population to environmental phenomena and by Lowenthal and Riel (1972) in a study of perception of varying environments.

This method appears to have potential for a study of human comfort climatology with the respondents being asked to scale the various facets of the weather which can then be summed to give an index of the attitude to the weather at the time of the questionnaire.

(vi) Personal Construct Theory and Repertory Grids (Kelly, 1955). This method assumes that people build up a mental representation of their environment and that this is vital to their behaviour and it is suggested that this representation takes the form of a large number of bi-polar constructs. The Repertory Grid test is a way of eliciting the constructs a person uses to discriminate among a set of elements and scores each element on each construct. An example of a group of elements is important buildings in a city and these may be described by a series of scales along bi-polar constructs such as high/low, and beautiful/ugly. This technique has been adopted in geography and can be illustrated by the work of Harrison (1974), Hudson (1974) and Sarre (1974) who conducted research at Bristol University in the late 1960s and early 1970s; their work will be used as examples to illustrate the use of this method of scaling.

The researcher using this technique often attempts to elicit a series of elements and constructs from the respondent. Sarre (1974) asked the respondents to list places of importance in Bath and to say why they were important. A list was then built up of elements and associated constructs and the respondent was then asked to scale the elements along the constructs. A seven point scale has been found adequate in most scaling techniques but Sarre used a nine point scale. The respondent was then presented with a standard grid of elements and constructs and the process repeated. In a second example of the use of this technique Harrison (1974), who was concerned with retailing in Bristol, used 27 elements and 8 constructs in his standard grid. Harrison and Sarre (1975) also used a system of 'triad sorting' in their survey asking people to consider three randomly selected elements and to consider how two were similar and why the third was different. As a result of people being given a free choice as to which elements and which constructs they select, initially it is difficult to build up an average model because many elements and constructs appear only once, for example in Sarre's (1974) work, of the 155 places mentioned by respondents 90 appeared only once and of the 76 constructs mentioned 43 appeared once and none appeared more than 9 times, less than 50% of responses. This method is extremely complex and time consuming; Hudson (1974) found that although 89 students were prepared to keep shopping diaries only 26 of these would answer the Repertory Grid test, mainly because of the length of time involved. Harrison's (1974) questionnaires varied in length from 1 to 5½ hours and Sarre's (1974) from 2 to 4½ hours. An undesirable result of this length of interview was a very small number of responses: Sarre's (1974) sample was only 20, Harrison's (1974) was 34 and Hudson (1974) achieved a very biased sample of 68 self-selected students.

This method is very complex and as a result research using this scaling technique has used small samples. Auliciems (1972) noted the importance of the use of large samples in the determination of optimum comfort conditions and for this reason and because of the time element this method appears to be unsuitable for this study.

It is clear from the consideration of the six major attitude scales that not all six fulfill the requirements laid out at the start of this section. The Guttman scale has the feature of reproducibility which makes it unsuitable, Rating Scales are too simple and are non-additive and the Thurstone scaling method and the Repertory Grid technique are at the other extreme in being too complex and difficult for the respondent to understand. Both the Likert Scale and the Semantic Differential method are relatively simple to use and to understand and they both include various facets of the weather yet both give a total score representing the attitude of the respondent. The final choice of attitude scale was therefore between these two methods.

With two scales fulfilling the requirements laid out initially it was necessary to consider further criteria on which the final selection could be made. Each respondent answering the questionnaire is experiencing a unique set of weather conditions which could only be related to his response. Any one respondent must therefore be representative of the total population under consideration with his response regarded as a sample from a normal distribution around the true mean for that particular set of weather variables. If an infinite number of responses were to be obtained to the same weather conditions then the better of the two scales under consideration would be the one which gives a normal distribution of responses around the mean value and has the lower variance. This property of low variance is important because it means that the sample response will lie relatively close to the true mean with a higher probability than if the variance is large.

In order to decide which scale was the more suitable, given these criteria, a pilot survey was conducted.

An infinite population in a survey is only theoretically possible and therefore in order to obtain a sufficiently large group of people to answer the pilot survey to compare the two scales it was decided that the best practical solution was to use a group of first year Geography students in this survey. A potential problem was that the students may not be representative in terms of age and sex structure of the final population. Work by Edholm and Bacharah (1965), Fanger (1967, 1970) and McIntyre (1972), which was noted in the last chapter, suggested that age and sex do not affect response to thermal conditions. If it is assumed that this can be extended to the total weather then the sample used in the pilot survey need not be representative of the age and sex structure of the final sample population.

The respondents used in the pilot survey had to be presented with two questionnaires, one based on a Likert scale the other on the semantic differential method. The format of the questionnaires was the next consideration. It was important to ensure that all pertinent aspects of the climate were considered. Givoni (1976) discussed six facets of the weather which he believed were important for human comfort, these were solar radiation, long wave radiation to the sky, air temperature, humidity, wind and precipitation. These facets needed to be incorporated into the questionnaires.

In measuring thermal comfort Hickish (1955) found the words 'warm' and 'cool' ambiguous and for this reason the words 'hot' and 'cold' which are more easily defined were incorporated into the scales. It was found to be difficult to phrase a statement to incorporate the concept of net radiation and it was felt that statements on sunshine and cloudiness would suffice to assess this. Humidity was another difficult concept to include and it was hoped that the words 'close and stuffy' with 'fresh and pleasant' as the bi-polar adjectives would be adequate. Five scales on temperature, wind, sunshine and cloudiness, humidity and precipitation were included in the questionnaire to cover Givoni's (1976) variables of importance to human comfort. It was also decided to add a sixth scale concerning the overall comfort of the respondent. The position of the questions in the questionnaire was decided using random numbers as was the wording of the statements in the Likert scale (whether favouring the positive or negative side of the weather in terms of human comfort) and the positioning of the positive end of the semantic differential scales. The questionnaire used in the pilot survey is shown in Figure 2.1.

The same group of students were given the questionnaire on two occasions, 5th and 12th December 1977, and the questionnaires were completed outside while the students were experiencing the weather. On the first day 54 students completed the questionnaire and 43 on the second. The questionnaire was readily understood and completed by all the students present.

The Likert scale was scored by allocating a score of five to the positive end of the scale ('strongly agree' to questions 1, 5 and 6 and 'strongly disagree' to the others) and a score of one to the negative end with scores of four, three and two inbetween the extremes. Scores for individual statements were allocated according to the position of the respondent's 'ticks' on the questionnaire and then these individual scores were summed to give a total score for each respondent which ranged from six to thirty.

The semantic differential scale was scored by allocating a score of seven to the positive, 'comfortable' end and a score of one to the negative end with five intermediate steps between the two extremes.

STUDY OF CLIMATIC PERCEPTION

This is a pilot survey to compare 2 questionnaire techniques and your co-operation would be appreciated.

Below are a number of pairs of words with a scale in between. Decide what you think about today's weather in relation to each pair of words and tick along the scale the position you think best describes the weather at the moment.

(I) hot	cold
(2) wet	dry
(3) clear	cloudy
(4) calm	windy
(5) close and stuffy	fresh and pleasant
(6) comfortable	uncomfortable

Below are a number of statements. Decide how strongly you agree or disagree with the statements. Please tick clearly <u>one</u> box for each statement.

Statement	Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
(I) Today's weather is hot.					
(2) Today's weather is close and stuffy.					
(3) It is cloudy today.					
(4) It is windy today.					
(5) Today's weather is dry.					
(6) I feel comfortable with the weather as it is today.					

FIGURE 2.I. The questionnaire used in the pilot survey.

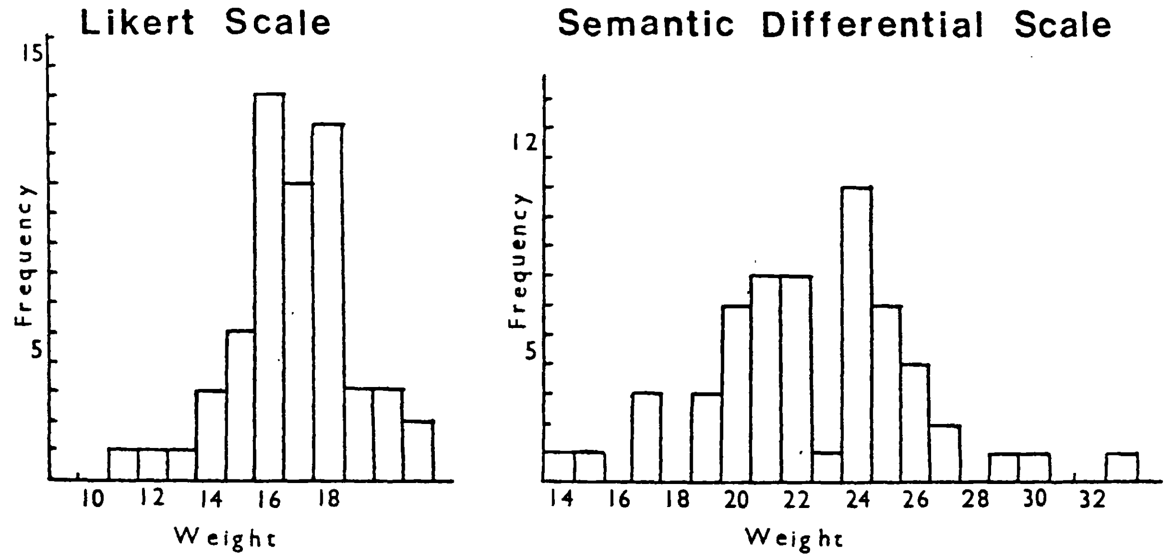
The scores for each respondent were allocated according to the position of the respondent's 'ticks' and summed to give a total score ranging from 6 to 42.

The results of the questionnaire for the total score are shown graphically together with some summary statistics in Figure 2.2. Visually the Likert scale appears to show the least variation even allowing for the wider scale adopted by the semantic differential technique. The coefficient of variation confirms this impression and is lower for the Likert scale on both days. The Likert scale therefore was considered to be the better scale for the purposes of this research.

A lack of consistency in the response to any individual question may have suggested ambiguity in the wording of the statement. It was therefore considered important to examine the responses to the statements and a breakdown of the responses to the Likert scale is shown in Table 2.1. In all statements over 50% of the responses to the Likert scale lay in one category and it was decided to accept the questions used in the pilot survey for the main survey. The final form of the questionnaire used is shown in Figure 2.3.

2.3 Measuring the Weather

The previous section reviewed the instruments developed in psychology for the study of attitudes and established the reasons for the final form of the questionnaire for this study of public perception of the weather. The present section reviews the instruments used to measure the weather. The importance of the respondent experiencing the weather while answering the questionnaire has already been discussed and as a result of this it was imperative that the weather should be measured as accurately as possible and also as near the time of the

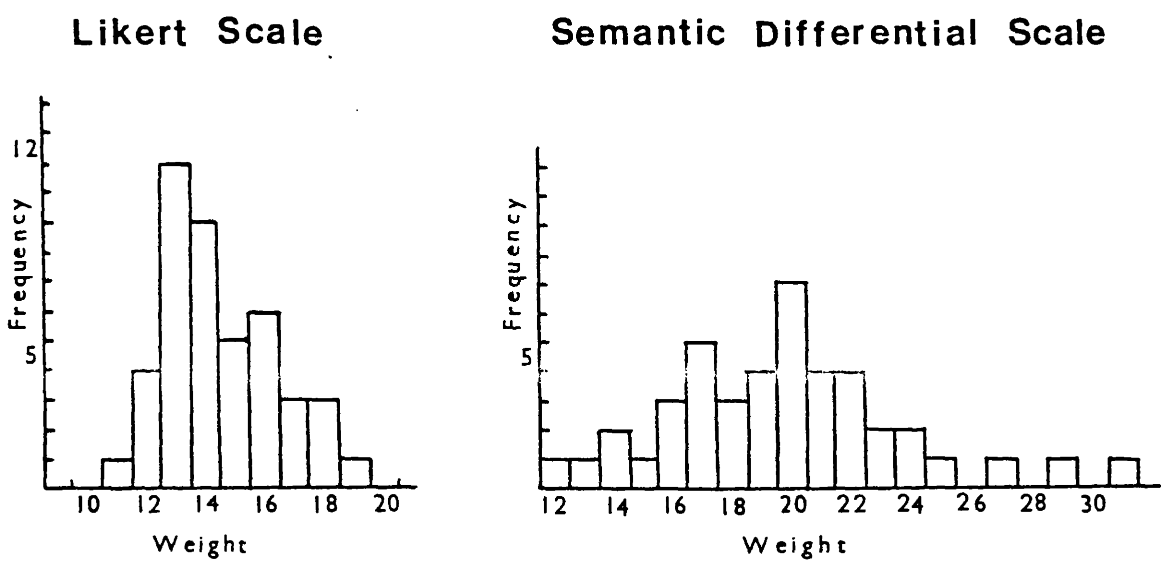


5th December 1977

N: 54

mean	:16.7778	mean	:22.6481
standard deviation	:2.025	standard deviation	:3.57297
coefficient of variation	:11.9573%	coefficient of variation	:15.44%

FIGURE 2.2



12th December 1977

N: 43

mean	:14.4884	mean	:19.7442
standard deviation	:1.9195	standard deviation	:3.9707
coefficient of variation	:13.0934%	coefficient of variation	:19.8754%

Table 2.1. An Analysis of the Statements used in the Likert Scale Questionnaires

STATEMENT USED IN THE QUESTIONNAIRE	WEIGHT	5th December 1977		12th December 1977	
		Number of Ticks	Percentage of Total	Number of Ticks	Percentage of Total
Today's Weather is Hot	1	51	99.44	29	67.44
	2	3	5.56	12	27.90
	3	0	0	1	2.33
	4	0	0	0	0
	5	0	0	1	2.33
Today's Weather is Close and Stuffy	1	36	66.67	1	2.33
	2	18	33.33	1	2.33
	3	0	0	0	0
	4	0	0	14	32.56
	5	0	0	27	62.78
It is Cloudy Today	1	31	57.41	23	53.49
	2	21	38.89	20	46.51
	3	1	1.85	0	0
	4	1	1.85	0	0
	5	0	0	0	0
It is Windy Today	1	0	0	5	11.63
	2	8	14.81	22	51.16
	3	14	25.93	9	20.93
	4	31	57.41	7	16.28
	5	1	1.85	0	0
Today's Weather is Dry	1	1	1.85	4	9.30
	2	6	11.11	32	74.41
	3	9	16.67	3	6.98
	4	32	59.26	3	6.98
	5	6	11.11	1	2.33
I feel Comfortable with the Weather as it is Today	1	8	14.81	4	9.30
	2	30	55.56	25	58.14
	3	4	7.41	5	11.63
	4	9	16.67	8	18.60
	5	5	5.55	1	2.33

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I am carrying out research into peoples' attitudes to the weather and your co-operation in filling in this very short questionnaire would be appreciated.

Please tick the box which nearest fits your attitude to each statement on the left.

A.Mumford.

	STRONGLY AGREE	AGREE	UNCERTAIN	DISAGREE	STRONGLY DISAGREE
(1) TODAY'S WEATHER IS HOT					
(2) TODAY'S WEATHER IS CLOSE AND STUFFY					
(3) IT IS CLOUDY TODAY					
(4) IT IS WINDY TODAY					
(5) TODAY'S WEATHER IS DRY					
((6) I FEEL COMFORTABLE WITH THE WEATHER AS IT IS TODAY					

Thank you.

FIGURE 2.3. The questionnaire used in the main survey.

questionnaire as possible. The weather elements included in the questionnaire were chosen in the light of Givoni's (1976) work and were temperature, humidity, sunshine, cloud, windspeed, precipitation and overall weather conditions and in order to be compatible it was important to measure these weather elements at the time of the questionnaire. Any instrument used to measure these elements needed to be portable, simple and quick to use as well as being accurate. A further constraint was that, as indicated in Figure 1.1, it was known at the outset that the results of the questionnaire would be used to develop a 'comfort climatology' of the British Isles using existing meteorological data. The data collected had, therefore, to be variables which were also collected as routine meteorological data. The only source of instantaneous data which are collected on a routine basis are the Daily Weather Reports and these were used as the data restriction which precluded, for example, the use of a radiometer to measure solar or net radiation. The elements which were included are considered below.

(i) Temperature. A Psychro-Dyne model PP100 Psychrometer (Plate 2.1) was used to measure the wet and dry bulb temperatures. The Psychro-Dyne is designed to provide 15 $ft.sec^{-1}$ air flow over the thermometers and is battery operated. The temperature can be read with an accuracy of $\pm 0.25^{o}C$.. The instrument is portable and simple to operate, but, problems can occur with irregular air flow if the contacts and batteries are not adjusted regularly. Care needs to be taken in avoiding holding close to the air intake otherwise higher temperatures can result, this can also happen if the Psychro-Dyne is kept running for too long because the light which is used to aid the reading of the temperatures may warm the thermometers. These deficiencies were noted in trials of the instrument and care was taken

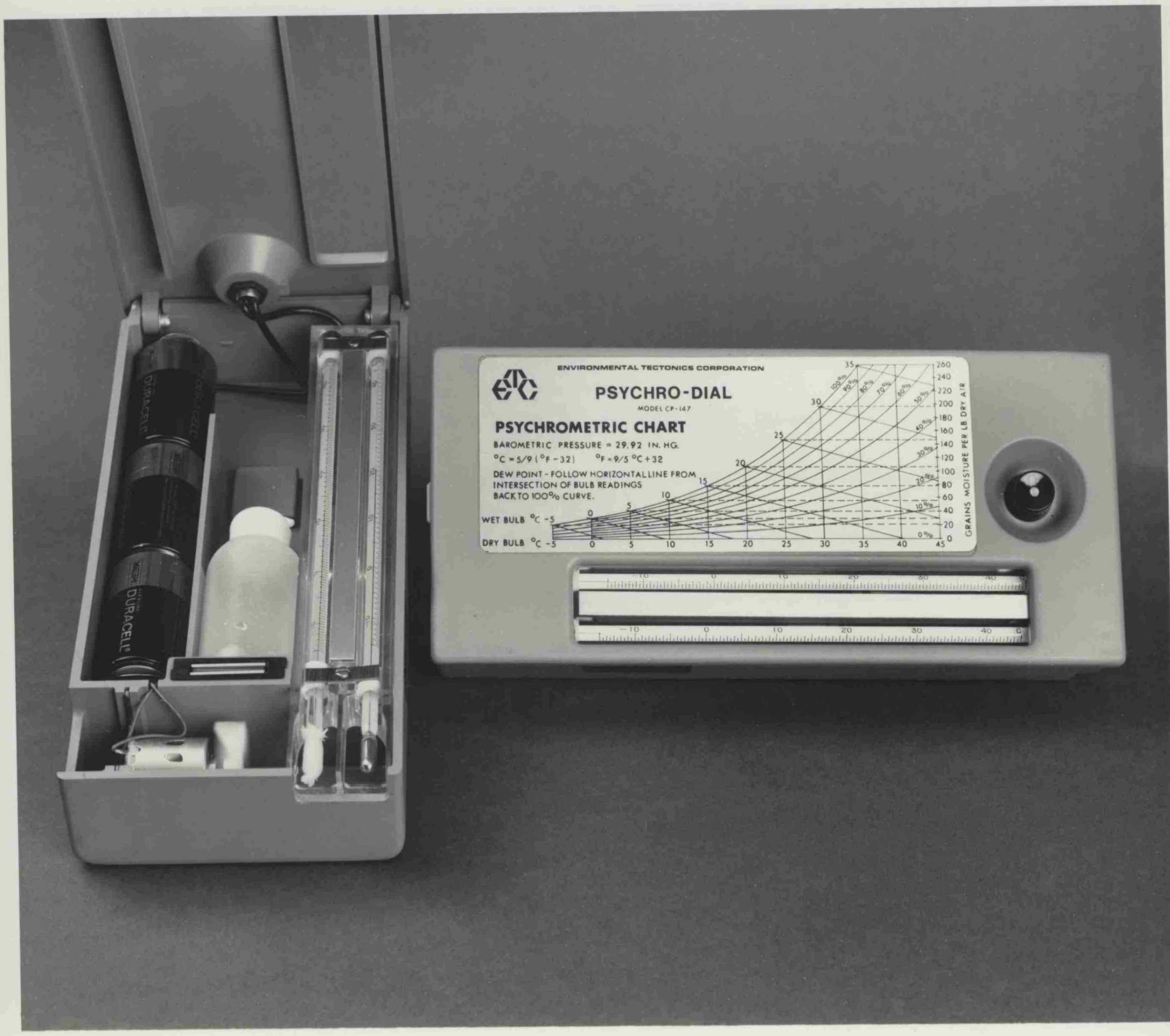


PLATE 2.I.

A Psychro-Dyne Model PPIOO Psychrometer.

to ensure that the results were not affected. This psychrometer was found to be a useful instrument for the survey.

(ii) Windspeed. The windspeed was measured using an AM5000 digital fan anemometer (Plate 2.2). During the questionnaires a run of wind in metres was measured over one minute. A correction value provided by the manufacturer was later added to the velocity obtained in the field. Since this type of fan is directional care needed to be taken to hold the anemometer into the direction of maximum windspeed.

(iii) Precipitation. The amount of precipitation in a day or a number of hours is of little value in a study of human comfort. A day of light drizzle may be more uncomfortable than a short rain shower lasting half an hour. It was assumed for this study that it was the presence of rain rather than the intensity which was important for human comfort. Precipitation was therefore noted on a binary scale with a code of one representing presence of precipitation and zero representing absence.

(iv) Cloud. It was decided to follow the example of the Meteorological Office and to code the cloud cover in octas by observation at the time of the questionnaire.

(v) Sunshine. Although sunshine is not incorporated into the Daily Weather Reports it was considered to be of such potential importance that it was included in a simple coded form on a five point scale similar to that recommended for use in photography, the scale is shown in Table 2.2.

Code	Description
1	Overcast
2	Dull
3	Bright, no shadows
4	Bright, indefinite shadows
5	Bright, definite shadows

Table 2.2. The Scale used for Recording Sunshine

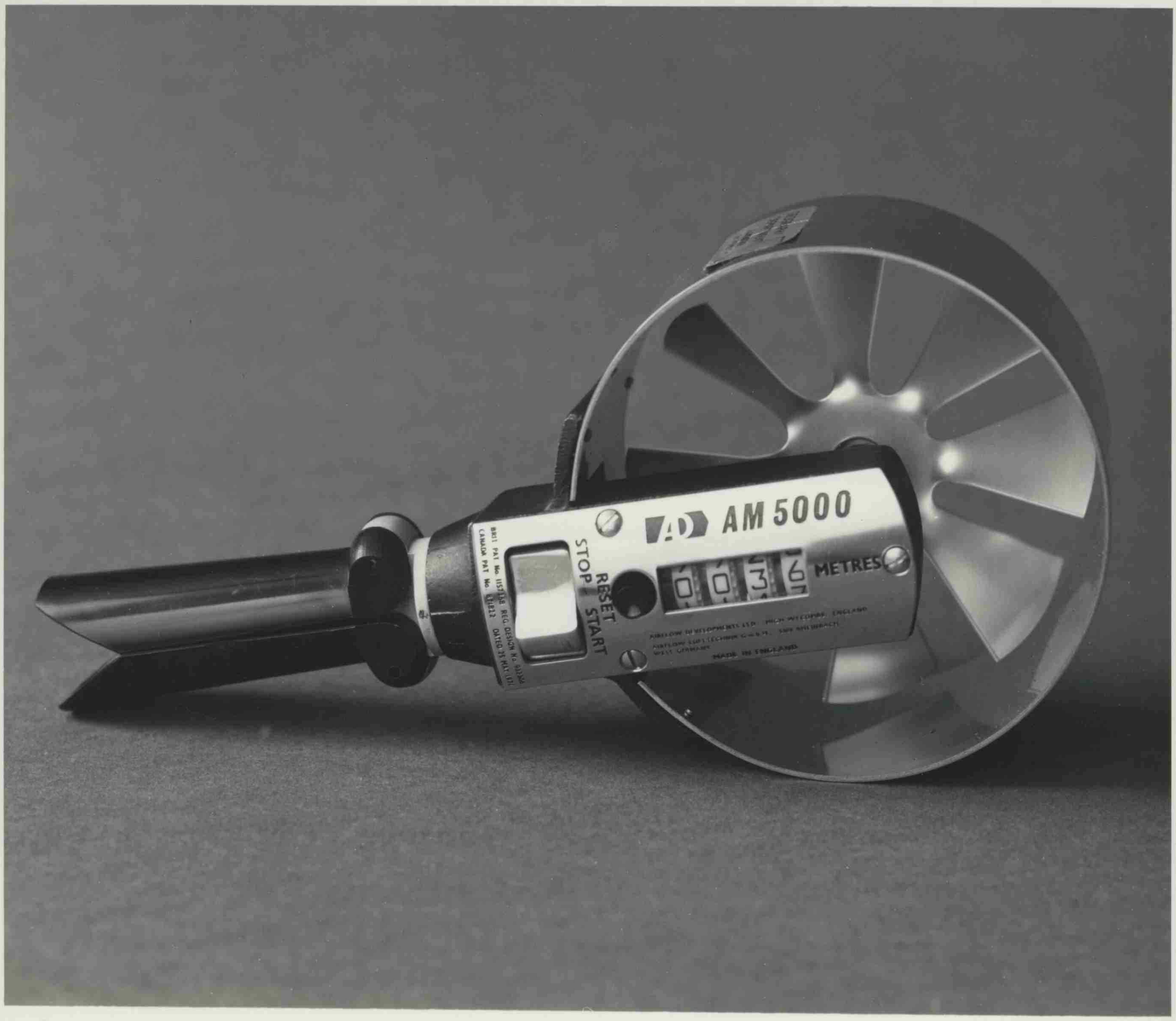


PLATE 2.2.

An AM5000 Digital Fan Anemometer.

Auliciems (1976) used a similar coding system in his work on weather perception.

(vi) Humidity. The percentage relative humidity was derived from the wet and dry bulb readings using a scale provided with the psychrometer.

(vii) The Overall Weather. Five measures of a more general nature were also used. First, the pressure at the time of the survey was obtained from the barograph in the Geography Department at the University of Leicester which is calibrated against a Fortin barometer standard. Second, the nature of the overall weather at the time of the questionnaire was noted using the Present Weather Code as defined by the Meteorological Office for the Daily Weather Reports.

The importance of indices measuring the combined effects of two or more facets of the weather was discussed in the last chapter. The third measure of overall weather considered the combined effects of wind and temperature in the Steadman (1971) Windchill Index and used the method of calculation shown in Table 2.3 incorporated into the SPSS programme shown in Appendix 1. The fourth general measure was also concerned with the combined effects of two variables and was the Temperature-Humidity Index (THI) (Thom, 1959) which measures the stress exerted by the joint effect of temperature and humidity. The index incorporated the dry and wet bulb readings taken at the time of the questionnaire and was calculated using the equation in the BASIC programme shown in Appendix 2, this programme also calculates the Siple and Passel (1945) windchill index which was initially calculated but later discarded in favour of the superior Steadman (1971) index for the reasons discussed in the last chapter.

A fifth type of measure of overall weather was based on the possibility that the past few days weather may affect the response, although

Table 2.3. The Calculation of the Steadman Windchill Index (Steadman, 1971)

1. Calculate the windspeed (V) for a moving person on the ground.

If $F \geqslant 6.4$ $\quad V = (F^2 + 10)^{0.5}$ m.p.h.

If $F < 6.4$ $\quad V = (F^2 + 10 + 7(6 \cdot 4 - F)^{0.5})^{0.5}$ m.p.h.

Where F = Windspeed in m.p.h. at 10 metres above the ground.

2. Calculate the Radiative Heat Loss (HR)

$$HR = 0.0135 \left[4\left(\frac{Tc + 273}{100}\right)^3 + 0.3\left(\frac{Tc + 273}{100}\right)^2 \right]$$

Where Tc = air temperature in degrees C..

3. Calculate the Convective Heat Loss (HC)

$$HC = (0.67 - 0.0008Tf)\ V^{0.75}$$

Where Tf = air temperature in degrees F..

4. Calculate the Surface Resistance (RS)

$$Rs = 1 / (HR + HC)$$

5. Calculate the Windchill Index (W)

$$W = (30 - Tc)/RS$$

the respondents were asked to think only of the weather at the time of the questionnaire. To make allowance for this possibility the dry bulb temperature reading and a sunshine code (as in Table 2.2) were noted at noon on the three days prior to each of the questionnaire days. Auliciems (1972) included similar variables for temperature in his work on the performance of children in schools and found that changes in temperature over the few days could affect performance.

The measures described above were designed to represent the total weather being experienced by the respondent. Humidity and the measures of the overall weather, except the Present Weather Code, were calculated after the questionnaires had been conducted. The other measures and the Present Weather Code described above had to be a measure of the weather at the time of the questionnaire. Ideally the measurements would have been taken at the same time as the questionnaire was being asked but this was impossible for one person to do so therefore the readings and the estimates were made immediately before asking the questionnaire.

2.4 Where to Conduct the Questionnaire

The third major consideration in the research design was where, when and who to question which clearly were related problems. In this section the first of these is considered. One of the major deficiencies in the research in human comfort climatology to date is that the work has been concentrated in the indoor environment rather than being concerned with the outdoor weather. This resulted in one of the major aims of this study being to ensure that the respondents were experiencing the weather which they were being asked to respond to. The way in which the response was elicited and the techniques used to measure the weather were discussed in the last two sections.

In the present work the use of a captive student audience, as used by Auliciems (1976) was not considered suitable for two reasons: first, in order to obtain a large sample either a small number of students would have had to be very patient and prepared to give up time over a long period which may have presented problems of lack of commitment, or a large number of students would have each had to give up a smaller amount of time which was more practicable but could have presented problems in the vacations which constitute 22 weeks of the year. The second reason was that if a wide range of respondents in terms of age and sex structure were obtained, which was not possible using student respondents, then tests could be carried out to establish whether or not there were any differences in weather perception between age and sex groups. This would test the results of Edholm and Bacharah (1965), Fanger (1967, 1970) and McIntyre (1972) who found no such differences and would therefore retrospectively test the justification made for the use of a student population for the pilot survey.

The use of a household survey was also considered and rejected as being inappropriate. Someone standing in the porch of a house is more aware of the indoor rather than the outdoor climate and will not therefore fulfil the survey requirement that the respondent should be experiencing the weather. The concern of this research was the daytime weather and the majority of people who are at home during the day are housewives and pensioners who do not present a representative sample of the total population.

There are therefore a number of problems with these survey types and the use of a street survey overcomes these to a large extent. In the street the respondents are all experiencing the weather which they are being asked to respond to. There is no practical way of overcoming the problem that people asked to respond would probably have come from a shop, office, bus or some shelter before answering the questionnaire and would therefore be aware of the indoor/outdoor contrast in climate. Any bias of this nature can probably be considered to be consistent for all respondents and therefore the results should be of value for the majority of people who are not exposed to the elements for very long periods. A street survey appeared to be the best method of conducting the research being described in this thesis and the decision was made at an early stage to use this survey method which had implications for the sample population which will be discussed later in this chapter.

In order to be practical, street questionnaires need to be carried out in a place where there are a sufficient number of people passing. Initially it was hoped to select a number of contrasting locations such as the city centre, a suburban shopping centre and an urban park. Pilot visits were made to a number of locations and in places other than the city centre there seemed no one location where a sufficient number of people passed at all times of the year to make a street survey worthwhile. It was therefore decided to carry out all the questionnaires in the city centre which had one major advantage in that it standardised the location and surroundings and therefore removed an unknown and possibly irrelevant variable from the analysis.

2.5 When to Conduct the Questionnaire

Having decided on the type of survey to be used the next stage was to decide when to conduct the survey. It must be stressed at this stage that for this survey the sampling frame was the weather and not the sample population so that the days selected needed to give a representative sample of the instantaneous weather; however it must be noted that this is very difficult to sample adequately because it varies rapidly in time, less rapidly in space, and is also subject to non-stationarity as the climate itself changes.

In order to give the results a wide application it was decided to obtain a representative sample of days, with a calculated sampling error, over a whole year. The problem which was presented therefore was to obtain a sample number of days which would adequately represent a total year's weather. In order to do this the sampling error of a particular weather element for a given number of days can be calculated using meteorological data to give some guide as to the number of days required. To ensure a spread of days throughout the year it was decided to use a stratified sample. Most studies use the four conventional seasons or the months of January, April, July and October as being representative of the year; but, for the reasons given in Lamb (1950) the so-called Natural Seasons are likely to be a better unit of study than either of these and were adopted for this stratified sample.

The choice of the number of sample days to be used was based on three considerations. First, it was decided to use the temperature which is readily available in standard data as a measure of the variability of the weather. Second, in order to give a guideline in the calculations, it was decided that the standard error of the mean of temperature in all the five seasons should not exceed 2°C.. Third, given the time and manpower limitations it was considered that a target of approximately 30 days would give a reasonable amount of data for analysis; this would give six days in each Natural Season.

The next step was to examine the standard error of the mean of temperature associated with a sample of six days for each season for a study conducted in Leicester. The Daily Weather Reports produced by the Meteorological Office are the only readily available source of instantaneous weather data for the British Isles and the three synoptic stations surrounding Leicester (Figure 2.4) were used to estimate Leicester's weather.

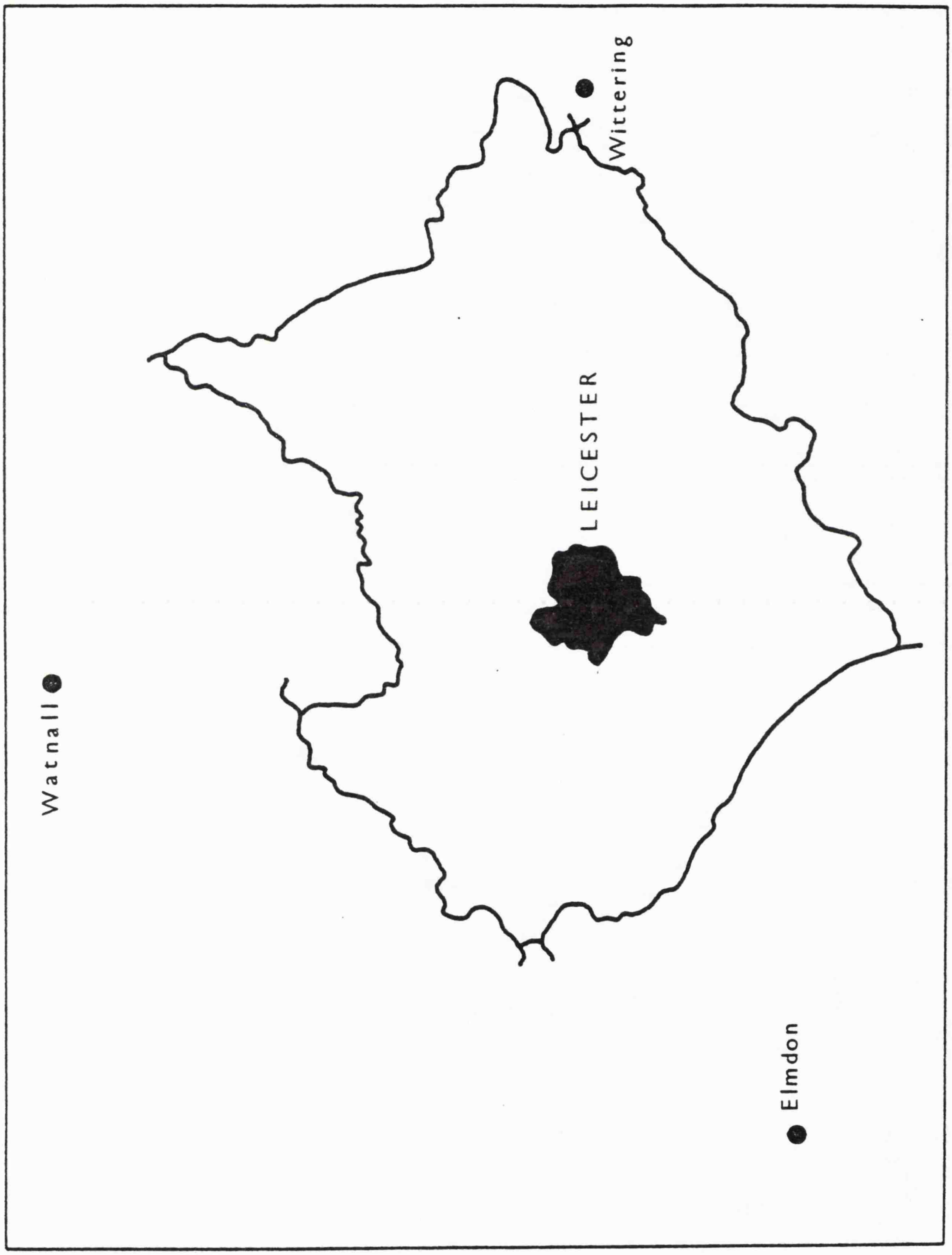


FIGURE 2.4. The three Synoptic Stations used to estimate Leicester's weather.

As a total run of the Daily Weather Reports for the British Isles could not be obtained from the Meteorological Office on magnetic tape it was necessary to sample from the published reports. A 5% random sample of the 15 years 1963 to 1977 stratified according to the Lamb Natural Seasons was used giving a total of 274 days. To reduce the sample and to make it representative of daytime conditions only the 1200 GMT data were used. Some summary statistics for the dry bulb temperature are shown in Table 2.4. The standard error of the mean is calculated for a sample of six days in each season. It can be seen that the standard error of the mean was no higher than 1.84°C. and this suggested that a sample of six days in each season should give an adequate sample of each season's weather with the estimated standard error for temperature shown in Table 2.4.

The final stage in this consideration of when to conduct the questionnaire was to select the sample 30 days. The decision to use a street survey resulted in the exclusion of Sundays and Bank Holidays from the sampling frame; a small number of unavoidable commitments and occasional illness also limited the eventual selection of days. The sample days were selected from the available days using a random sample stratified according to the Natural Seasons. The sample days used are shown in Appendix 3 and the sample year commenced at the start of Late Winter 1978.

It will be remembered from Chapter 1 that one of the major deficiencies in the literature to date is a failure to consider the spatial variations in human comfort. It has already been noted in this chapter that the Daily Weather Reports for 1200 GMT present the only available source of instantaneous daytime data and it was realised at an early stage in the research that these Reports would have to form the basis for any mapping of the results of the survey. To ensure that the survey

Table 2.4. <u>Leicester's Estimated Temperature for 1200 GMT</u>

SEASON	DATES	SAMPLE MEAN (^{o}C.)	SAMPLE STANDARD DEVIATION (^{o}C.)	STANDARD ERROR OF THE MEAN when n = 6
SPRING	30 March - 17 June	12.68	4.30	1.76
HIGH SUMMER	18 June - 9 September	17.63	2.97	1.21
AUTUMN	10 September - 19 November	13.49	3.23	1.32
EARLY WINTER	20 November - 19 January	5.77	4.50	1.84
LATE WINTER	20 January - 29 March	5.09	3.66	1.49

was comparable the questionnaires were conducted around 1200 GMT, between 1030 and 1330 local time.

2.6 The Selection of the Respondents

The sampling frame for this study was the weather and therefore there was no obvious criterion for selecting either the number or the type of people to interview. The decision was taken to conduct 25 questionnaires on each of the 30 days because this number could be carried out comfortably within the allocated time around 1200 local time. This gave a large total sample of 750 responses over the year.

The use of a street survey meant that a true probability sample could not be adopted in that every person in Leicester did not have an equal probability of selection. Gray and Corlett (1950) noted that there are many situations when a rigorous sampling procedure cannot be adopted but that this should not deter the researcher in his work. It will be remembered from the discussion of the pilot survey that the experiment assumed that there is a common perception of the weather so that any one person's response is an estimate of the 'true' score for the particular conditions. This assumption made the use of any form of quota sampling irrelevant. Perhaps the most important consideration in the choice of the respondents was that the weather measurements should be made as near-simultaneous as possible to the response being elicited and therefore the procedure adopted for the questionnaires was as follows: the measurements of the weather were made and then the next person to pass the surveyor was asked if he would be willing to answer the questionnaire, if he refused the next person was asked. If more than one person refused, or if it was not possible to approach a second person immediately, then the weather measurements were repeated to ensure that they were representative of the weather experienced by the respondent immediately prior to answering the questionnaire.

Although the primary concern of the sampling considerations was the weather and not the respondents it was decided to take some consideration of respondent type, to make some initial examination of possible group differences. To eliminate a possible source of bias it was decided to first ask the respondent if he was a Leicestershire resident, if not the questionnaire proceeded no further. The respondent's sex and age were recorded, the latter being recorded as one of the age groups shown in Table 2.5.

Table 2.5 The Age Groups used for the Questionnaire

Group	A	B	C	D	E	F
Age Range	Under 20	20-29	30-39	40-49	50-59	Over 60

To establish whether or not clothing affected the response the 'clo' unit of the respondent was estimated using the approximations shown in Table 2.6. The multi-racial nature of Leicester's population also presented a possible source of bias and therefore a binary variable was incorporated to the analysis to indicate whether or not the respondent had spent most of his life in the British Isles . No further questions, such as concerning occupation, were asked of the respondent for two main reasons. First, a street survey in a city centre invariably results in a bias towards 'white collar' workers and although socio-economic status has been found to be important in many studies in human geography where quota sampling of the population has been used, it was not included in this study where the main priority for sampling procedure was the weather. Second, the only previous work concerned with group differences has used sex, age, nationality and clothing as factors in

Table 2.6. Clo Unit Estimates. (After Fanger, 1970, page 33)

Clothing	Clo Units
Shorts	0.1
Shorts, Shirt, Socks, Sandals	0.3 - 0.4
Track Suit	0.35
Light trousers, Short sleeved shirt	0.5
Shirt, Trousers, Socks, Shoes	0.7
Light business suit	1.0
Suit and Cotton coat	1.5
Shirt, Trousers, Light jacket	0.9
Heavy suit	1.5
Suit and Coat	1.5 - 2.0

assessing the response to the thermal environment (Fanger, 1967, 1970) and enables comparisons to be made with this study leaving more detailed analysis until appropriate methodologies for conducting such research have been obtained.

2.7 Summary and Conclusions

This chapter has described the design of the experiment to assess public perception of the weather. In order to quantify the perception as a function of the weather it was necessary to measure both the perception and the actual weather. The potential scales for measuring the perception were discussed in Section 2.2 and the final choice was a Likert Scale which consisted of six statements about the weather which the respondents were asked to consider and to analyse their agreement or disagreement to each. The instruments used to measure the 'objective' weather were discussed in Section 2.3 and the major considerations when choosing these were their accuracy, portability and ease in use. Other more general measurements of the overall weather and the weather of the three days prior to the questionnaire were also made.

Having discussed the decisions to use particular instruments to measure the perception and the weather the Chapter then continued with a discussion of where and when the questionnaire was to be conducted and on whom. A street survey in the City of Leicester was deemed most appropriate and 30 sample days were chosen after a consideration of the temperature variability in Leicester. The sample days were stratified equally according to Lamb's (1950) five Natural Seasons. The sampling frame for the study was the weather and therefore there was less concern regarding the sampling of the respondents. Previous work suggests that any respondent regardless of age and sex should be representative of the total population. It was decided to place no restrictions on the sample other than the close proximity in time to the weather measurements and to conduct 25 questionnaires on each of the 30 sample days.

Although many of the decisions described in this chapter were arbitrary it is hoped that they have been justified to a large extent. In a field such as human comfort climatology with little similar past research it is inevitable that such rather arbitrary decisions must be made.

Chapter Three

A Univariate Analysis

3.1 Introduction

The design of an experiment to examine attitudes to the weather was described in the previous chapter. Its result was a data file of 750 responses to an attitude scale questionnaire, each response being related to a simultaneous set of weather measurements carried out on a stratified sample of days during 1978/9. This chapter examines some preliminary results of the questionnaire in three major sections. In the first, the sample population is considered and its representativeness is examined; the second discusses the sample weather and the third examines some initial results of the attitude scale. The analyses reported in this chapter are univariate, concentrating on the representativeness of the sample weather and surveyed population. A multivariate analysis of the same data is presented in the succeeding chapter.

3.2 The Sample Population : Age, Sex and Clothing

As outlined in the previous chapter, the major interest in the survey was to obtain a good probability sample of differing weather conditions, and this necessitated a rather unsatisfactory quasi-random street survey of individual respondents. It is therefore of some importance to establish that the sampled population is at least a reasonably representative one, containing no obvious bias due to non-response, to age, sex, nationality or even to the type of clothing worn.

The first possible source of bias is in non-response. Although no detailed record was kept of the type of people who refused to answer the questionnaire, there appeared to be no systematic pattern in the type of person who refused. A number of people seemed initially suspicious possibly because in the past they had answered questionnaires which sought to extract personal information. The majority of people who refused did so because they did not have the time to answer. Few children were in the city centre at the time of the questionnaire and the respondents were all over 15 years old.

Figure 3.1 (a-h) presents population pyramids based on the 1971 Census of the age/sex structure of Great Britain and Leicestershire together with similar pyramids for the sampled population on an annual and seasonal basis. The population pyramids show that all age categories were represented in each season. The samples show some bias towards certain age groups in the different seasons; in Spring 28% of the sample of 150 were females in their twenties; in High Summer there was a concentration of both males and females in their twenties; in Autumn 18.6% of the sample were males over 60 years of age with the rest of the sample fairly evenly distributed as were the Early and Late Winter sample populations. The overall population pyramid for the total sample (Figure 3.1(h)) shows a relatively even distribution of the sample through the age categories but with people in their twenties being the best represented.

The age structure of the Great Britain (Figure 3.1(a)) and the Leicestershire (Figure 3.1(b)) populations are very similar, with the twenties and sixties age categories having the largest representation; the 15 to 19 age group has the lowest number of people because of the fewer years incorporated in this category. Chi-square tests were carried out to test the association between the Great Britain data and those for each season and the year as obtained from the surveyed population, and the results shown in Table 3.1. The level of significance at the 0.01 level is 24.72 showing that only the two winter seasons had sample populations which were representative of the Great

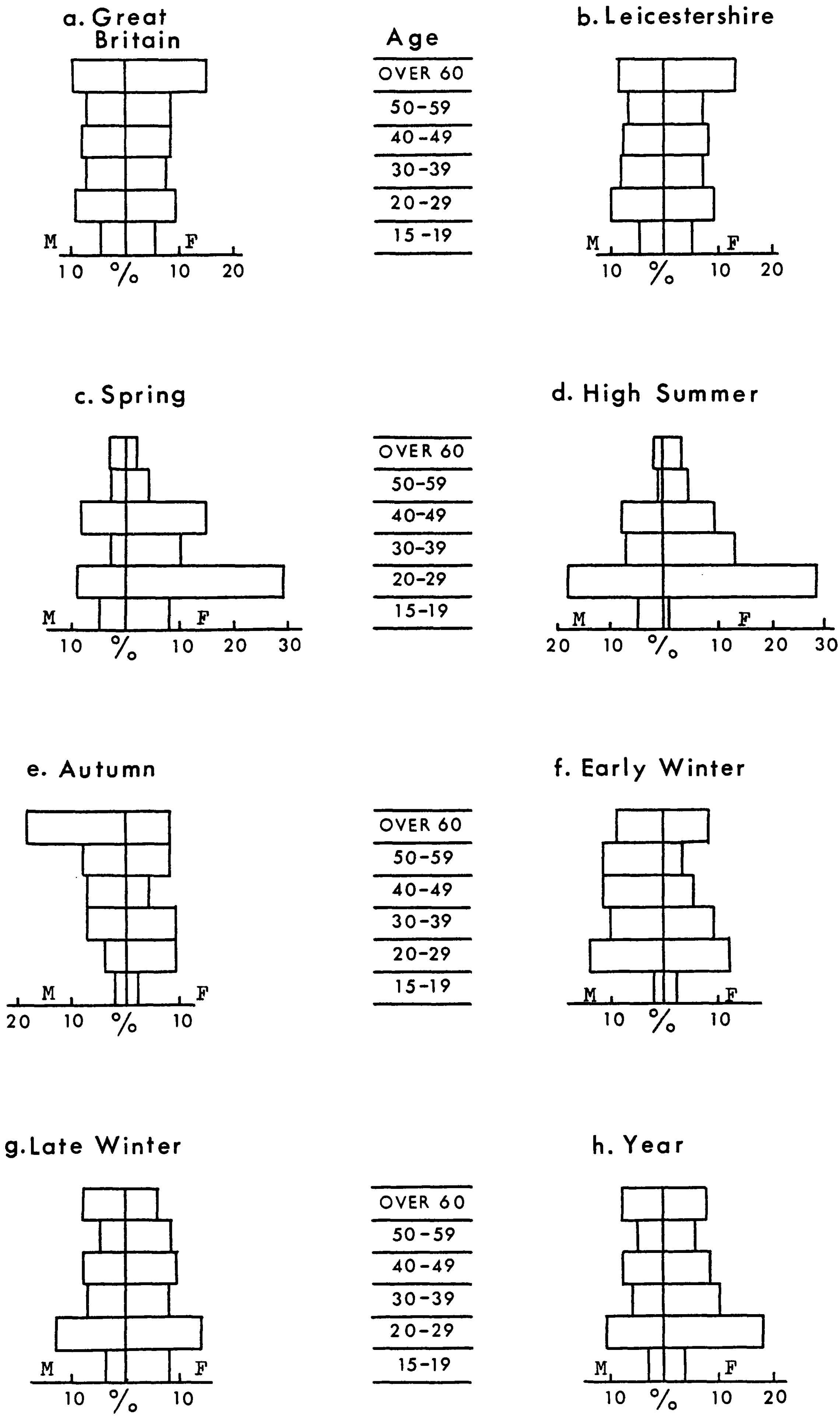


FIGURE 3.I. Population pyramids for Great Britain,Leicestershire and the sample population.

Table 3.1. Chi-square statistics for examining the association between the Great Britain population and the sample population

Sample population	Chi-square statistic
Spring	115.06
High Summer	111.01
Autumn	26.98
Early Winter	24.14
Late Winter	19.84
Year	116.80

Britain population in its age and sex structure. The reason for the disparity in the other seasons and the year as a whole is due to the relatively large number of respondents in their twenties, which is possibly representative of the people in the city centre at lunchtime, and also the proportionally low number of respondents over sixty which, again, is not unexpected. With the exception of these groups the rest of the sample is fairly representative. Despite these disparities each age and sex group was represented in the sample and therefore comparisons could be made with Fanger's (1970) work to see if age and sex affected the respondent's perception of the weather.

A third possible source of bias was from immigrants who may have had experience of living under very different climatic conditions in, for example, Asia or the West Indies. Each respondent was therefore asked where he had spent the majority of his life and a binary variable was coded zero if the answer was the U.K., one otherwise. Many of the recent immigrants in Leicester speak very little English and the majority of these who were approached did not understand what was required and as a result only 31 of the 750 respondents had spent most of their lives abroad.

Finally it is possible that the clothing worn at the time of the interview affected weather perception in a systematic way. The clothing of the respondent was estimated in clo units to produce the results shown in Figure 3.2. Unlike the analysis of population where the Census provides an overall 'target' by which to evaluate the sample, there are no published survey data on what clothing, as measured by the clo equivalent, people actually wear on a day to day basis. The results are therefore of considerable interest and importance. The annual clo estimate ranged from 0.4 which corresponds to very light summer clothing, such as a T-shirt and skirt or shorts to 2.6 corresponding to a suit and heavy overcoat with a modal class of 1.0 representing 37% of the sample; one clo unit is an ordinary man's suit which many of the male respondents were wearing. It can be seen that the distribution shown in Figure 3.2 is bimodal, perhaps reflecting a tendency for respondents to dress in clothes suitable for hot or cold weather without much other variation. The clo unit also varied seasonally as shown in Table 3.2. The variation is as might be expected,

Table 3.2. Seasonal Variation in the Estimated Clo Unit of the Respondents

Season	Maximum	Mean	Minimum
Spring	2.0	1.1	0.4
High Summer	1.8	1.0	0.4
Autumn	2.0	1.3	0.6
Early Winter	2.6	1.6	0.9
Late Winter	2.0	1.5	0.9

and varies from a mean of 1.6 in Early Winter to 1.0 in High Summer; the minima and maxima also vary in this way. These figures can be compared to those calculated for Canada by Hare and Thomas (1974) which are shown in Table 3.3. The estimated values for the clo units of the respondents are fairly similar to those found by Hare and Thomas for Vancouver and London, Ontario, although the winter maxima are higher

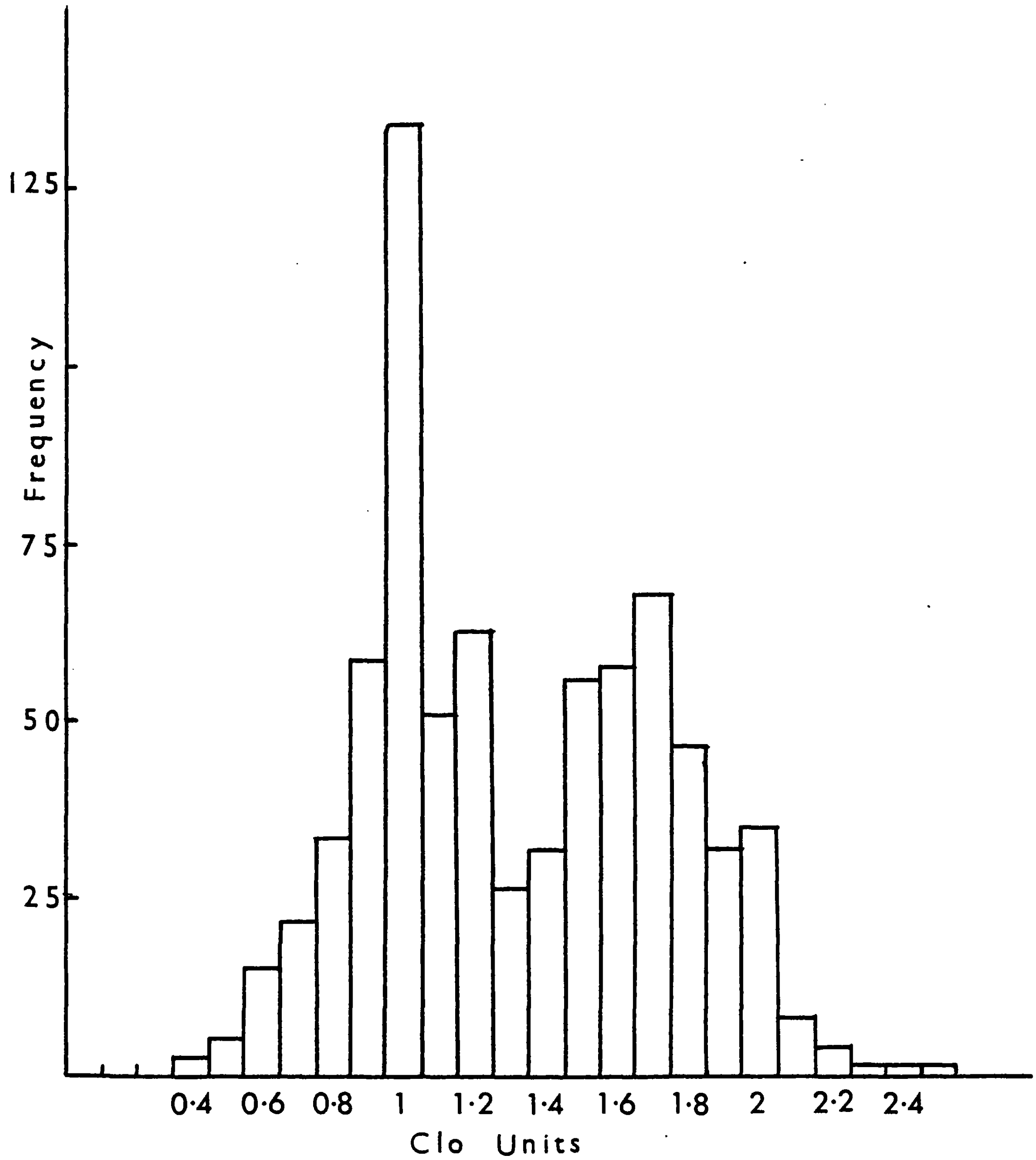


FIGURE 3.2. The estimated Clo Unit for the respondents.

Table 3.3. Clo unit requirements in Canada (after Hare and Thomas, 1972)

	Vancouver, B.C.			London, Ontario			Yellowknife, N.W.T.		
Months	Max.	Normal	Min.	Max.	Normal	Min.	Max.	Normal	Min.
Sept.-Nov.	1.5	1.0	0.5	1.5	1.0	0.5	3.0	2.5	1.0
Dec. - Jan.	2.5	2.0	0.5	3.0	2.5	1.0	5.0	4.0	1.5
March-April	2.0	1.5	0.5	2.5	2.0	0.5	3.5	2.5	1.0

than the maxima recorded for the respondents. No comparative figures were available for summer, although clothing insulation is less important in that season.

In conclusion there are three major points to note from this section on the sample population. First, the sample, drawn on a quasi random basis in the city centre of Leicester, was reasonably representative in age and sex characteristics of the overall population of Leicestershire and Great Britain which allowed some analysis of group differences although this had not initially been planned. Second, it was unlikely that any examination of differing perception due to nationality could be examined because only a small proportion of the respondents had spent most of their lives abroad. Third, the estimated clo unit for the respondents showed interesting variation throughout the year.

3.3 The Sample Weather

A major aim of the experimental design was to ensure that the days on which questionnaires were conducted were representative of the range of weather considered normal in Leicester. The weather data which were collected for each respondent were described more fully in the previous chapter and included the near-surface wet and dry bulb temperatures, windspeed, cloud cover, sunshine, pressure, the presence or absence of precipitation and the Present Weather Code. These data are summarised in Table 3.4 and Table 3.5 for the five Natural Seasons and for the

Table 3.4. A Summary of the Weather Data Collected at the Time of the Questionnaire

SEASON	STATISTIC	Dry Bulb Temperature (°C)	Wet Bulb Temperature (°C)	Wind ($m.s^{-1}$)	Pressure (mb.)	Cloud Cover (Octas)	Sun Code (1-5)	Present Weather Code	Proportion of Raindays
SPRING	mean	13.20	8.5	0.68	1013.4	6.02	3.02	6.5	0.0
	standard deviation	5.25	2.98	0.4	11.52	2.32	1.54	8.75	-
HIGH SUMMER	mean	18.3	13.98	0.61	1014.33	6.69	2.91	13.33	0.167
	standard deviation	2.39	1.83	0.39	7.59	1.73	1.56	17.6	-
AUTUMN	mean	14.84	12.34	3.83	1012.33	6.43	2.83	8.73	0.1
	standard deviation	2.34	1.83	3.13	6.75	2.49	1.59	17.76	-
EARLY WINTER	mean	3.31	2.08	3.09	1011.33	5.99	2.67	25.09	0.287
	standard deviation	2.73	2.55	2.4	19.3	2.75	1.78	31.21	-
LATE WINTER	mean	9.16	7.23	0.99	1003.21	6.71	1.95	24.11	0.147
	standard deviation	2.58	2.36	0.47	12.93	2.36	1.49	17.94	-
YEAR	mean	11.76	8.8	1.84	1012.72	6.37	2.68	15.56	0.14
	standard deviation	6.09	4.79	2.24	13.76	2.38	1.62	21.44	-
	maximum	22.0	16.5	14.9	1030.0	8.0	5	84	-
	minimum	-0.75	-2.25	0.02	970.0	0.0	1	0	-

Table 3.5. A Summary of the Variables Included in the Analysis which were not Directly Measured at the Time of the Questionnaire

SEASON	STATISTIC	Relative Humidity %	THI	Windchill $cal m^{-2} s^{-1}$	Temperature (day-1)	Temperature (day-2)	Temperature (day-3)	Sun (day-1)	Sun (day-2)	Sun (day-3)
SPRING	mean	56.63	56.27	58.53	10.08	7.33	10.47	3.17	2.67	1.83
	standard deviation	15.49	5.93	17.66	6.41	4.72	4.47	1.21	1.37	0.69
HIGH SUMMER	mean	64.78	63.84	41.25	13.17	12.5	13.33	2.5	1.5	1.83
	standard deviation	9.5	2.92	8.04	5.96	5.74	5.99	1.12	1.26	1.21
AUTUMN	mean	77.32	60.16	71.15	13.38	13.29	12.17	3.67	3.0	3.0
	standard deviation	15.03	2.77	22.49	0.8	2.71	0.83	0.75	1.0	1.29
EARLY WINTER	mean	80.6	44.48	114.04	5.04	4.54	3.33	1.83	2.5	1.83
	standard deviation	6.45	3.79	23.83	2.2	2.87	3.25	0.69	1.61	1.07
LATE WINTER	mean	88.34	52.41	73.05	7.55	7.47	8.38	2.0	2.67	2.83
	standard deviation	5.14	3.51	8.61	2.36	3.84	3.61	0.58	1.25	1.34
YEAR	mean	73.54	55.43	71.58	9.84	9.03	9.54	2.67	2.3	2.53
	standard deviation	15.95	7.76	29.74	5.29	5.32	5.34	1.08	1.22	1.31
	maximum	100	67.42	201.45	20.0	18.4	17.25	5	5	5
	minimum	35	38.44	28.33	-0.5	0.0	-0.25	1	1	1

whole year and in Figures 3.3 to 3.6 as frequency distributions for the whole year. The statistics are self explanatory and are of most interest when compared with Leicester's mean weather and then related to the results of the questionnaire.

To assess how representative the weather data relating to each respondent had been a comparison was made with the estimated long term means for Leicester. A 5% random sample for the 15 years 1963 to 1977 inclusive was obtained from the Daily Weather Reports, the sample being stratified according to Lamb's Natural Seasons (Lamb, 1950). For the reasons already discussed, Leicester's weather was estimated from the means of the three synoptic stations surrounding the city. The data from these stations, together with the other synoptic stations were processed using the FORTRAN programmes shown in Appendix 4 and Appendix 5 and the results are shown in Table 3.6. Only some of the weather data as measured at the time of the questionnaire can be compared with those in the Daily Weather Report but it is hoped that this will give an indication of the representativeness of the sample days. Before examining the individual elements in turn it is worth noting three points regarding the results. First, there appears to be seasonal variation in much of the data suggesting that the Lamb (1950) Natural Seasons are a useful way of stratifying the year for climatic purposes. Second, the sample of questionnaire days was not large and some of the discrepancies may be a result of this. Third, the questionnaires were conducted in the city centre but the Daily Weather Report data are often based on observations in open spaces such as airfields and therefore any comparisons between the two data sets may show disparities.

(i) Temperature. The frequency distributions of the dry and wet bulb temperatures (Figures 3.3(a) and (b)) on the survey days show no systematic pattern. A comparison of the mean dry bulb temperature

Table 3.6. The Estimated Mean Weather Data for Leicester

SEASON	STATISTIC	Air Temperature (°C)	Windspeed ($m.s^{-1}$)	Pressure (mb)	Cloud Cover (Octas)	Present Weather Code	Proportion of Raindays	Relative Humidity %	THI	Windchill cal $m^{-2} s^{-1}$
SPRING	mean	12.68	5.55	1013.67	5.95	15.39	0.13	67.68	56.38	96.55
	standard deviation	4.30	2.54	10.13	2.02	22.09	-	13.43	3.51	35.22
HIGH SUMMER	mean	17.63	5.58	1015.13	6.12	13.78	0.14	65.76	60.43	67.75
	standard deviation	2.97	2.48	6.35	1.99	23.17	-	14.71	2.65	27.42
AUTUMN	mean	13.49	5.49	1013.12	6.14	13.67	0.13	74.76	57.04	93.35
	standard deviation	3.23	2.78	12.09	1.98	22.00	-	12.93	2.65	29.31
EARLY WINTER	mean	5.77	5.55	1015.14	5.92	20.21	0.20	83.6	50.75	132.06
	standard deviation	4.49	2.74	10.81	2.64	23.78	-	10.9	3.65	35.89
LATE WINTER	mean	5.09	5.68	1014.99	6.49	24.04	0.27	80.58	50.17	137.09
	standard deviation	3.66	2.99	13.76	2.31	18.82	-	12.99	3.01	34.14
YEAR	mean	11.36	5.6	1014.4	6.13	17.20	0.17	73.64	55.30	103.31
	standard deviation	6.1	2.72	10.78	2.2	23.96	-	14.92	4.98	40.78

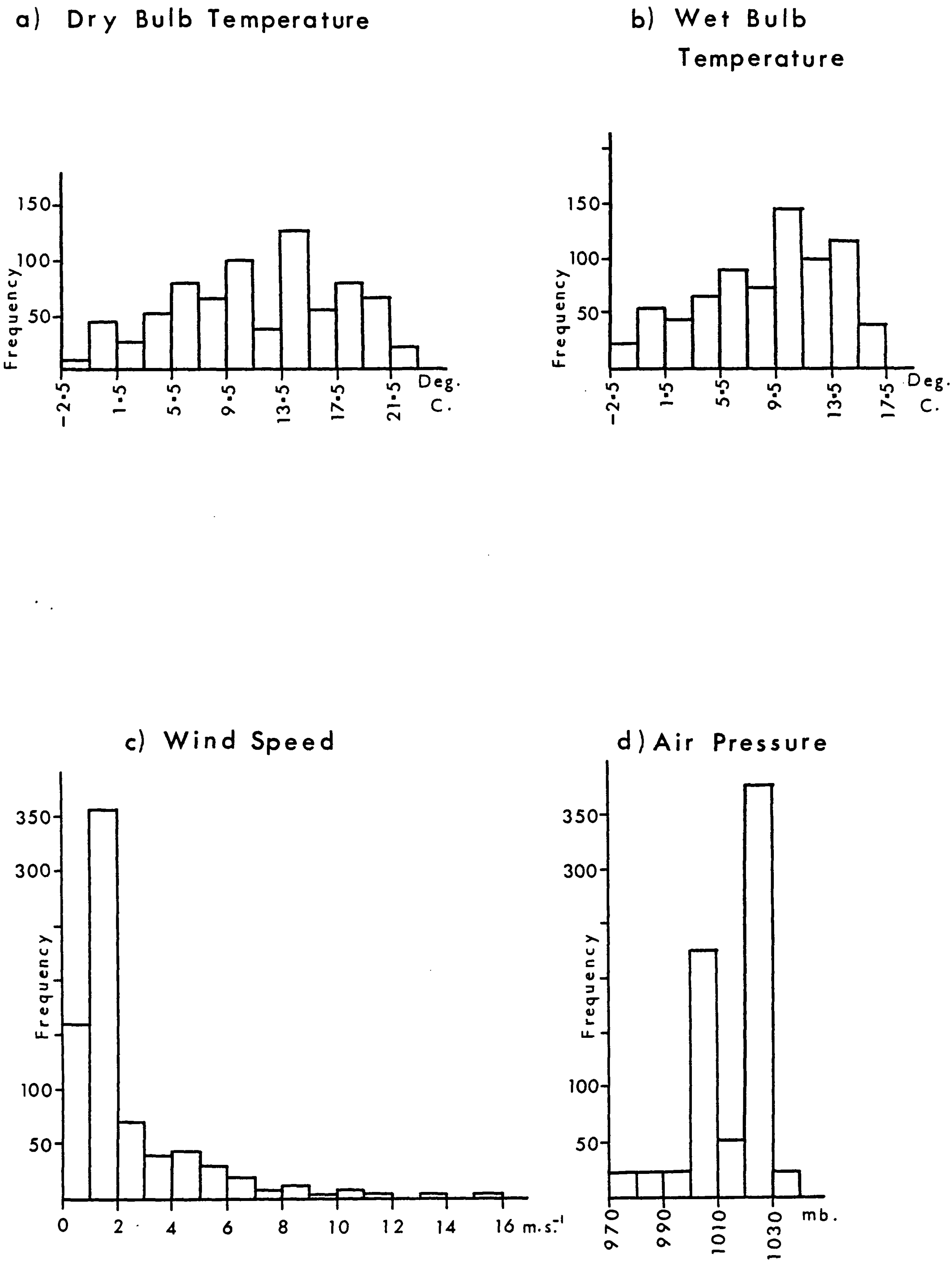


FIGURE 3.3. Frequency distributions for the weather data collected at the time of each questionnaire.

for the survey days (Table 3.4) and the long term mean temperature (Table 3.6) shows that the difference is less than 1°C. in Spring and High Summer and in Autumn is 1.3°C., the difference in Early Winter is however 2.46°C. and in Late Winter 4.07°C.. In all seasons the mean survey temperature exceeded the long term mean which may have been a result of the rural/urban difference in temperature. The differences may also have been due to the relatively small sample of weather which was taken, however, the annual long term mean of 11.36°C. is very close to the mean temperature as measured at the time of the questionnaires which was 11.76 and the standard deviations are also similar. The temperature data suggest therefore that the Winter temperatures were considerably higher than might have been expected given the long term mean although the other three seasons and the annual mean were very similar to the expected values.

(ii) Windspeed. The frequency distribution of windspeed as measured at the time of the survey (Figure 3.3(c)) emphasises the low values which were recorded on the majority of occasions. The values are for a run of wind over one minute which may reduce the effect of gustiness which is more common in cities than in rural areas (Chandler, 1965) and mean values of windspeed have been found to be between 20 and 30% lower in urban areas than in rural areas where the Daily Weather Report data are invariably collected (Landsberg, 1970). It can be seen from Table 3.6 that the Daily Weather Report data suggest that the mean values should be higher than those obtained on the survey days in the city centre possibly because of rural/urban differences and because the Report data are collected at a height of 10 metres above the ground whereas the survey measurements were made at head height. An appropriate correction factor from 10 metres to head height is presented in Smithson and Baldwin (1978) which reduces the mean values shown in Table 3.6 to between 3.16 m.s.$^{-1}$ in Spring and 3.24 m.s.$^{-1}$ in Late Winter which compare more favourably with the survey data.

(iii) Air Pressure. The air pressure was generally constant over the period of the 25 questionnaires conducted on each survey day. The distribution shown in Fig. 3.3(d) shows little pattern except a tendency for the pressure to fall within the ranges 1000 to 1010 mb and 1020 to 1030 mb. The long term mean pressure varies little during the year (Table 3.6) and is in general higher than that experienced during the questionnaire period. This difference is not large and the annual means differ by only 2 mb.

(iv) Cloud and Sunshine. The frequencies of cloud cover (Figure 3.4(a)) show a marked negative skew in their distribution and the sunshine figures reflect this to some extent although this frequency distribution (Figure 3.4(b)) is more 'U' shaped. Cloud cover can be compared with the long term estimates for Leicester (Table 3.6) and are found to be very similar with both having a minimum in Early Winter although the larger variance is experienced in this season. The values are however slightly higher for the sample days (Table 3.4) than for the estimated mean which may be due again to rural/urban differences and is in accordance with Landsberg (1970) who reported that cloud in cities tended to be between 5 and 10% higher than in rural areas. Chandler (1965) suggested that this may be a result of the increased mechanical and thermal turbulence over a city.

(v) Present Weather Code. This code ranges from 0 to 100 with values over 50 implying that precipitation has reached the ground at the time of the observation, the intensity of any type of precipitation being indicated by different values of the code. The lowest code recorded was 1 implying that 'cloud development was not observed'

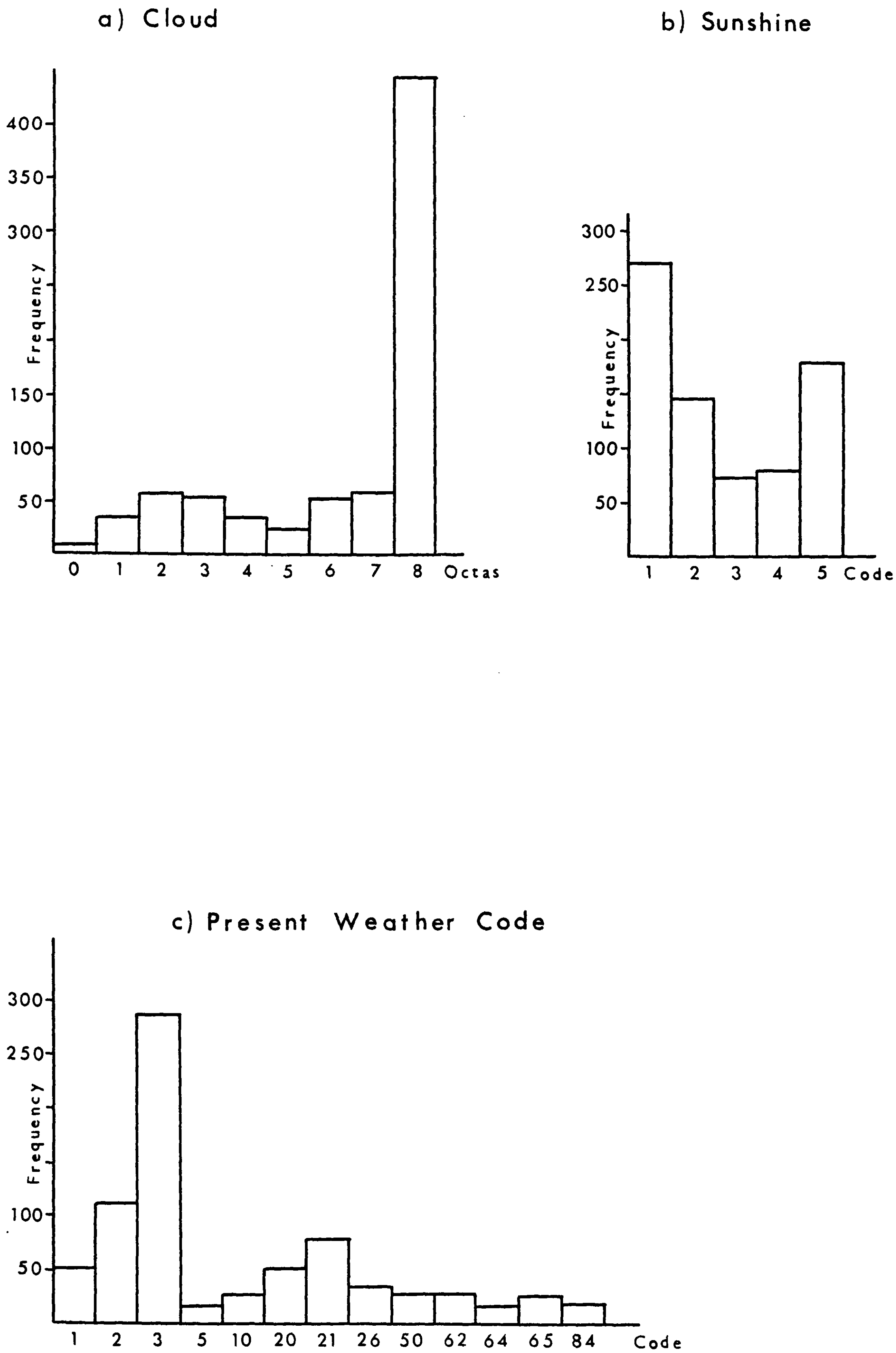


FIGURE 3.4. Frequency distributions for the weather data collected at the time of each questionnaire.

whilst the maximum observed code was 84 indicating 'showers of rain and snow, moderate or heavy' were falling at the time of the questionnaire. In general low values indicate better weather for human comfort than do high values and using this criterion Spring had the best weather and Early Winter the worst. The annual frequency distribution is shown in Figure 3.4(c) and shows a bias towards the more favourable end of the spectrum. Because of the coded nature of this measure of the weather the summary data for the survey (Table 3.4) and for the long term (Table 3.6) do not have very much meaning although it can be seen that in general terms the figures are similar.

(vi) Precipitation. This was the final datum recorded at the time of the questionnaire and the proportions of questionnaires carried out while precipitation was falling are shown in Table 3.4. In Spring no questionnaires were conducted during precipitation and the highest number was 43 in Early Winter with a total of 105 out of the 750 responses conducted in the rain. This binary variable was possibly the one most subject to disparities from the long term mean as a result of a poor sample. The proportions do not however differ too much from the long term values (Table 3.6) and the overall number of 105 gives an adequate sample number in this category for meaningful analysis.

(vii) Relative Humidity. This was the first of a series of extra variables to be derived in an attempt to obtain a more accurate objective evaluation of the human comfort climate being experienced at the time of the questionnaire. The Relative Humidity was derived from the wet and dry bulb temperature readings using a scale provided by the manufacturers of the psychrometer. The frequency distribution shown in Figure 3.5(a) shows a negative skew with a modal class at 81 to 90%. Table 3.5 shows that the highest mean values were recorded in the winter seasons when the standard deviations were lowest. The lowest mean value

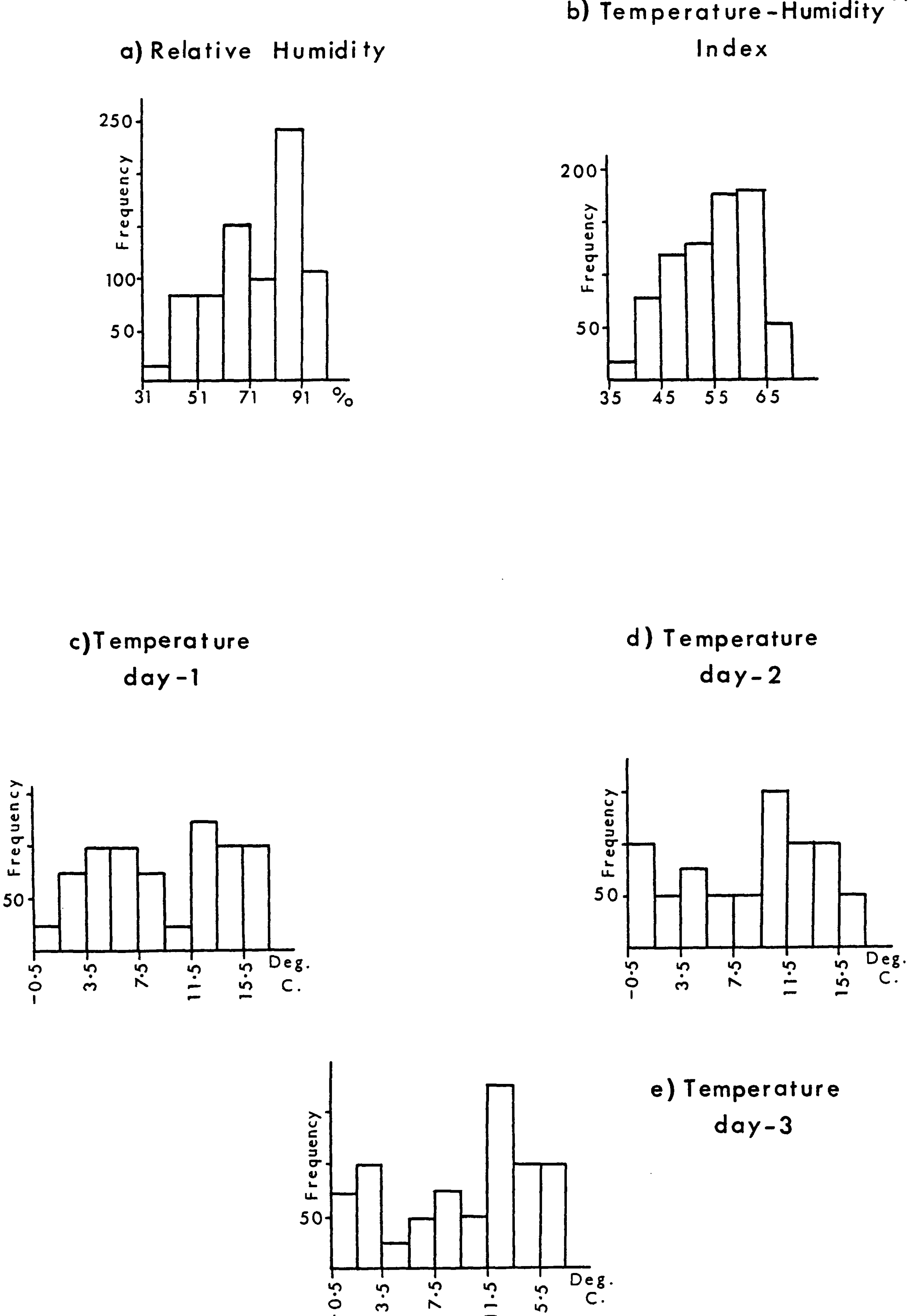


FIGURE 3.5. Frequency distributions for further data included in the analysis for each respondent.

and the highest standard deviation were found in Spring. These values measured at the time of the questionnaires show very similar values to those obtained from the Daily Weather Reports (Table 3.6) to estimate Leicester's weather.

(viii) Temperature Humidity Index (THI). This Index never reached Thom's (1959) discomfort level of 70; the highest recorded value being 67.42. The frequency distribution shown in Figure 3.5(b) is negatively skewed reflecting the pattern shown by the Relative Humidity (Figure 3.5(a)) used in its derivation. As with the Relative Humidity, the survey data (Table 3.5) compare favourably with the Daily Weather Report data (Table 3.6).

(ix) The Weather of the Three Previous Days. The temperatures at noon on the three days prior to the questionnaire survey were also included in the analysis together with the sunshine code for those times. The frequencies shown in Figures 3.5(c) to (e) and Figures 3.6(a) to (c) are in multiples of 25 because, of course, the values were constant for each survey day of 25 questionnaires. The distributions are similar to that of the temperature at the time of the questionnaire (Figure 3.3(a)) although the ranges and the mean values (Table 3.5) are slightly lower. The sunshine codes also show a similar frequency distribution (Figures 3.6(a) to (c)) to those recorded at the time of the questionnaire (Figure 3.4(b)) with all the frequency diagrams having strongly positive skews. The mean values (Table 3.5) were also of a similar order of magnitude to the data included from the survey (Table 3.4). Without increasing the sample fourfold it was not possible to compare these values to the Daily Weather Report values.

(x) Windchill. The windchill values reflect aspects of the component values of temperature and windspeed. The values (Table 3.5) were low compared to those found by Smithson and Baldwin (1978) and

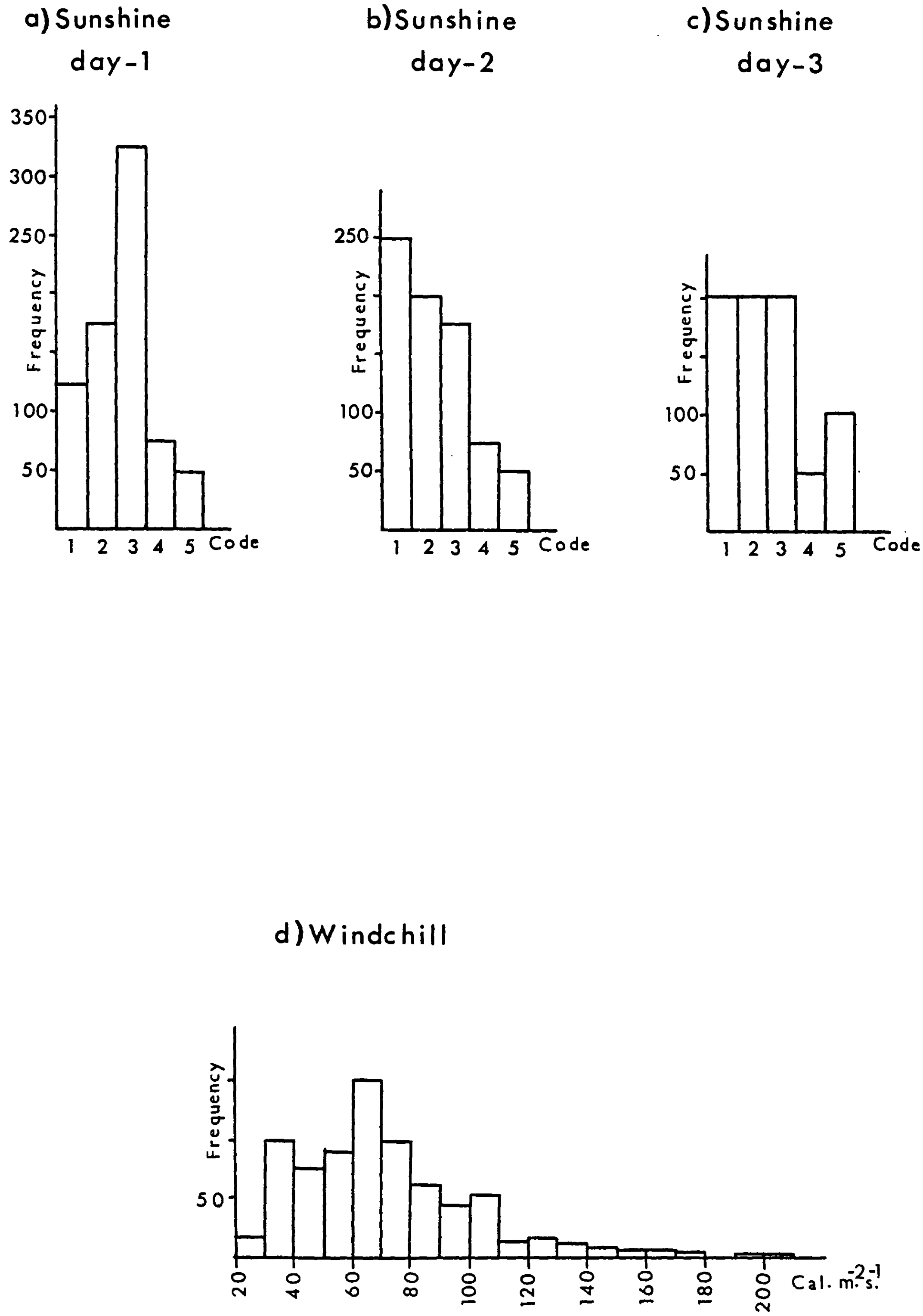


FIGURE 3.6. Frequency distributions for further data included in the analysis for each respondent.

Mumford (1979) for the Midlands and also compared to those calculated from the Daily Weather Reports (Table 3.6). This is mainly because of the windspeed values being low for the reasons given above in the discussion of windspeed. The Windchill frequency distribution shown in Figure 3.6(d) also reflects the windspeed distribution (Figure 3.3(c)) in its marked positive distribution.

The frequency distributions and the summary data discussed above indicate that a fairly wide range of weather conditions were experienced on the survey days. Given that the location of the survey was the city centre, it seems probable that this will have affected the weather conditions, relative to those measured in rural sites for the Daily Weather Reports, in the manner indicated by Landsberg (1970). This seems consistent with the discussion above on the comparison between the survey data and Leicester's data as estimated from the Daily Weather Reports. It can be concluded therefore that, with the possible exception of windspeed, weather measured on the survey days appears to be representative of that experienced by the population of Leicester within the city centre.

3.4 The Response to the Attitude Scale

The attitude measurement technique used was a Likert Scale and its advantages in a study of human comfort were discussed in the previous chapter. It will be remembered that the scale adopted consisted of six statements with each of which the respondent expressed a level of agreement or disagreement. The statements were coded from one to five for each respondent the scores for each statement being added to give a total for that respondent. This section examines the univariate results of the attitude scale before going on in the next chapter to consider the relationship between the response and the weather. The examination considers first, the response to the individual statements and second, the overall response to the scale.

The frequencies of the responses to the six statements are shown for each season in Table 3.7. All the statements show seasonal differences in response although the modal group is the same in some of the seasons. For example, the response to the statement 'It is hot today' had 'disagree' as its model group in all seasons although other frequencies of response varied seasonally, for example, in Spring, 34 of the respondents were in agreement with this statement compared to none in Early Winter. The agreement with this statement in Summer was not as strong as in Spring despite the higher mean temperature (Table 3.4) which may be a result of higher expectations in the High Summer season. This expectation is probably more true of temperature than of other weather variables such as rainfall or wind which may be short-lived. To combat any bias due to expected seasonal temperature a further variable was incorporated into the analysis. This variable is the anomaly between the temperature at the time of the questionnaire and the seasonal temperature for Leicester (Table 3.6) as estimated from the Daily Weather Reports as described earlier in this chapter. The frequency distribution and a statistical summary are shown in Figure 3.7. The modal class is just above zero which suggests that slightly higher values were experienced during the survey than might have been expected. This index added a further dimension to the analysis which has not been considered by other researchers in the field of human comfort climatology.

Most respondents disagreed with the statement 'Today's weather is close and stuffy' with the modal class in all seasons except one being 'disagree'. In Early Winter the modal class was 'uncertain' which was a class more used in response to this statement than to any other

Table 3.7 The seasonal frequencies of responses to the attitude scale

SEASON	Strongly Agree	Agree	Un-Gertain	Dis-agree	Strongly Disagree
1) 'IT IS HOT TODAY'					
Spring	4	30	15	57	44
High Summer	0	32	14	73	31
Autumn	0	12	47	85	6
Early Winter	0	0	0	72	78
Late Winter	0	10	2	70	68
2) 'TODAY'S WEATHER IS CLOSE AND STUFFY'					
Spring	0	12	14	96	28
High Summer	0	55	14	71	10
Autumn	0	26	52	66	6
Early Winter	17	29	49	39	16
Late Winter	3	15	14	81	37
3) 'IT IS CLOUDY TODAY'					
Spring	13	86	6	40	5
High Summer	17	118	3	10	2
Autumn	6	107	10	19	8
Early Winter	50	43	20	23	14
Late Winter	35	84	3	20	8
4) 'IT IS WINDY TODAY'					
Spring	6	70	15	58	1
High Summer	0	47	17	85	1
Autumn	31	71	25	23	0
Early Winter	6	50	58	36	0
Late Winter	8	65	13	56	8
5) 'TODAY'S WEATHER IS DRY'					
Spring	24	97	16	12	1
High Summer	7	100	14	26	3
Autumn	6	122	7	15	0
Early Winter	9	30	37	50	24
Late Winter	13	41	20	44	32
6) 'I FEEL COMFORTABLE WITH THE WEATHER AS IT IS TODAY'					
Spring	10	84	10	36	10
High Summer	6	82	10	44	8
Autumn	0	40	46	51	13
Early Winter	20	5	0	63	62
Late Winter	10	84	10	36	10

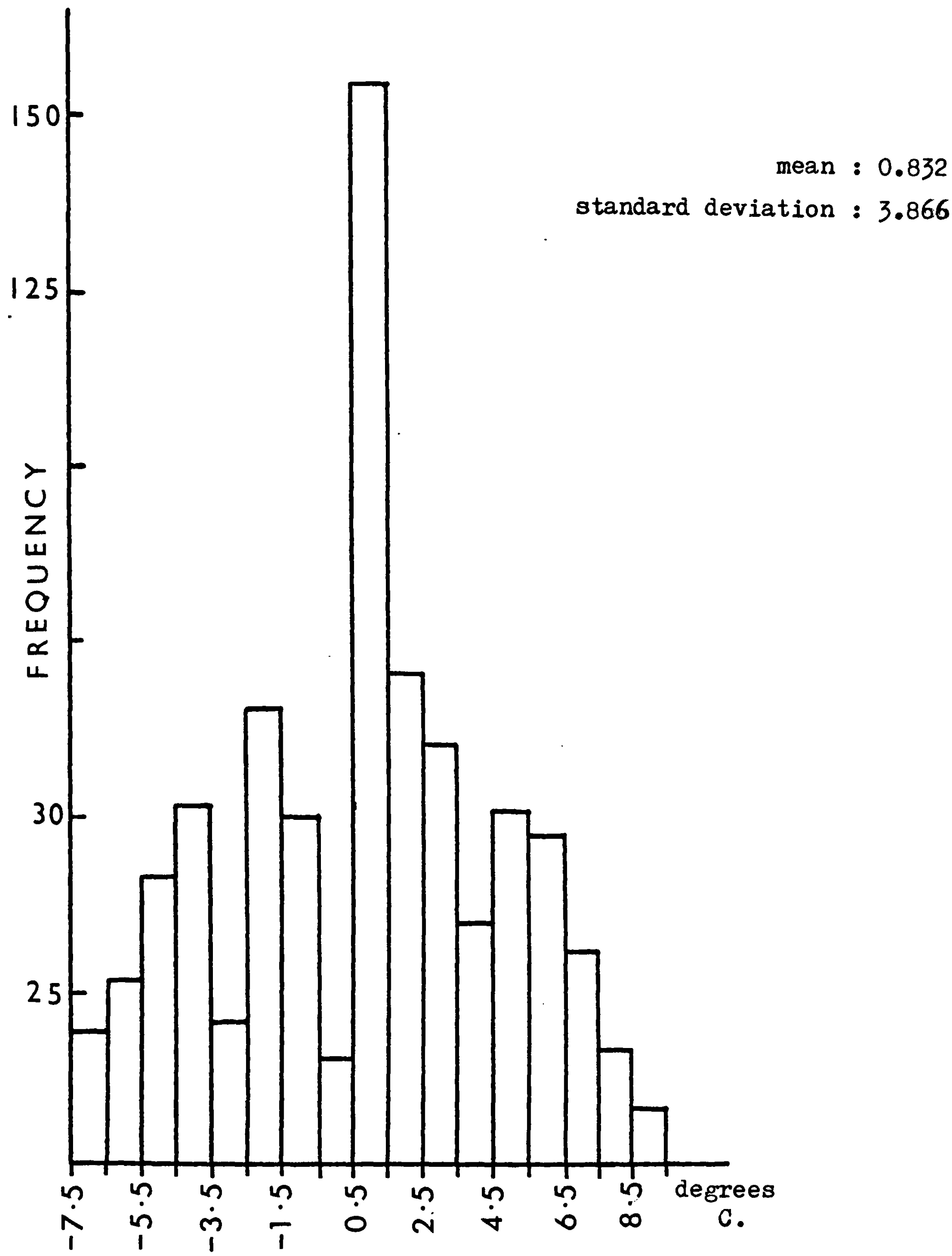


FIGURE 3.7. The anomaly between the temperature at the time of the questionnaire and the seasonal mean.

throughout the year. It is difficult to assess the reason for this indecision, it may be due to a genuine location of attitude along the scale or it may be due to uncertainty because of a lack of understanding of the statement. Few respondents expressed uncertainty about responding to any of the statements and it is hoped that the former is the case for all the frequencies of response.

The frequency distribution of cloud cover (Figure 3.4(a)) is negatively skewed and this is reflected in the response to the statement 'It is cloudy today' with which the majority of people were in agreement. The weather data are also reflected in the response to the statement 'It is windy today' showing the highest frequency of agreement in Autumn corresponding to the highest mean windspeed (Table 3.4) and most disagreement in High Summer when the mean windspeed was lowest.

The importance of having a large number of respondents in studies of attitudes is illustrated in the responses to possibly the least ambiguous statement 'Today's weather is dry'. In Spring there were no rain days and no days when rain had fallen during the day and yet 13 respondents disagreed with the statement. This 'error' probably occurred in all the responses but is most easily identified by this statement. In general however the responses to this statement are in agreement with the proportion of raindays (Table 3.4).

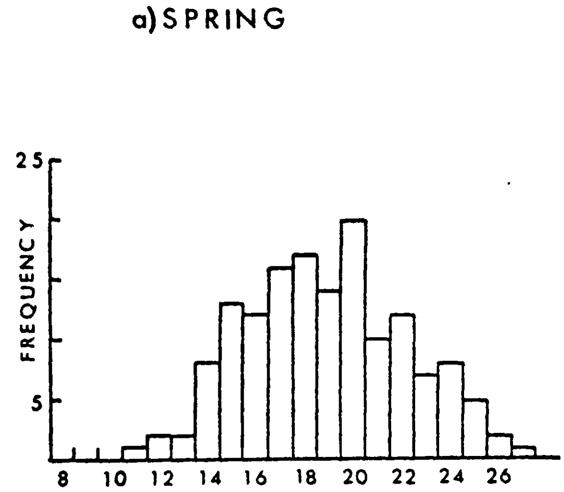
The response to the statement 'I feel comfortable with the Weather as it is Today' showed a more than 50% agreement in Spring, High Summer and Late Winter with Autumn having a fairly even distribution of responses among the middle three groups and Early Winter having a strong skew towards disagreement. Comfort clearly varies with different combinations of weather elements and possibly with season. The multivariate analysis described in the next chapter aimed to discover the reasons for this variation.

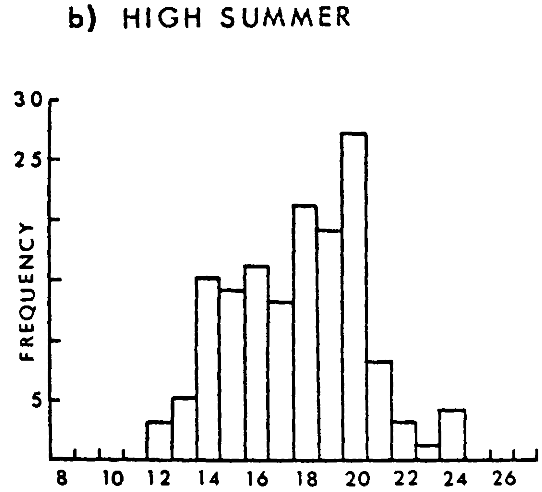
This statement-by-statement analysis is a useful confirmation of the logic of the questionnaire suggesting that in general the scale measured the property for which it was designed. However the main purpose of the questionnaire was to produce a single overall response for each person with this response value representing the attitude to the total weather at the time at which the questionnaire was conducted. The remainder of this section therefore examines this total response.

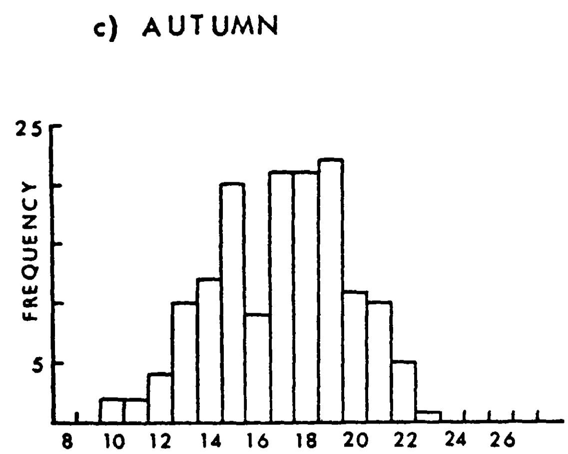
The total score for each respondent was obtained by summing the scores for the six individual statements giving a total score within the limits six to thirty. The total score measured the attitude to the total weather and was therefore considered to be a measure of relative human comfort. Hereafter this total score is referred to as the Index of Human Comfort, or simply the Index. Histograms of this Index for each season are shown in Figure 3.8 and for the whole year in Figure 3.9. with the associated summary statistics in Table 3.8.

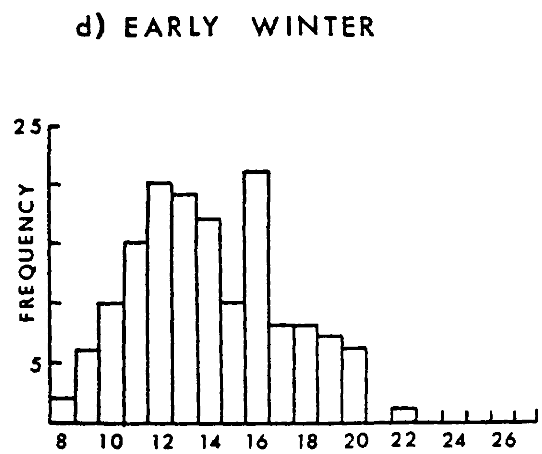
It can be seen from Table 3.8 that the Index reached a maximum mean of 18.9 in Spring and a minimum of 14 in Early Winter. The Spring maximum, rather than a Summer one, was probably the result of rain being recorded during the Summer surveys but not during Spring. The variation as shown by the standard deviation and the coefficient of variation were however lower in Summer than in Spring and the lowest absolute range of 13 was experienced in Summer and Autumn with Late Winter having the largest range of 17. Although High Summer did not have the maximum mean Index the season did have the highest minimum value of 12, suggesting that although High Summer did not have the best weather for human comfort it was more consistently high than in other seasons.

The frequency distributions for each season and for the year (Figures 3.8 and 3.9) show that the responses were near-symmetrical about the mean. The Late Winter distribution (Figure 3.8(e)) shows









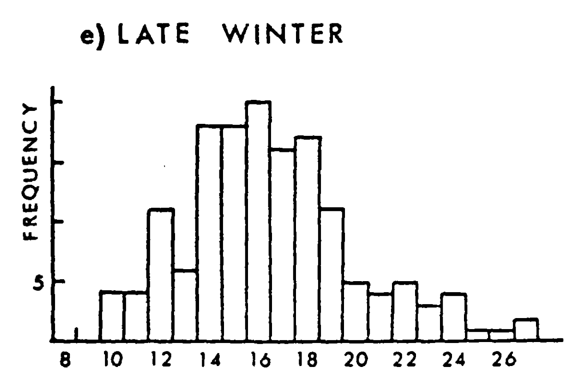


FIGURE 3.8.
Frequency distributions of the Index of Human Comfort by season.

Table 3.8. A Summary of the Index of Human Comfort obtained from the Likert Scale Questionnaire

SEASON	NUMBER OF CASES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	MAXIMUM	MINIMUM	RANGE
SPRING	150	18.9	3.3183	17.5563	27	11	16
HIGH SUMMER	150	17.7	2.7417	15.4896	25	12	13
AUTUMN	150	16.9867	2.7761	16.3426	23	10	13
EARLY WINTER	150	14.0	3.0	21.4286	22	8	14
LATE WINTER	150	16.58	3.5426	21.3669	27	10	17
YEAR	750	16.827	3.48	20.682	27	8	19

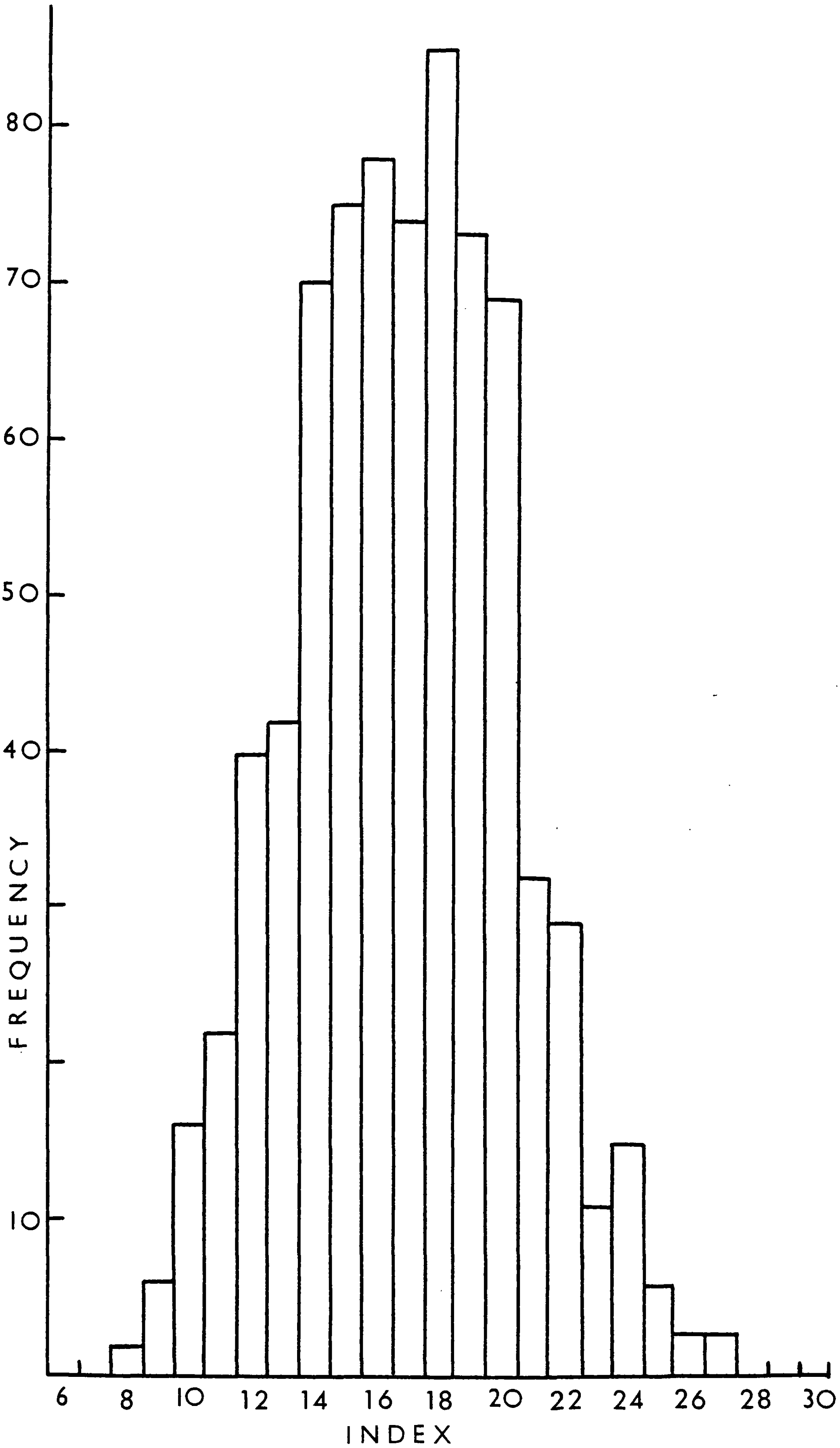


FIGURE 3.9. The annual frequency distribution of the Index of Human Comfort.

a slightly positive skew reflecting the poor weather experienced during this season; although the weather was not often very cold many of the days were dull and wet. The High Summer frequency distribution (Figure 3.8(b)) has a slightly negative skew with the modal Index being 20. Apart from these two seasons the frequency distributions of the Index for the seasons and for the year are near-normal.

The Index used up 19 of the 23 possible units along the scale with only the extremes being unrepresented. As the weather during the questionnaires never reached extremes it can be concluded that the Index of Human Comfort produced by the attitude scale is capable of representing a wide range of weather conditions.

3.5 Summary and Conclusions

This chapter has concentrated on a univariate examination of the questionnaire data. Although the main purpose of this research is to conduct a multivariate analysis it is important to examine the individual variables for any bias which may make them unsuitable for further analysis, and also to ensure that the weather data are, in general, representative of the range of weather which Leicester residents might expect to experience and, finally, that the sample population is representative of the Leicestershire population. The analysis was carried out in two steps first, by examining the frequency diagrams of the variables and second, by comparing the means and standard deviations to appropriate standard data.

The sample population was compared with the Leicestershire population as obtained from the 1971 Census. Although variations in the sample were found between seasons there was a reasonable number of respondents in each group enabling the testing of the relationship between the response to the questionnaire and the sex and age of the respondent to be made which is discussed in the subsequent chapter.

An examination of the frequency distributions of the weather variables revealed that these were as expected with, for example, the temperatures showing little pattern, the windspeed and associated wind-chill showing marked positive skews and cloud cover a negative skew. When the means and standard deviations were compared to those for Leicestershire, as estimated from the DWR data, many of the variables such as temperature, humidity, pressure and cloud were found to have similar values. Windspeed, however, was considerably lower at the time of the questionnaire than was found from the DWR and this can probably be explained by the rural/urban differences in windspeed and also by the lower elevation of the measurements at the time of the questionnaire. Probably the most difficult variable to obtain a representative sample of was the number of rain days. In Spring there were no rain days at all although the other seasons showed more similarity to the expected proportions of rain days.

The final consideration of this chapter was the response to the Likert scale questionnaire. An examination of the seasonal response to each question revealed that the response varied seasonally and that a wide range of conditions appeared to have been experienced in each season. No bias was apparent in any of the responses and an initial consideration suggested that the questionnaire seemed appropriate for examining attitudes to the weather within the range of conditions experienced.

One interesting point which does emerge from all the analysis described in this chapter is that there appear to be considerable differences between the seasons for all the variables and for the response. This suggests that the Lamb (1950) Natural Seasons form an appropriate way of stratifying the year for the purposes of research in climatology.

Chapter Four

The Multivariate Analysis

4.1 Introduction

This chapter describes the results of a multivariate analysis of the questionnaire data which were discussed in the previous two chapters. The experiment was designed to examine public attitudes to the weather as a function of the objective weather according to the model:

$$\text{attitude} = f\ (\text{objective weather}) \qquad (4.1)$$

There are, however, three major difficulties in this approach. First, although it is asserted that public attitude is 'some function' of the weather as objectively measured, we have no real idea as to the form of the functional relationship. This is particularly true in a pioneering study such as this. The simplest form of model which could be tested using the available data is of the general form:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 +, \ldots, \beta_n X_n \qquad (4.2)$$

where Y = measured attitude

α and $\beta_1 \ldots \beta_n$ = constants

$X_1 \ldots X_n$ = objective weather variables.

Such a linear function can be calibrated by ordinary least squares regression, and this is what is attempted here.

The second difficulty is that the data are mixed mode and are not ideally suited for multivariate analysis (Mather and Openshaw, 1974). They range from measurements on an interval scale, such as temperature, to binary scale allocations such as the presence or absence of precipitation. The nominally and ordinally scaled variables, such as cloud, sunshine, age and sex, used in this study present a common analytical problem. The analysis of such categorical variables has been discussed by a number of authors, notably Wrigley (1979). The problem in the use of categorical data in this particular study and the method used to overcome it is described in section 2 of this chapter.

The third problem involves the difficulty of data meeting specific assumptions of the technique used to fit the model. Poole and O'Farrell (1971) summarized these for linear regression into six main assumptions:

(i) Each value of X_i and Y_i is observed without measurement error.

(ii) The relationship between Y and each of the independent variables X_i is linear in the parameters of the specific functional form chosen.

(iii) Each conditional distribution of the error has a mean of zero.

(iv) The variance of the conditional distribution of the error is constant for all such distributions.

(v) The values of the error are serially independent.

(vi) The independent variables X_i are linearly independent of each other.

The compliance of the data to these assumptions is discussed in section 3 of this chapter.

4.2 The Categorical Data

Variables incorporated into a regression model usually can take values over some continuous range; temperature, windspeed, windchill and the THI are examples of such. Categorical data which have distinct levels are unsuitable in their raw state for inclusion in the analysis. In the list of variables incorporated into the experiment which was described in Chapter 2 there were a number which were measured in categorical form including sex, age, sunshine code, cloud (measured in octas) and season. Some, or all, of these variables may be crucial in explaining people's attitudes to, and perception of, the weather as measured by the questionnaire and it was therefore important to include them in an appropriate way in the analysis.

Variables which are strictly categorical may take possible values over a large range, for example the Present Weather Code which ranges between 0 and 100 and the Index of Human Comfort which ranges from six to thirty. For human comfort both of these variables are considered to be ordinally scaled. If, however, all these variables are treated as categorical, the result would be an analysis based on a very large multidimensional contingency table with so many categories that the frequency in each cèll would often be extremely low. In order to carry out multivariate analysis it seems preferable to treat such data as continuous. This same argument applies to some methodologies which propose that any mixed mode data should be treated as categorical and thus any continuous data collapsed into categories and categorical data analysis methods used. For this study a more efficient method was to use Multiple Regression Analysis and to incorporate the categorical data into the model as so-called dummy variables (Draper and Smith, 1966; Gujurati, 1970(a) and (b); Chatterjee and Price, 1977).

The dummy variable method treats each category of each variable as a separate variable in itself and these new variables, not the original ones, are used in the regression analysis. To form a dummy variable a series of dichotomous variables are created each scored one if an individual belongs in the corresponding category and zero otherwise. For example, if cloud amount is divided into three categories, 0 to 2, 3 to 5, and greater than 5 octas, we can form

$$X_1 = \begin{cases} 1 & \text{if cloud cover is less than 3 octas} \\ 0 & \text{otherwise} \end{cases}$$

$$X_2 = \begin{cases} 1 & \text{if cloud cover is between 3 and 5 octas inclusive} \\ 0 & \text{otherwise} \end{cases}$$

$$X_3 = \begin{cases} 1 & \text{if cloud cover is greater than 5 octas} \\ 0 & \text{otherwise.} \end{cases}$$

The individual scores on X_1, X_2 and X_3 for four respondents could read as in Table 4.1.

Table 4.1 Example scores for four respondents for the cloud dummy variables

Respondent Number	X_1	X_2	X_3
1	0	0	1
2	0	1	0
3	1	0	0
4	0	0	1

It can be seen from Table 4.1 that one of the dummy variables is superfluous; if a person's score on two of the three dummy variables is known then the third is also known. In this sense one dummy variable is redundant and is always excluded from the analysis. If this were not done the dummy variables would exhibit perfect multicollinearity which would make ordinary least squares regression impossible. Reynolds (1977) notes that it is mathematically immaterial which category of the variable is eliminated so that the decision depends solely on the desired interpretation. Hence a categorical variable with n categories is transformed into n-1 dichotomous variables which are included as independent variables in the regression model which for the Index of Human Comfort on cloud cover is:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \text{(other variables)} + e \qquad (4.3)$$

where X_1 and X_2 are as defined above, α and β are constants and e is the disturbance term.

Fitting this model creates what in effect are two separate regression equations for each dummy variable assuming that there are other terms in the equation given in 4.3. For example the dummy variable X_1 has the same value for the 'other variables' term in equation 4.3 but different intercepts depending on the presence or absence of the characteristic measured by the dummy variable; if the cloud cover is 6 octas then X_1 and X_2 are both 0 and therefore the intercept is α, but if the cloud cover is one octa then the intercept of the regression line is $\alpha + \beta_1$, and if the cloud cover is 4 octas then the intercept of the regression line is $\alpha + \beta_2$. Mather (1976) describes the extension of this to a situation which allows the coefficients for X_1, X_2, X_3 .... X_n to differ by the inclusion of different intercepts and different partial regression coefficients in the regression equation. In practice this involves the inclusion of the product of all combinations of dummy variables into the regression analysis, and such an analysis results in a 'saturated' model. The example used by Mather included three dummy variables for a data set of 40 and other work which he summarized also used few dummy variables. When a large number of dummy variables are to be included in the analysis it becomes impossible to generalize from a saturated model, such as Mather described, because of the very large number of coefficients. There are very few examples of work using dummy variables other than those of a purely illustrative nature. One practical example is in a North West Sports Council (1972) document which used a large number of dummy variables in a questionnaire analysis on sporting and leisure activities and the final model was of the form shown in Equation 4.3 and not the saturated one.

Although other methods were examined, notably log linear models (Payne, 1977), dummy variables were considered to be the best method for dealing with the categorical data especially as they allowed the final result to be a single regression equation. The Statistical Package for the Social Sciences (SPSS) allows the incorporation of dummy variables into the Multiple Regression subroutine (Nie et al., 1970) and was used for this analysis. The sex, age and the binary variable for length of residence were included as dummy variables in the Multiple Regression analysis. The use of dichotomous dummy variables was also appropriate for some of the weather data with sunshine, for example, both at the time of the questionnaire and at noon on the previous three days, having been measured on a five point scale and therefore four dummy variables were created for each of these sunshine variables. Cloud was measured in octas and the resulting distribution (Figure 3.4) showed a marked negative skew. To ensure that there were sufficient data in each class, the cloud amount was split into three classes: less than three octas cloud cover; three to five octas inclusive; and more than five octas cover. Two dummy variables were then formed from these three categories. Precipitation was measured as a binary presence or absence and this was treated as a dichotomous dummy variable. Finally, in order to discover if there was any seasonal variation in public attitudes to the weather, four dummy variables representing the 5 Lamb Natural Seasons were also included in the analysis.

The dummy variables described above were incorporated into the analysis together with the data which could be measured on a continuous scale, namely the wet and dry bulb temperatures, windspeed, relative humidity, THI, Steadman windchill index, pressure and Present Weather Code. For the reasons described earlier it was decided to use the regression model shown in Equation 4.3 rather than the saturated model described by Mather (1976). If such generalisation had proved unsatisfactory a saturated model could then have been used.

4.3 The Multiple Regression Analysis

This section describes the multiple regression analysis used for the data described above. The assumptions of this form of multivariate analysis were described in the introduction to this chapter and these will be examined in relation to the data set being analyzed in this section.

The first assumption of multiple regression is that each value of

X_i and Y_i is observed without measurement error. Poole and O'Farrell (1971) note that in most experiments the error is unknown and point out that the measurement error can be ignored if the sole objective of the regression analysis is to predict the value of Y corresponding to a given set of X_i values. The instruments chosen for measuring the weather were selected for their accuracy and therefore the measurement error should be low. The measurement error of the respondents' attitudes was impossible to define and, like in many other such studies, must be assumed to be unimportant.

The second assumption of linear regression is that the relationships between Y and each of the independent variables X_i are linear in the parameters of the specific functional form. The angle and intercept of the regression line for the response index and each of the independent continuous variables were found using the subprogramme 'Scattergram' in SPSS. The regression coefficients together with their significance are shown in Table 4.2.

Table 4.2 The Pearson Product Moment Correlation Coefficients for the Index with the Continuous Variables

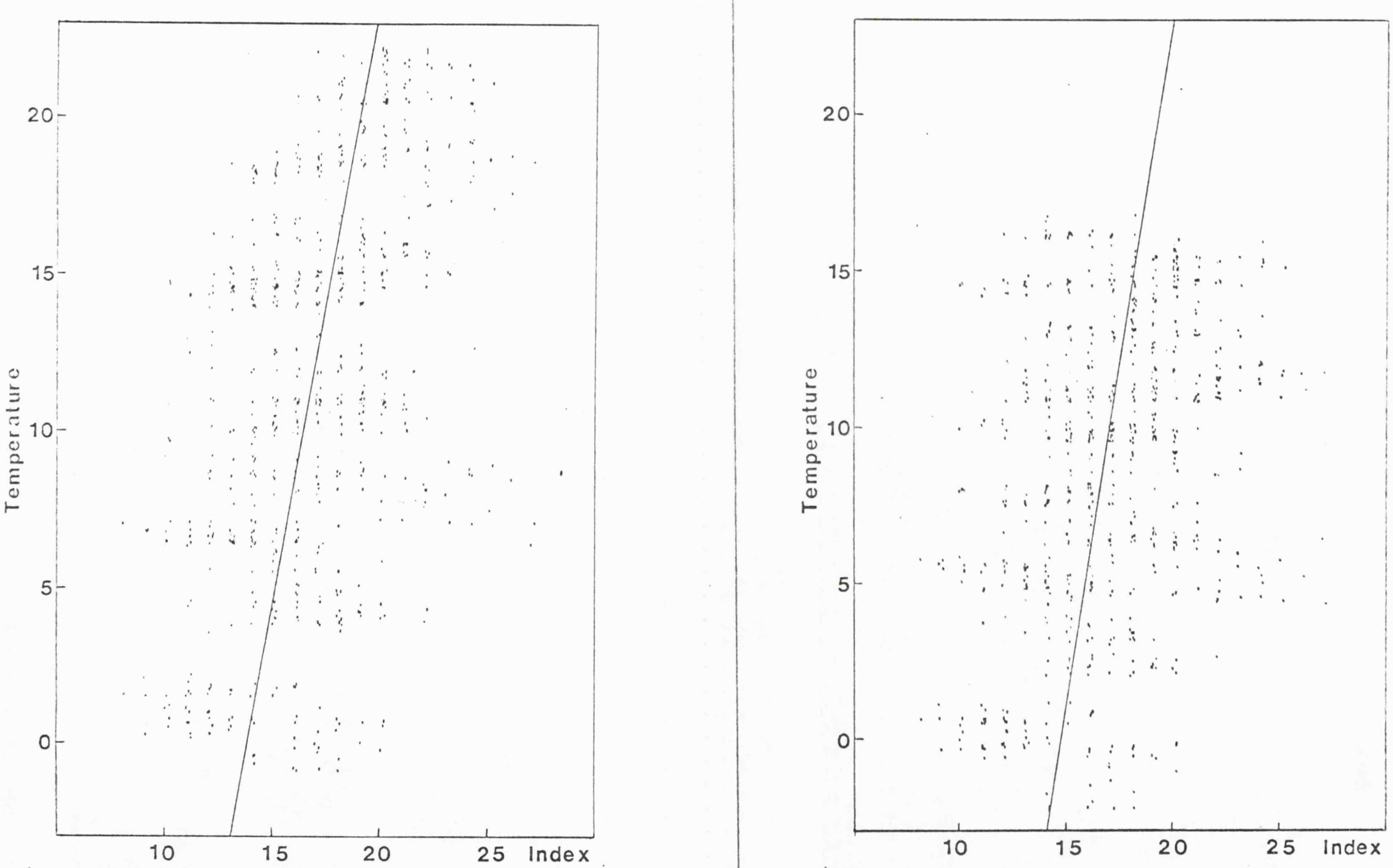
Variable	r	Significance level
Dry Bulb Temperature	0.4515	0.00001
Wet Bulb Temperature	0.3198	0.00001
Temperature (Day-1)	0.2149	0.00001
Temperature (Day-2)	0.1279	0.00022
Temperature (Day-3)	0.2351	0.00001
Temperature Anomaly from Seasonal mean	-0.2737	0.00001
Windspeed	-0.2378	0.00001
Relative Humidity	-0.5455	0.00001
Pressure	0.3630	0.00001
Present Weather Code	-0.5408	0.00001
THI	0.3987	0.00001
Windchill	-0.4697	0.00001
Clo Unit	-0.2737	0.00001

Plots of the Index against each of the continuous variables were drawn using Ghost (1978) subroutines available at the Leicester University Computer Laboratory and regression lines superimposed on the plots as shown in Figures 4.1 to 4.7. The plots and the regression analysis were carried out for the continuous variables only as it would have had little meaning for the dichotomous dummy variables.

There is a large degree of scatter around all the regression lines shown in Figures 4.1 to 4.7 which is possibly a result of the number of points plotted and the subjective nature of the index which cannot be expected to show a perfect relationship with any single variable. The temperature plots (Figure 4.1) show a positive correlation with the Index and show no obvious systematic deviation from the regression lines. Windspeed (Figure 4.2(a)) shows a concentration of values towards the lower end of the scale reflecting the negative skew discussed in Chapter 3. The distribution of points around the regression line, which has a negative slope, is fairly even and this is also true of the plot of relative humidity on the Index (Figure 4.2(b)) although there is a tendency for the points to concentrate towards higher values.

Pressure and Present Weather Code often remained constant over the Survey 'day' of 25 questionnaires and this resulted in the banded patterns revealed by the plots of these variables on the Index (Figure 4.3). These plots do not show any bias either side of the regression lines which have a positive slope for pressure and a negative one for Present Weather Code. The temperatures as measured at noon on the three days prior to the survey day are plotted against the Index in Figures 4.4 and Figure 4.5(a) and these also show a banded pattern for the same reason; again systematic variation in the plots is not apparent around the regression lines, which show positive slopes. The temperature anomaly from the seasonal mean is plotted in Figure 4.5(b) and the regression line for this variable with the Index has a positive slope.

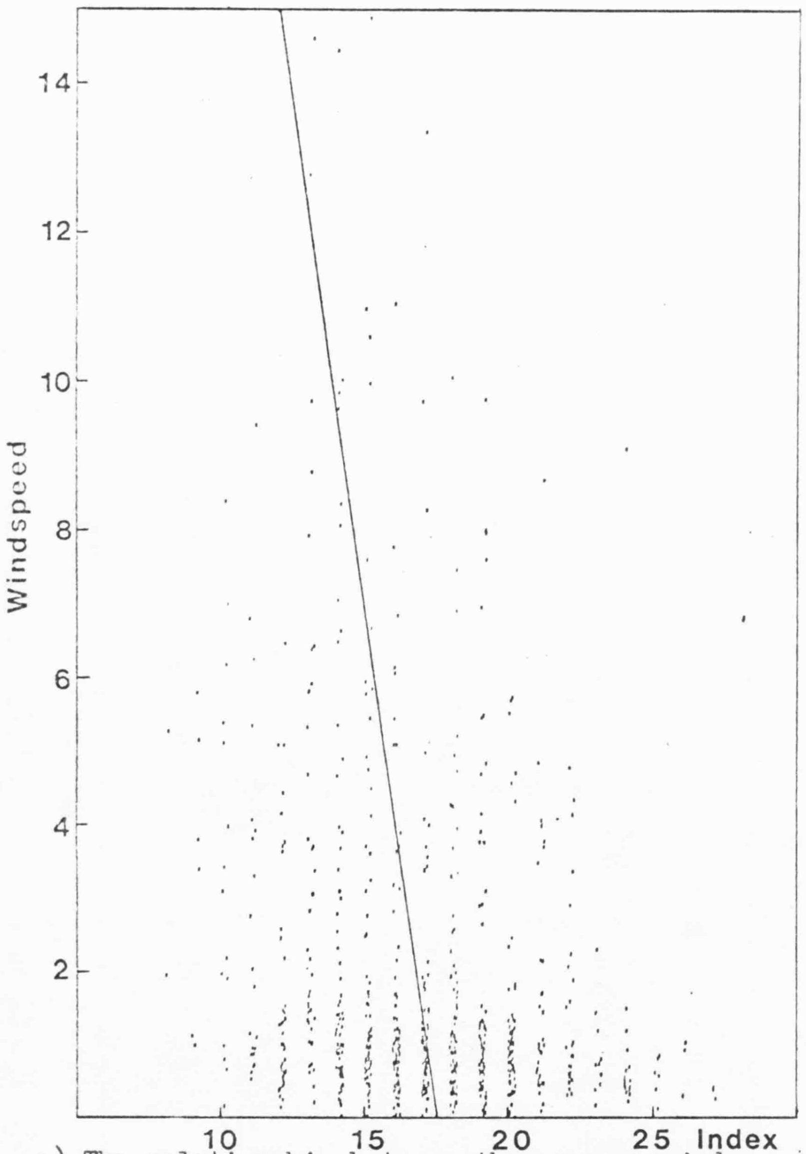
FIGURE 4.1.



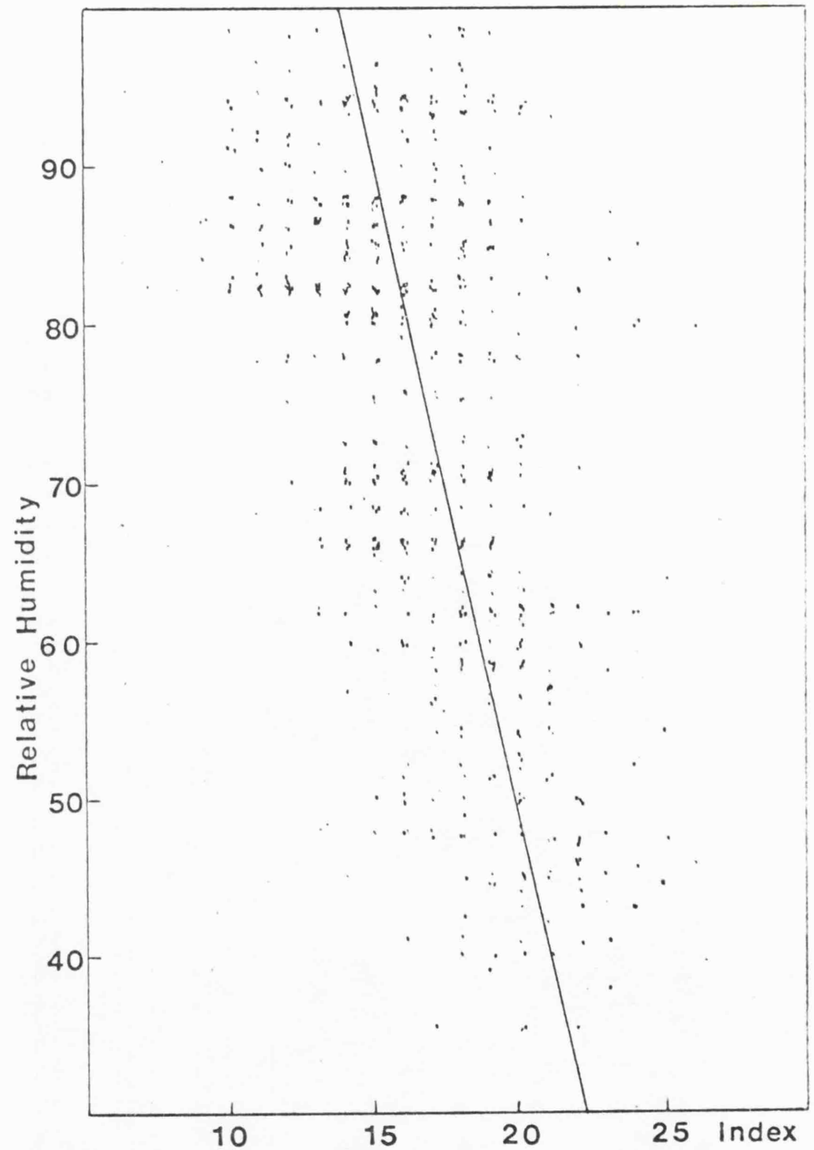
a) The relationship between the response index and the dry bulb temperature (deg.C.).

b) The relationship between the response index and the wet bulb temperature (deg.C.).

FIGURE 4.2.

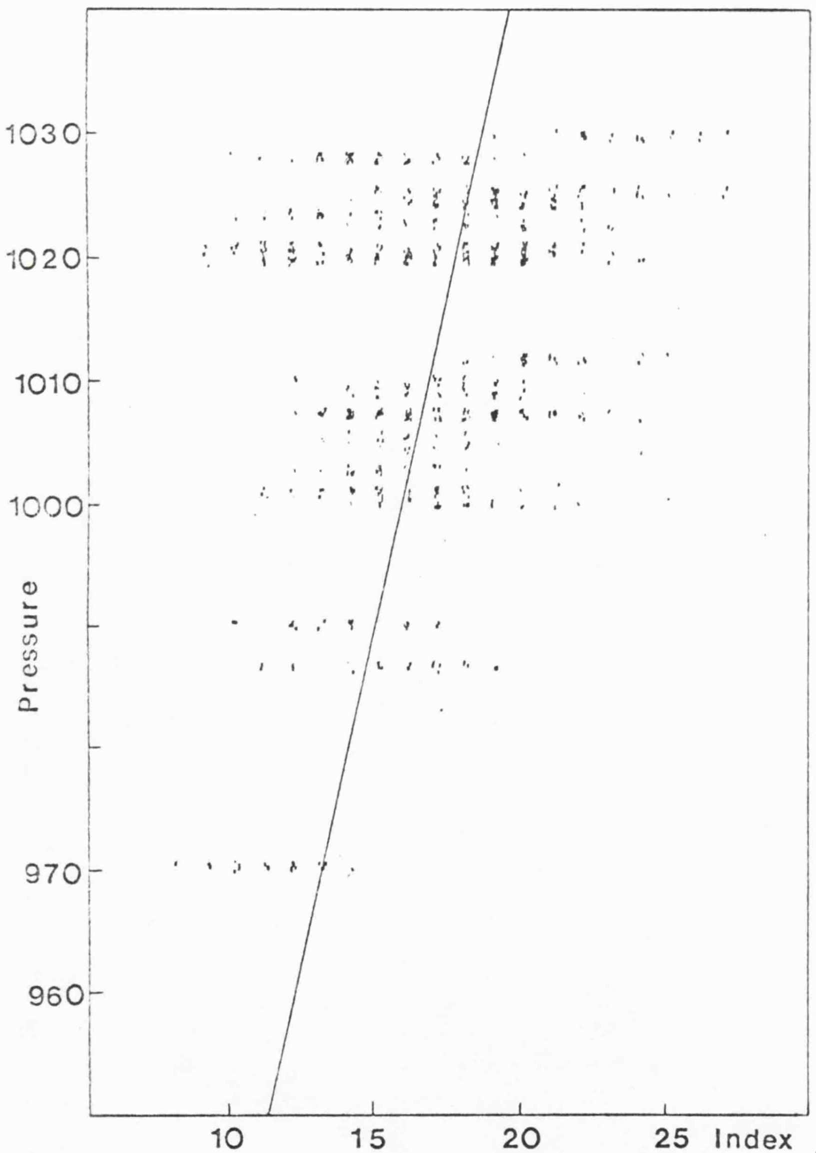


a) The relationship between the response index and the windspeed (m/s).

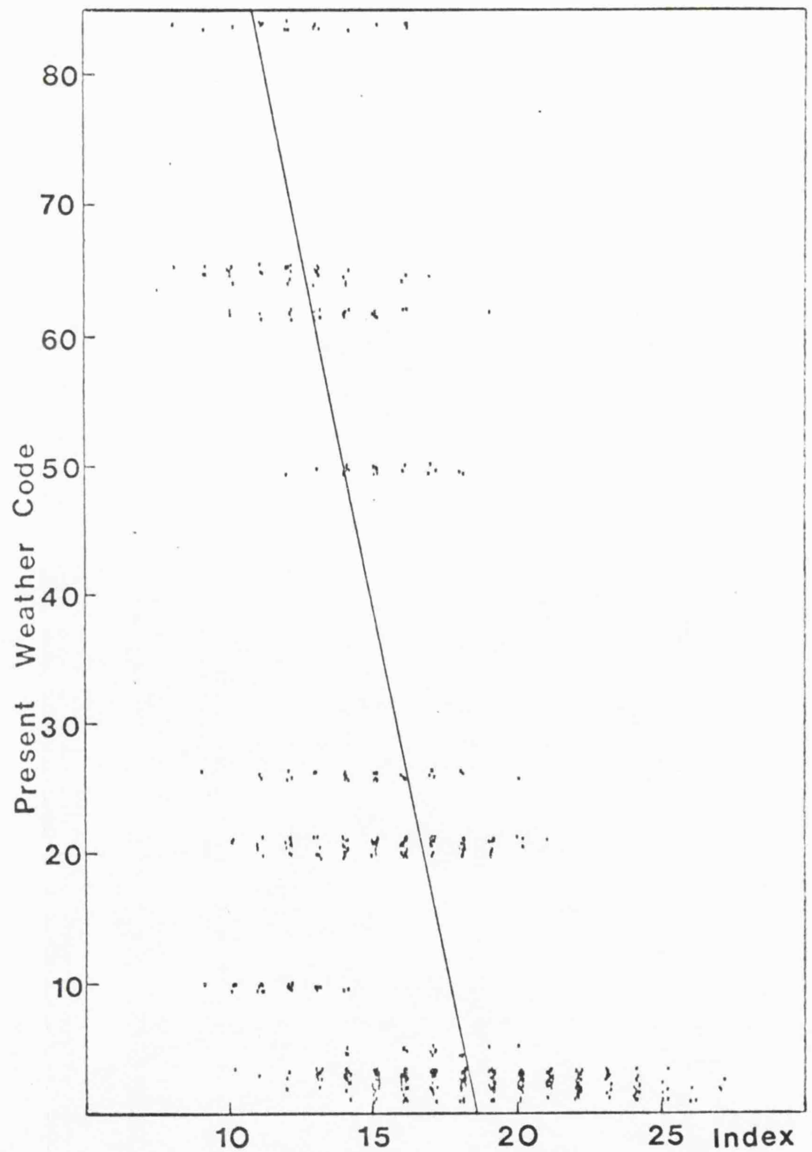


b) The relationship between the response index and the relative humidity (%).

FIGURE 4.3.

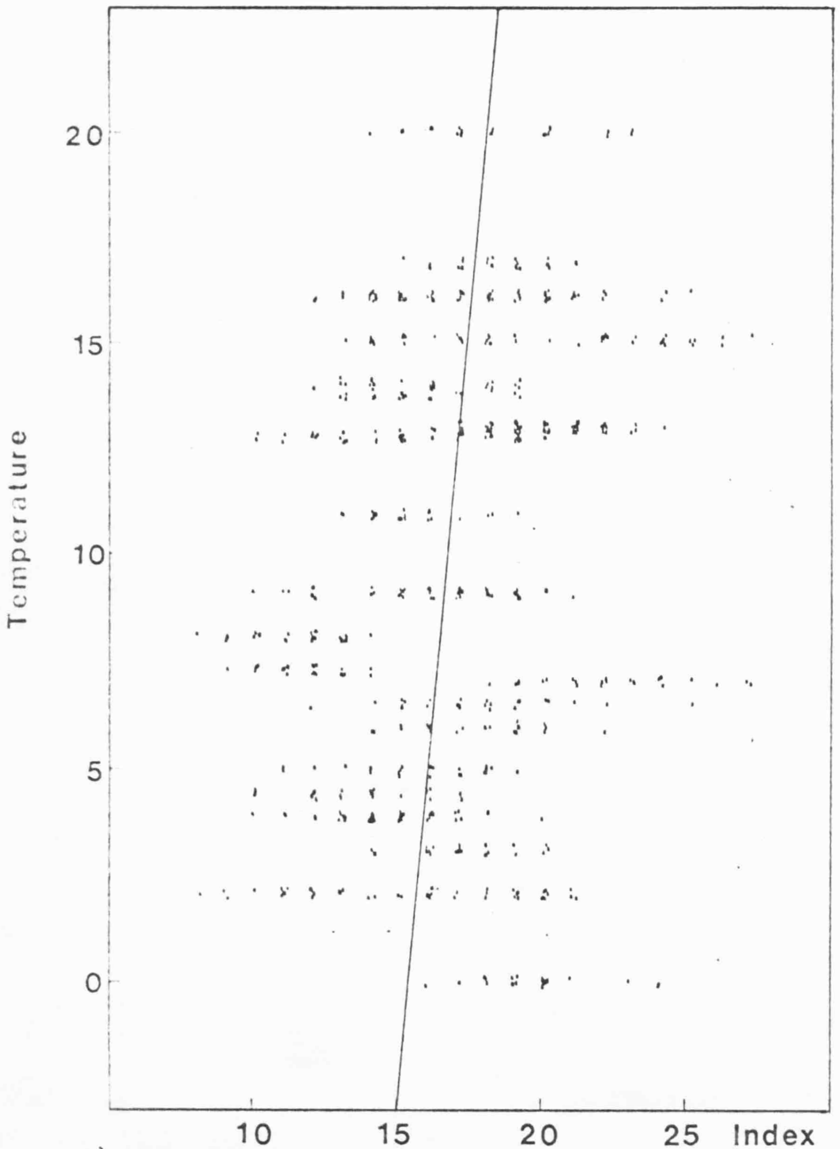


a) The relationship between the response index and the air pressure(mb.).

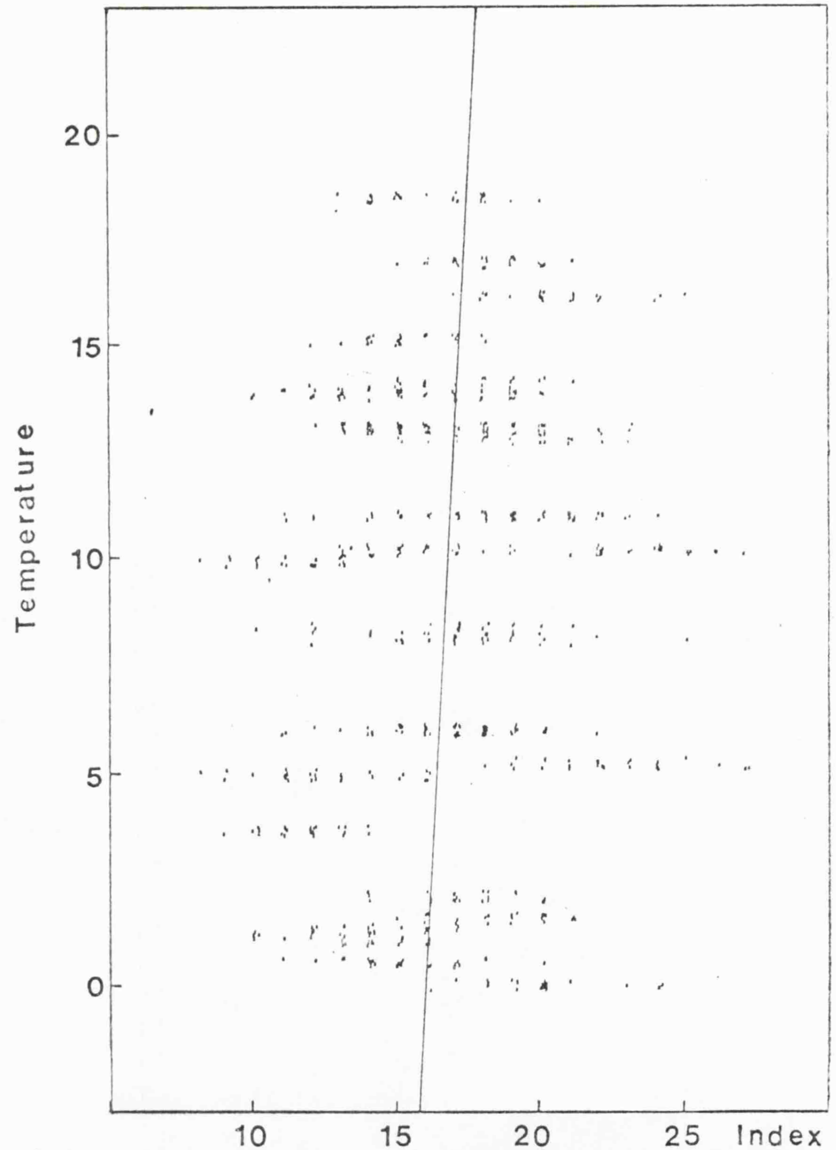


b) The relationship between the response index and the Present Weather Code.

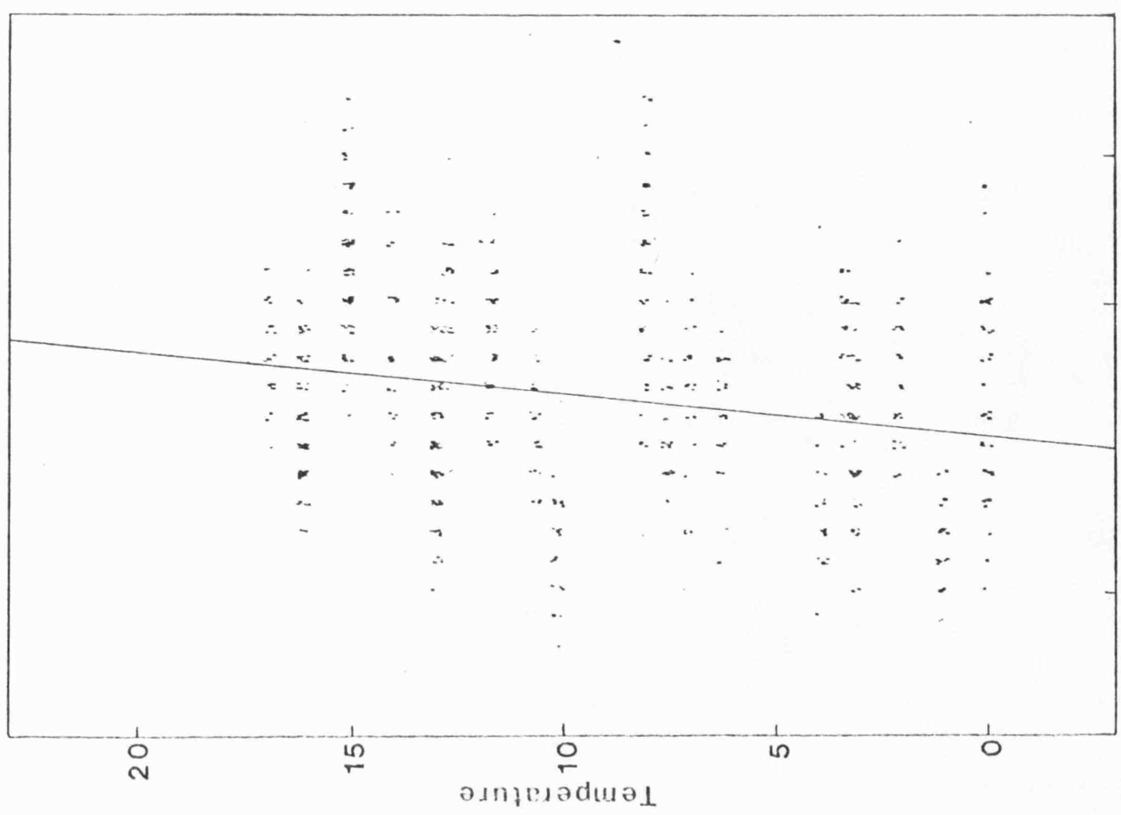
FIGURE 4.4.



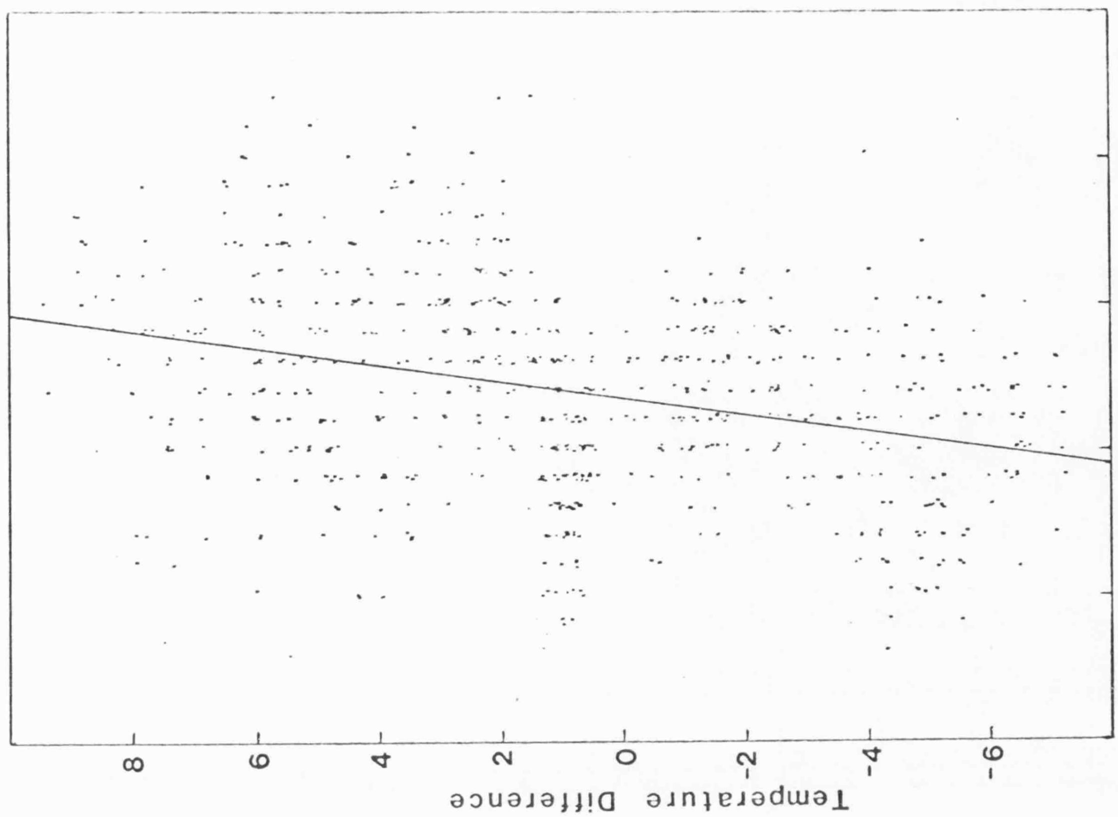
a) The relationship between the response index and the temperature (deg.C.) for the day before the questionnaire.



b) The relationship between the response index and the temperature (deg.C.) for two days before the questionnaire.



a) The relationship between the response index and the temperature (deg.C.) for three days before the questionnaire.



b) The relationship between the response index and the temperature anomaly from the seasonal mean.

FIGURE 4.5.

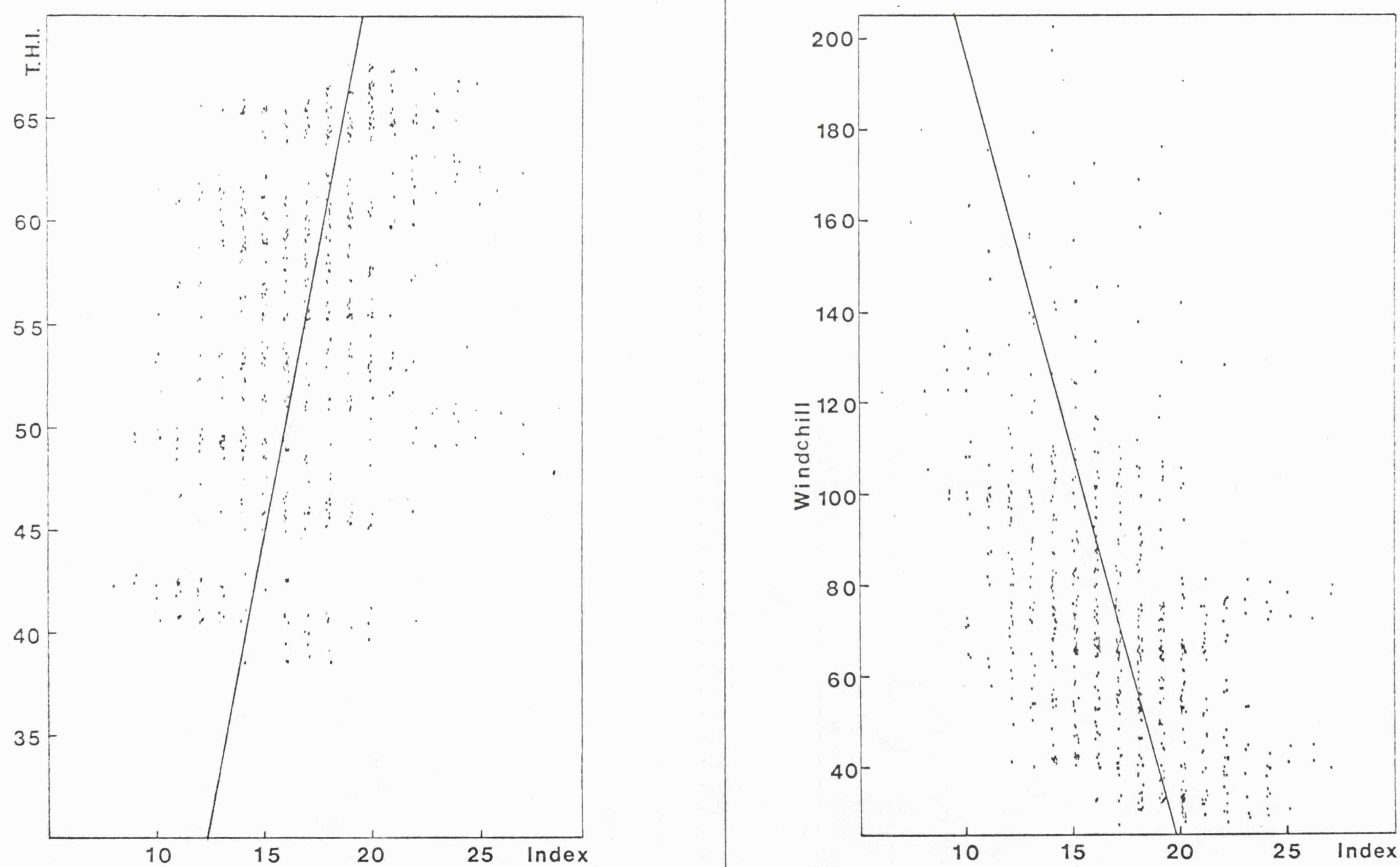
The slopes of the regression lines shown in Figure 4.6 are less steep than those already considered reflecting a greater direct relationship with the Index. The THI has a positive relationship with the Index and the Windchill has a negative relationship. The THI plot reflects the relative humidity plot (Figure 4.2(b)) in that there is a concentration towards higher values and the windchill index reflects the windspeed plot in having a concentration of low values. Neither plot shows any apparent systematic variations about the regression line.

The plot of the Clo unit against the Index (Figure 4.7) shows little clear trend although the regression analysis produced the negatively sloping line which might be expected. Again the points are evenly distributed about the line.

It can be seen from Table 4.2 that all the relationships are significant at the 0.01 level of significance. The dry bulb temperature, relative humidity, and windchill have the highest correlation coefficients with the Index, but in no case is the correlation particularly high. The plots shown in Figures 4.1 to 4.7 and the statistics shown in Table 4.2 suggest that the data comply with the second assumption of linear regression, namely that the relationship between Y and each of the independent variables X_i is linear. The statistics also make intuitive sense in that the slope of the regression line is as might be expected, for example temperature is positively correlated and windchill is negatively correlated with the Index.

Table 4.2 shows that no single variable gives a correlation better than -0.5455 equivalent to a 29% reduction in residual sums of squares. This is in accord with the multivariate nature of the 'weather' and collinearity between variables, and emphasises the necessity for the use of a multivariate approach such as is given by multiple regression analysis. Two of the assumptions of linear regression have been

FIGURE 4.6.



a) The relationship between the response index and the T.H.I.(Thom,1959).

b) The relationship between the response index and the Windchill Index (Steadman,1971).

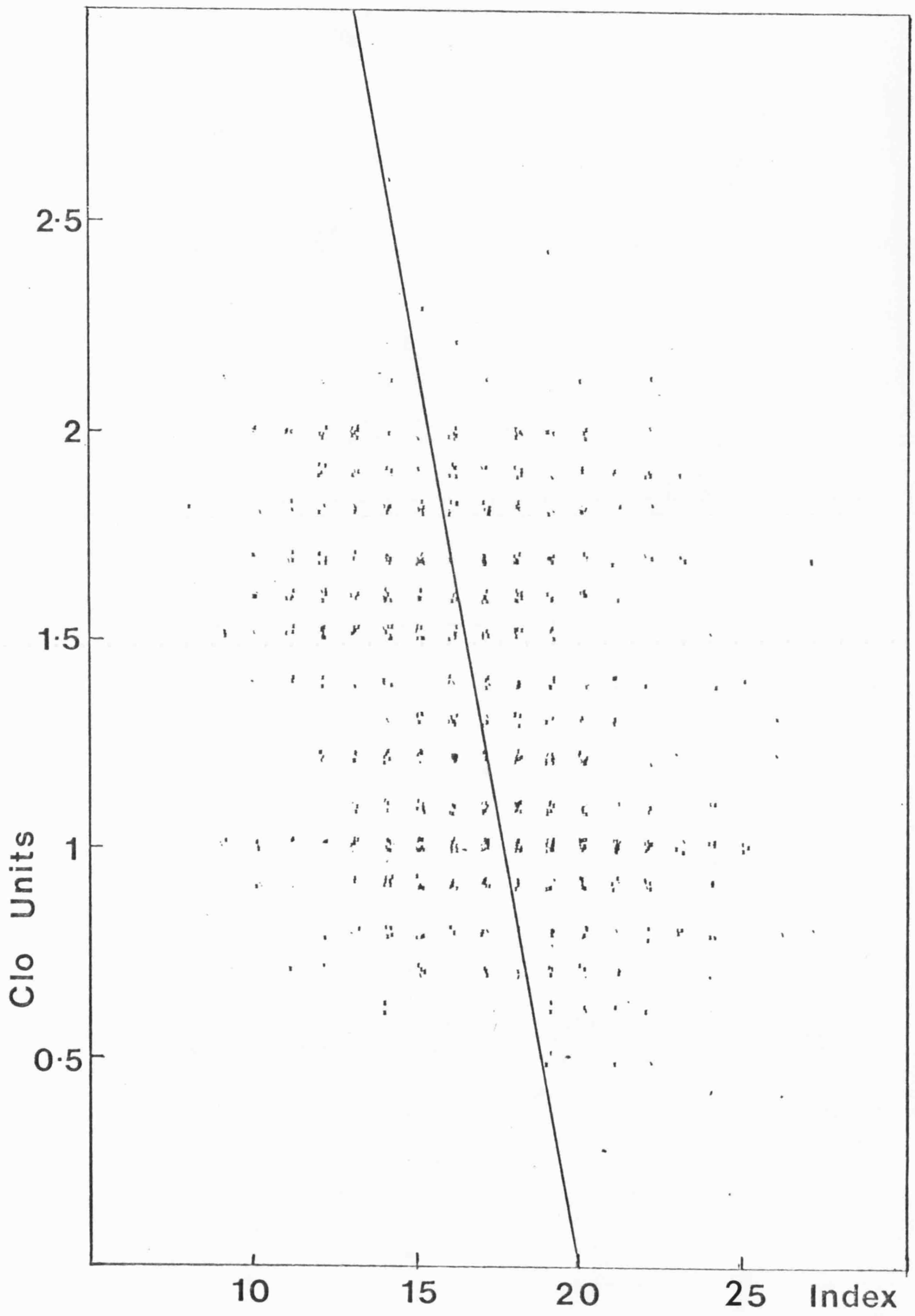


FIGURE 4.7. The relationship between the response index and the estimated clo unit.

examined but the four remaining assumptions could only be assessed after the analysis was carried out using the variables described in this and Chapter 2 and listed in Table 4.3.

As Table 4.3 shows there were 43 independent variables 13 of which were measured along a continuous scale and 30 of which were dummy variables representing 10 further variables. The multiple regression analysis was carried out using the subroutine 'Regression' in the SPSS package which allows the inclusion of dummy variables in the manner shown in the SPSS listing in Appendix 1. The output included a full correlation matrix, summary statistics including the 'F' statistic for each variable with its associated significance level, and the standardised and unstandardised Beta coefficients.

The results of the regression with all the variables need only brief consideration at this stage because four of the assumptions of linear regression are still untested and it is probable that some variables need to be dropped from the analysis as a result of low significance levels. The regression of the Index as the dependent variable on the 43 independent variables gave an R value of 0.82992 ($R^2 = 0.68876$) and a highly significant F statistic of 37.25127. Ferguson (1977) pointed out that visual inspection of the residual plots generally provides the simplest and often the best check of the assumptions of linear regression and these plots will be used in the testing of three of the four remaining assumptions.

The third assumption of linear regression noted by Poole and O'Farrell (1971) was that each conditional distribution of the error has a mean of zero. They suggested that to assess this tests can be carried out on the residuals using them as estimates of the pattern of disturbances. Ferguson (1977) supported this method and noted that there should be no obvious trend in a plot of the residuals on the predicted Y. A scattergram

Table 4.3 The Variables Included in the Multiple Regression Analysis

Variable	Description
Index of Human Comfort	DEPENDENT VARIABLE
	INDEPENDENT VARIABLES
Clo Unit	
Age	5 dummy variables
Sex	1 dummy variable
Nationality	1 dummy variable
Dry Bulb Temperature	
Wet Bulb Temperature	
Windspeed	
Pressure	
Present Weather Code	
Sunshine	4 dummy variables
Cloud	2 dummy variables
Precipitation	1 dummy variable
Steadman Windchill Index	
THI	
Relative Humidity	
Temperature anomaly from seasonal mean	
Season	4 dummy variables
Temperature (day - 1)	
Temperature (day - 2)	
Temperature (day - 3)	
Sunshine (day - 1)	4 dummy variables
Sunshine (day - 2)	4 dummy variables
Sunshine (day - 3)	4 dummy variables

of the residuals on the predicted Y from the regression of the Index with all the 43 independent variables is shown in Figure 4.8. The visual impression from this is that there is no pattern in the plot; the Pearson Product Moment Correlation coefficient of the residuals with the predicted Index is 1.46205×10^{-3} which supports the view that there is no systematic linear pattern present. A runs test was carried out to test if there was any apparent pattern in the runs above and below the zero line. The total number of runs was 370 which indicated that at the 0.01 level of significance the distribution shown in Figure 4.8 was a random one. These results suggest that the data used in the multiple regression analysis probably upheld the third assumption of linear regression.

The fourth assumption of linear regression is that the variance of the conditional distribution of the disturbances is constant for all such disturbances. As Poole and O'Farrell (1971) have stated, no precise test of this homoscedasticity is possible but Ferguson (1977) has suggested that this can be most effectively judged by an examination of the plot of the residuals on the predicted Y (Figure 4.8) with any systematic trend being indicative of a violation of this assumption. The plot shown in Figure 4.8 was examined when the third assumption was tested and it was concluded that no systematic pattern was present which suggests that the fourth assumption of linear regression is not violated by the data under consideration.

The fifth assumption is that the values of the disturbances are serially independent and thus show no evidence of autocorrelation. Again, this can be assessed by an examination of the residual plot shown in Figure 4.8 with similar conclusions to those described above being drawn, suggesting that this assumption is upheld.

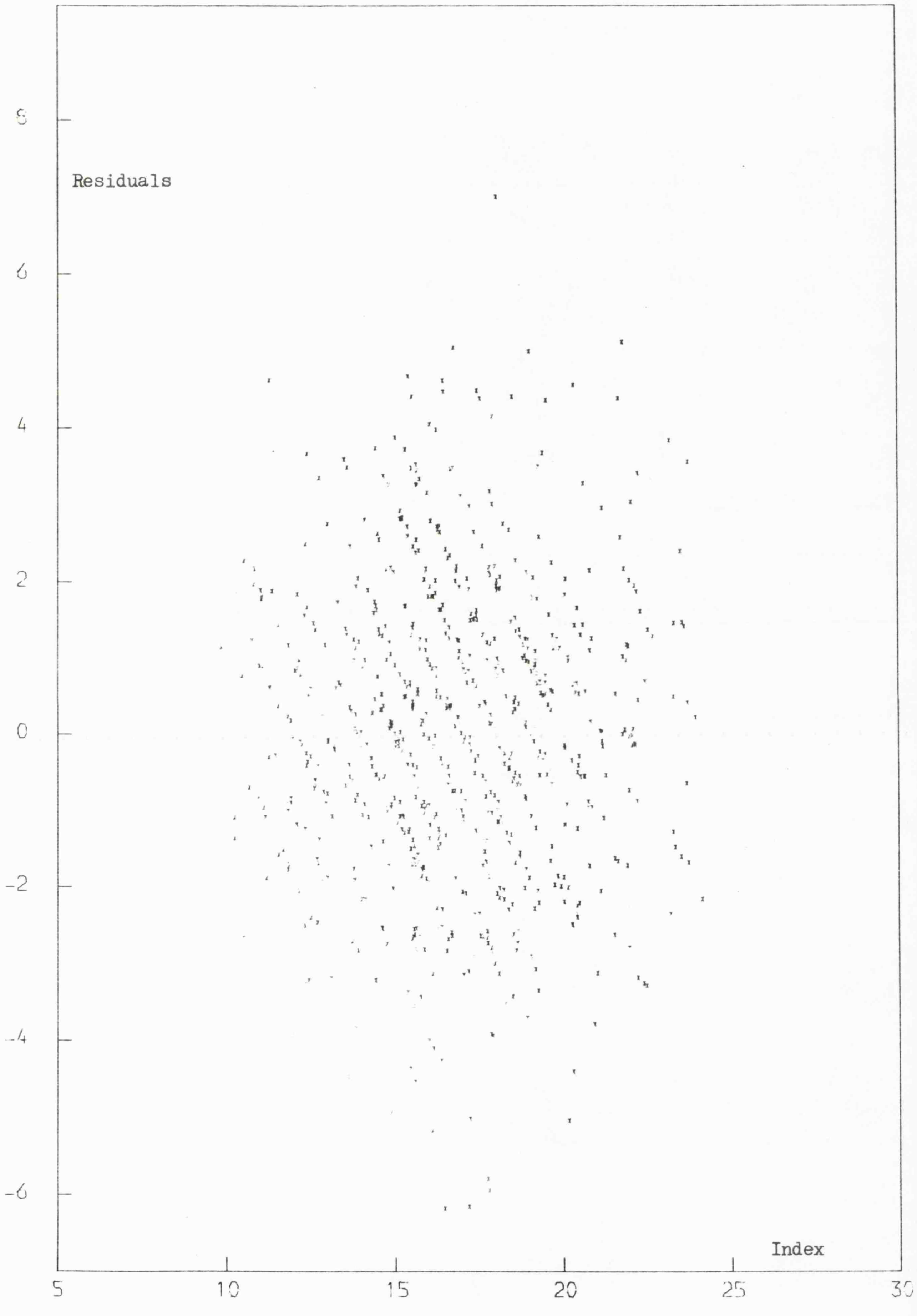


FIGURE 4.8. Plot of the residuals on the predicted Index of Human Comfort for the regression with all the variables.

By conducting tests on the data and on the residuals it has been shown that five out of the six assumptions of linear regression noted by Poole and O'Farrell (1971) were probably upheld by the data described in Chapter 3. The sixth assumption which stated that the independent variables are linearly independent of each other presented problems with this data set and led to the rejection from the analysis of a number of the independent variables. The use of weather data made it inevitable that some of the variables exhibited multicollinearity. The dry and wet bulb temperatures, the windspeed and the relative humidity were obviously highly correlated with the THI and the windchill index which were derived from them. It therefore seemed appropriate to include the two composite indices, the THI and windchill, rather than their component parts. These indices also have more meaning for human comfort than the individual weather variables.

Sunshine and cloud also exhibited multicollinearity. One of the four dummy variables representing sunshine was not significant and all were less significant than the two cloud dummy variables. In addition, unlike cloud cover which is reported, sunshine is not incorporated into the Daily Weather Report data. For these reasons it was decided to eliminate sunshine and incorporate the two cloud dummy variables into the final analysis.

The temperatures at noon on the three days prior to the questionnaire were highly correlated with the temperature and the related THI for the survey all having correlation coefficients greater than 0.65. This was probably due to seasonal trends in the temperature and to persistence of particular spells of weather. Because of this multi-collinearity the temperatures of the three days prior to the questionnaire were eliminated from the analysis.

The seasonal dummy variables were highly correlated with the temperature-related variables of THI and windchill. It was noted in Chapter 3 that the Lamb seasonal divisions seemed to be well defined in relation to the sample weather data and the temperature-related indices for the survey period also appear to adequately reflect the seasonal changes in the weather making the inclusion of the four seasonal variables unnecessary.

The respondents seemed surprisingly well clothed for the day's weather with the estimated clo unit showing a significant (at the 0.01 level of significance) positive correlation with the windchill index and a significant negative correlation with the THI; for the reasons stated above these two indices were to be included in the further analysis and therefore the clo unit was excluded.

The Present Weather Code was highly correlated with the precipitation dummy variable and as a number of elements of the Present Weather Code were to be included - such as cloud and rain - it was decided that these were to be preferred to the Present Weather Code which was not originally defined for the purpose of analysing human comfort or as a linear scale.

Many of the variables in the analysis were thus eliminated because of the multicollinearity assumption which invalidated the use of multiple linear regression on all the variables, although, as already noted, the other five assumptions as suggested by Poole and O'Farrell (1971) were upheld. The next step was a regression of the Index with the remaining variables which were sex, age, length of residence, cloud, THI, windchill, pressure, the temperature anomaly from the seasonal mean, the precipitation variable and the sunshine codes for the three days prior to the questionnaire. With the dummy variables included this gave 26 independent variables in the second regression.

The significance of the variables was tested using the F statistic and a significance level of 0.05 was adopted. The regression gave an

R value of 0.78373 (R^2 = 0.61424) with a significant overall F statistic of 44.2773. When the F values for each variable were tested only six variables were significant at the 0.05 level of significance, these being the windchill index, THI, pressure, the dummy variable representing whether or not it was raining at the time of the questionnaire, and the two cloud dummy variables.

It was interesting that none of the respondent-related variables were significant, although the reason for the length of residence variable being non significant may have been a result of the low number of respondents (30 out of 750) who had spent most of their lives abroad. These results support and extend the laboratory work of Fanger (1970) who concluded that age, sex and, in his work, nationality did not affect people's response to the thermal environment.

A third regression was than carried out using only the six independent variables which had been shown to be significant by the second regression analysis. The Pearson Product Moment correlation coefficient was 0.7583 with a significant overall F statistic of 167.56705 giving 58% explanation of the variation in the Index of Human Comfort. A summary of the results is shown in Table 4.4 which shows that the six variables were all significant at the 0.05 level.

Table 4.4 A Summary of the Results of the Third Multiple Regression Analysis

Variable	F Statistic	Significance
Windchill	88.8617	0.000
THI	4.4770	0.035
Pressure	8.1925	0.004
Cloud 3-5 octas	36.7883	0.000
Cloud > 5 octas	262.7389	0.000
Rain	95.5034	0.000

The third, fourth and fifth assumptions of linear regression, as noted at the start of this chapter, are concerned with the distribution of the error and can be most accurately tested by examining the plot of the residuals on the predicted Y which should be random. This scattergram is presented for the third regression in Figure 4.9. The visual impression is that there is no systematic pattern which is borne out by the very low Pearson Product Moment Correlation Coefficient of 9.8942×10^{-4}. A runs test was also carried out and the resulting standard normal deviate was -0.8753 leading to the conclusion that the distribution shown in Figure 4.9 was a random one and therefore that the third, fourth and fifth assumptions of linear regression were probably upheld by the data.

The first five assumptions of linear regression noted by Poole and O'Farrell (1971) were therefore upheld in this final regression with six independent variables. The sixth assumption is that of multicollinearity, that is that the independent variables are linearly independent of one another. This assumption was tested by inspecting the correlation matrix for the six remaining variables which is shown in Table 4.5.

Table 4.5 Correlation Matrix of the Six Variables in the Final Regression

Variable	Cloud 3-5 octas	Cloud >5 octas	Pressure	Rain	THI	Windchill
Cloud - 3-5 octas	1.0	-0.6792	-0.0936	-0.1664	0.1926	-0.1650
Cloud - >5 octas		1.0	-0.2606	0.2450	-0.1007	0.0827
Pressure			1.0	0.3823	0.1591	-0.1391
Rain				1.0	-0.0600	0.1127
THI					1.0	-0.7703
Windchill						1.0

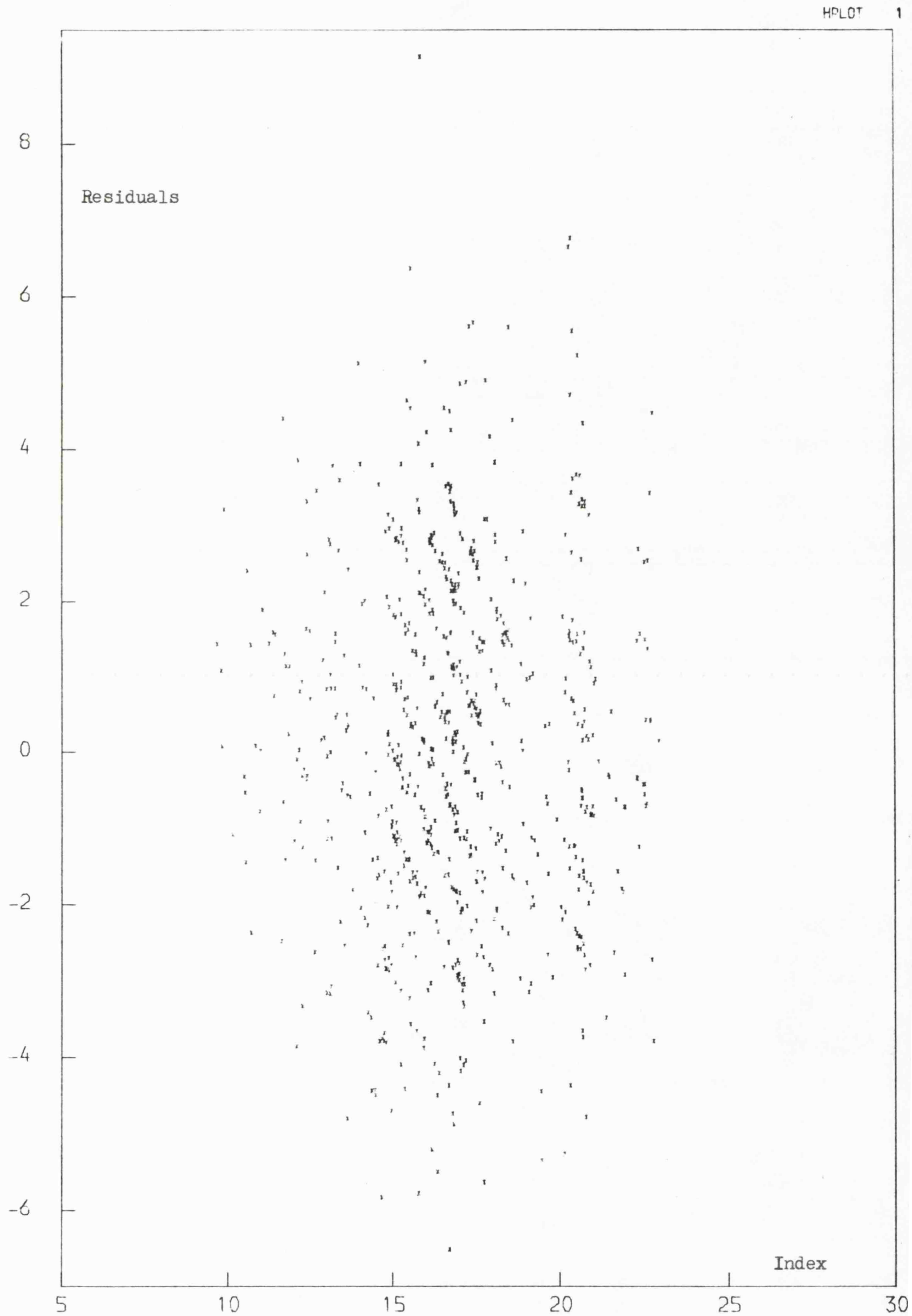


FIGURE 4.9. Plot of the residuals from the final regression against the predicted Human Comfort Index.

There are a number of points worth noting about this matrix. First, the majority of the independent variables show little relationship between themselves. Second, the high correlation between the two cloud dummy variables is inevitable because of the very nature of dummy variables in that they are mutually exclusive with one of the three categories being excluded; any related dummy variables would show this relationship. Third, there is a high negative correlation (-0.7703) between the THI and the windchill index which arises because both are related to temperature, the THI increasing and the windchill decreasing with increased temperature. Both, however, are dependent on another aspect of the weather, the THI being related to humidity and the windchill index to the windspeed and importantly they examine different aspects of human comfort. It was considered that both aspects of human comfort needed to be incorporated into the equation and therefore they were included in the final equation despite the apparent multicollinearity. This equation is evaluated and discussed in Chapter 6.

4.4 A Consideration of the Effects of Age, Sex and Clothing on the Residuals

Laboratory tests by Fanger (1970) and McIntyre (1972) have suggested that there is no difference in preferred levels of thermal comfort between age, sex and nationality groups. Earlier in this chapter it was found that neither age nor sex were significant in explaining the variance in the Human Comfort Index suggesting that the results of Fanger (1970) and McIntyre (1972) for indoor climates could be corroborated by the research being described here for the outdoor climate. It was decided, however, to consider further this crucial aspect of comfort and to examine the residuals for any differences between sex and age groups.

In order to carry out this examination, a contingency table cross-tabulating the age and sex groups with the residuals was built up as shown in Table 4.6. Separate chi-square tests for both males and females were carried out, giving values of 10.4855 and 4.7234 respectively and suggesting that the residual values show no association at the 0.05 level of significance with age group for either sex. A chi-square test was also carried out on the total frequencies for males and females and a test statistic of 1.09425 obtained, again suggesting no association.

The results of the multiple regression analysis and the examination of the residuals for different groups suggested that the age and sex of the respondent did not affect the response to the attitude scale which examined perception of the weather. This suggests therefore that the findings of Fanger (1970) and McIntyre (1972), that age and sex did not affect the preferred level of thermal comfort indoors, can also be applied to the total outdoor weather. However, it must be noted at this stage that it is possible that the old and very young may be more sensitive to extremes of weather which were not experienced during the survey period. It has been shown, for example, that in the exceptional 1976 hot spell the old and the very young were the most susceptible (Tout, 1978). In general, however, the results presented in this thesis are valid.

The residuals were also examined to see if there was any bias caused by the clothing of the respondent. It will be remembered that, because of its high multicollinearity with the temperature variables, the clo unit was not used in the regression analysis. In order to produce a contingency table the estimated clo frequency diagram (Figure 3.2) was examined to find suitable breaks which were identified at 1.3 (close to the mean), at 0.8 and at 1.8 clo units. The resulting contingency table is shown in Table 4.7.

Table 4.6 The Contingency Table used for the Examination of the Effects of Sex and Age on the Residuals

Sex/Age \ Residuals from zero	< -1 standard deviation	-1 to 0 standard deviations	0 to +1 standard deviations	> +1 standard deviations
Females				
15 - 19	3	11	12	7
20 - 29	22	50	51	22
30 - 39	11	30	26	13
40 - 49	12	19	16	11
50 - 59	6	14	13	6
60+	11	22	19	8
Males				
15 - 19	2	9	10	5
20 - 29	17	25	29	17
30 - 39	7	17	19	10
40 - 49	10	18	23	12
50 - 59	7	13	14	10
60+	8	25	24	4
All Females	65	146	137	67
All Males	51	107	119	58
Totals	116	253	256	125

Table 4.7 Contingency Table for the Examination of the Effect of Clothing on the Residuals

Clo unit \ Residuals from zero	< -1 standard deviation	-1 to 0 standard deviations	0 to +1 standard deviations	> +1 standard deviations
0.8	11	11	15	8
0.8 to 1.29	53	114	121	57
1.3 to 1.79	35	90	75	34
1.8	17	38	45	26

The chi-square statistic associated with this table is 8.2883 suggesting that there is no association between the residuals and the respondents' clothing as estimated in clo units. This result is not surprising in that, as was commented earlier in this chapter, the respondents seemed to be suitably dressed for the weather they were experiencing.

4.5 Summary and Conclusions

This chapter has focused on the multivariate analysis of the data collected at the time of the questionnaires with the aim of finding the combination of weather and respondent variables which best explained the variation in response as measured by an attitude scale. When choosing a suitable methodology a major concern was the mixed mode nature of the data with, for example, temperature and windspeed being measured along a continuous scale and sunshine and cloud on a discrete scale. The use of dummy variables in a multiple regression analysis presented a practical solution to this problem.

Before carrying out the multiple regression analysis it was necessary to ensure that the six basic assumptions of linear regression were upheld. The assumptions concerning measurement error and linearity were tested prior to the analysis and found to be reasonably upheld. The other four assumptions, however, could not be tested before carrying out a multiple regression analysis since testing is based mainly on an examination of the residuals as an indication of the error. Initially a multiple regression analysis was carried out using 43 independent variables, 13 of which were measured along a continuous scale and 30 of which were dummy variables representing 10 further variables. No pattern was found in the plot of the residuals against the predicted index suggesting that the three assumptions related to the distribution of the error were probably upheld. The assumption that the data exhibit no multicollinearity presented more serious problems as a result of the nature of weather data which clearly showed this feature in many of the variables. The exclusion of these variables with high collinearity allowed a second regression to be carried out with 25 independent variables representing 10 weather variables. This resulted in six independent variables being significant with an R value of 0.7583 when these six variables were regressed on the index. Compliance with the assumptions of linear regression was also a feature of this final analysis in which the six significant variables were the THI, windchill, rainfall, pressure and the two dummy variables representing cloud cover.

An interesting discovery was that none of the respondent variables, that is sex, age and length of residence, were found to be significant in explaining the response, which supports previous laboratory work carried out on perception of the thermal environment. The clothing of the respondent, as estimated by the clo unit, was found to be highly correlated with the temperature-related indices and was thus excluded.

The Beta coefficients of the six variables allow them to be combined into an index which explains the response to the attitude scale and is, in effect, an index of human comfort. Before considering this index and its spatial distribution over the British Isles in Chapter 6, an examination is made first, in Chapter 5, of the climatology of the five component variables.

Chapter Five

A Study of the Climatology of the Significant Variables

5.1 Introduction

The multiple regression analysis described in the previous chapter produced six significant variables which statistically 'explain' the public's attitude (as measured by a Likert Scale) to the weather. These were the Steadman windchill index, THI, pressure, a binary variable for presence or absence of rain and two dummy variables representing cloud cover. One of the aims of the experiment described in this study was to consider the previously neglected aspect of the spatial variation in human comfort in the British Isles and of the factors likely to affect this comfort. This chapter examines the climatologies of the variables extracted by the multiple regression analysis.

5.2 The Data

In order to produce a climatology of the variables it was necessary to obtain a suitable data set. Such data were found in the Daily Weather Reports (DWR) published by the Meteorological Office. The advantage of these data for human comfort studies is that they are reported as instantaneous values at 0000, 0600, 1200 and 1800 hours G.M.T.. Although most of the indices of comfort are based on such instantaneous measures very few studies (Winslow and Herrington, 1935; and Auliciems, 1976 being exceptions) have attempted to consider the human comfort climate except by using longer term mean values, the use of which removes the important covariance of the input weather elements.

To overcome problems of diurnal variation and to correspond to man's working day and to the timing of the questionnaires, 1200 G.M.T. values were used in the calculations. Because of the large quantity of data published it was necessary to sample these reports and a 5% random sample of the 15 years daily data up to the date of the research, that is the period 1963 to 1977 inclusive, stratified according to the Lamb Natural Seasons (Lamb, 1950) was taken. A total of 62 stations, shown in Figure 5.1 were reported during this period, although not all appeared for the entire 15 years. This sampling gave 14,706 station days divided seasonally as shown in Table 5.1.

Table 5.1 Seasonal division of station days 1963-1977 inclusive used in the analysis

Natural Season	Dates	Number of days in the sample	Number of Station Days
Spring	30 March - 17 June	60	3235
High Summer	18 June - 9 September	63	3375
Autumn	10 September- 19 November	52	2787
Early Winter	20 November - 19 January	47	2518
Late Winter	20 January - 29 March	52	2797
Total		274	14706

The number of days sampled in each season was proportional to the length of that season.

With the notable exception of Eskdalemuir, the stations shown in Figure 5.1 are representative of Lowland rather than Highland Britain. The climatologies of the variables, and of the Index of Human Comfort discussed in the next chapter, inevitably reflect this bias and therefore the Eskdalemuir values have a marked effect on many of the mapped distributions. Greater attention should therefore be paid to the distributions of the climatic variables in the lowland areas in which, after all, most people live.

As shown in Table 5.1 the sample was stratified according to the

FIGURE 5.I. The stations which appeared in the Daily Weather Reports during the sample period I963-I977 inclusive.

Station Number	Station	Station Number	Station
5	Lerwick	578	Mildenhall
I0	Sule Skerry	586	Honington
22	Benbecula	590	Wattisham
26	Stornoway	627	Ross-on-Wye
49	Cape Wrath	628	Bristol
75	Wick	703	Hartland Point
9I	Dyce	707	Chivenor
I00	Tiree	715	Rhoose
I3I	Mull of Galloway	746	Boscombe Down
I35	Prestwick	772	London Airport
I40	Abbotsinch	775	Kew
I4I	Renfrew	776	Gatwick
I62	Eskdalemuir	797	Manston
I7I	Leuchars	804	Scilly
204	Ronaldsway	809	Culdrose
222	Carlisle	8I7	St. Mawgan
244	Acklington	827	Plymouth
257	Leeming	862	Hurn
26I	Dishforth	87I	Thorney Island
262	Tynemouth	9I7	Aldergrove
302	Valley	952	Roches Point
3I8	Squires Gate	953	Valentia
334	Manchester	962	Rineanna
354	Watnall	965	Birr
360	Finningley	969	Collinstown
395	Manby	976	Belmullet
396	Spurn Head	980	Malin Head
4I4	Shawbury		
462	Wittering		
485	West Raynham		
495	Coltishall		
497	Gorleston		
502	Aberporth		
534	Elmdon		
559	Cardington		

Lamb Natural Seasons (Lamb, 1950) which are based on frequency curves of long spells of types of weather. Particular weather types are therefore more typical of some seasons than of others, and certain seasons have more consistent types of weather than do others. In order to examine the representativeness of the sample of days from the DWR, the weather type for each of the 274 sample days was obtained from the Daily Register of Circulation Patterns available from the Meteorological Office (Lamb, 1972) and the results compared to the weather types which could be expected in each season.

There are eleven weather types used in the Daily Register which are shown in Table 5.2. It can be seen from the table that all but three of the weather types are directional, the exceptions being Anticyclonic, Cyclonic and Unclassified. The data obtained from the Register are summarized in Table 5.3 and can be compared to Lamb's (1950) comments on the seasonal frequency of weather types. The dominance of Westerly weather types over the year is in accordance with Lamb's (1950) figures although this is more marked over the longer period used by Lamb. Perry (1976) has noted that northerly and easterly weather types are common during the Spring season a feature which is also revealed by the data in Table 5.3. The Southerly type reaches a maximum in this season, although this weather type only accounts for 5.47% of the total types in the season. Cyclonic and anticyclonic types are also important in Spring as in all five seasons. Westerly and cyclonic weather types are common in Summer with the former reaching a maximum in that season. Lamb (1972) found a Winter maximum of the westerly weather type although Summer showed a secondary peak. The cyclonic weather type reaches a maximum in Autumn which is also in agreement with Lamb (1950) and this season is dominated by cyclonic and westerly types. In contrast Early Winter has a wide variety of weather types with none being particularly

Table 5.2 The Weather Types used in the Daily Register of Circulation Patterns

Code used in Table 5.3	Weather Type	Code used in Table 5.3	Weather Type
A	Anticyclonic	S	Southerly
C	Cyclonic	NE	North Easterly
W	Westerly	SE	South Easterly
NW	North Westerly	SW	South Westerly
N	Northerly	U	Unclassified
E	Easterly		

Table 5.3 The Weather Types in each Season for the Sample Days (number and percent of days)

Season		A	C	W	NW	N	E	S	NE	SE	SW	U	Total Number
Spring	No.	7	7	9	4	7	12	6	1	2	3	2	60
	%	11.67	11.67	15.0	6.67	11.67	20.0	10.0	1.67	3.33	5.0	3.33	
High Summer	No.	6	12	20	8	2	4	2	2	1	1	5	63
	%	9.52	19.05	31.75	12.7	3.17	6.35	3.17	3.17	1.59	1.59	7.94	
Autumn	No.	7	14	15	2	1	6	0	0	1	1	5	52
	%	13.46	26.92	28.85	3.85	1.92	11.54	0.0	0.0	1.92	1.92	9.62	
Early Winter	No.	5	5	9	5	3	4	4	3	2	5	2	47
	%	10.64	10.64	19.15	10.64	6.38	8.51	8.51	6.38	4.26	10.64	4.26	
Late Winter	No.	11	5	10	5	1	5	3	3	4	2	3	52
	%	21.15	9.62	19.23	9.62	1.92	9.62	5.77	5.77	7.69	3.85	5.77	
Year	No.	36	43	63	24	14	31	15	9	10	12	17	274
	%	13.14	15.69	22.99	8.76	5.11	11.31	5.47	3.28	3.65	4.38	6.20	

dominant although the Westerly weather type has the largest percentage of occurrences. All these features are in accordance with Perry's (1976) discussion of the synoptic climatology of the British Isles. The anticyclonic weather type maximum is found in Late Winter and this weather type is commonly associated with cold winters. The second most common type in this season is the westerly weather type which brings the contrasting mild, wet winter weather. These types are typical of this season.

It can be concluded from the above discussion that the sample of days from the DWR data appears to be at least qualitatively representative of the long term average conditions in the frequency of weather types.

The data reported in the DWR are in the form of a string of coded numbers for each station incorporating the station number, cloud (in octas), windspeed, the Present Weather Code, pressure, air temperature and the dew point temperature as well as other variables which were not used in this analysis. In order to avoid transcription errors the whole of these data were extracted from the DWRs and punched onto cards, usually with two station days to a card. A FORTRAN computer programme (Appendix 4) was written to extract and decode only the useful variables and to calculate other variables such as the relative humidity and the THI. It also uses the Present Weather Code to produce a binary variable indicating whether or not precipitation was falling at the time of observation. The results produced by this programme were written onto a magnetic tape for further use. A second major FORTRAN programme written for the analysis described in this and the succeeding chapter is shown in Appendix 5. This carried out an analysis of all the data according to the Lamb Natural Seasons by calculating each index for each station day and then finding the various seasonal means and standard deviations. A sample of the output is shown in Appendix 6.

Before analysing the data it had been expected that the means and standard deviations of the variables could be most usefully combined and mapped as the coefficient of variation but the nature of the results made this undesirable. Gregory (1963) has pointed out that in many data sets the relationship between the measure of central tendency and the associated measure of dispersion is positive and linear, with the two giving similar spatial patterns when mapped. The coefficient of variation usefully amalgamates the two descriptive measures to give a single comparative measure. The data used in this experiment often failed to exhibit this expected relationship between the mean and standard deviation. For example, the THI has a Pearson Product Moment Correlation Coefficient of -0.2354 between the mean and standard deviation and the Index of Human Comfort (examined in the next chapter) has a coefficient of -0.3636 for this same relationship. The associated plots are shown in Figures 5.2 and 5.3. These negative relationships mean that any attempt to calculate and map the coefficient of variation will result in a loss of the true patterns exhibited by these statistics. It was therefore decided to map the mean and standard deviation separately for each variable and season. It can be seen from Appendix 6 that a vast amount of data were produced by this analysis of the DWRs; the rest of this chapter, however, concentrates on the six variables which were extracted by the multiple regression analysis as giving the most appropriate statistical 'explanation' of the respondents' attitudes to the weather. Each of these variables is examined in turn.

5.3 The Windchill Index

It is often the combination of weather elements acting in conjunction to affect the energy balance of the human being which causes most discomfort to the individual. Physiologically, one of the most unfavourable

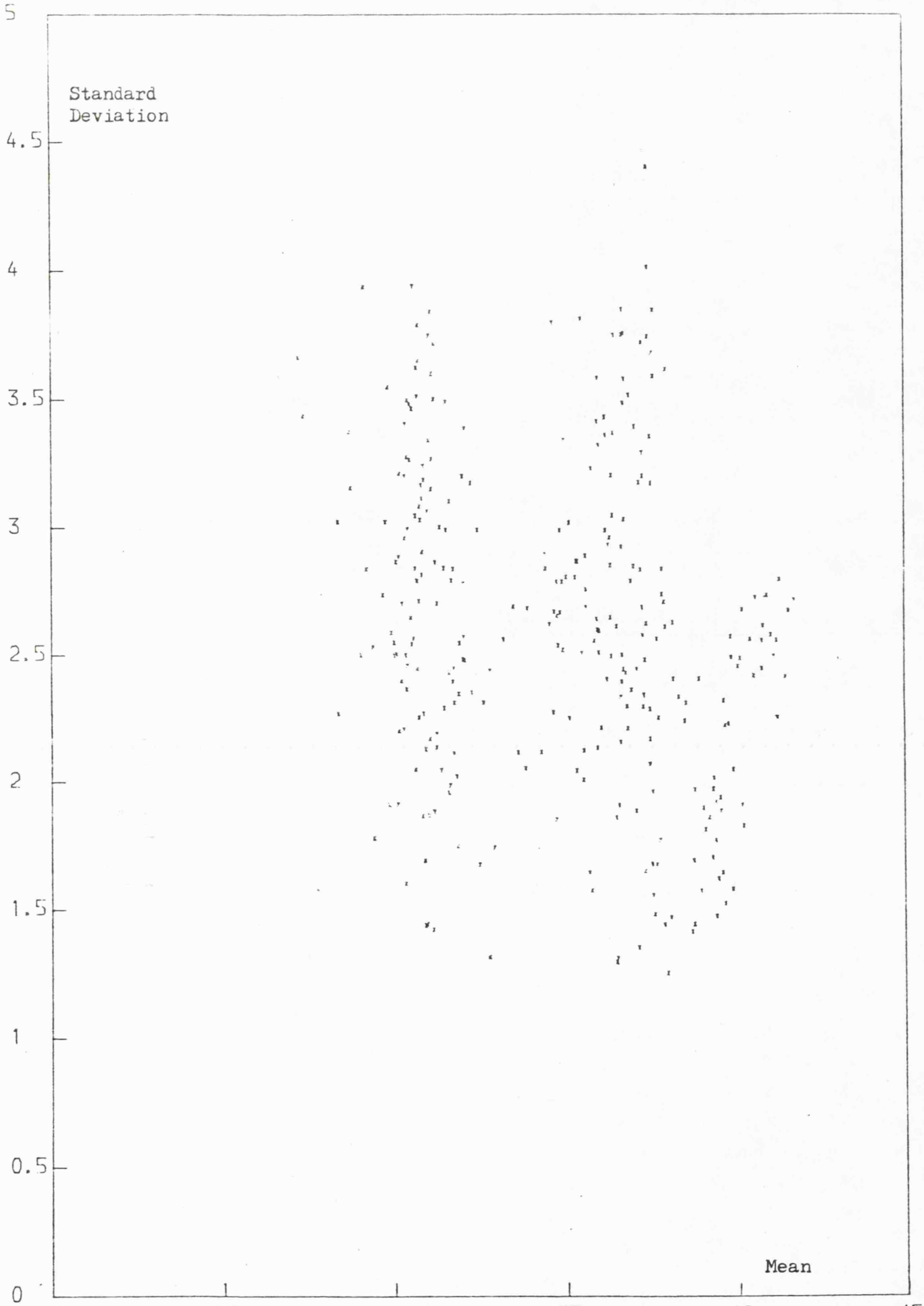


FIGURE 5.2. The relationship between the mean and standard deviation for the T.H.I..

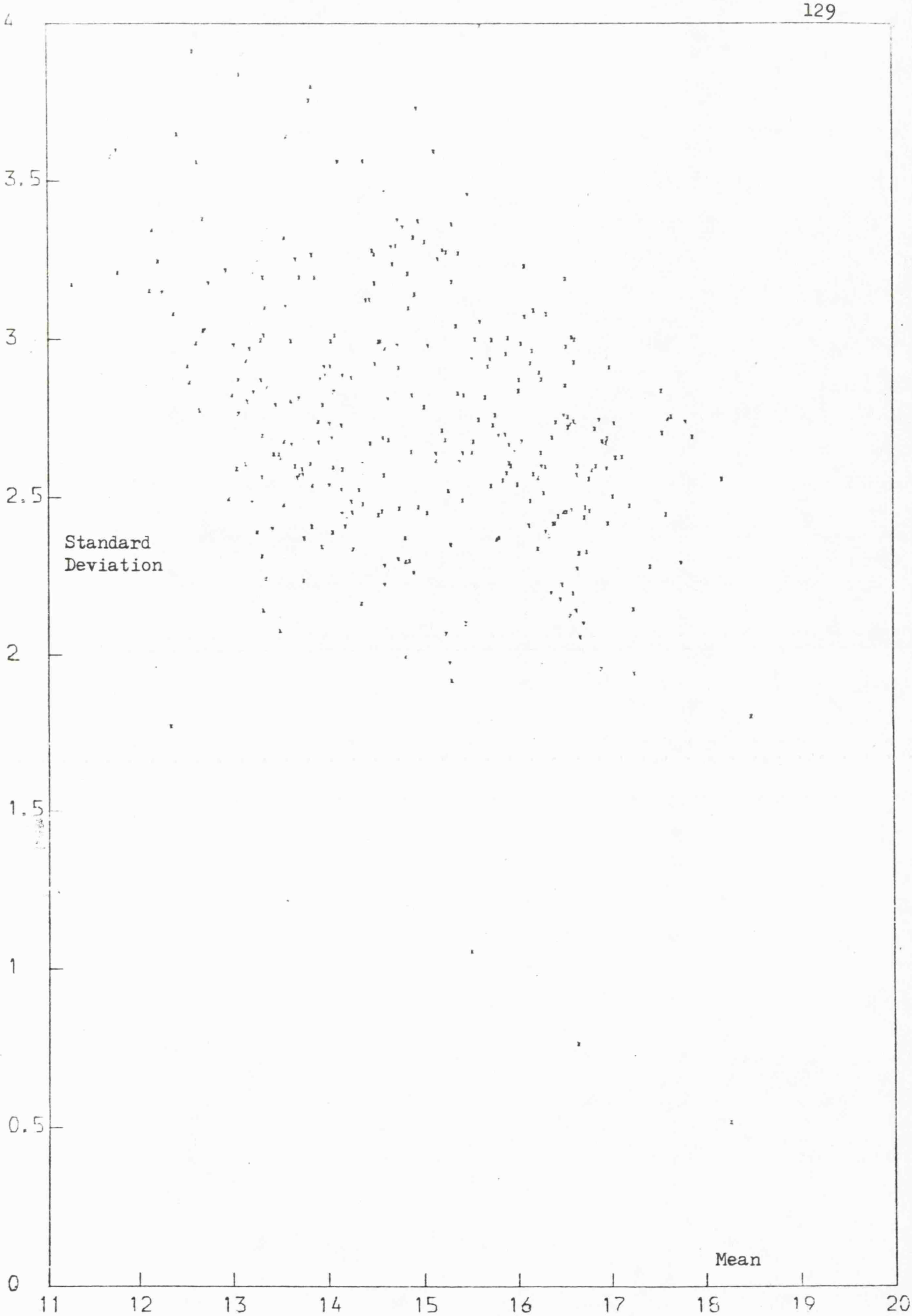


FIGURE 5.3. The relationship between the mean and standard deviation for the Human Comfort Index.

weather events is the combination of low temperature and high windspeed which can lead to hypothermia and, during extreme and prolonged exposure, to possible death (Smithson and Baldwin, 1978). The development of a reliable measure of this windchill was discussed in Chapter 1 and the Steadman (1971) index was outlined in Table 2.3. This index is the most realistic model of windchill in that it is based on the energy balance of a mobile, clothed human being and as such was adopted for use in the analysis described in the previous two chapters.

Previous work on the climatology of windchill is limited. Smithson and Baldwin (1978) calculated windchill indices for Lowland Britain from monthly means of temperature and wind for one year (1973) and for an 18 year period (1956 to 1973). In a later paper (Baldwin and Smithson, 1979) they carried out a similar study for Highland Britain. Their maps have the major deficiency that they are based on an index calculated from independently time averaged values of wind and temperature, yet the index used is derived for instantaneous conditions. The physiology of the human being reacts to the instantaneous weather and not to climatic averages: man may have some idea of the expected seasonal weather but he will adjust his behaviour according to his perception of the individual day's weather.

As outlined in Chapter 1 the use of averages also removes the covariance of wind and temperature inherent in the windchill index. The human being also reacts to such combinations of weather elements and studies which include indices of human comfort must use data which reflect the covariance of the elements used. The failure of Smithson and Baldwin (1978) and Baldwin and Smithson (1979) to do this can be seen by considering the period mean of the simplest type of product term which occurs in the windchill formula. If the instantaneous values of windspeed (V) and temperature (T) are represented in terms of the period means (-) and departures therefrom ('), then

$$\overline{VT} = \overline{(\bar{V} + V')(\bar{T} + T')} \tag{5.1}$$

$$= \bar{V}\,\bar{T} + \overline{V'T'}$$

Since the means of products involving a mean value and a departure are zero. The covariance $\overline{V'T'}$ which occurs in addition to the product of the period mean values of V and T may be significant since wind and temperature variations are often correlated. In the lowland areas under discussion, for example, low temperatures frequently occur in association with low windspeeds yet substitution of monthly mean values in the Steadman formula does not reflect this and a tendency to overestimate lowland windchill values may be suspected. There is also a tendency in using mean values to average out important diurnal variations. Of necessity the windchill values computed by Smithson and Baldwin (1978) also tend to regress towards a mean and so may conceal the extreme values which are a reflection of the potential windchill stress. It is impossible to obtain an expected range of windchill values using monthly means which mask the true range of the wind and temperature taken in conjunction. The use of monthly means also gives a spatial problem in that the co-variance of wind and temperature is not likely to be uniform over the whole country. For these reasons the maps produced by Smithson and Baldwin (1978) for Lowland Britain and Baldwin and Smithson (1979) for Upland Britain have only very general relevance to public perception of the weather.

The use of DWR data reported earlier attempts to overcome these problems. The Steadman (1971) windchill index was calculated for each of the 14,706 station days using the FORTRAN programme shown in Appendix 5, seasonal means and standard deviations were calculated and mapped in

Figures 5.4 to 5.8. Before looking at each season in more detail some general points are worth noting. From Table 5.2 it can be seen that the highest average value is 178 at Malin Head in Early Winter and the lowest is 54 at Mildenhall in High Summer. These average values are of

Table 5.4 The Range of Average Windchill Values. Units $cal.m^{-2}s^{-1}$

Season	Maximum (Station)	Minimum (Station)	Range
Spring	145 (Lerwick)	83 (Ross-on-Wye)	62
High Summer	112 (Lerwick)	54 (Mildenhall)	58
Autumn	131 (Lerwick	78 (Ross-on-Wye)	53
Early Winter	178 (Malin Head)	113 (Ross-on-Wye)	65
Late Winter	168 (Malin Head)	114 (Ross-on-Wye)	54

much the same magnitude as those found by Smithson and Baldwin (1978) although the recalculation enabled the absolute maxima and minima to be obtained and these will be discussed later in this section. Smithson and Baldwin's absolute maximum of 181 was found at Lerwick in January and the minimum of 51 at Hampton and Kew in July. Their maximum range was 76 in January and their minimum range was 47 and in August. On the basis of the range of values Smithson and Baldwin (1978) identified their winter months as being December to March and the Summer months as June to September which coincide with the Lamb Natural Seasons (Table 5.1) which are used in this study.

There are a number of points which can be made regarding the spatial distribution of mean windchill as shown in Figures 5.4 to 5.8. First, the results for Scotland and Western England show a similar pattern to those found by Smithson and Baldwin (1978). Second, Ireland, which is not mapped in their paper, has a distribution of windchill similar to the rest of the British Isles in that there is a general decline from north to south as well as an inland minimum. Third, the recalculation of windchill with instantaneous data shows a steeper gradient of windchill in eastern Scotland and England with higher values being reached along the east coast than were found by Smithson and Baldwin (1978). This is probably a result of cold onshore winds at coastal sites whose wind/temperature covariance is lost in the mean data. Fourth, the recalculation results in lower windchill values in southern England, the overestimation of the original work is again probably the result of the removal of the element of covariance. It is only in areas where the averages coincide with the true covariance as measured instantaneously that the use of averaged data gives a correct picture of windchill variation. Fifth, as in the Smithson and Baldwin (1978) results, proximity to the coast and latitude seem to be the most important factors in windchill variation.

Having identified these major controls it is necessary to consider each seasonal mean pattern and its associated distribution of variability, as measured by the standard deviation, shown in Figures 5.4 to 5.8. Many of the patterns shown on the maps are clearly related to the synoptic climatology. This relationship will be discussed with particular reference to weather types on which the Lamb Natural Seasons, used in the stratification adopted in this experiment, were based.

(i) Spring (Figure 5.4). In this season the mean windchill varies from 145 cal.$m^{-2}s^{-1}$ at Lerwick in the Shetlands to 83 cal.$m^{-2}s^{-1}$ at Ross-on-Wye. This range of 62 cal.$m^{-2}s^{-1}$ is the second largest after the Early Winter Season (Table 5.2). The north west coastline of Scotland and the east coast of Britain north of Harwich have the highest values especially at Mull of Galloway which consistently registers high values. The north east coast of Ireland also has high windchill values. In both England and Ireland the windchill values decrease inland and also westwards and there is a latitudinal effect with the windchill decreasing southwards.

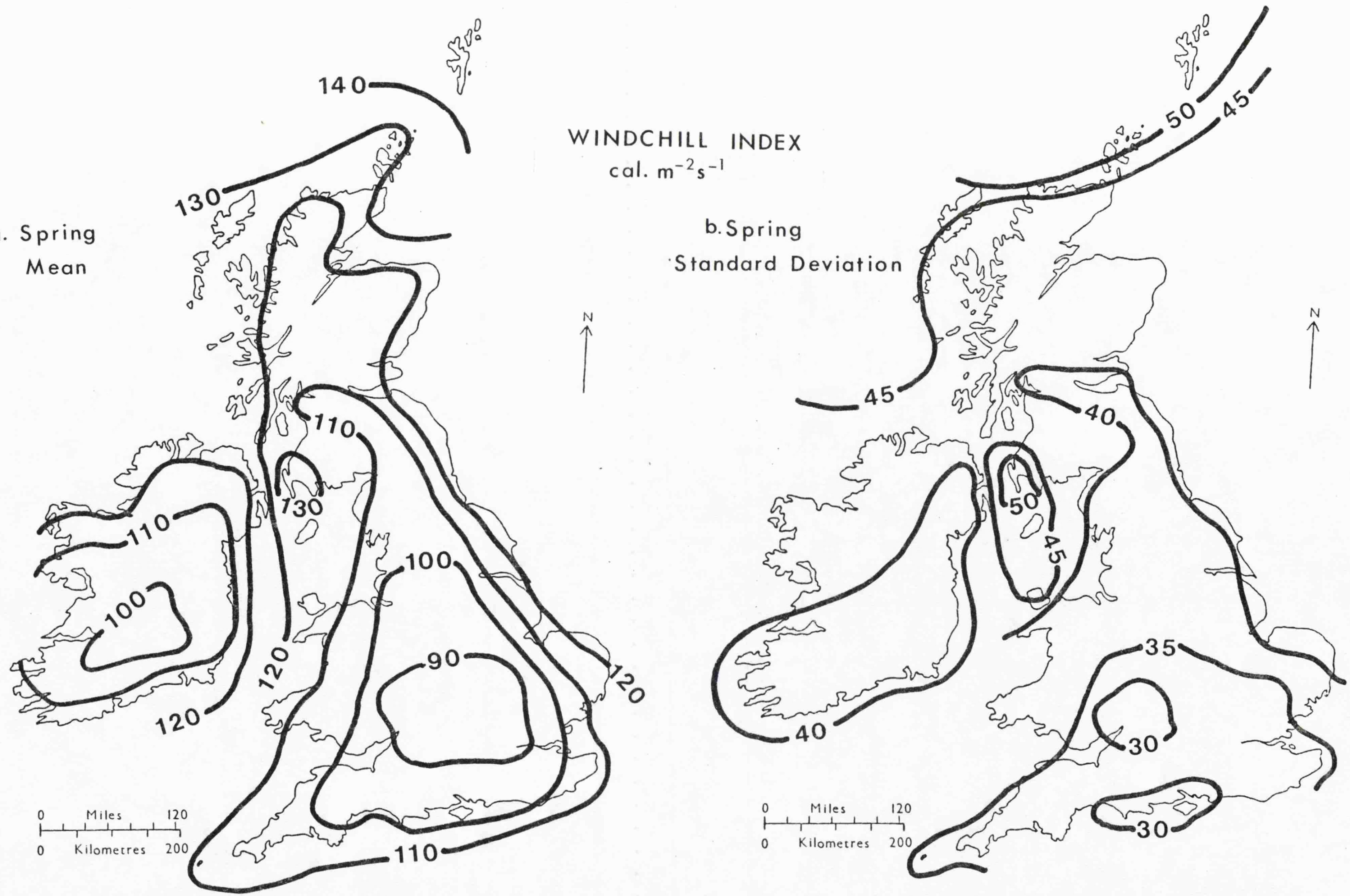

WINDCHILL INDEX
cal. $m^{-2}s^{-1}$
a. Spring
Mean
140
130
110
130
110
100
120
120
100
90
120
110
0 Miles 120
0 Kilometres 200
b. Spring
Standard Deviation
50
45
45
40
50
45
40
35
30
30
0 Miles 120
0 Kilometres 200
N
N

FIGURE 5.4.

This pattern of lower windchill values on the west coast than on the east was not reflected in Smithson and Baldwin's (1978) paper and is therefore worthy of further discussion. In discussing Lamb's Natural Seasons, Perry (1976) noted that northerly and easterly weather types tend to be frequent in Spring. The northerly weather type is generally associated with a blocking anticyclone to the west of Britain and brings cold weather which is often accompanied by high winds particularly on the east coast which could explain the high windchill values found on the eastern seaboard. In addition higher windchill values are also likely to occur on the east coast during a spell of the easterly weather type, resulting from high pressure over Scandinavia, which often brings cool weather to the east coast.

The distribution of the Spring standard deviation of windchill (Figure 5.4(b)) is similar to those for Autumn (Figure 5.6(b)) and the two Winter seasons (Figures 5.7(b) and 5.8(b)) with the main controls being latitude and proximity to the coast with the standard deviation decreasing southwards and inland. This distribution does not reflect the changeability which Lamb (1964) found to be most characteristic of the Spring season with few long spells of weather types being experienced southwards and inland.

(ii) High Summer (Figure 5.5). The maximum mean windchill value in High Summer is 112 cal.$m^{-2}s^{-1}$ at Lerwick and the minimum is 54 cal.$m^{-2}s^{-1}$ at Mildenhall giving a seasonal range of 58 cal.$m^{-2}s^{-1}$. The distribution of mean windchill (Figure 5.5(a)) is very similar to that produced by Smithson and Baldwin (1978) for July. This is probably because of the frequency of long spells of weather in High Summer which result in the averages giving a fairly true reflection of the covariance of wind and temperature.

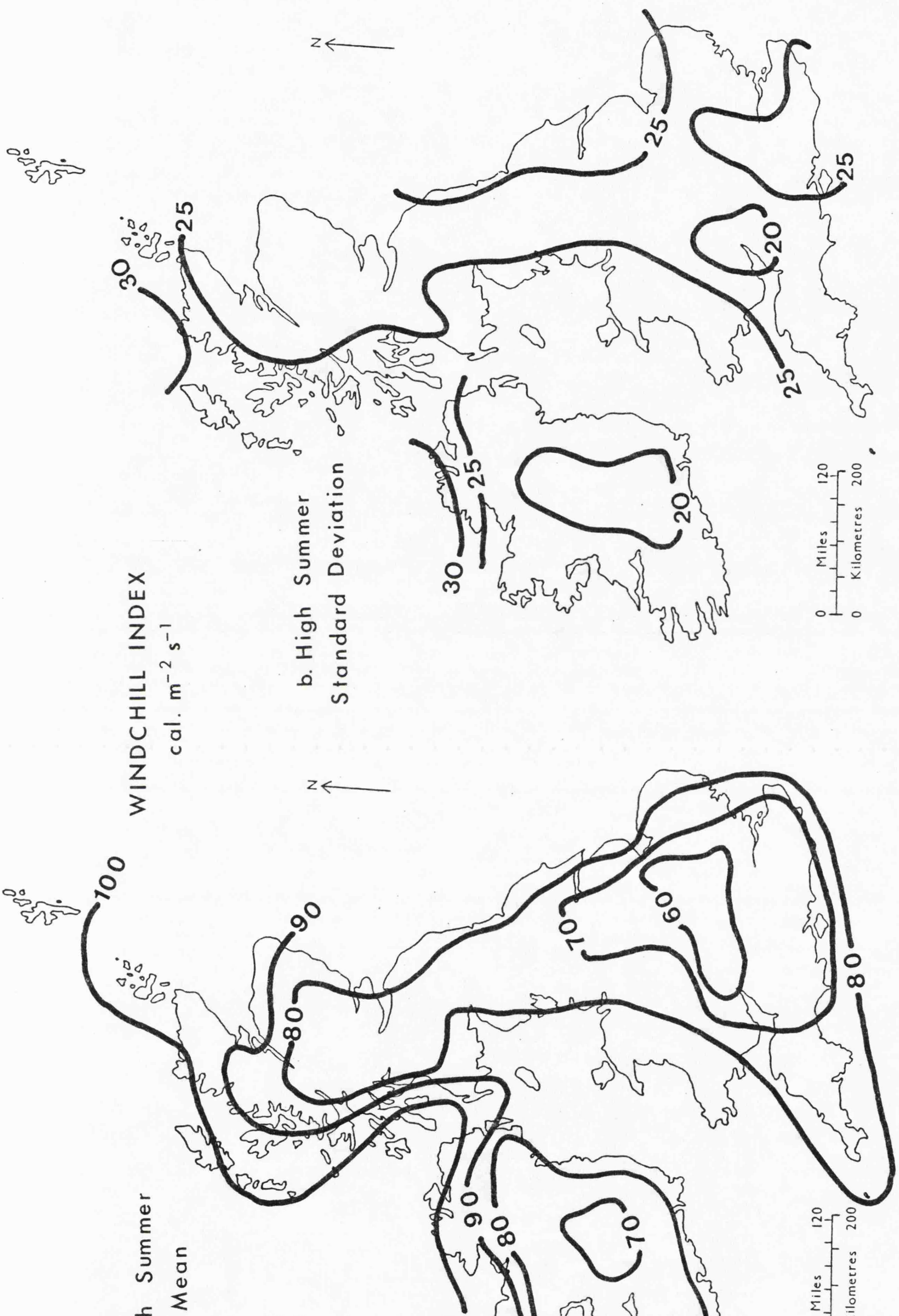

WINDCHILL INDEX
cal. m^{-2} s^{-1}
a. High Summer
Mean
b. High Summer
Standard Deviation
N
100
90
80
70
60
30
25
20
0 Miles 120
0 Kilometres 200

FIGURE 5.5.

The windspeed varied less in High Summer than in the other seasons and the main control of the distribution of windchill was temperature. The north west coastal areas have the highest windchill values possibly as a result of fronts giving unsettled and changeable conditions. These fronts are characteristic of a synoptic situation with high pressure to the south of Britain and low to the north giving a series of depressions whose centres pass just to the north of Britain. The low windchill values in the Midlands and south east of England may be associated with warm continental air flows which are caused during the latter stages of an anticyclonic spell when the high centre moves eastwards to Germany or Denmark.

There is rather less variation in windchill in High Summer (Figure 5.5(b)) than in Spring (Figure 5.4(b)), the lower variation being a function of the more settled weather in this season, the major pattern in the distribution of the standard deviation being a decrease in the windchill variation inland.

(iii) Autumn (Figure 5.6). The spatial distribution of mean windchill in Autumn is again very similar to that produced by Smithson and Baldwin (1978). It shows some features which are seen on the High Summer mean distribution (Figure 5.5) but windchill values are around 10 to 20 $cal.m^{-2}s^{-1}$ higher in Autumn. The maximum mean value is 131 $cal.m^{-2}s^{-1}$ at Lerwick and the minimum mean is 78 $cal.m^{-2}s^{-1}$ at Ross-on-Wye.

The north west coastline of Scotland and Ireland have the highest windchill values which may be associated with the stormy cyclonic conditions typical of the later part of this season. There is a reduction in windchill from north to south and also inland with the Midlands and south of England having the lowest values. Lamb (1964) comments that the types which give fine and calm weather in the south

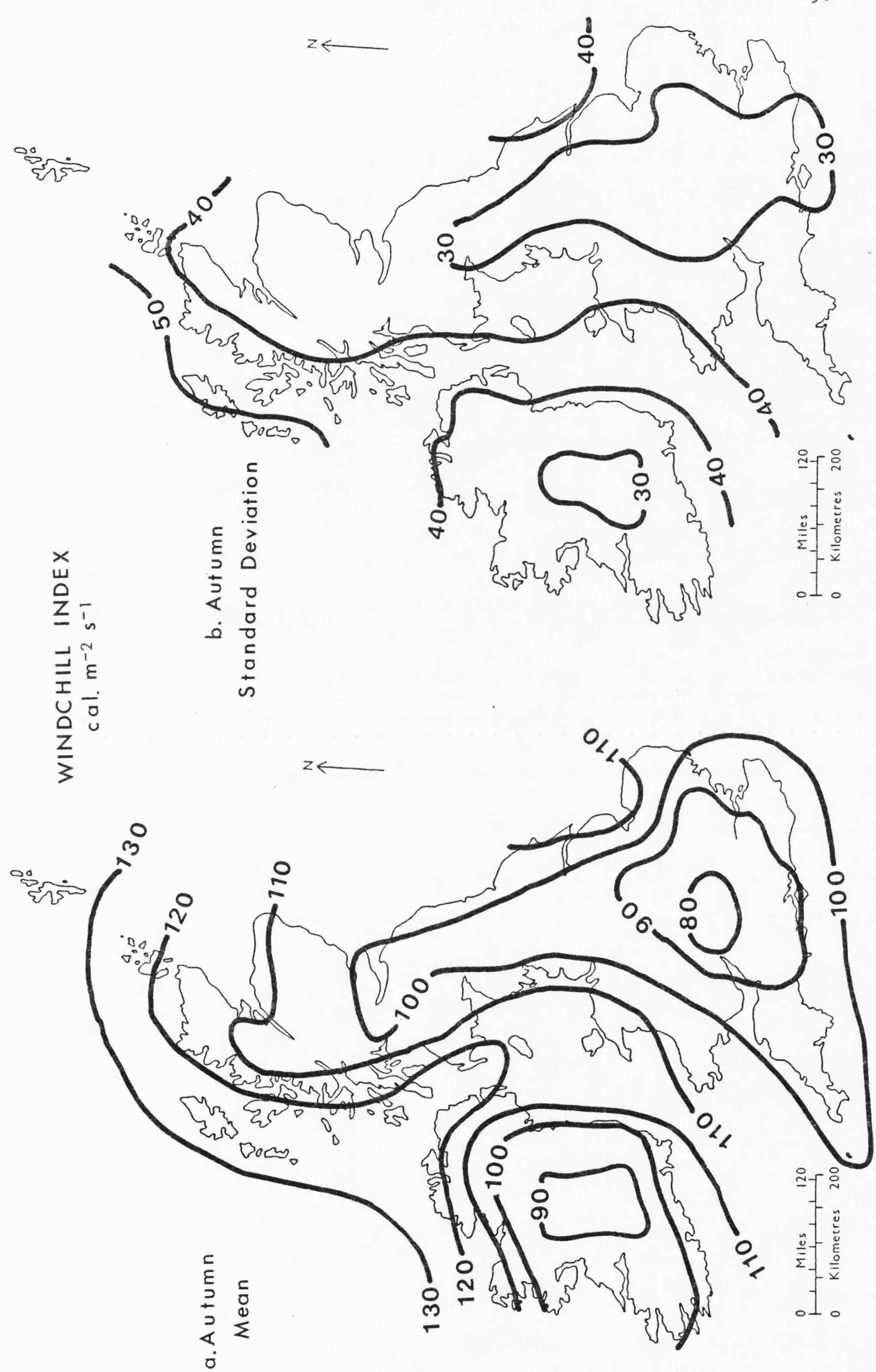

WINDCHILL INDEX
cal. m⁻² s⁻¹
a. Autumn
Mean
b. Autumn
Standard Deviation
N
130
120
110
100
90
80
50
40
30
0 Miles 120
0 Kilometres 200

FIGURE 5.6.

of England are typical of the first half of this season. The western coastlines of Scotland and Wales and the northern coast of Ireland have the highest standard deviation. Apart from differences in the coastal extremes there is little variation between eastern and western England.

(iv) Early Winter (Figure 5.7). The most characteristic feature of this season is a reduction inland in windchill, although superimposed upon which is again a north-south change with the lowest values in the south. The highest mean windchill value for the sample in this season was 178 cal.$m^{-2}s^{-1}$ at Malin Head (Ireland) with the lowest mean being 113 cal.$m^{-2}s^{-1}$ at Ross-on-Wye giving the largest seasonal range of 65 cal.$m^{-2}s^{-1}$ which is probably a reflection of the changeability of the weather during this season. The most consistent weather type during this season is the westerly type which results from a blocking anticyclone developing over Eastern Europe with depressions consequently stagnating over the sea between Iceland and Scotland which have westerly winds on their southern flanks bringing mild weather to Britain. If these depressions take a more southerly track they often result in cold snowy conditions in Britain. Cyclonic conditions are common in this season.

The distribution of the standard deviation also shows the influence of proximity to the coast (Figure 5.7(b)). The variation is not very marked but, in general, the north western coastal extremities, which are more affected by the westerly cyclonic weather type, have the highest variation and coastal areas in general have higher variation than inland areas at the same latitude.

(v) Late Winter (Figure 5.8). Finally, the distribution of windchill values for Late Winter is similar to that of Early Winter (Figure 5.7(a)) although the inland gradient is less marked. The maximum mean value is 168 cal.$m^{-2}s^{-1}$ at Malin Head and the minimum is 114 cal.$m^{-2}s^{-1}$ at Ross-on-Wye, giving a range of 54 cal.$m^{-2}s^{-1}$, less than in Early

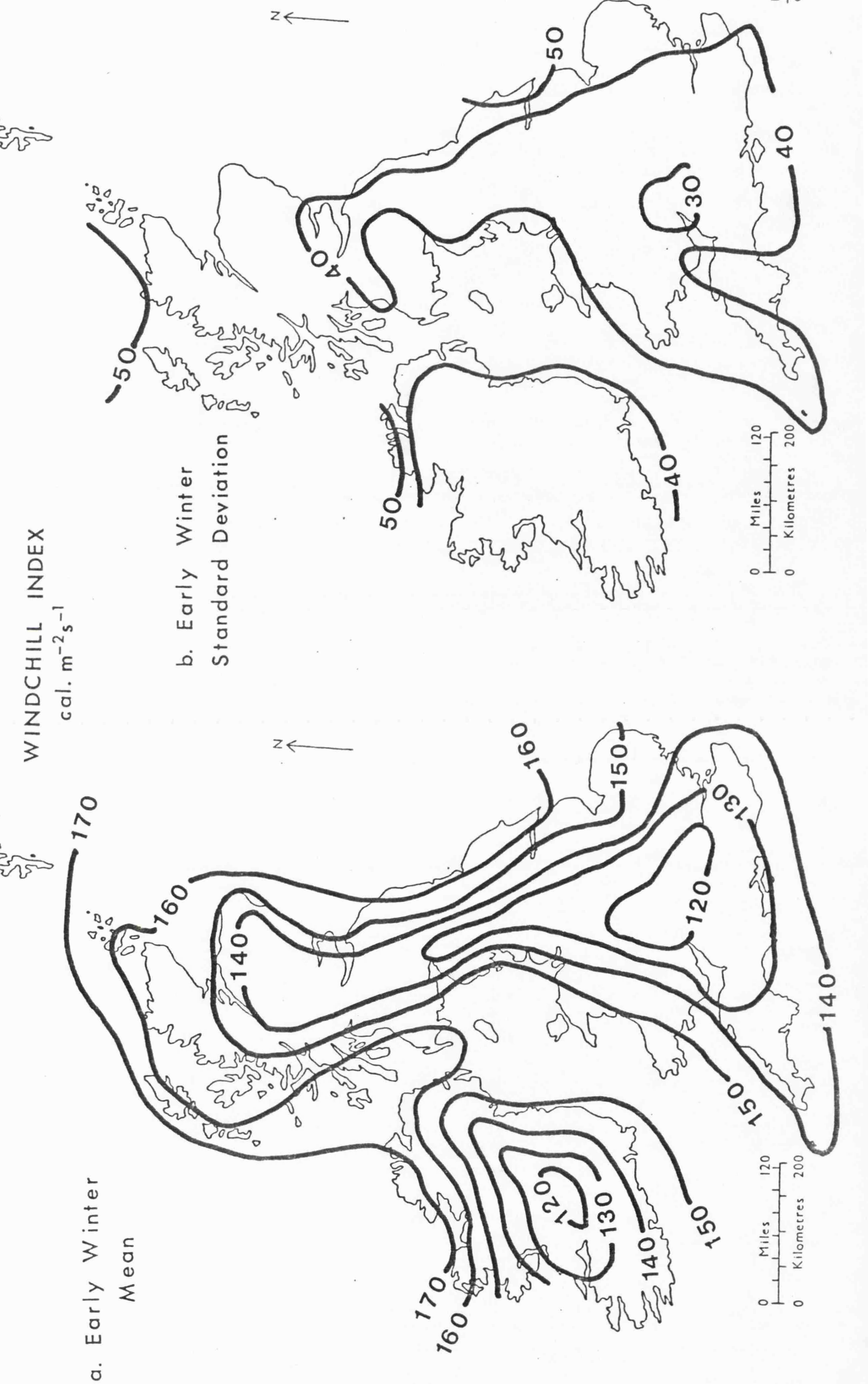

WINDCHILL INDEX
cal. m-2s-1
a. Early Winter Mean
b. Early Winter Standard Deviation
N
170
160
150
140
130
120
50
40
30
Miles 0 120
Kilometres 0 200

FIGURE 5.7.

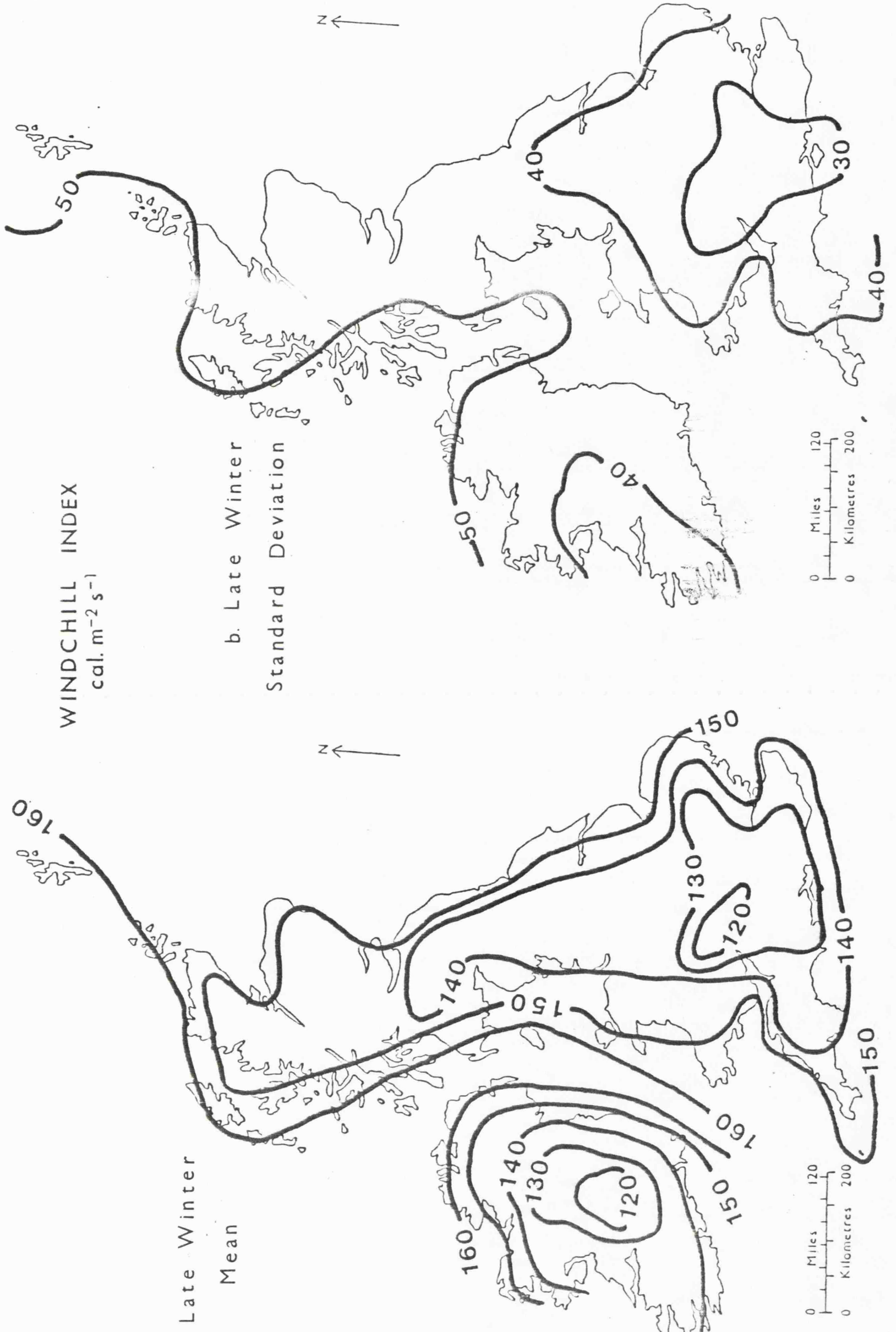

WINDCHILL INDEX
cal. m⁻² s⁻¹
a. Late Winter
Mean
b. Late Winter
Standard Deviation
N
160
150
140
130
120
160
150
140
130
120
150
140
150
50
40
30
40
50
40
0 Miles 120
0 Kilometres 200
0 Miles 120
0 Kilometres 200

FIGURE 5.8.

Winter which is possibly due to the longer spells of weather types experienced during the second winter season. It can be seen from Figure 5.8(a) that the values are consistently 30 cal.$m^{-2}s^{-1}$ higher in Late Winter than in the succeeding Spring season and is a result of the long spells of easterly and cyclonic weather types which bring cold weather to the whole area under consideration. The cold northerly weather type is also common and, although it rarely lasts more than 5 to 7 days (Perry, 1976), it often results in very severe winters in Scotland. Minimum windchill values occur in south central England and central Ireland.

The standard deviation of windchill in Late Winter (Figure 5.8(b)) exhibits a distribution slightly different from that of the other seasons. The north west coastal areas of Scotland, which are particularly subject to the effects of northerly weather types, have the highest standard deviation with the variation decreasing southwards and inland to a minimum at Ross-on-Wye.

The distributions of the annual mean windchill and the associated standard deviation are shown in Figure 5.9 (a and b) and they clearly summarize much of the detail discussed above. There is little difference in windchill values between the east and west coast except in the north western coastal extremities where the values are higher than on the east coast at the same latitude. This is probably a result of the susceptibility of these areas to the worst weather in the country as a result of the northerly and north westerly weather types. The south coast of England and the mid-west coast of Ireland appear to be the most favoured coastlines although south-central England has the lowest wind-chill values with the lowest mean annual windchill values (88 cal.$m^{-2}s^{-1}$) at Ross-on-Wye and Mildenhall. Lerwick has the highest annual mean

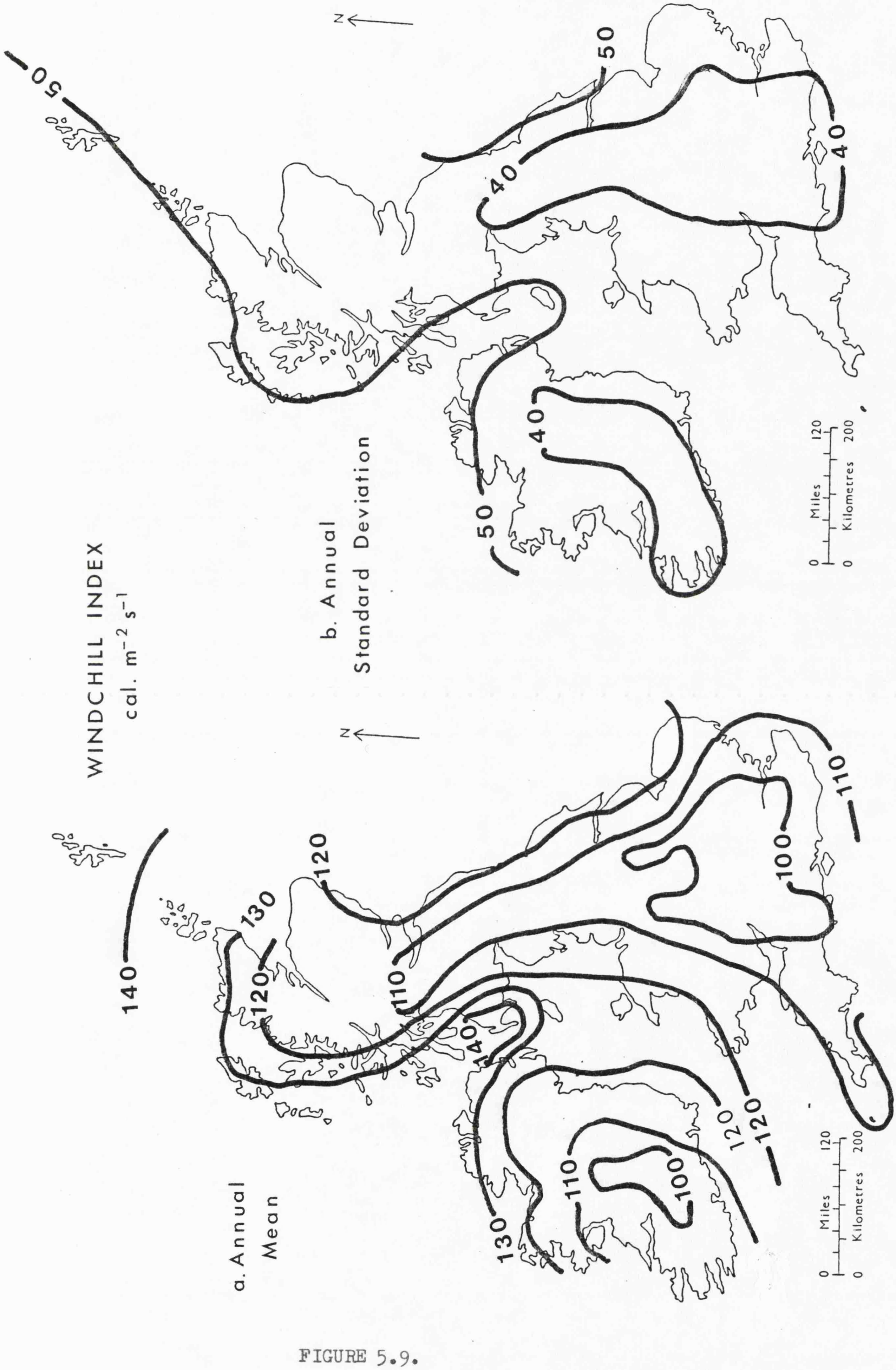

WINDCHILL INDEX
cal. m-2 s-1
a. Annual Mean
b. Annual Standard Deviation
N
140
130
120
110
100
50
40
Miles 0 120
Kilometres 0 200

FIGURE 5.9.

windchill of 144 cal.$m^{-2}s^{-1}$. Both the mean annual windchill distribution (Figure 5.9(a)) and that of the standard deviation (Figure 5.9 (b)) are controlled primarily by latitude and proximity to the coast which is a feature that was noted in many of the seasonal maps.

The use of instantaneous data rather than mean data also allows the inspection of extreme midday values. The absolute maximum windchill values are shown in Figure 5.10 and vary from 393 cal.$m^{-2}s^{-1}$ at Cape Wrath in Late Winter to 96 cal.$m^{-2}s^{-1}$ at Ross-on-Wye in High Summer. These maps give an insight into potential discomfort in the British Isles. Their main features are a general decrease of maximum windchill inland and from north to south. Of more interest is the discovery that lowland eastern England has a tendency for higher maximum windchill values than does lowland western England. Perry (1976) has commented that the coldest winter days occur in Late Winter when long spells of easterly and anticyclonic types accompany persistent blocking in the Scandinavia-Iceland area resulting in snow and sleet, often associated with strong winds, being experienced along the east coast. This synoptic situation does not usually adversely affect areas further west to the same extent and the longest hours of sunshine and highest temperatures are often recorded in the Western Isles. Cold northerly spells, although more transitory, are also common during the winter and, as has already been commented, result in strong winds along the east coast. The occurrence of these synoptic types during the sample period can be expected to have lowered the mean values along the east coast.

Stress may be caused by the probable occurrence of very high or very low windchill values at a particular location. A potential annual stress index can be devised by subtracting the absolute minimum from the absolute maximum windchill. From Figure 5.11 the distribution of the 'stress index' reveals a number of features similar to those already considered,

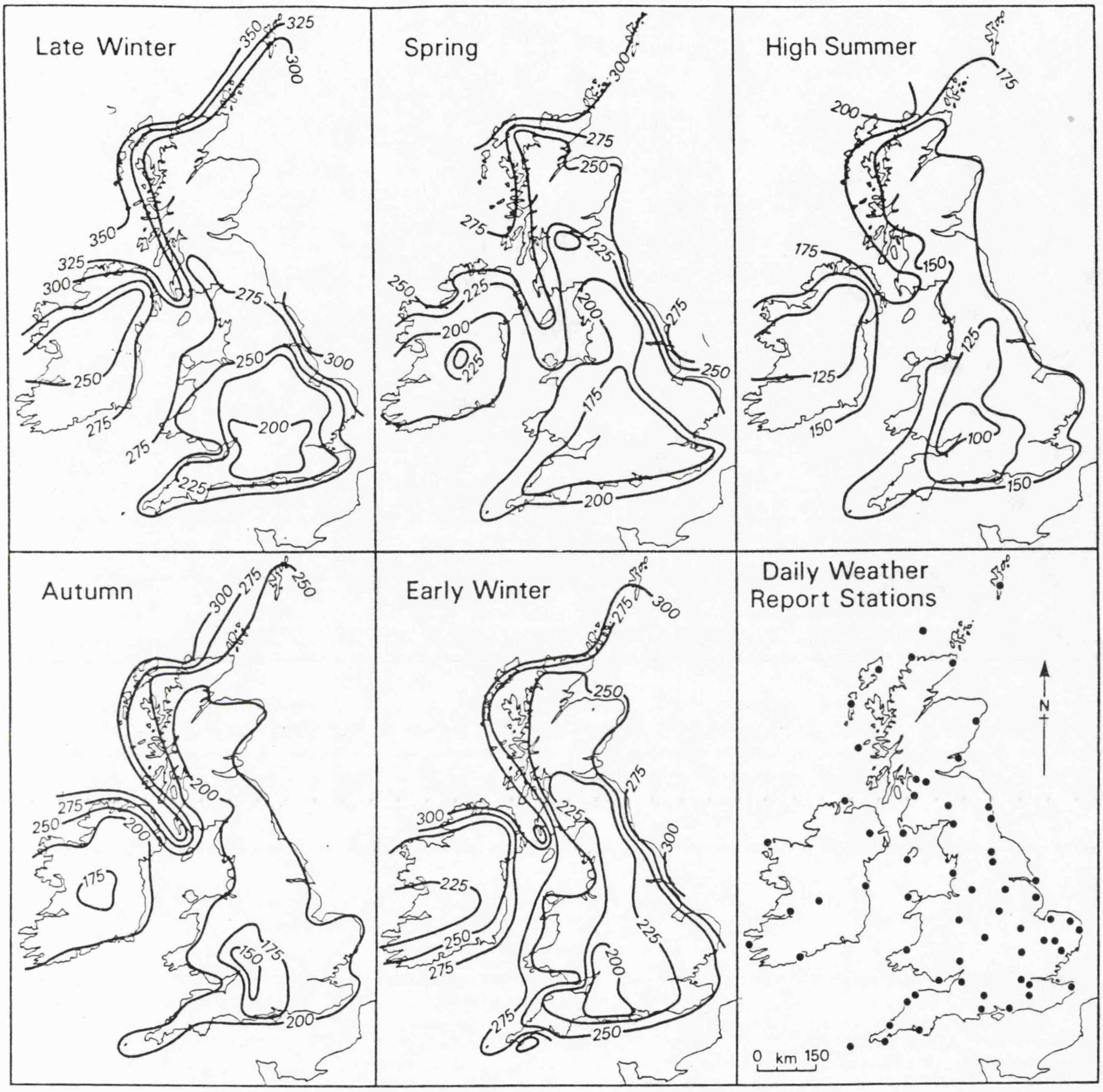


FIGURE 5.IO. The absolute maximum Windchill Index for each season.

Units cal.$m^{-2}s^{-I}$.

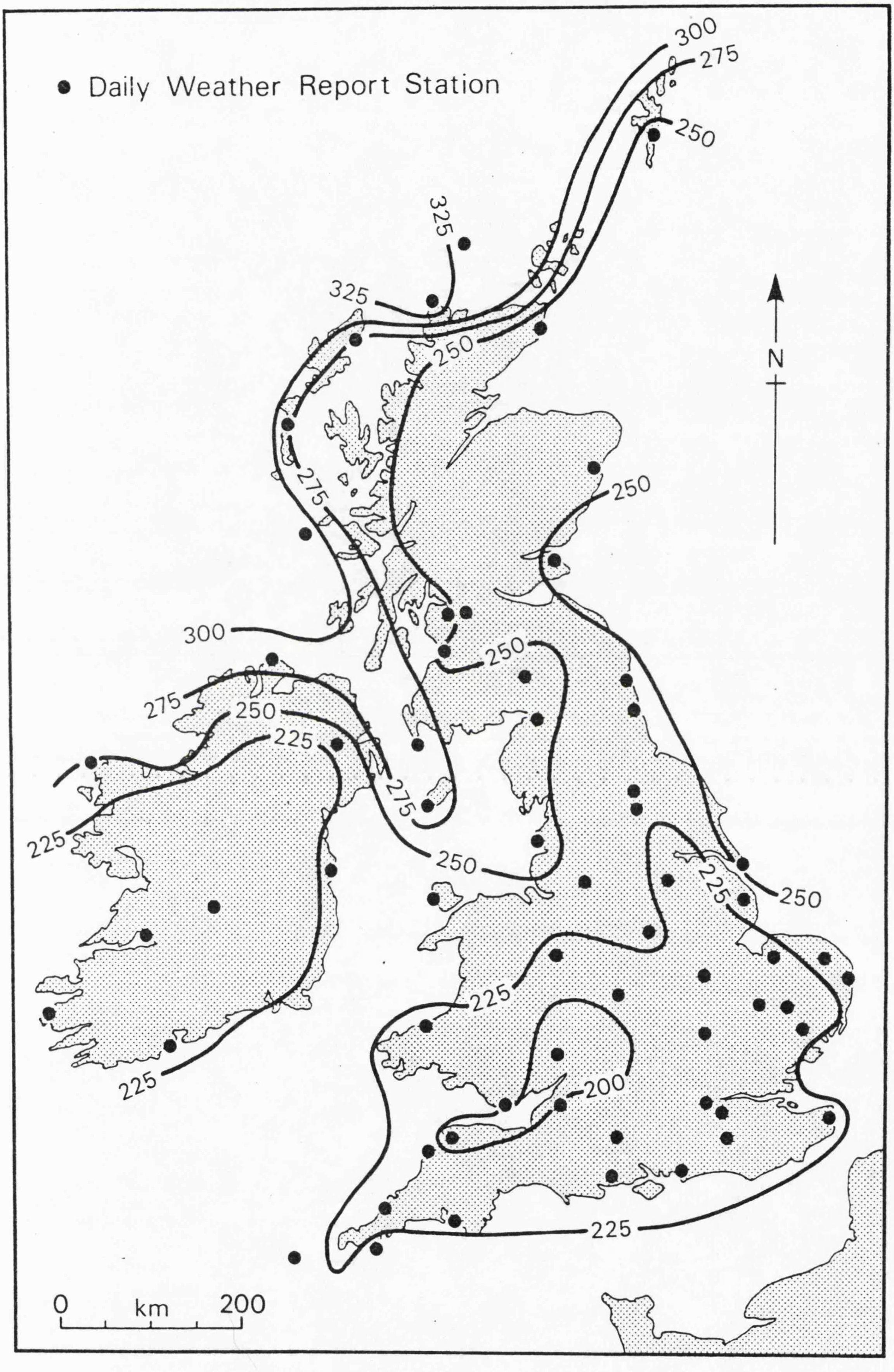


FIGURE 5.II.Annual Windchill stress (absolute maximum-absolute minimum).

Units cal.$m^{-2}s^{-1}$.

in particular a general north-to-south and coast-to-inland decrease in windchill 'stress'. The Midlands, the south of England, Wales, and southern Ireland, show relatively little spatial variation in the potential range of the windchill index.

This calculation of the windchill index from instantaneous, rather than average, values incorporates the covariance of wind and temperature which is the essence of the original index (Steadman, 1971) and therefore not only are the distributions discussed in this section more representative of average conditions than those presented by Smithson and Baldwin (1978), but also the method allows the study of maximum windchill for a given time of day and the range of values, the stress, that can occur.

5.4 The Temperature Humidity Index (THI)

The second composite index which was significant in explaining the response to the attitude scale was the THI. Man can tolerate extremes of temperature but when these extremes are combined with extremes of other elements, such as wind and particularly humidity, greater physiological discomfort is experienced. The windchill index discussed above considers the wind and temperature effects while the THI discussed in this section is concerned with the physiological effect of temperature and humidity combinations.

The THI was originally designed for the United States Weather Bureau by Thom (1959) for use in assessing indoor comfort and his original equation is presented in equation 1.3 in Chapter 1. Gates (1972) notes that the THI can also be calculated using equations 5.1 and 5.2, the choice being dependent on the available data:

$$THI = 0.55\,Td + 0.2\,Tdp + 17.5 \qquad (5.1)$$

$$THI = Td - 0.55(1 - 0.01RH)(Td - 58) \qquad (5.2)$$

where Td = dry bulb temperature (deg. F.)
Tdp = dew point temperature (deg. F.)
RH = relative humidity (%).

Thom (1959) felt that the THI gave an accurate impression of the degree of discomfort with people feeling discomfort as the THI rises above 70, over half uncomfortable at 75 and everyone uncomfortable with the index at 79 with most people feeling the discomfort acutely at this level. As the index passes above 80 discomfort becomes more serious.

Thom (1959) plotted the distribution of the THI for July 1956 and found that the average daily index for nearly half of the United States reached levels of discomfort. The distribution showed a north-to-south increase in discomfort with maxima in California and Louisiana. The average 1500 hours THI showed that the majority of the population live in areas subject to some discomfort. Thom (1959) also used the THI as a basis for cooling degree days using a THI value of 60 as the base level.

During the days in which the questionnaire survey was conducted the THI never reached the discomfort level of 70 as defined by Thom because high relative humidities were, in general, associated with lower temperatures with a Pearson product moment correlation coefficient of -0.5694 between the two variables. This relationship resulted in the THI remaining below the level of discomfort and the Index of Human Comfort, as measured by the attitude scale, was found to increase with the THI, a product moment correlation coefficient of 0.4515 being obtained with a positive estimated Beta coefficient of 0.036048. The survey results therefore suggested that an increasing THI indicated an improvement in the weather for human comfort and that in this context the THI was not indicative of discomfort levels in the range of conditions experienced. The THI is valid, however, in that it usefully combines two weather elements into a single index which is related to human comfort as derived from the attitude scale.

Having found this positive relationship between the THI and human comfort, as measured by the attitude scale, it was important to ensure that this relationship was also maintained in the longer time period data in the sample of DWRs used to produce the climatologies of the variables. If this relationship does not hold for the long term then the THI is inappropriate as an input into the Human Comfort Index outside the range of conditions experienced during the period of the questionnaire survey. The examination of the THI is made in two parts, first by a consideration of seasonal values and, second, by an examination of the extremes in order to assess how common discomfort, as measured by the THI, is in Britain.

The seasonal distributions of mean THI are shown, together with their respective standard deviations in Figures 5.12 to 5.16. The calculation of these values was carried out using the FORTRAN computer programme in Appendix 5 which implements equation 5.2 and a summary of the results is given in Table 5.5. The spatial and temporal variations of THI are discussed below.

Table 5.5 A summary of the THI values for the Lamb Natural Seasons

Season	Maximum Mean	Minimum Mean	Range	Maximum Standard Deviation	Minimum Standard Deviation	Range
Spring	57.9	48.7	9.2	6.8	4.1	2.7
High Summer	64.3	54.9	9.4	4.6	2.5	2.1
Autumn	58.4	50.2	8.2	5.8	3.2	2.6
Early Winter	48.4	39.7	8.7	8.2	3.6	4.6
Late Winter	48.2	40.9	7.3	6.9	2.7	4.2

(i) Spring (Figure 5.12). The distribution of mean Spring values is shown in Figure 5.12(a). It can be seen from Figure 5.12(a) that the

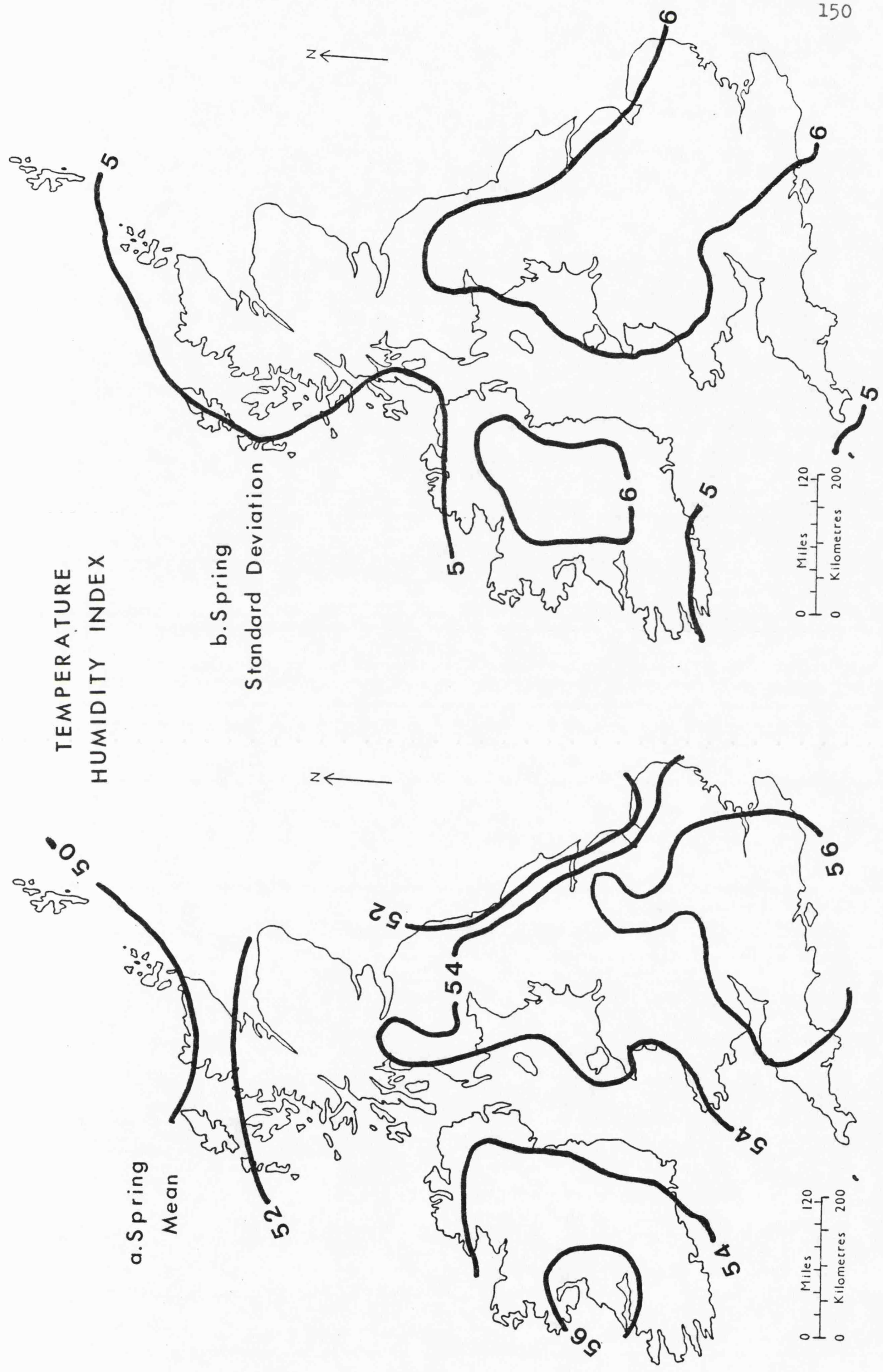

TEMPERATURE
HUMIDITY INDEX
a. Spring
Mean
b. Spring
Standard Deviation
N
50
52
54
56
5
6
0
120
Miles
0
200
Kilometres

FIGURE 5.I2.

distribution of mean Spring values increases from north to south and inland. The maximum mean THI in this season is 57.9 at Heathrow and the minimum is 48.7 at Lerwick giving a relatively large range of 9.2 compared with the Autumn and the two Winter seasons (Table 5.5).

The distribution of mean values shown in Figure 5.12(a) can be compared to those of temperature and humidity for this time of year. For example, Ward (1976) has shown that the annual relative humidity decreased southwards and also inland whilst Tout (1976) has suggested that for Spring temperatures, latitude and distance from the sea are important controlling variables with the coasts being cooler than the inland and with central southern England having the highest temperatures. The temperature distributions presented by Tout (1976) also show a tendency for western parts of Ireland and England to have higher temperatures than along the east coasts at the same latitudes.

As represented by its standard deviation, the Spring THI shows little spatial variation over the British Isles (Figure 5.12(b)). The main trend is from north west to south east with a range of 4.1 at Sule Skerry to 6.8 at Watnall. There is a slight tendency for inland areas to have a higher variation than those nearer the coast.

(ii) High Summer (Figure 5.13). The distribution of the High Summer mean shown in Figure 5.13(a) increases from north west to south east, with a minimum of 54.9 at Lerwick and maximum of 64.3 at Manston. In England there is a tendency for inland areas to have a higher THI than coastal areas and again the distribution is similar to that of July mean temperatures produced by Tout (1976). The standard deviation shown in Figure 5.13(b) shows a similar distribution, ranging from 2.5 at Lerwick to 4.6 at Finningley. This is the lowest seasonal variability and is true of other variables such as the windchill, and is most probably a result of the more settled nature of the weather during this season.

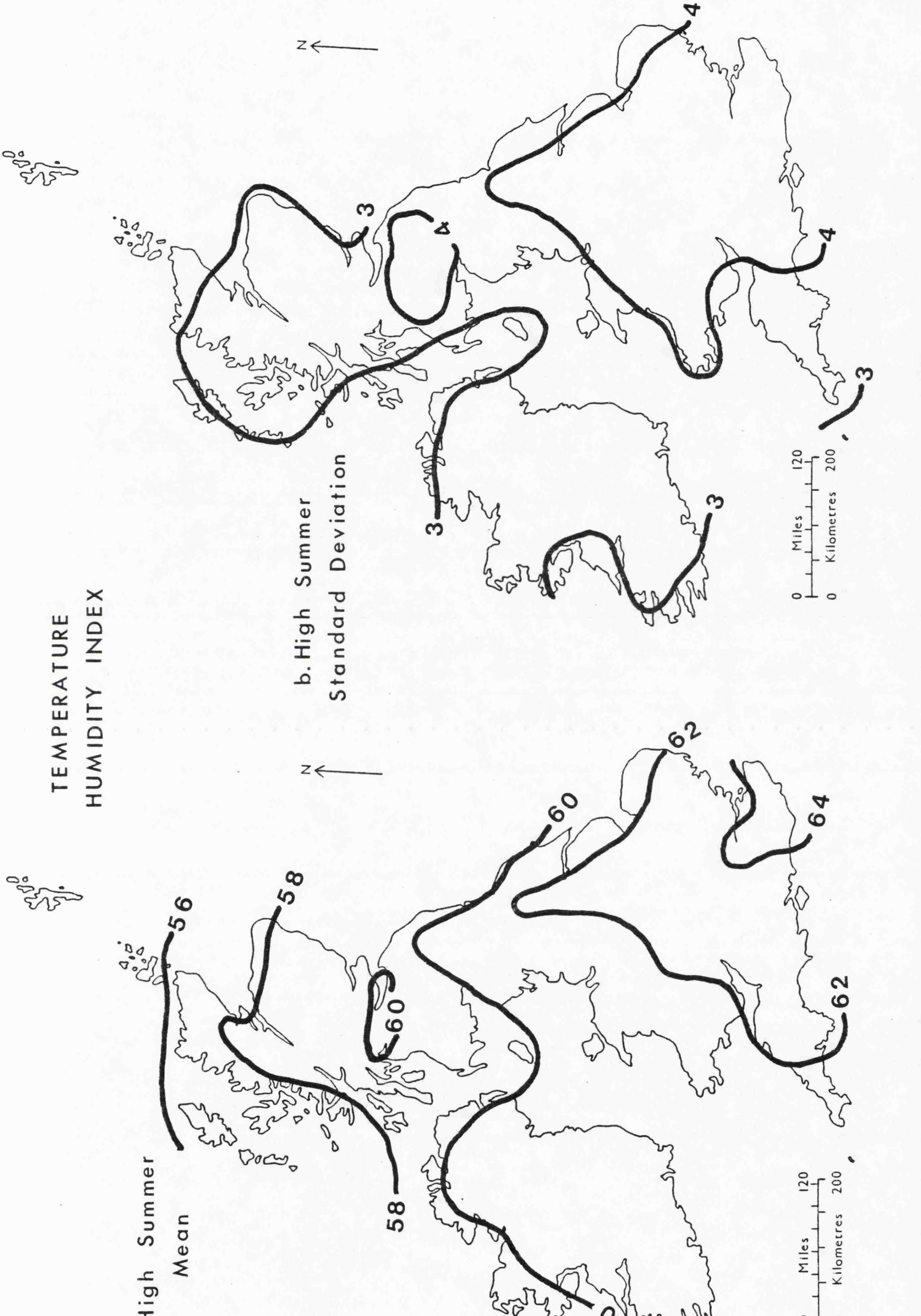

TEMPERATURE
HUMIDITY INDEX
a. High Summer
Mean
b. High Summer
Standard Deviation
56
58
58
60
60
60
62
62
64
3
3
3
3
4
4
4
Miles 0 120
Kilometres 0 200
Miles 0 120
Kilometres 0 200

FIGURE 5.13.

(iii) Autumn (Figure 5.14). In Autumn the major influence on THI is latitude (Figure 5.14(a)) since there is an increase in values from 50.2 at Lerwick to 58.4 at Hurn with a slight tendency for the west coast to have higher values than the east which appears to reflect the pattern of October temperatures (Tout, 1976). The standard deviation of THI for Autumn (Figure 5.14(b)) shows an east-to-west trend with western areas having less variation than eastern ones. The difference, between 3.2 in the Scilly Isles to 5.8 at Abbotsinch, Leuchars and Leeming, is not large and reflects the stability of the weather types in this season.

(iv) Early Winter (Figure 5.15). The general north-to-south alignment of the isolines in Figure 5.15(a) reflects the winter temperature pattern presented by Tout (1976) who noted that this is caused by the dominant Atlantic maritime influence resulting in a warmer Ireland, Wales, south western and extreme southern England. The mean THI varies between 48.4 in the Scilly Isles to 39.7 at Eskdalemuir. From Figure 5.15 it is evident that Eskdalemuir is an anomaly amongst the stations in that its data show pronounced relief influences. It will be remembered from an earlier discussion that Eskdalemuir is the only upland station and that the isopleths are generally only valid for Lowland Britain.

The standard deviation values and the range are larger than those in the three seasons already considered (Table 5.5) and reflect the less stable pattern of weather types in this season. The smallest variation is at Sule Skerry where the standard deviation is 3.6 and the maximum variation is 8.2 at Ross-on-Wye which is the largest value for the year (Table 5.5). The distribution of the standard deviation (Figure 5.15(b)) shows a marked coast-to-inland increase in variation with the east coast having a slightly greater variation than the west coast at the same latitude. Superimposed on this main trend is a north-to-south increase in the standard deviation although the major control is clearly a maritime one.

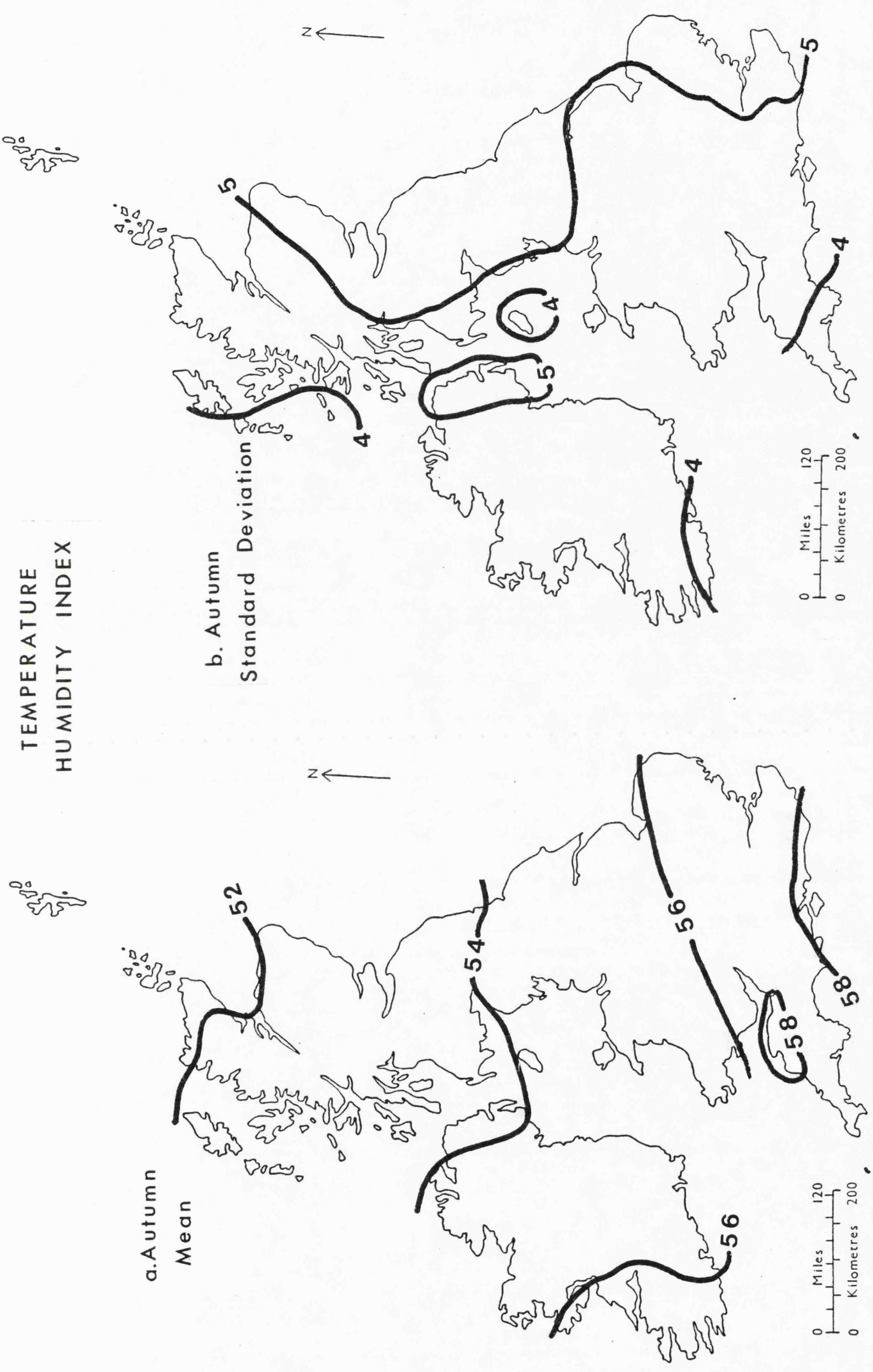

TEMPERATURE
HUMIDITY INDEX
a. Autumn
Mean
b. Autumn
Standard Deviation
N
52
54
56
58
5
4
Miles 0 120
Kilometres 0 200

FIGURE 5.14.

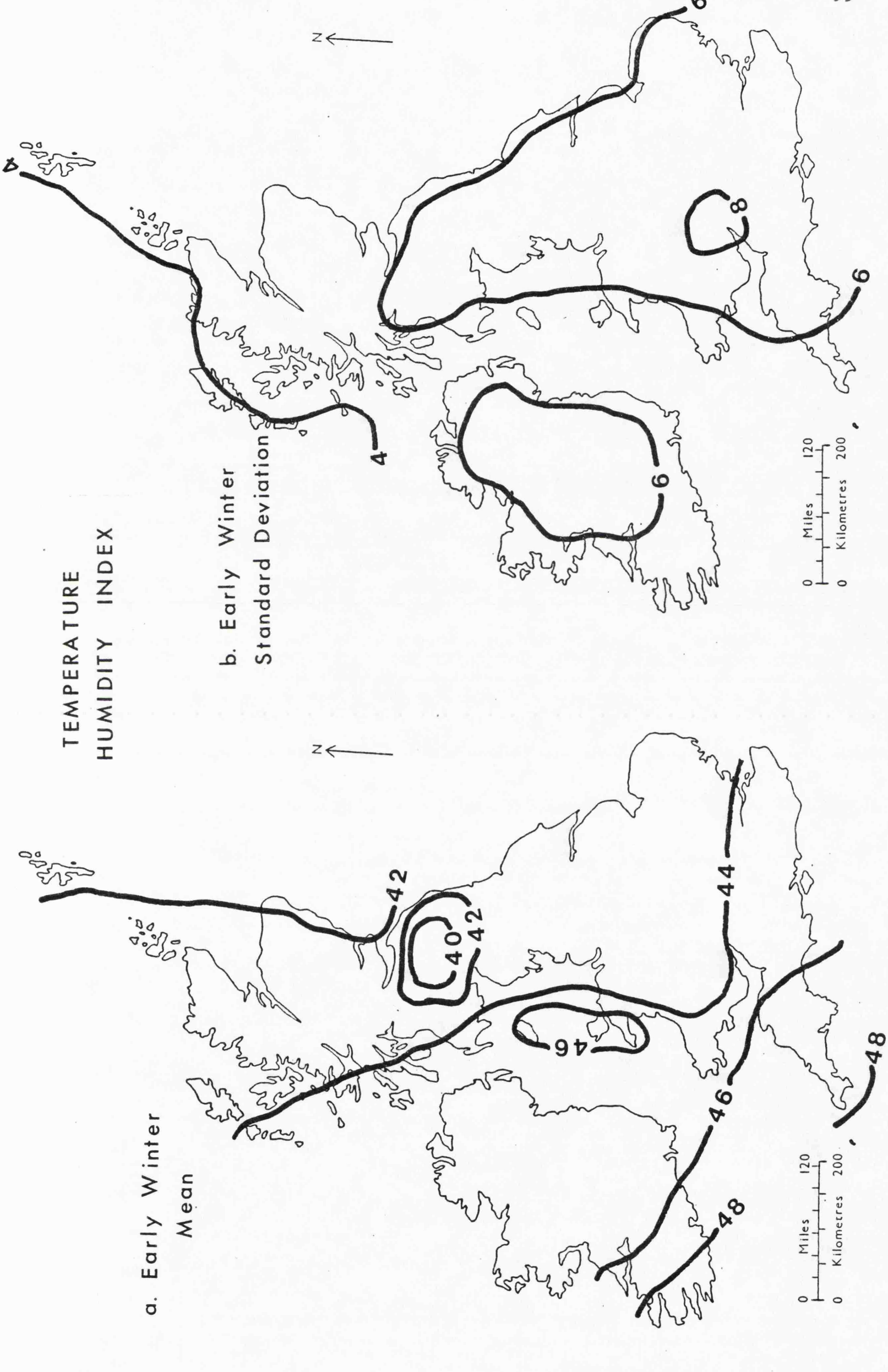

TEMPERATURE
HUMIDITY INDEX
a. Early Winter
Mean
b. Early Winter
Standard Deviation
N
42
40
42
44
46
46
48
48
4
4
6
6
6
8
6
Miles
0
120
Kilometres
0
200

FIGURE 5.I5.

(v) Late Winter (Figure 5.16). This season has the lowest mean maximum of 48.2 in the Scilly Isles (Table 5.5) and its minimum mean of 40.9 at Lerwick is the second lowest. The coldest winter days tend to occur in Late Winter particularly when long spells of easterly and anti-cyclonic weather types accompany persistent blocking in the Scandinavia-Iceland area (Perry, 1976) giving low temperatures and humidities. The distribution of the Late Winter THI is similar to that of Early Winter with the influence of the Atlantic being marked giving western areas higher THI values than eastern areas at the same latitude (Figure 5.16(a)).

The range of the standard deviation is the second largest after Early Winter and varies from 6.9 at Shawbury and Cardington to 2.7 at Stornoway and Benbecula. The maritime influence represents the strongest control on the distribution with the variation increasing inland (Figure 5.16(b)). The higher mean values on the western coastlines are, in general, related to low standard deviations with the Atlantic exerting a moderating influence over these areas.

The foregoing seasonal analysis has shown that the mean THI remains at levels below Thom's (1959) discomfort threshold of 70. This suggests that, in general, in Great Britain the public will not often feel thermal discomfort. This analysis, however, was only concerned with mean values and it is possible that there may be individual days when values exceeded the comfort threshold. To examine this possibility the absolute maximum THI was found and its distribution mapped in Figure 5.17(a). The resulting distribution shows many of the features which have already been discussed with proximity to the coast and latitude as the major controls. It can be seen from Figure 5.17(a) that inland England, the central lowlands of Scotland and western Ireland have values which exceed 70 reaching a maximum of 74.5 at Ross-on-Wye. The lowest maximum THI value is 60.7 at Lerwick.

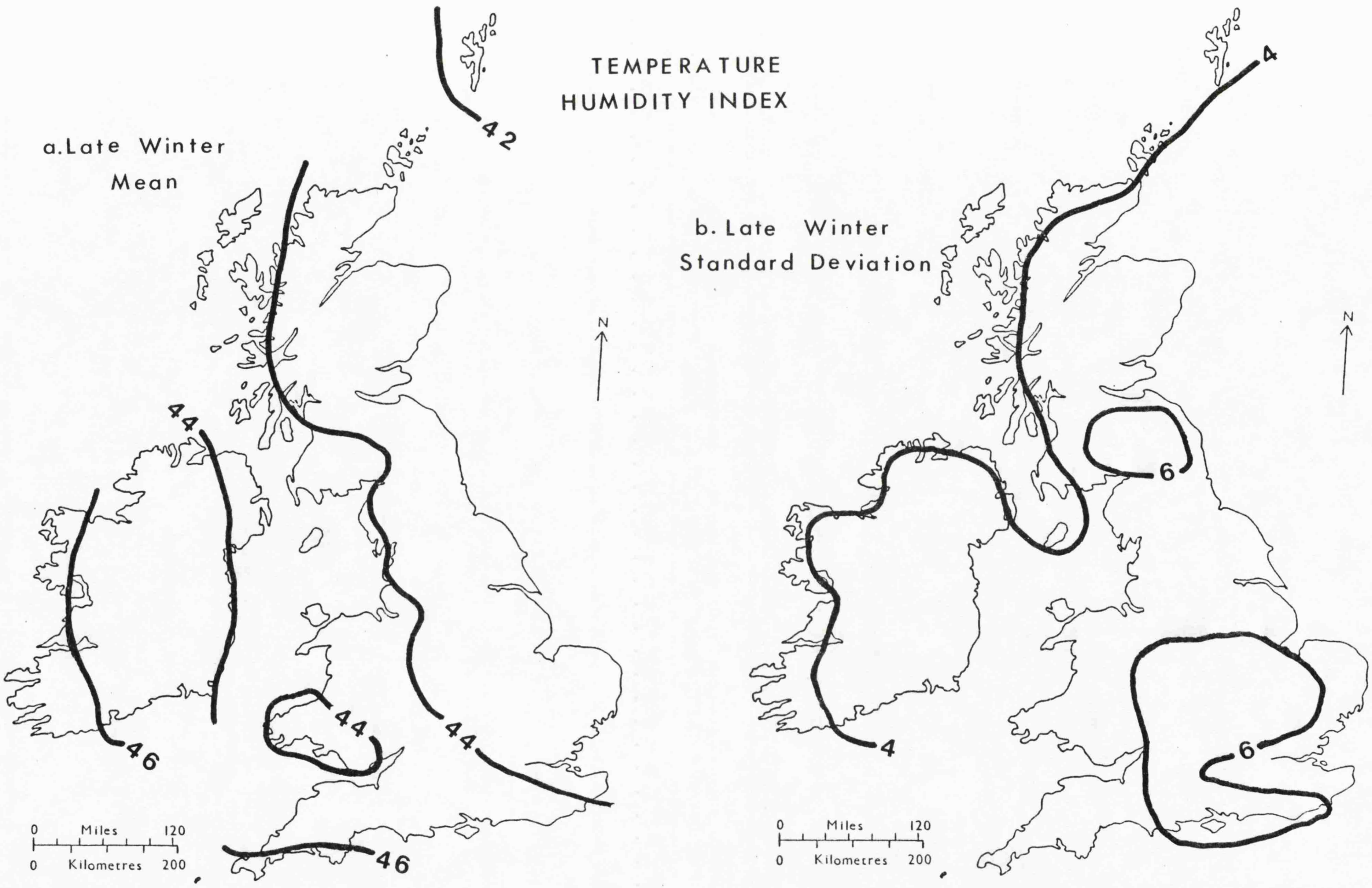

TEMPERATURE
HUMIDITY INDEX
a.Late Winter
Mean
b. Late Winter
Standard Deviation
42
44
44
44
46
46
4
4
6
6
N
N
0 Miles 120
0 Kilometres 200
0 Miles 120
0 Kilometres 200

FIGURE 5.I6.

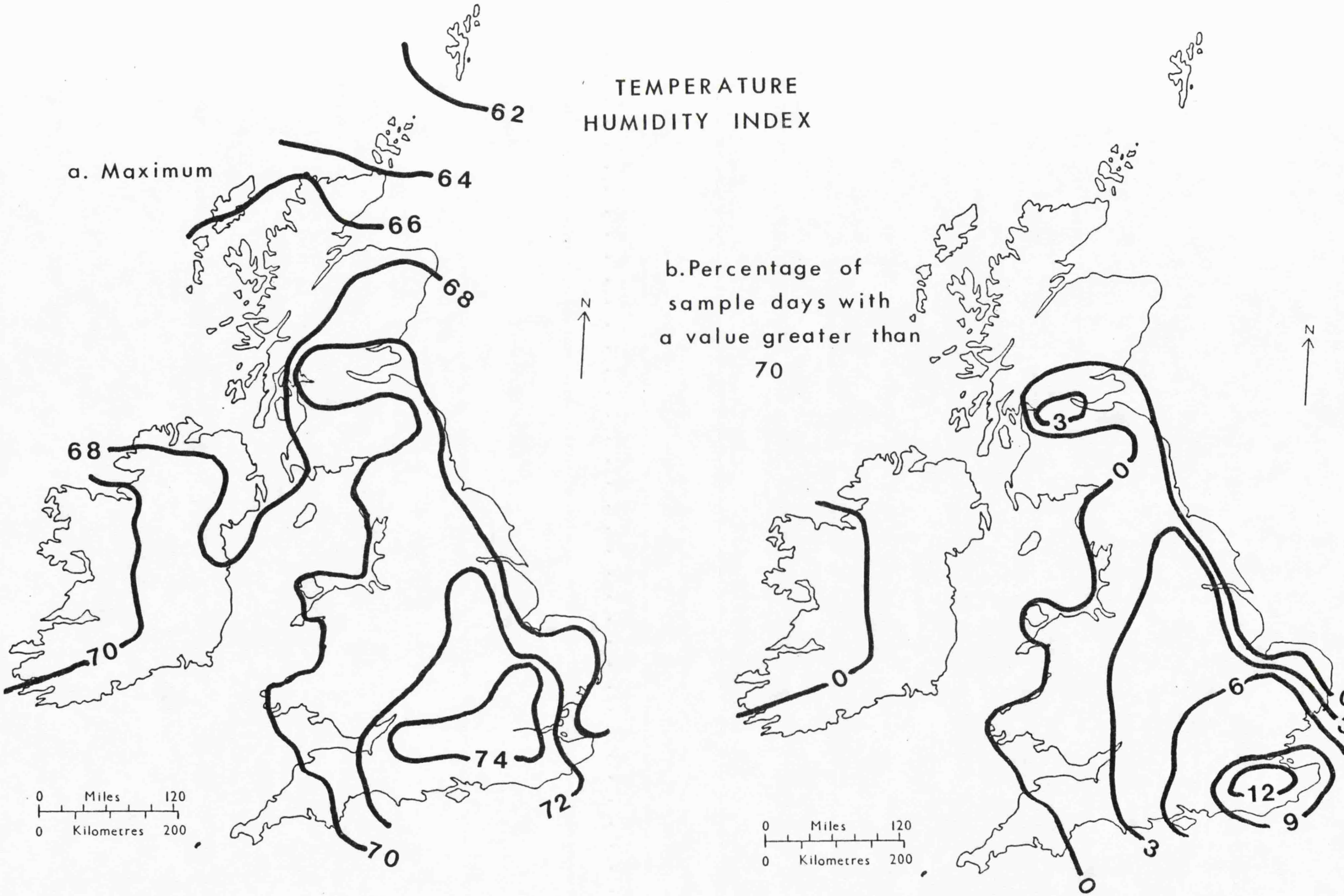

TEMPERATURE
HUMIDITY INDEX
a. Maximum
62
64
66
68
68
70
70
72
74
b. Percentage of
sample days with
a value greater than
70
0
3
0
0
3
6
0
3
9
12
N
0 Miles 120
0 Kilometres 200

FIGURE 5.17.

In order to place these values into the perspective of the sample the percentage of station days on which the 1200 G.M.T. THI exceeded 70 was obtained and the results shown in Table 5.6. The values in the Table suggest that discomfort is not common with a maximum of 2.5% of

Table 5.6 The Percentage of Station Days in each Season when the 1200 G.M.T. THI exceeded 70

Season	Percentage of Days THI > 70
Spring	0.4871
High Summer	2.4526
Autumn	0
Early Winter	0
Late Winter	0

season days in High Summer when the threshold of 70 THI is exceeded. Certain areas may, however, be more liable to experience discomfort than others and in order to examine this a map was constructed showing the distribution of the percentage of days when the THI exceeded 70 in High Summer (Figure 5.17(b)). The distribution shows a north west to south east increase to a maximum of 12.6% at Gatwick which is 3% higher than the next highest percentage at Manston. This pattern suggests that the public living in central, eastern and south eastern England can expect to feel some discomfort during the summer season as a result of heat and humidity extremes.

Since these results were based on a sample taken over 15 years it is possible that the extreme THI values were the result of a few exceptional days during the sample. To examine this the total THI values which exceeded 70 were obtained together with the day on which they occurred. The THI exceeded 70 on 20 of the total of 274 sample days, 5 in Spring and 15 in High Summer. On 10 of these days only one station exceeded the threshold value and by less than one THI unit, suggesting that discomfort was not particularly prevalent on those days; on a further three days only three stations exceeded the threshold leading to similar conclusions. This left one day in Spring and six days in High Summer when discomfort, as defined by Thom (1959), was felt more widely and, therefore, it is worth examining the synoptic situations which resulted in this discomfort.

The first day was on 10 June 1963 late in the Spring season when nine stations experienced a THI greater than 70. The synoptic situation showed a weak anticyclone near Iceland and a shallow depression over France giving easterly air flow over the British Isles resulting in cloudy, cool conditions over the east coast, but warm, sunny and humid conditions resulting in high THI values in south west England, the Lancashire coast and western Ireland. Five of the synoptic stations, in southern England and western Ireland, experienced their absolute maximum THI for the sample on this day.

The second day was 19 August 1966 when a 'featureless pressure distribution' (DWR) gave a very warm and sunny day over the British Isles and THI values over 70 were found at 9 stations in central England with absolute maximum values for the sample being experienced at Leeming, Watnall and Shawbury. The third day was 9 August 1969 when high temperatures were experienced in the area to the east of a cold front situated over Ireland and western Scotland. Eleven stations in central England recorded THI values over 70 and eight stations experienced their absolute maximum on this day. High temperatures were also experienced in the advance of a similarly placed cold front on 6 July 1970 when seven stations in south eastern England experienced discomfort levels with absolute maximum values for the sample at two of these stations. On 13 July 1975 Britain was subject to south westerly air flow associated with a depression near western Ireland resulting in six stations in south east and central England experiencing a THI value in excess of 70.

The most significant day for discomfort due to high THI values was 7 July 1976 when 24 synoptic stations recorded weather conditions which gave a THI value in excess of 70. The synoptic situation showed an anticyclone over the Norwegian Sea and an occluded front over Ireland and south western England. To the east of this front easterly air flow was in evidence giving clear skies and warm conditions. The stations experiencing THI values above the threshold were in central, southern and north western England, Wales and the central lowlands of Scotland. A third of the synoptic stations experienced their absolute maximum THI on this day and these stations were mainly on the west of the mainland and in central England. Finally, on 2 August 1977 areas in south east and south central England were subject to south westerly air flow which gave warm and clear conditions in this area resulting in THI values greater than 70 at 11 stations.

It can be seen from the discussion above that only seven out of the total sample of 274 days were significant for discomfort resulting from high THI values and of these seven one day in the hot summer of 1976 was particularly exceptional. The results suggest that, although discomfort levels are reached, discomfort due to excessive heat and humidity is not common in any area. It must further be noted that the absolute maximum values, although they exceed 70 at some stations, never reached higher than 74.5. The interpretation of the THI values is that when the value 70 is reached discomfort is experienced by some of the population and when it reaches 75 by about 50% of the population. This level of 75 is never reached in the sample even on 7 July 1976 when the highest THI values were recorded. These considerations placed the sampled THI values in perspective and, therefore, it can be stated that discomfort to the total population of the British Isles as a result of excessive heat and humidity is not common.

Also these conclusions are supported by the relationship between temperature and humidity which has a Pearson product moment correlation coefficient of -0.3599 resulting in the THI being kept at low values with both high temperatures and humidities being uncommon. This is similar to the relationship found during the survey period.

Finally it can be concluded that the weather during the survey period was typical of the long term situation as measured by the sample of DWRs, that the THI does not in general exceed the comfort threshold, and that discomfort is not excessive when the threshold is exceeded. The Index of Human Comfort, as defined by the Likert scale, is therefore generally applicable but may need modification when extremes of heat and humidity are experienced. This modification however is probably unnecessary for this sample, where the THI value is not excessive, because the associated Beta coefficient is sufficiently low (0.036) to make little difference to the calculated Index of Human Comfort between values just above and just below the comfort threshold. The results further suggest that the derived Index of Human Comfort may not be applicable to areas such as the United States where the THI consistently reaches higher values.

5.5 Cloud

In the multiple regression analysis cloud was split into two dummy variables, the first representing cloud cover greater than five octas and the second representing cloud cover between three and five octas inclusive. Unlike the sunshine variable to which they are closely related, both cloud variables gave significant Beta coefficients. Cloud cover was therefore included as an important variable in the analysis.

A number of previous workers have included 'sunshine' in some form in their analysis of human comfort. Winslow and Herrington (1935) found that sunshine hours were strongly correlated with people's assessment of the 'pleasantness' of the weather (r = 0.78). Similarly Auliciems (1976) found that while the assessment of other parameters varied, sunshine, as measured by a 5 point code, was universally regarded as pleasant. Auliciems (1976) also found a product moment correlation coefficient of 0.45 between the response to the statement 'Today's weather is pleasant' and the sunshine. Neither Winslow and Herrington (1935) nor Auliciems (1976) calculated their indices of comfort for data other than that measured at the time of their questionnaire survey. A series of rather subjective indices of preferred weather appeared in the journal Weather during the 1960s (Poulter, 1962; Fergusson, 1964; Rackliffe, 1965; Davis, 1968). All these indices recognised the importance of sunshine but used simply the total sunshine hours for June, July and August which were weighted in some subjective way to produce a final index. However, a relatively more complex index was devised by Maunder (1962) in which he included mean annual duration of sunshine together with measures of rainfall, temperature, humidity and wind which were weighted 7, 8, 6, 5 and 4 respectively.

For any study which includes sunshine as a variable, data availability is a severe problem. The DWR data do not include any instantaneous measurement of sunshine and the duration of sunshine can only be obtained from the monthly weather reports for a limited number of stations. It was with an awareness of this lack of data together with the significance tests for the variables that cloud was selected for the final equation in the hope that the importance of sunshine is truly reflected by the cloud variables. The questionnaire results suggest that this is the case.

As with the variables already considered the means and standard deviations for each station and season were calculated and their distributions shown in Figures 5.18 to 5.22. Barrett (1976) has shown that, in general, cloud cover is greater in the north of the British Isles than the south and that topography is also an important differentiating factor. This general north-to-south decrease in cloud amount can be seen in the distributions of mean cloud at 1200 G.M.T. (Figures 5.18(a) to 5.22(a)). In Spring, with the exception of the north west peripheries which have a lower-than-expected cloud cover, this is the case. In High Summer (Figure 5.19(a)), although the trend is again from north to south, the west coast of south Scotland, northern England and Wales have as favourable a cloud amount as southern England. The Autumn map (Figure 5.20(a)) shows a similar distribution to Spring but in winter (Figures 5.21(a) and 5.22(a)) there is very little trend, particularly in Late Winter (Figure 5.22(a)) when cloud amount varies very little.

The ranges of cloud cover amounts for the seasons are shown in Table 5.7.

Table 5.7 Summary of the Mean Cloud Cover Data (Octas)

Season	Maximum (Station)	Minimum (Station)	Range
SPRING	6.7 (Eskdalemuir)	5.2 (Scilly)	1.5
HIGH SUMMER	6.7 (Rineanna, Birr)	5.0 (Manston)	1.7
AUTUMN	7.0 (Birr)	5.3 (Thorney Isl.)	1.7
EARLY WINTER	6.6 (Lerwick)	5.5 (Valley)	1.1
LATE WINTER	6.6 (Birr)	5.4 (Scilly)	1.2

The minimum range is found in winter and the maximum means are lower in the two winter seasons than in the other three seasons. Ireland and Scotland have the highest mean values and southern England, Anglesey and the Scilly Isles show the lowest mean values.

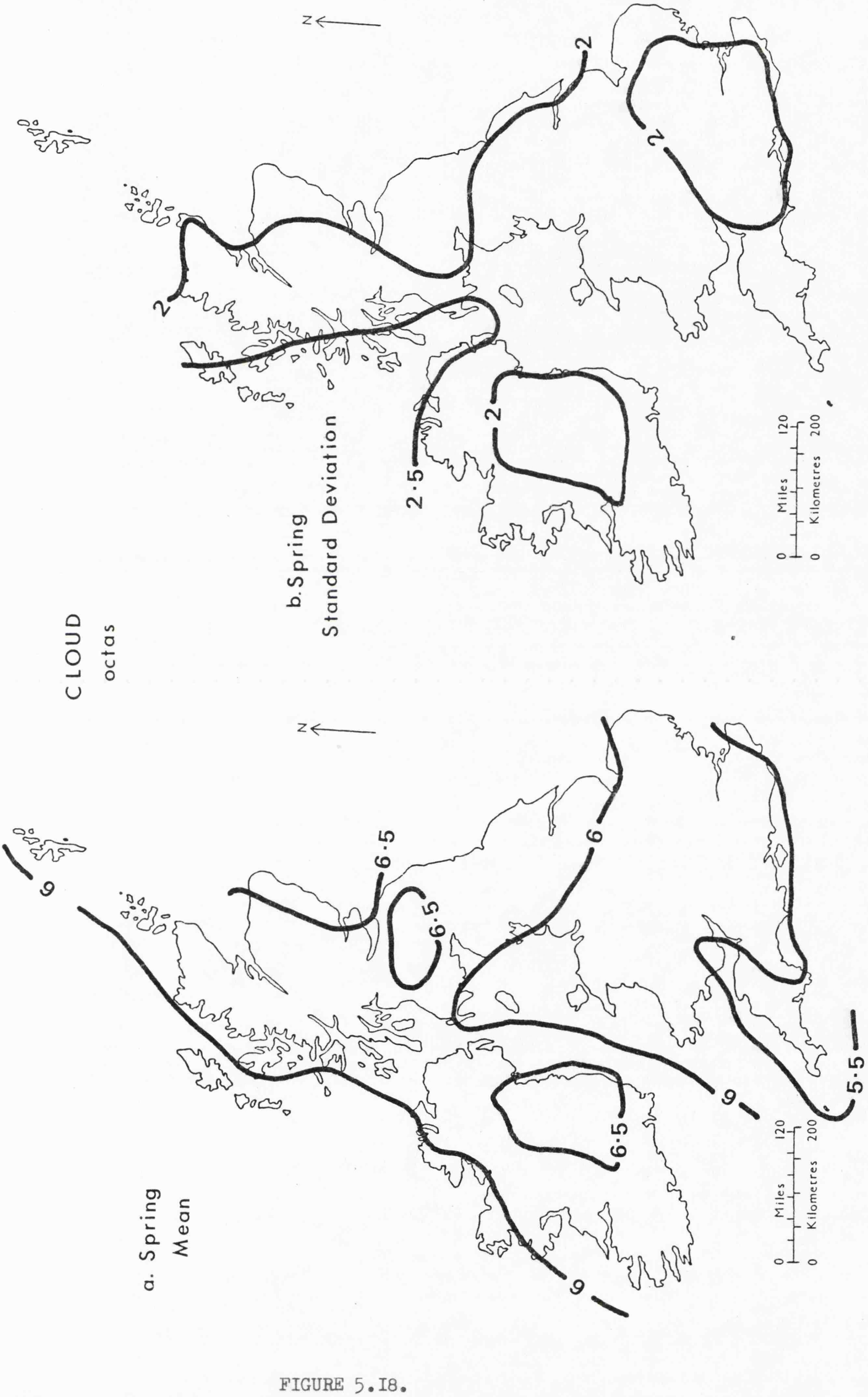

CLOUD
octas
a. Spring
Mean
6
6.5
6.5
6
6.5
6
5.5
6
b. Spring
Standard Deviation
2
2
2.5
2
2
Miles
0
120
Kilometres
0
200

FIGURE 5.I8.

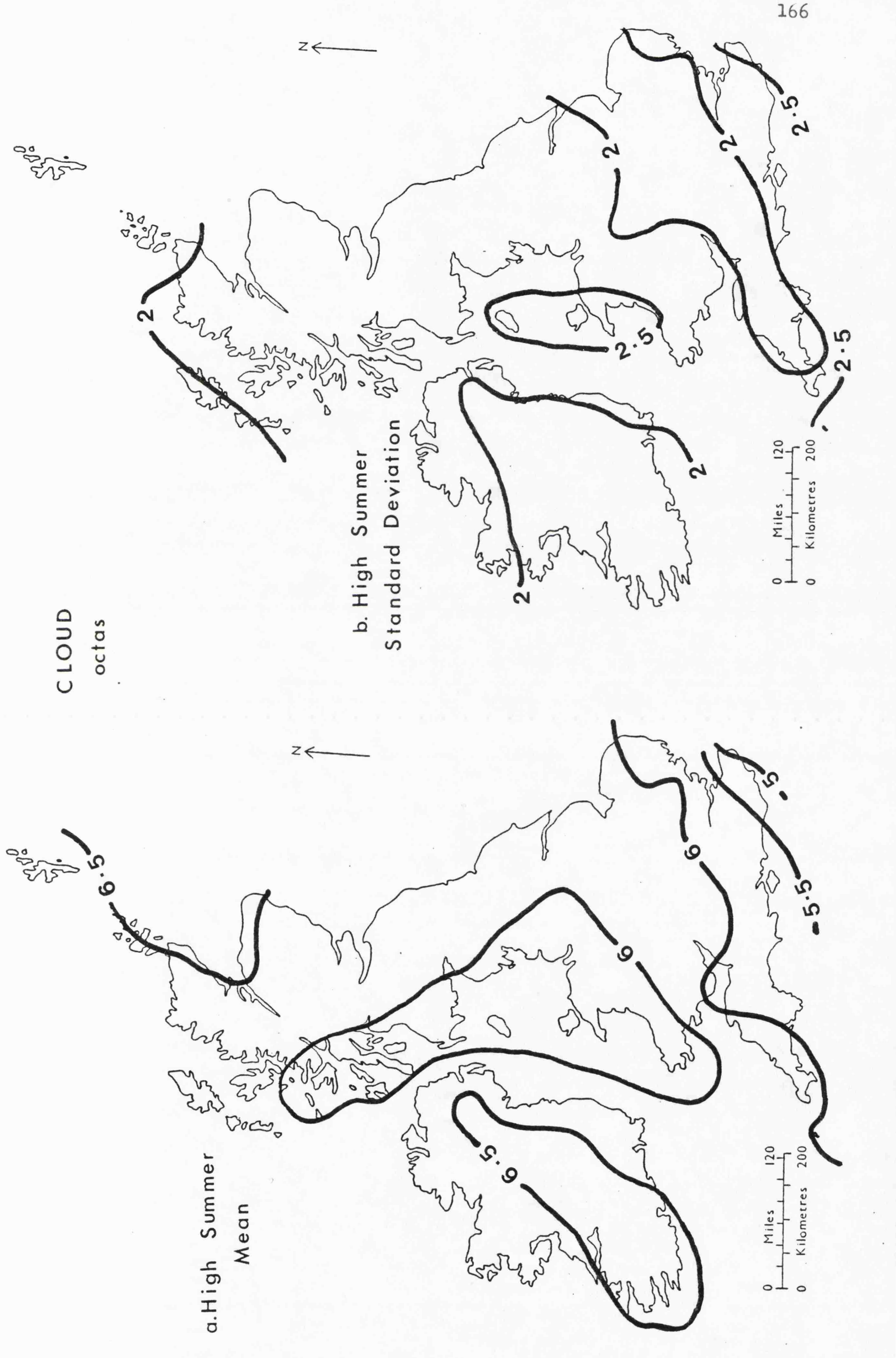

CLOUD
octas
a.High Summer
Mean
b. High Summer
Standard Deviation
N
6.5
6
5.5
5
2
2.5
0 Miles 120
0 Kilometres 200

FIGURE 5.I9.

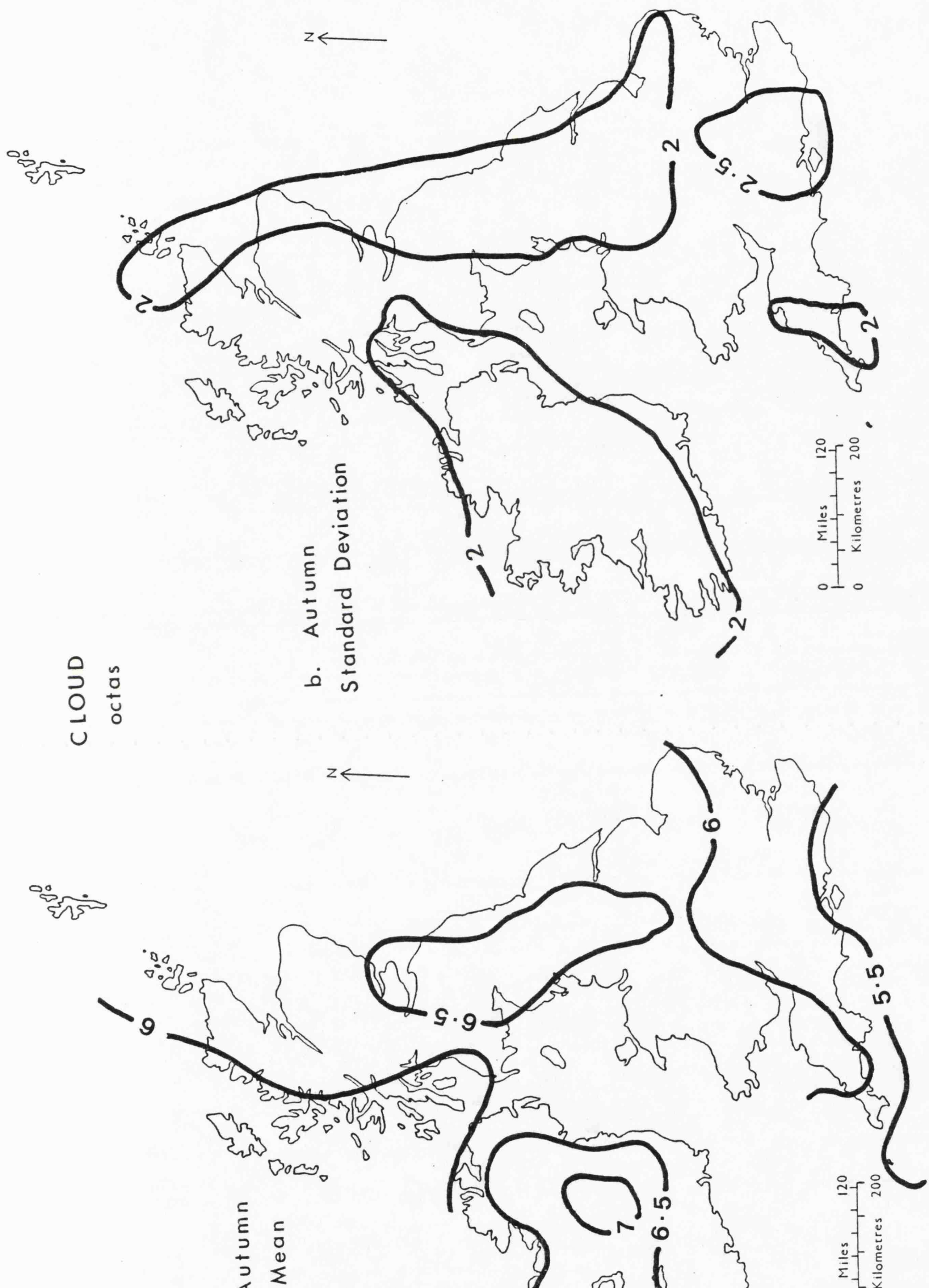

CLOUD
octas
a. Autumn
Mean
b. Autumn
Standard Deviation
6
6·5
7
5·5
2
2·5
N
0
Miles
120
0
Kilometres
200

FIGURE 5.20.

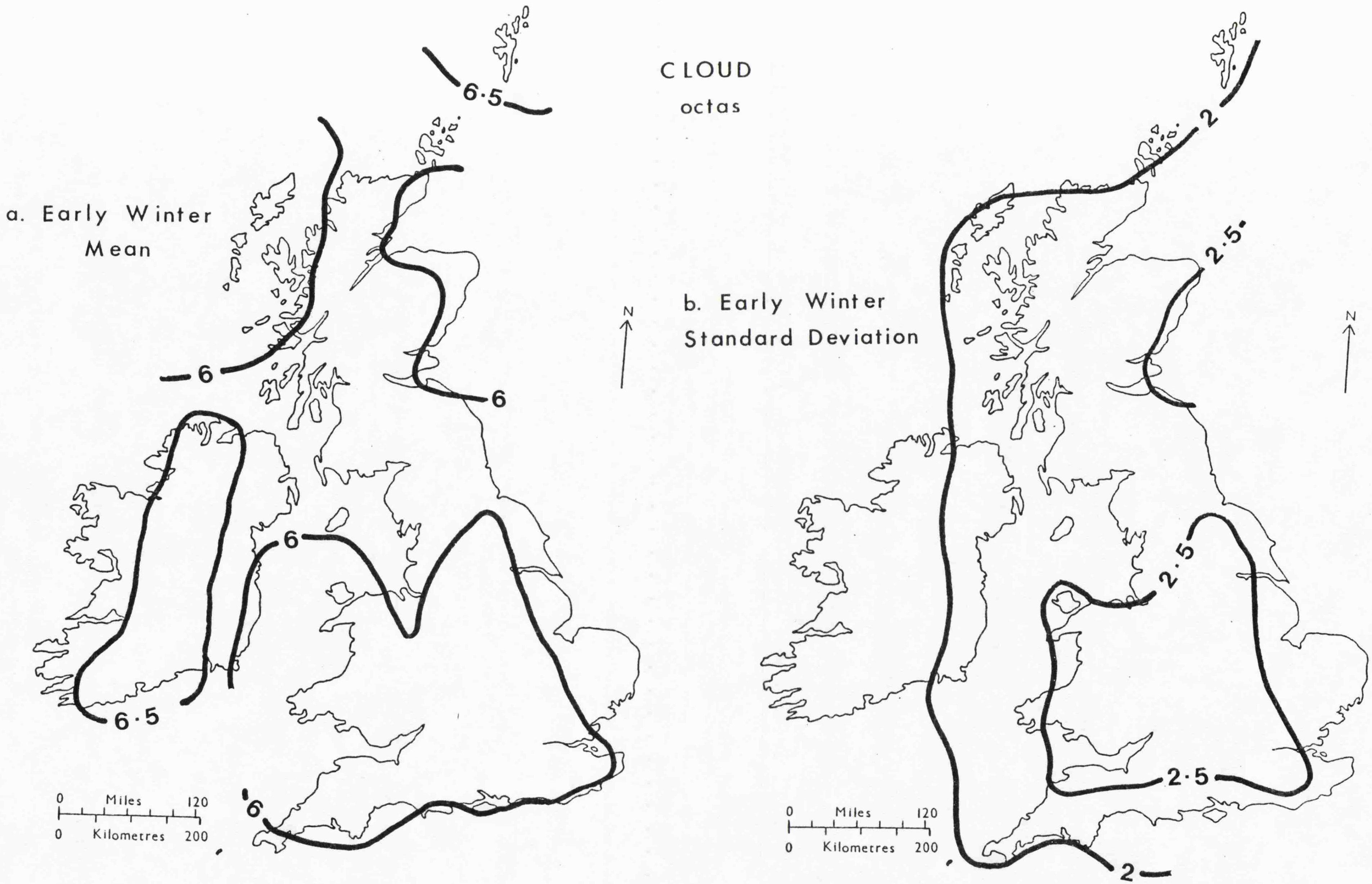
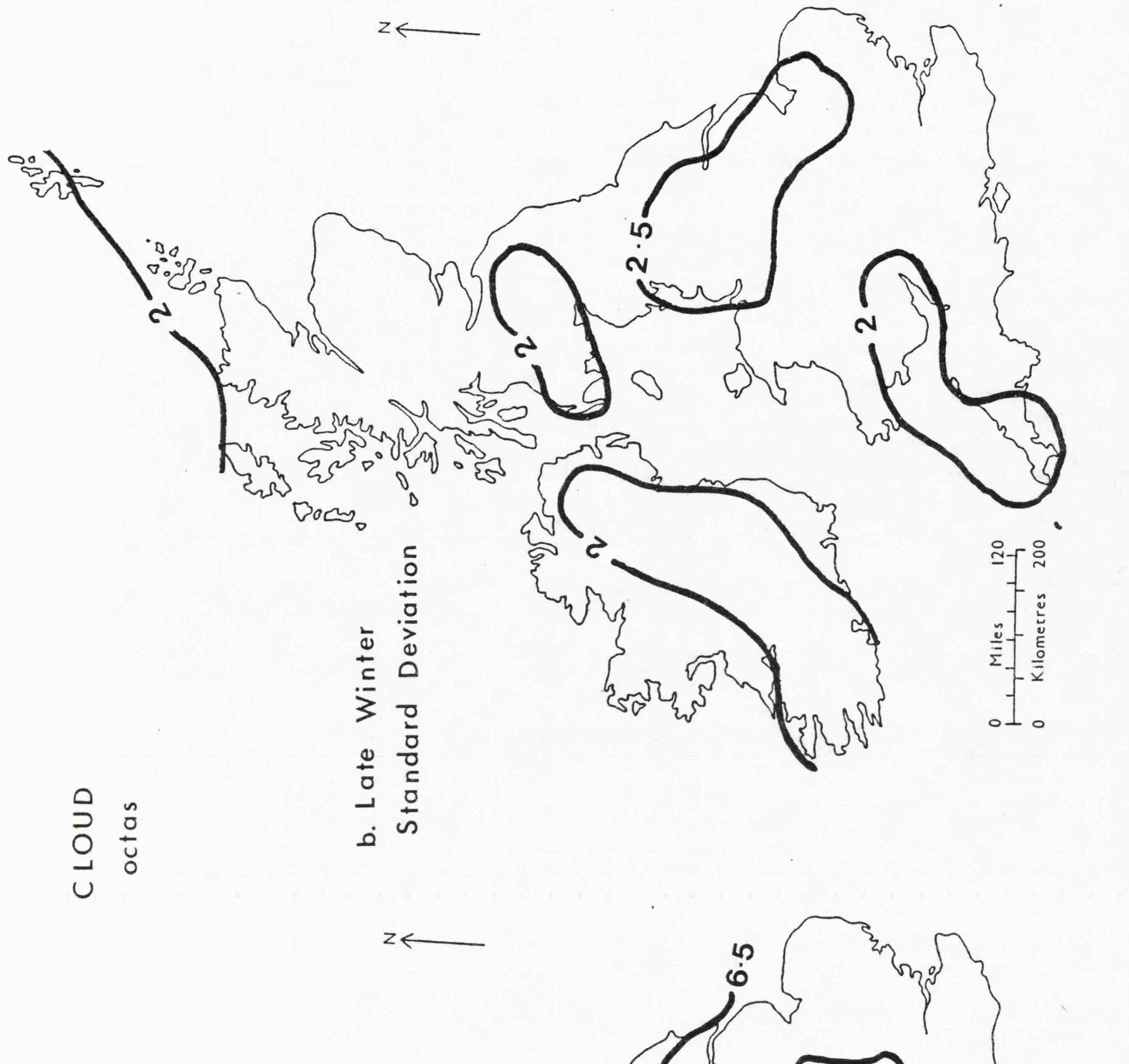

CLOUD
octas
a. Early Winter
Mean
6·5
6
6
6·5
6
6
0 Miles 120
0 Kilometres 200
b. Early Winter
Standard Deviation
2
2·5
2·5
2·5
2
0 Miles 120
0 Kilometres 200
N
N

FIGURE 5.2I.



CLOUD
octas
a. Late Winter
Mean
6·5
6·5
6·5
6·5
6·5
6
b. Late Winter
Standard Deviation
2
2
2·5
2
2
N
0 Miles 120
0 Kilometres 200

FIGURE 5.22.

The distributions of the standard deviation of cloud cover (Figures 5.18(b), 5.19(b), 5.20(b), 5.21(b) and 5.22(b)) show little variation over the country as a whole but a few rather weak trends can be noted. Although the north western peripheries have a lower mean cover than one might expect given the general north-to-south decrease in cloud cover, these areas also have a higher standard deviation in Spring and Autumn when this trend was most marked. In Spring (Figure 5.18(b)) the south east and the north eastern coastline of the mainland and central Ireland have the least variation. In Early Winter (Figure 5.21(b)) the distribution is reversed with the western margins having the least variation.

In conclusion it can be said that there is little variation in mean cloud amount and less variation in the standard deviation over the British Isles. It is the instantaneous contribution of cloud to the overall human comfort which is of prime importance and this will be considered in the next chapter.

5.6 Rainfall

According to Maunder (1962) rainfall is the most significant weather variable in an examination of human comfort and, therefore, gave it the largest weighting in his index which incorporated the mean annual rainfall and the mean duration of rain. The latter is an interesting variable since it incorporates the idea that although little rain may fall a day long drizzle is less pleasant than a rain storm in which twice as much rain falls but which only lasts half an hour.

The series of indices produced in Weather in the 1960s (Poulter, 1962; Fergusson, 1964; Rackliffe, 1965; Davis, 1968) also realised the importance of rain. Poulter (1962), Fergusson (1964), and Davis (1968) used rain amount which does not take any account of the duration of rain days. Rackliffe (1965), however, used the total number of raindays with rainfall over 0.01 inches which appears to be more relevant to comfort than rain amount.

Any rainfall causes discomfort and the use of rainfall amounts will not necessarily reflect this discomfort. At the time of the questionnaire survey the presence or absence of rain was noted and a binary variable incorporated into the analysis. As the results of the multiple regression described in Chapter 4 showed, this binary variable was a significant contributor to the explanation of overall comfort. The inclusion of the Present Weather Code in the DWR allows a binary variable denoting whether or not precipitation was falling at the time of observation to be extracted from the data, a Present Weather Code of 50 or more indicating that precipitation was falling to the ground. This code was transformed into the binary variable for precipitation in the FORTRAN programme shown in Appendix 5 which also calculates the proportion of days in each season with rainfall at 1200 GMT. These proportions were then mapped and the distributions are shown in Figures 5.23 to 5.25. The patterns revealed by these distributions are not altogether clear but some general points can be made.

In Spring (Figure 5.23) there is a north west to south east trend in the proportion of rain days. The maximum however is at Valentia, the station which is furthest west and the minimum is at Manston, one of the stations furthest east. In general, as might be expected, the east coast has a lower proportion of rain days than the west coast at the same latitude. The north and west coasts of Ireland have the highest proportion of raindays with Scotland, particularly in the higher areas as represented by Eskdalemuir, having over 20% of the Spring sample observations recording rainfall. As commented earlier Eskdalemuir is anomalous in that it is the only upland station. The High Summer (Figure 5.24(a)) distribution shows a general west to east decline with

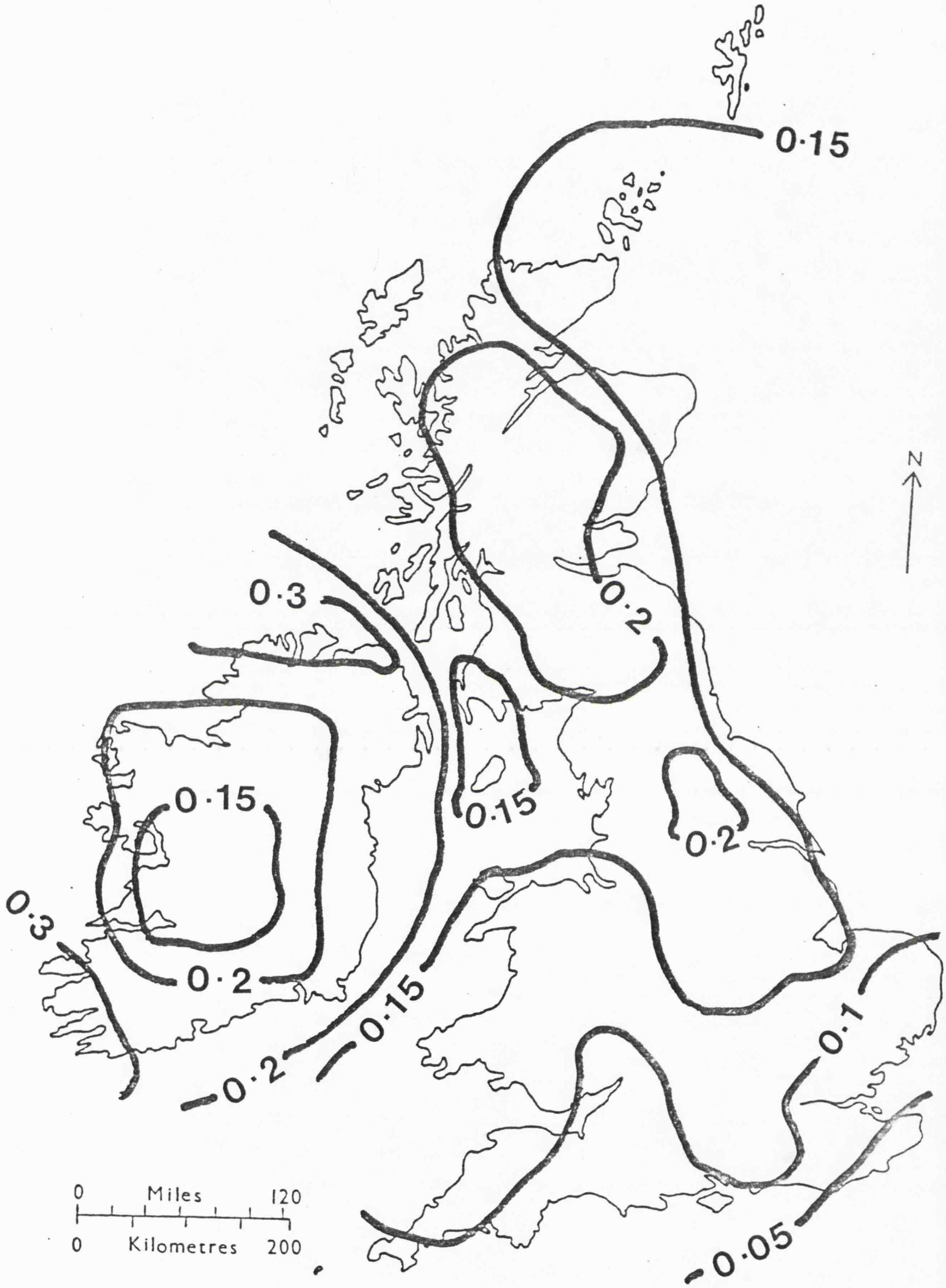


FIGURE 5.23. Proportion of raindays for Spring.

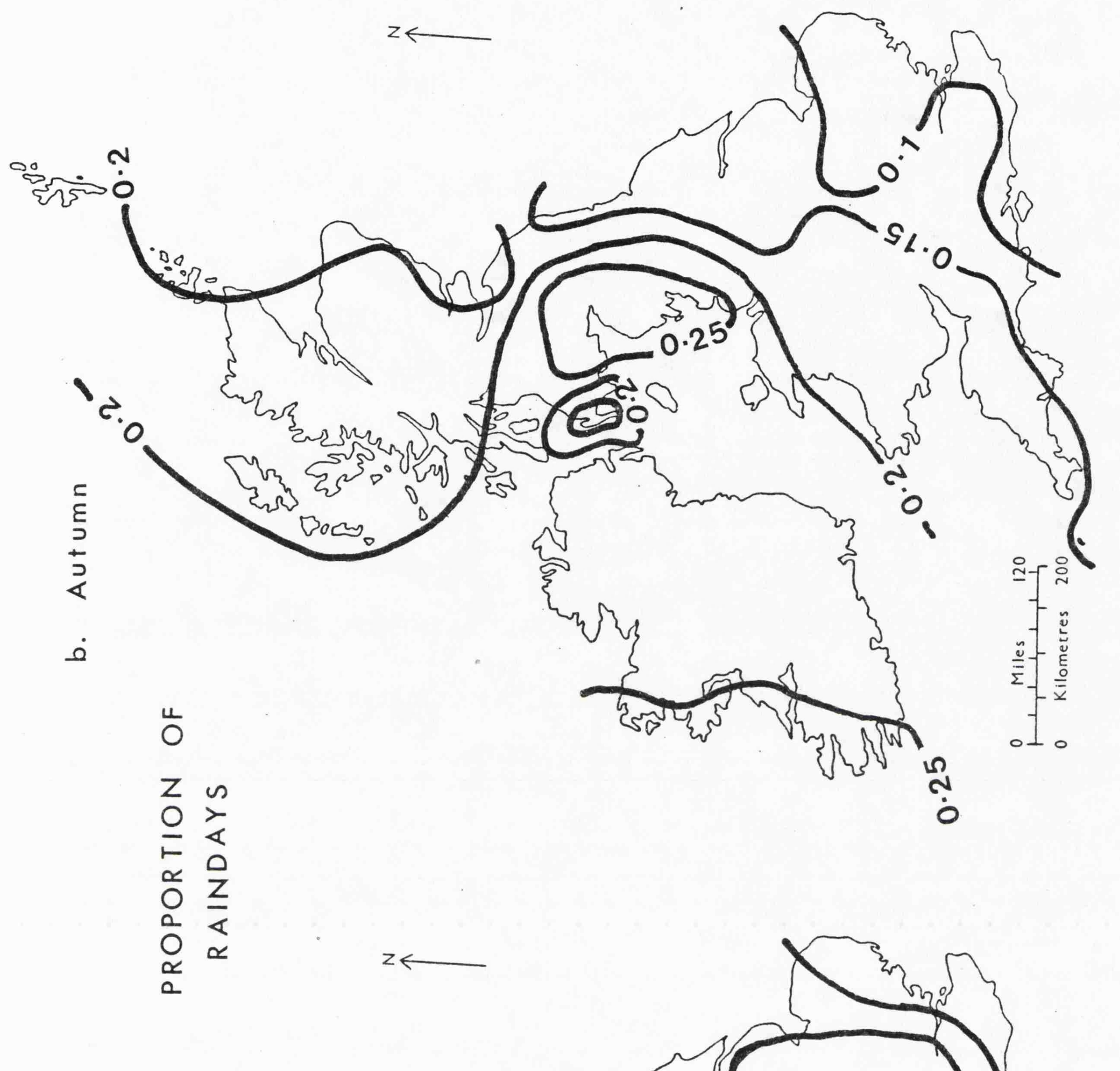

PROPORTION OF RAINDAYS
a.High Summer
b. Autumn
N
0·2
0·15
0·25
0·1
0·2
Miles 0 120
Kilometres 0 200

FIGURE 5.24.

Eskdalemuir again showing anomalously. The western margins of England and Wales, such as the Scilly Isles, Anglesey and the Isle of Man have less raindays than might be expected given this general trend. In Autumn (Figure 5.24(b)) the west to east pattern is more marked with the proportion of raindays varying from 0.29 at Valentia to 0.07 at Honington in East Anglia. The proportion of raindays along the Lancashire and Cumbrian coastlines is higher in Autumn than in any other season. In Winter the distribution is more complex. The Early Winter distribution (Figure 5.25(a)) shows a north west to south east reduction, the maximum being 0.35 at Sule Skerry and the minimum 0.10 at Manston. Again Eskdalemuir has a high proportion of raindays and the Isle of Man, Anglesey and the Scilly Isles have a lower proportion of raindays than might be expected given the general distribution pattern, but orgographic effects are not marked in these peripheral areas. The Late Winter distribution (Figure 5.25(b) again shows a general north west to south east pattern with Eskdalemuir having the highest proportion of raindays (0.31) and Gorleston the lowest (0.10). In this season inland England has a higher proportion of raindays than the west coast at the same latitude which is contrary to what might be expected given the actual mean rainfall distribution. The Welsh coast and the south coast of England are fairly favourable with most stations recording precipitation at 1200 GMT on less than 15% of days.

The use of proportional data for rainfall in studies of human comfort seems to be intuitively reasonable. People experience discomfort during a light drizzle as well as a rainstorm; discomfort during the former may be greater than the latter particularly if the drizzle is prolonged. The recording of the Present Weather Code in the DWR allowed the calculation and seasonal analysis of the spatial patterns of the proportion of raindays. This method seems to be the most useful way of incorporating rainfall into a human comfort index.

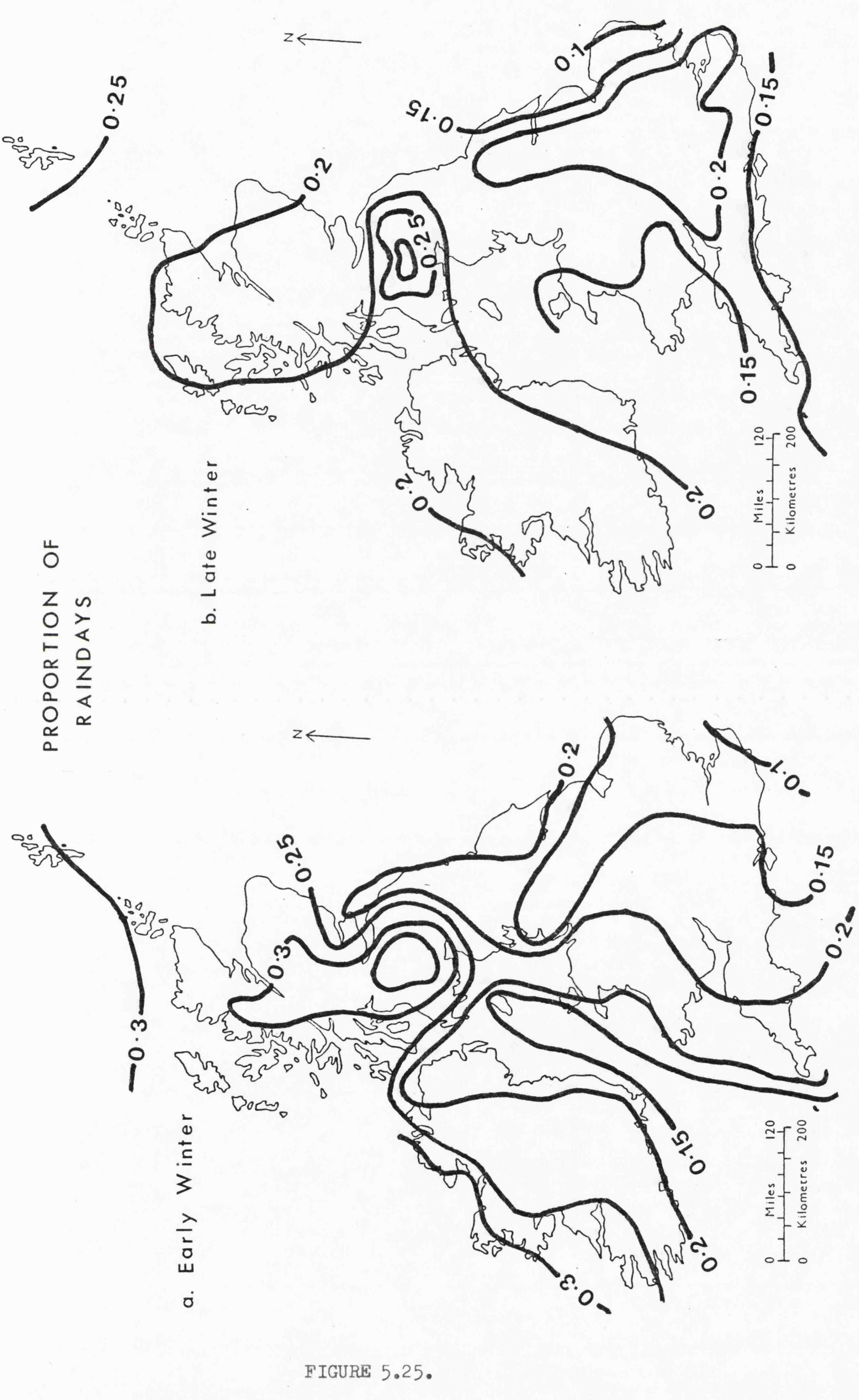

PROPORTION OF RAINDAYS
a. Early Winter
b. Late Winter
N
0·3
0·25
0·2
0·15
0·1
0·25
0·2
0·15
0·1
Miles
Kilometres
0
120
0
200

FIGURE 5.25.

5.7 Pressure

The final significant variable identified in the analysis of human comfort was that of pressure. The correlation of pressure with the comfort index is the most difficult to explain. Winslow and Herrington (1935) incorporated barometric pressure into their analysis and noted that its effects were mainly secondary ones. The pressure sums up the weather in a way no other variable can and is therefore a useful variable in studies of comfort climatology.

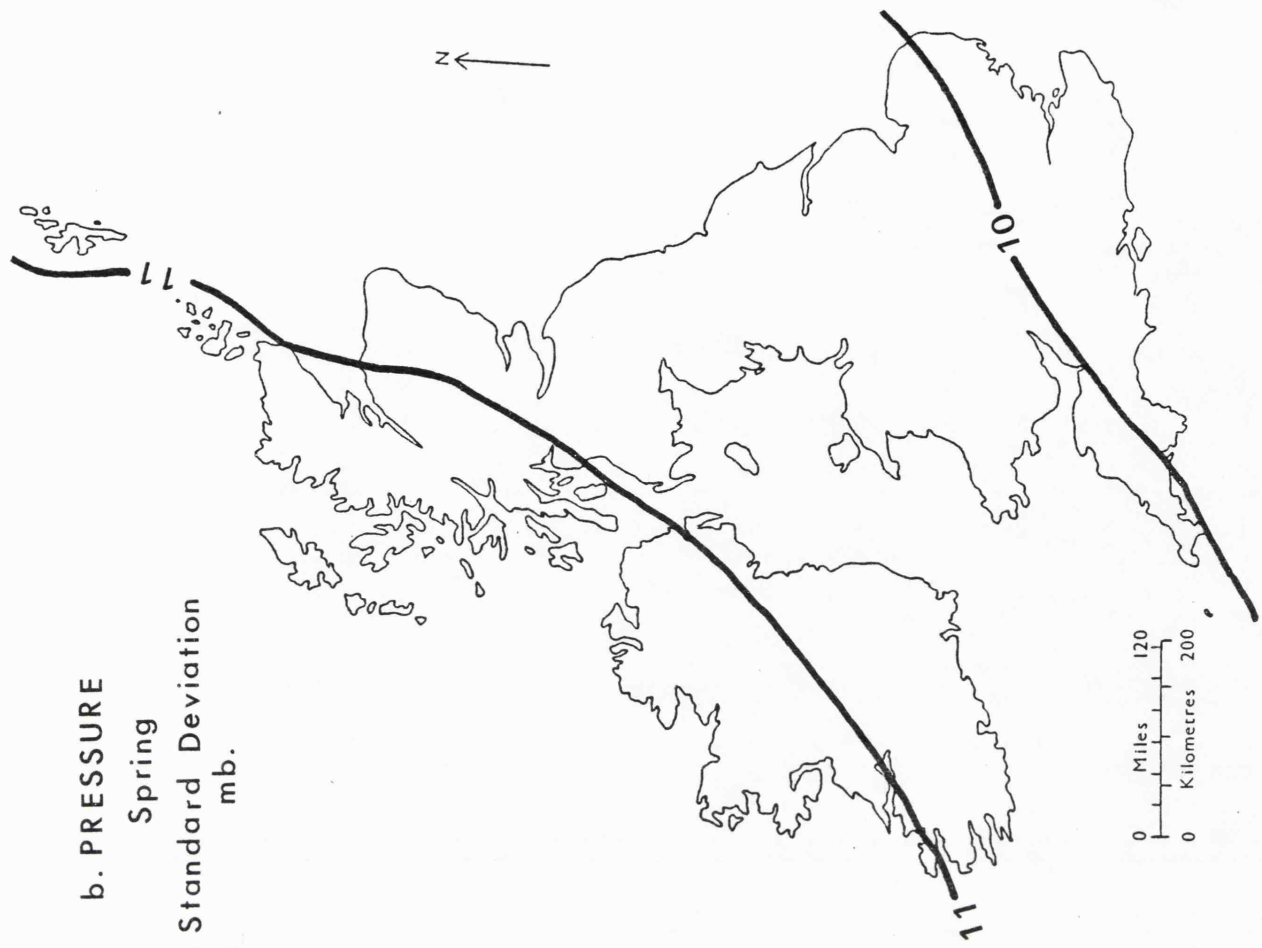
The distributions of mean pressure and the associated standard deviations are shown in Figures 5.26 to 5.30 and the data are summarized in Table 5.8.

Table 5.8 A Summary of the Pressure Data

Season	Maximum Mean	Minimum Mean	Range	Maximum Standard Deviation	Minimum Standard Deviation	Range
Spring	1014.5	1012.4	2.1	11.7	9.6	2.1
High Summer	1018.2	1010.9	7.3	9.8	5.4	4.4
Autumn	1015.1	1007.3	7.8	14.6	10.5	4.1
Early Winter	1016.6	1009.1	7.5	14.2	9.6	4.6
Late Winter	1016.3	1010.2	6.1	16.5	12.2	4.3

It is worth noting that these maps give the mean surface geostrophic wind for the Natural Seasons and the distributions shown are similar to the pressure maps presented by Walton and Hardman (1973) for the 1941-1970 30 year averages.

In Spring (Figure 5.26) there is little difference over the British Isles in both the mean and the standard deviation of pressure. The pattern which exists shows a north west to south east increase in mean pressure and a corresponding decrease in the standard deviation. The mean pressure varies from 1014.5 mb. at Thorney Island to 1012.4 mb. at


b. PRESSURE
Spring
Standard Deviation
mb.
N
11
11
10
0 Miles 120
0 Kilometres 200

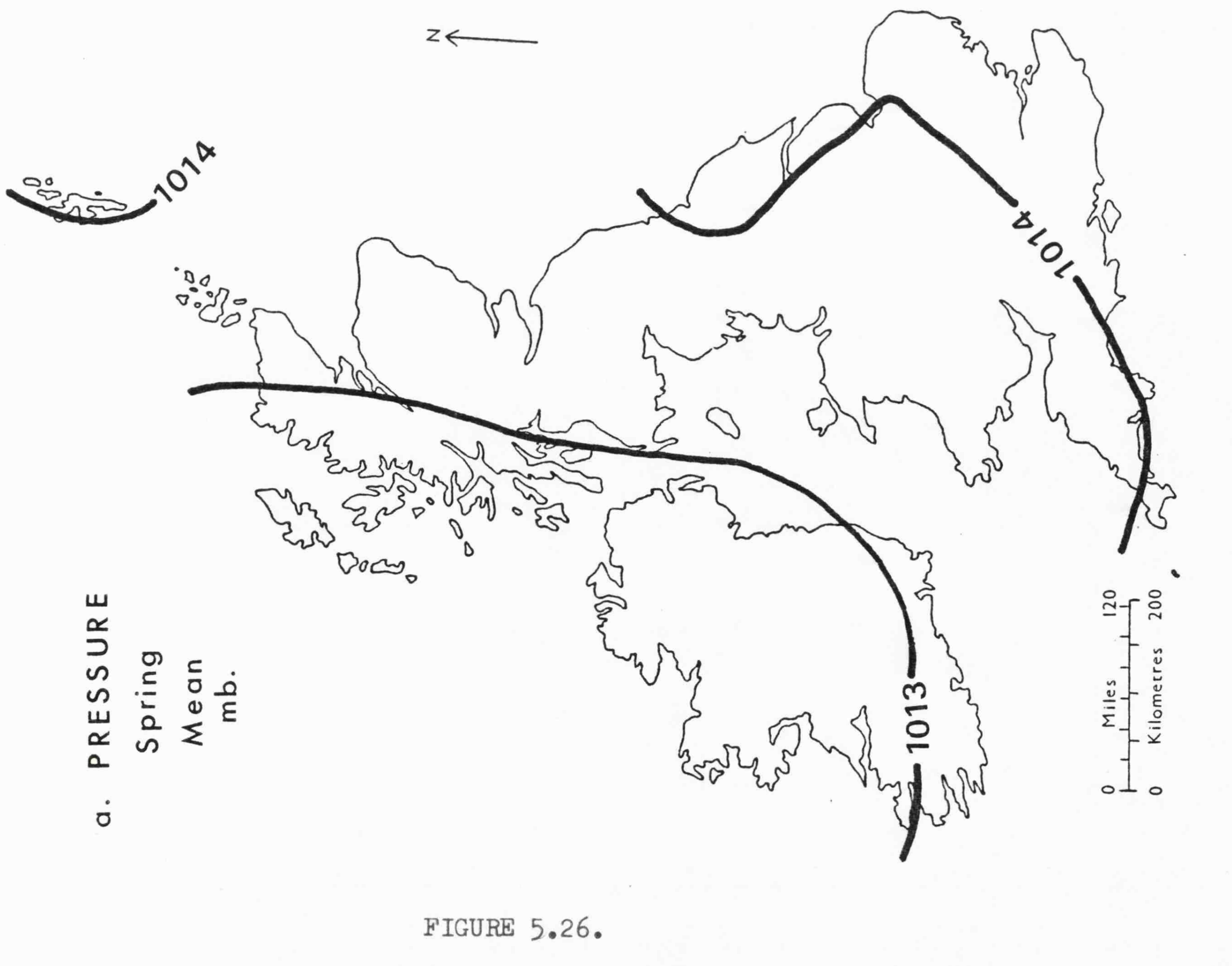

a. PRESSURE
Spring
Mean
mb.
N
1014
1014
1013
0 Miles 120
0 Kilometres 200

FIGURE 5.26.

Belmullet, the range of only 2.1 mb. which is the lowest seasonal range as is also the range of the standard deviation which varies from 11.7 at Benbecula to 9.6 at Wattisham and Gorleston suggesting settled weather conditions during this season.

The High Summer (Figure 5.27(a)) distribution of pressure is clearly latitudinal. The mean shows a north to south increase in pressure from 1010.9 mb. at Lerwick to 1018.2 at Scilly which is a result of passing fronts associated with depressions to the north affecting northern areas and warm continental air flows affecting southern parts. This frontal weather is associated with larger variations in pressure in the north and this is shown in the distribution of the standard deviation (Figure 5.27(b)) which ranges from 9.8 at Lerwick to 5.4 at Thorney Island. Latitude also affects the Autumn mean pressure pattern (Figure 5.28(a)) although the trend is more markedly north west to south east. The mean pressure ranges from 1015.1 at Thorney Island to 1007.3 at Lerwick, the largest seasonal variation. The northern half of the area has little difference in pressure variation (Figure 5.28(b)) but the Midlands and south of England have decreasing variation towards the south east.

In Winter (Figures 5.29 and 5.30) the mean pattern is a north to south one ranging in Early Winter (Figure 5.29(a)) from 1016.6 mb. at Thorney Island to 1009.1 mb. at Lerwick and in Late Winter (Figure 5.30 (a)) from 1016.3 mb. at Thorney Island to 1010.2 mb. at Cape Wrath. The variation in pressure, as shown by the distributions of the standard deviation, reveals a marked west north west to east south east trend ranging in Early Winter (Figure 5.29(b)) from 14.2 mb. at Benbecula to 9.6 mb. at Gorleston and in Late Winter from 16.5 mb. at Cape Wrath to 12.2 mb. at Manston. This is a result of the Atlantic maritime influences being stronger in the west and having the effect of larger variations in pressure than in eastern areas.

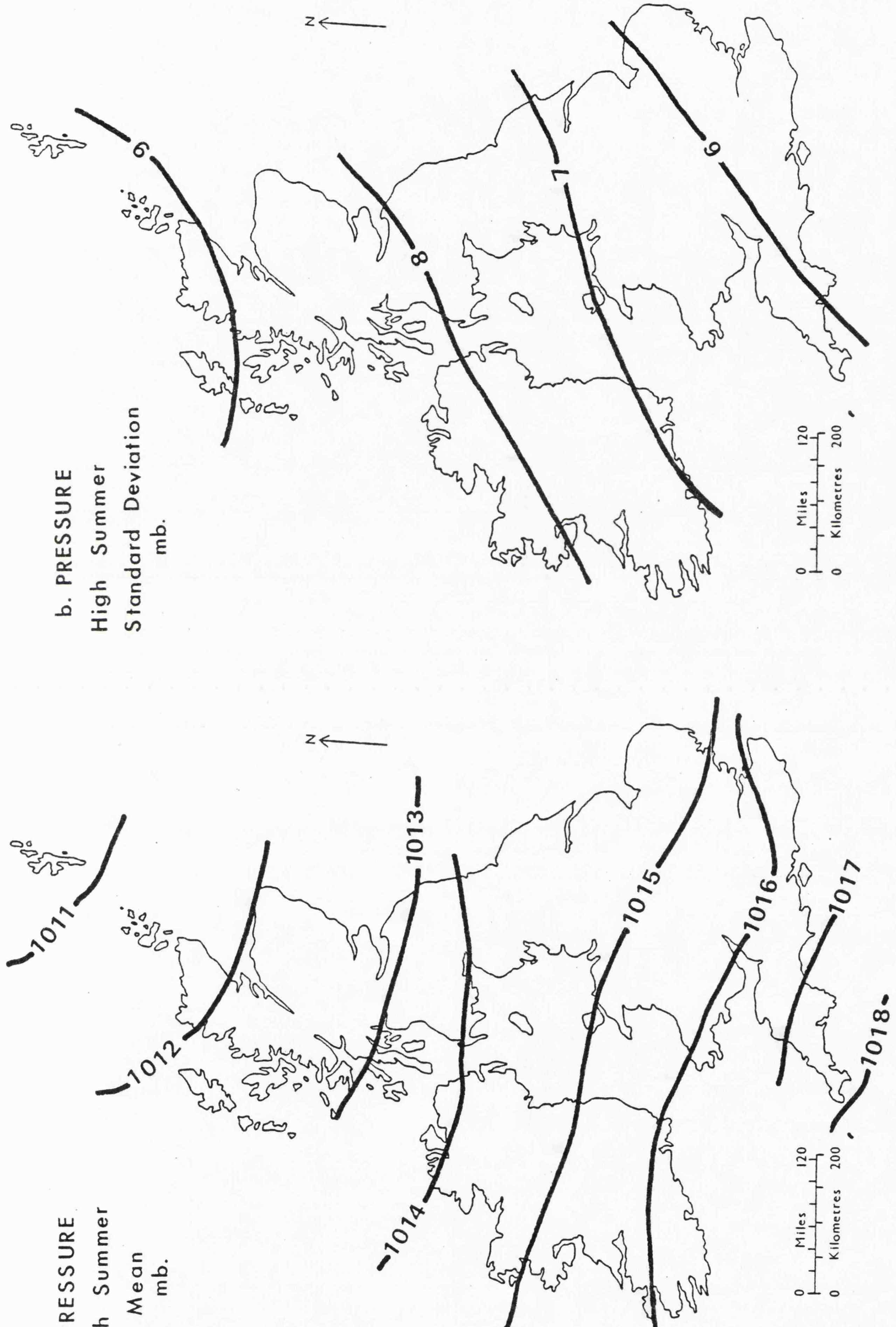

b. PRESSURE
High Summer
Standard Deviation
mb.
6
7
8
9
9
a. PRESSURE
High Summer
Mean
mb.
1011
1012
1013
1014
1015
1016
1017
1018
N
0 Miles 120
0 Kilometres 200

FIGURE 5.27.

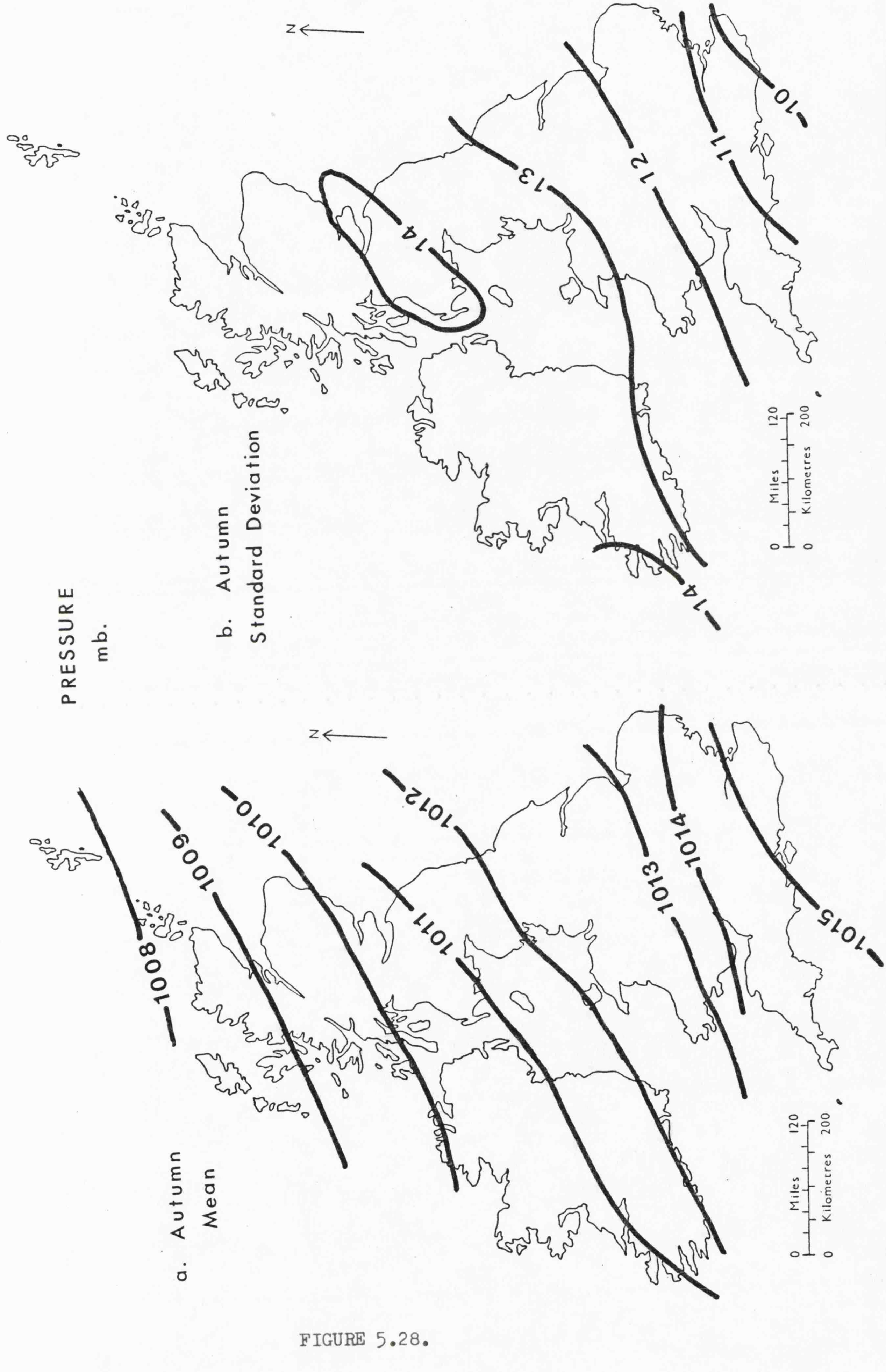
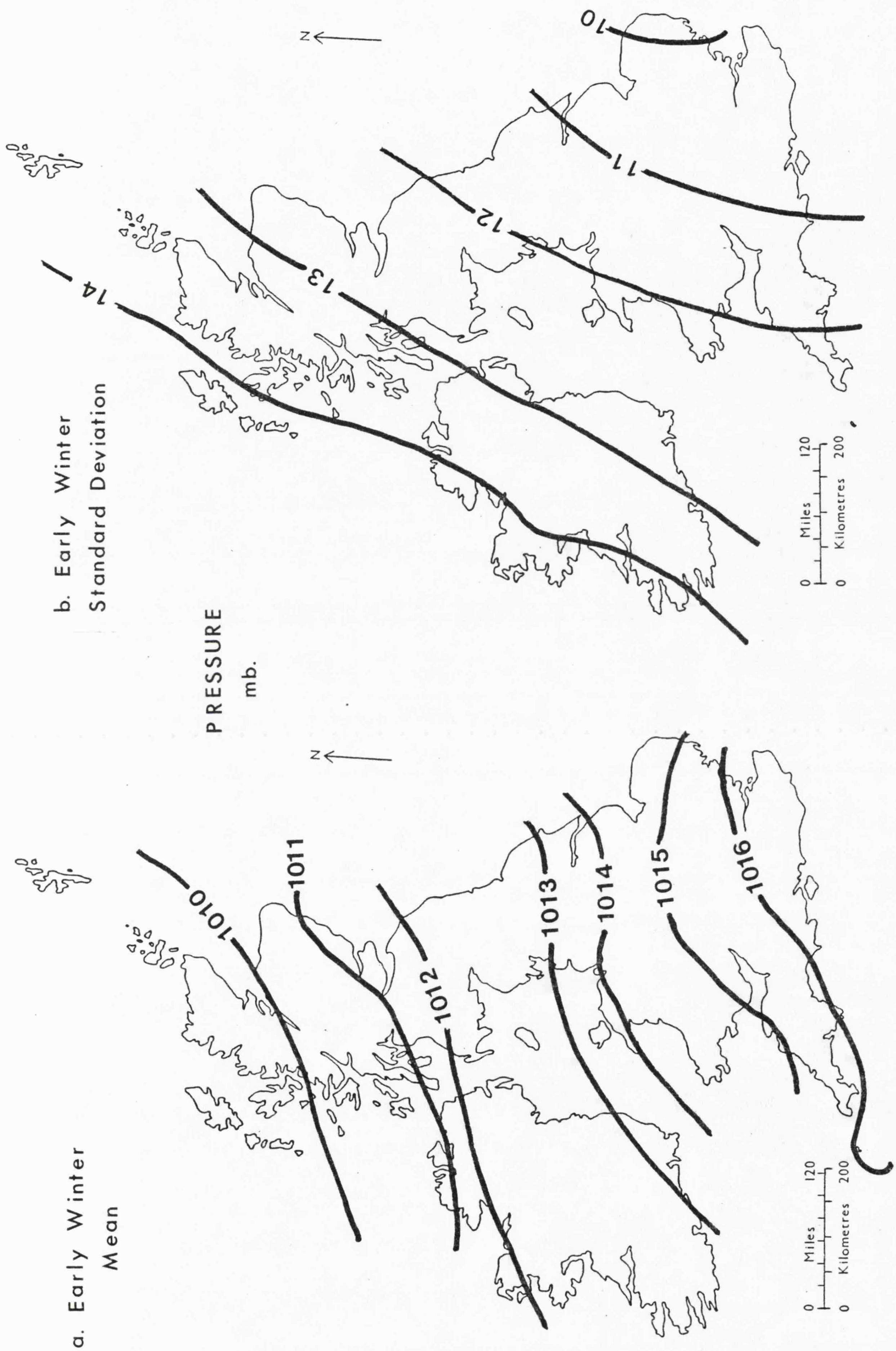

PRESSURE
mb.
a. Autumn
Mean
b. Autumn
Standard Deviation
N
1008
1009
1010
1011
1012
1013
1014
1015
10
11
12
13
14
14
0 Miles 120
0 Kilometres 200

FIGURE 5.28.



a. Early Winter
Mean
b. Early Winter
Standard Deviation
PRESSURE
mb.
N
1010
1011
1012
1013
1014
1015
1016
10
11
12
13
14
0 Miles 120
0 Kilometres 200

FIGURE 5.29.

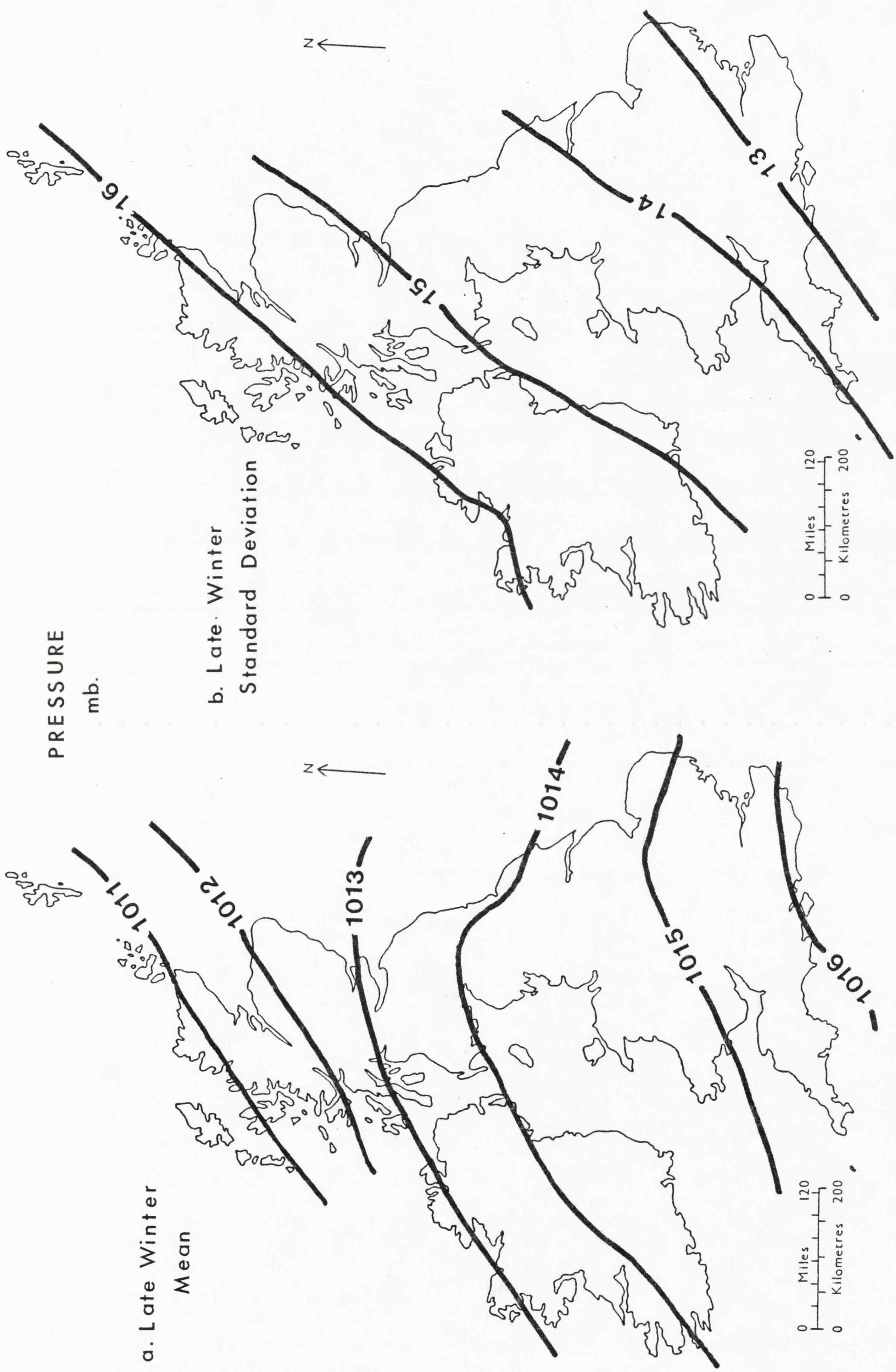

PRESSURE
mb.
a. Late Winter
Mean
b. Late Winter
Standard Deviation
N
1011
1012
1013
1014
1015
1016
16
15
14
13
0 Miles 120
0 Kilometres 200

FIGURE 5.30.

5.8 Conclusions

The spatial variation of the variables which had significant Beta coefficients in the multiple regression analysis has been discussed in this chapter. These variables were, the Steadman (1971) windchill index, THI, cloud cover, rainfall and pressure. The discussion concentrated on the windchill index and the THI which were developed to measure particular aspects of comfort and which have been used very little in previous work, the latter never having previously been mapped for the British Isles.

The climatologies were based on a sample of DWR data stratified according to the Lamb Natural Seasons (Lamb, 1950). A comparison of the weather types recorded on the 274 sample days and those found over the longer term by Lamb (1950, 1972) and by Perry (1976) suggested that this sample was a representative one. The resulting distributions of the mean and standard deviation of the variables showed seasonal differences which have been analysed. The discussion concerned itself mainly with explanations of the distributions by reference to the synoptic climatology of the British Isles and in particular with the incidence of weather types on which the Natural Seasons are based. This proved to be a useful way of examining the distributions which were clearly influenced by the synoptic climatology with proximity to the coast and latitude also exerting controls over the spatial variation of the variables.

The use of instantaneous data also made it possible to examine the extremes of the windchill and THI which have not been previously studied. This examination of the potential stress was particularly interesting and revealed that discomfort due to excesses of heat and humidity is not common in the British Isles.

The aim of the multiple regression analysis was to discover which variables were significant in explaining the variation in the response to the weather as measured by the attitude scale. The significant variables which have been discussed in this chapter are combined in the next chapter to form an Index of Human Comfort.

Chapter Six

The Human Comfort Climatology

6.1 Introduction

The multiple regression analysis which was described in Chapter 4 extracted six variables which were significant in explaining public attitudes to the weather. These variables were the Windchill Index, THI, cloud cover (2 dummy variables), rainfall and pressure. The climatology of these variables has been discussed in the previous chapter. In the present chapter an attempt will be made to combine these variables in order to devise an Index of Human Comfort; then this Index will be compared with other indices which have been used to measure human comfort and, finally, the climatology of this Index of Human Comfort will be examined.

6.2 The Index

The estimated Beta coefficients associated with the six variables are shown in Table 6.1. The unstandardised estimated Beta coefficients

Table 6.1 The estimated Beta coefficients associated with the significant variables (to 5 decimal places)

Code	Variable	Unstandardised Beta	Standardised Beta
W	Windchill ($cal.m^{-2}s^{-1}$)	-0.41625×10^{-1}	-0.35570
	THI	0.36048×10^{-1}	0.08040
C1	Cloud cover 3-5 octas inc.	-2.0030	-0.20298
C2	Cloud cover >5 octas	-4.33479	-0.55292
R	Rain (presence/absence)	-2.58572	-0.25798
P	Pressure	0.19470×10^{-1}	0.07697
	Constant	1.91011	

can be used to combine the variables, using the raw data, into an equation reflecting the public's attitude to the weather. The regression equation can be used to predict with reasonable accuracy the value of the Index (I), which would result from a specified combination of the independent variables windchill, THI, cloud cover, rainfall and pressure. This 'Index of Human Comfort' is given by:

$$I = 1.91011 - 0.41625 \times 10^{-1}.W + 0.36048 \times 10^{-1}.THI - 2.003.C1 - 4.33479.C2 - 2.58572.R + 0.19470 \times 10^{-1}.P \qquad (6.1)$$

where the variables are defined in Table 6.1.

The standardised estimated Beta coefficients enable a consideration to be made of the relative effects of each variable on the final Index and these are examined in order of importance.

(i) It can be seen from the standardised Beta coefficients that the greatest contribution was made by the dummy variable representing cloud cover over five octas. In general it was found that there was a high correspondence between this category and the sunshine code with 'dull' and 'overcast' codes frequently being recorded when the cloud cover was greater than five octas. When the cloud cover falls into this category then the Index of Human Comfort is 2.3 units less than when the cloud cover falls between three and five octas inclusive, and 4.33 units less than when the cloud cover falls below three octas. In an Index which ranges from six to thirty this represents a considerable contribution to the overall magnitude.

(ii) The second most important contributor to the Index of Human Comfort is the Steadman Windchill Index (Steadman, 1971) which relates wind and temperature in an energy balance equation, and was discussed at length in the previous chapter. This exerts a negative effect on the Index with high values of the Windchill Index indicating increasing discomfort.

(iii) The third ranked variable is the dummy variable representing whether or not precipitation was observed at the time of observation and this variable also exerts a negative effect on the final Index. When precipitation reaches the ground at the time of observation then the Index is 2.58 units lower than when no precipitation is observed. The presence of precipitation therefore reduces the Index by 10% of its total range.

(iv) The second cloud dummy variable, representing cloud cover between three and five octas inclusive, is the fourth ranked variable and, like the other cloud dummy variable, is negatively related to the Index of Human Comfort. When cloud cover falls into this category at the time of observation then the resulting Index is 2.0 units lower than when cloud cover is less than three octas.

(v) The THI is positively related to the Index and is its fifth ranked contributor. As noted in the last chapter, the unstandardised estimated Beta coefficient used in the equation is sufficiently small to be insensitive to any slight discomfort felt by some of the population as the THI rose to its maximum values above 70 at some stations.

(vi) Pressure is the least contributor to the Index of Human Comfort with a higher pressure resulting in a higher Index.

For the reasons discussed in Chapter 1, the approach to the study of human comfort used in the experiment which is described in this thesis is clearly different from previous work within the field. This is the case particularly in relation to its concern with obtaining respondents' direct assessments of the weather as measured at the same time. It is inevitable, therefore, that the variables incorporated into the Index of Human Comfort will also differ from this earlier work. In order to discover the nature of any differences a summary of the variables included in the current Index and in previous indices is shown in Table 6.2.

Table 6.2 The Variables Incorporated into Indices of Human Comfort

Index	Temperature	Wind-speed	Sun	Cloud	Rain	Humidity	Pressure	Human Activity	Composite Indices
Maunder (1962)	✓	✓	✓		✓	✓			
Auliciems, de Freitas and Hare (1973)	✓	✓	✓	✓				✓	
Poulter (1962)	✓		✓		✓				
Fergusson (1964)	✓		✓		✓				
Rackliffe (1965)	✓		✓		✓				
Hughes (1967)	✓		✓		✓				
Davis (1968)	✓		✓		✓				
Terjung (1966, 1967)	✓		✓						✓
Winslow and Herrington (1935)			✓			✓	✓		
Auliciems (1976)	✓	✓	✓	✓		✓			
Human Comfort Index	(✓)	(✓)		✓	✓	(✓)	✓	(✓)	✓

All the previous indices incorporate temperature in some form or other, although Winslow and Herrington (1935) found that sunshine and humidity were more important. With the exception of the indices devised by Auliciems, de Freitas and Hare (1973) and Terjung (1966, 1967) none of the earlier indices of man's response to the total weather combine temperature with other variables to produce composite indices to improve explanation. Two such indices are the Windchill Index and THI which were found to be more significant than the individual variables of temperature, humidity and windspeed in explaining the attitudes to the weather as measured in the current experiment. Amongst the indices of human comfort those devised by Terjung (1966, 1967) are of more value than many of the more subjective ones in that he incorporated some objective measures, including a measure of windchill, into his equation. He calculated his 'stress index' using mean data which were not ideal but Terjung (1966, 1967), like many other researchers, found that ideal data are only seldom available.

The method used to include rainfall in this experiment also differed from previous work in that it incorporated a binary variable representing presence or absence of rain at the time of observation. Earlier work has tended to either ignore rainfall (Auliciems, de Freitas and Hare, 1973; Winslow and Herrington, 1935) or to include mean quantity of precipitation (Poulter, 1962). The approach adopted for the research described in this thesis was based on the premise that people respond to the instantaneous weather and therefore the mean rainfall figures have little meaning for human comfort.

All the indices listed in Table 6.2 include sunshine or the related cloud cover with the majority incorporating mean sun hours which are readily available in standard meteorological reports for a limited number of stations. In contrast instantaneous measures were used by Auliciems, de Freitas and Hare (1973) who included solar angle and cloud cover and Auliciems (1976) who also included cloud cover as well as a five point sunshine scale similar to that used in photography which was also adopted for the current research. The relationship between cloud cover and sunshine found by Auliciems (1976) with a product moment correlation coefficient of 0.85 was similar to that found in this study.

It is surprising that only a few of the previous indices included windspeed in their computation, although the mean values, on which most earlier work is based, are of little relevance to human comfort. Those indices which do incorporate windspeed use instantaneous data and include the energy balance based clo unit (Auliciems, de Freitas and Hare, 1973), and Auliciems (1976) who included windspeed in the series of measurements made at the time of his questionnaire survey, although he only obtained a low correlation between the responses and windspeed. On the other hand, Maunder (1962) incorporated windspeed into his index by the use of the number of days for each season when windspeed exceeded two limits (40 and 60 m.p.h.). In contrast the current work discovered more value in linking windspeed with temperature in a windchill index, rather than using the component parts, in the final equation.

None of the earlier indices included pressure as an important variable with most of them concentrating on variables with fewer composite effects such as temperature and rainfall. An exception is the work of Winslow and Herrington (1935) who included pressure in their analysis although not in their final index.

The clo index devised by Auliciems, de Freitas and Hare (1973) is the only index which incorporates human activity within the equation. This they achieved by the inclusion of the metabolic rate. On the other hand, Steadman's Windchill Index, which is incorporated into the Index of Human Comfort, involves the use of a windspeed conversion appropriate for a walking person.

The Index of Human Comfort produced by this experiment differs from previous work not only in its composition of variables but also in at least two other basic ways.

(i) It uses instantaneous data in contrast to the majority of other indices of human comfort which incorporate mean data and, as indicated earlier, these data have little meaning when related to human comfort. The use of instantaneous data often presents practical problems concerning data availability. In the British Isles the only source of such data are the DWRs which do not, for example, include sunshine, thus, necessitating the use of a surrogate such as cloud cover. This experiment has indicated that this is not a great handicap and that the advantages of obtaining the true covariance of the variables far outweighs any data limitations.

(ii) Compared with previous indices the procedures adopted in the construction of the Index in this experiment have greater objectivity because, with the exception of the clo unit, the indices listed in Table 6.2 are based on relatively arbitrary weightings. In contrast the attitude scale adopted in this study standardised the method of response and the associated weather measurements were all made in a standard way. The use of a multiple regression analysis to obtain the significant variables and their associated weights also removed much of the subjectivity associated with earlier work.

For all the reasons discussed in this section it can be seen that the Index of Human Comfort was developed using different approaches and methodologies to those used in the past. It is believed that it also represents an improvement of this previous work.

6.3 The Human Comfort Climate

Despite a number of attempts to devise comfort indices, only rarely have their authors gone on to derive and map the climatology. The limited knowledge of the spatial variation in human comfort is probably due to three main factors which are worthy of consideration at this stage.

(i) Very few geographers have worked in this field of human comfort with the result that an examination of the spatial variation of comfort has not formed an important end result. Physiologists and psychologists have been more concerned with producing an index of man's physical or mental response to varying thermal conditions and not in spatial or temporal variations.

(ii) The indices produced by geographers and others may have had little meaning in a spatial context. Maunder (1962), for example, calculated his index for various stations in New Zealand but did not map the results. In fact, the values he quotes for his index show relatively little spatial pattern.

(iii) There is often a lack of appropriate data for mapping and this may have deterred researchers from this stage in their work . However, those who have mapped the distributions of their indices have certainly added to our knowledge on human comfort climatology, for example, Terjung (1966, 1967) plotted the distribution of a wind effect index and the Effective Temperature for the United States and then combined these to produce a physiological climatology which he further developed in a 1967 paper using the concept of cumulative stress. Regarding the distributions Terjung came to four major conclusions: first, that the overall pattern corresponded generally to the major annual air mass distribution; second, that there were few areas in the United States in which the population experience comfortable conditions throughout the year; third, that the most variable climates are in the northern Mid-West; and fourth, that in the east the comfort climatic associations are latitudinal and in the west are longitudinal. Although Terjung's work can be criticised for its subjectivity and poor data sources his work represents a major contribution to the field.

A further example of a general climatology produced using a poor data source is found in Davis (1968) and is the only example to date of a comfort climatology of Great Britain. His index, which is for summer only, incorporates mean temperature, sunshine and rainfall with the weightings being derived from the ratios of the standard deviations of the three variables. Davis mapped the distributions of his index using the monthly means for 30 stations in England, Wales and Scotland, finding that proximity to the coast and altitude were the main controls with the index reaching a maximum in the south east of England.

The only example to date of research which defines an index for the total climate and then uses appropriate data to map the resulting distribution is found in Auliciems, de Freitas and Hare (1973) in their work on the clo unit. This they mapped for Canada over each of the conventional seasons and found latitude and distance inland to be the overriding factors in explaining the spatial patterns observed.

The experiment described in this thesis was concerned from the outset with producing a relatively objective index for which suitable data were available for calculation allowing spatial and temporal variations in comfort to be analysed. The DWR data described in the previous chapter were used to calculate the seasonal mean and associated standard deviation of the Index for the synoptic stations using the FORTRAN programme shown in Appendix 5 which calculates Equation 6.1. The resultant distributions are shown in Figures 6.1 to 6.5 and a summary of the data in Table 6.3.

Table 6.3 Summary of the Seasonal Values of the Index of Human Comfort

Season	Maximum Mean	Minimum Mean	Range	Maximum Standard Deviation	Minimum Standard Deviation	Range
Spring	16.68	13.69	2.99	3.7	2.1	1.6
High Summer	18.16	14.88	3.28	3.2	2.0	1.2
Autumn	17.03	14.09	2.94	3.5	2.2	1.3
Early Winter	15.45	11.43	4.02	3.7	2.1	1.6
Late Winter	14.83	12.22	2.61	3.9	2.1	1.8

The distributions of the means and standard deviations are, obviously, related to the variables which make up the Index and whose climatologies were examined in the previous chapter. The seasonal maps are discussed below and then some overall features of the revealed spatial distributions of human comfort are examined. The location of the synoptic stations mentioned in the discussion can be obtained by reference to Figure 5.1.

(i) Spring (Figure 6.1). The distribution of the Spring mean Index (Figure 6.1(a)) shows a general north to south increase in human comfort ranging from 13.67 at Lerwick to 16.68 at Ross-on-Wye giving an overall range of 2.99 with Somerset, Dorset and Kent having the most favourable human comfort climate. The isolines turn southwards along both east and west coasts on the mainland although, to the north of Harwich, the east coast has a less favourable human climate than the west reflecting a similar pattern to that exhibited by the Windchill Index (Chapter 5). This is also seen in Ireland which also has a higher level of human comfort on the west coast than on the east. The Scilly Isles have a mean Index of just over 16.5 which is favourable compared with the mainland at this time of the year.

The standard deviation (Figure 6.1(b)) varies from 3.7 at Lerwick

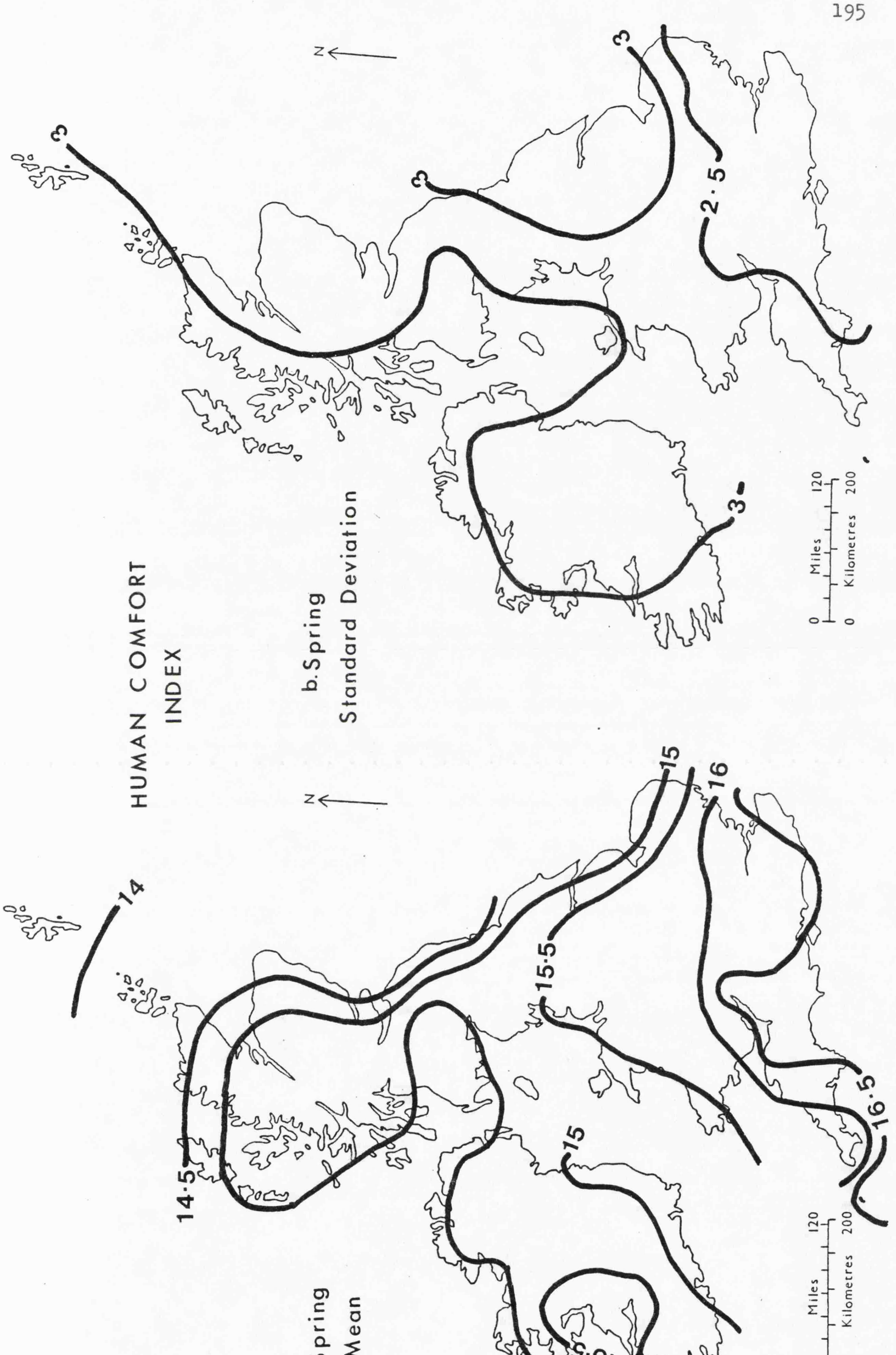

HUMAN COMFORT
INDEX
a. Spring
Mean
14
14·5
15
15·5
16
16·5
Miles 0 120
Kilometres 0 200
N
b. Spring
Standard Deviation
3
2·5
Miles 0 120
Kilometres 0 200
N

FIGURE 6.I.

to 2.1 at Manston. In Spring the north west coastal margins have the largest variation around relatively low mean values. A high variation is also found in Yorkshire and Humberside where the standard deviation is over three units. The lowest variation is found in the south and south east of England and is associated with relatively high mean values. These results indicate that the south of England not only has the highest mean values of human comfort in Spring but that these values also have a higher probability of occurrence in any one year than have the lower mean values in other parts of the study area where comfort levels are more likely to fluctuate from year to year.

(ii) High Summer (Figure 6.2). The High Summer distribution of comfort has obvious importance for holidaymakers for whom an area which shows least variation around a high mean level of comfort is clearly the best climatic choice. The general trend of mean comfort levels for this season (Figure 6.2(a)) is a north west to south east one varying from a minimum of 14.88 at Lerwick to 18.16 at Manston giving a relatively large seasonal range of 3.28. Again, the isolines turn southwards parallel to both east and west coasts on the mainland indicating that inland areas, particularly in England, are preferable to coastal areas at the same latitude although the south east of England and the Scilly Isles have the highest values. This tendency for a coast to inland increase in human comfort is not as marked as in the Spring season (Figure 6.1(a)).

The standard deviation distribution (Figure 6.2(b)) shows the least variation in High Summer varying from 3.2 at Abbotsinch to 2.0 at Gorleston giving a range of 1.2 units. These values indicate that there is a higher probability of the actual mean falling close to the long term mean Index than in any other season. The most variation in

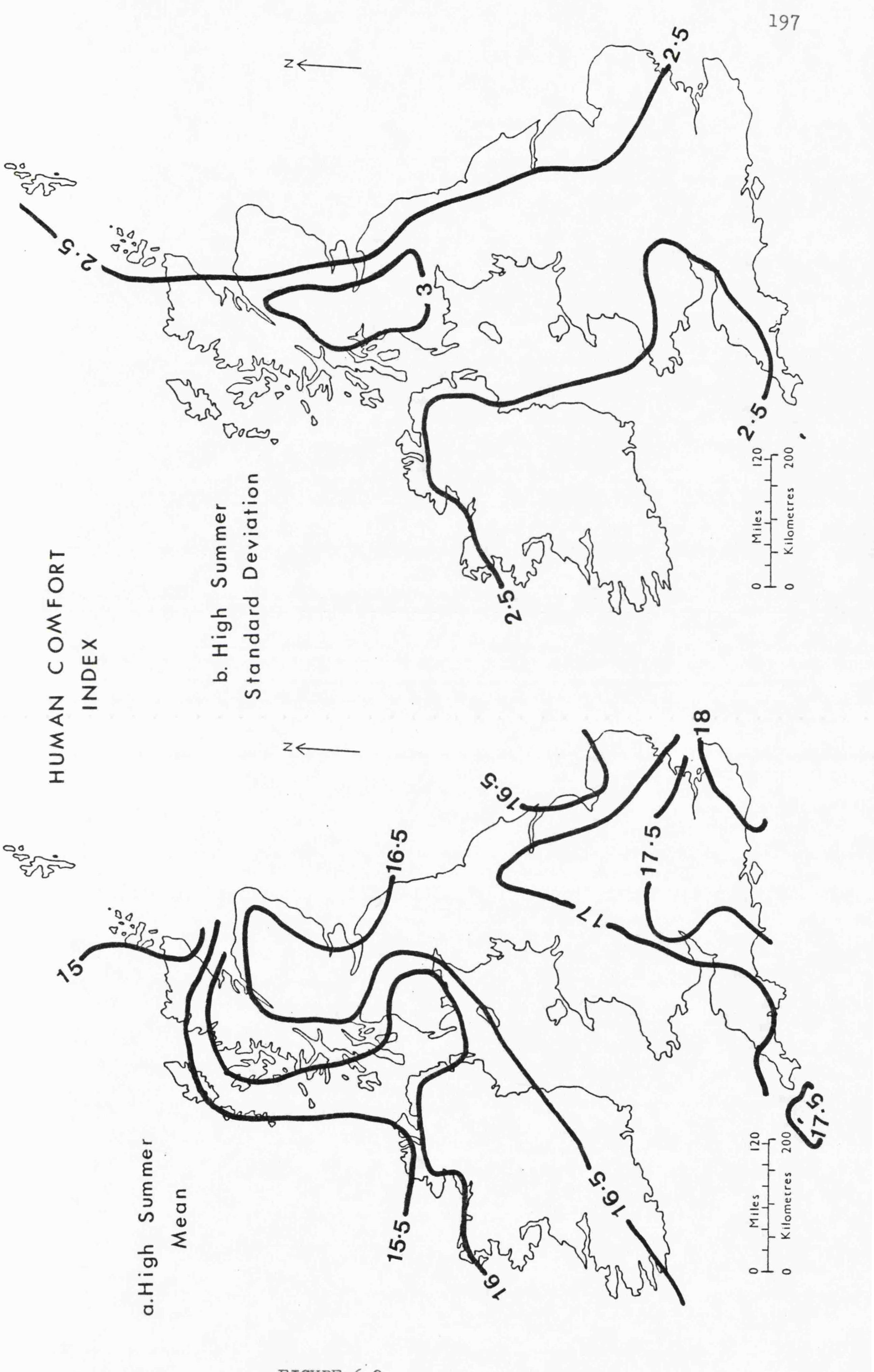

HUMAN COMFORT INDEX
a.High Summer Mean
b. High Summer Standard Deviation
N
15
15·5
16
16·5
17
17·5
18
2·5
3
Miles 0 120
Kilometres 0 200

FIGURE 6.2.

comfort is found in central and southern areas of Scotland, in particular, and also the Midlands of England. Ireland, South Wales, the Cornish coastline and the majority of the east coast of the mainland have the lowest standard deviation values, and it can be seen that these areas are often those with the highest mean values.

It was commented in the previous chapter that this relationship between high mean and low standard deviation values is an unusual one in general but is in fact common for measures of comfort as applied to the British Isles. For this reason the mapping of the coefficient of variation would have masked rather than highlighted the spatial distributions of the variables. However, having considered the mean and standard deviation for High Summer it is worth examining the High Summer coefficient of variation as an indicator of holiday weather with the lowest values representing the preferred areas. The distribution of the coefficient of variation is shown in Figure 6.3 revealing that the measure varies from 19.58% at Abbotsinch to 11.65% at Gorleston. The distribution suggests that the east coast of the mainland is to be preferred to the west coast with Suffolk and Essex being particularly favourable although the extreme south west and south east of England are also favourable and have higher mean values (Figure 6.2(a)) than do Suffolk and Essex. The coefficient of variation in central Ireland is also low although this is due to the low standard deviation values rather than to high mean values. The distribution shown in Figure 6.3 reflects the reliability of the weather in High Summer and as such may be of value for holiday-makers.

(iii) Autumn (Figure 6.4). The mean Autumn distribution (Figure 6.4(a)) shows a general north to south trend and, as in the two seasons already considered, Lerwick has the lowest mean value of 14.09 whereas

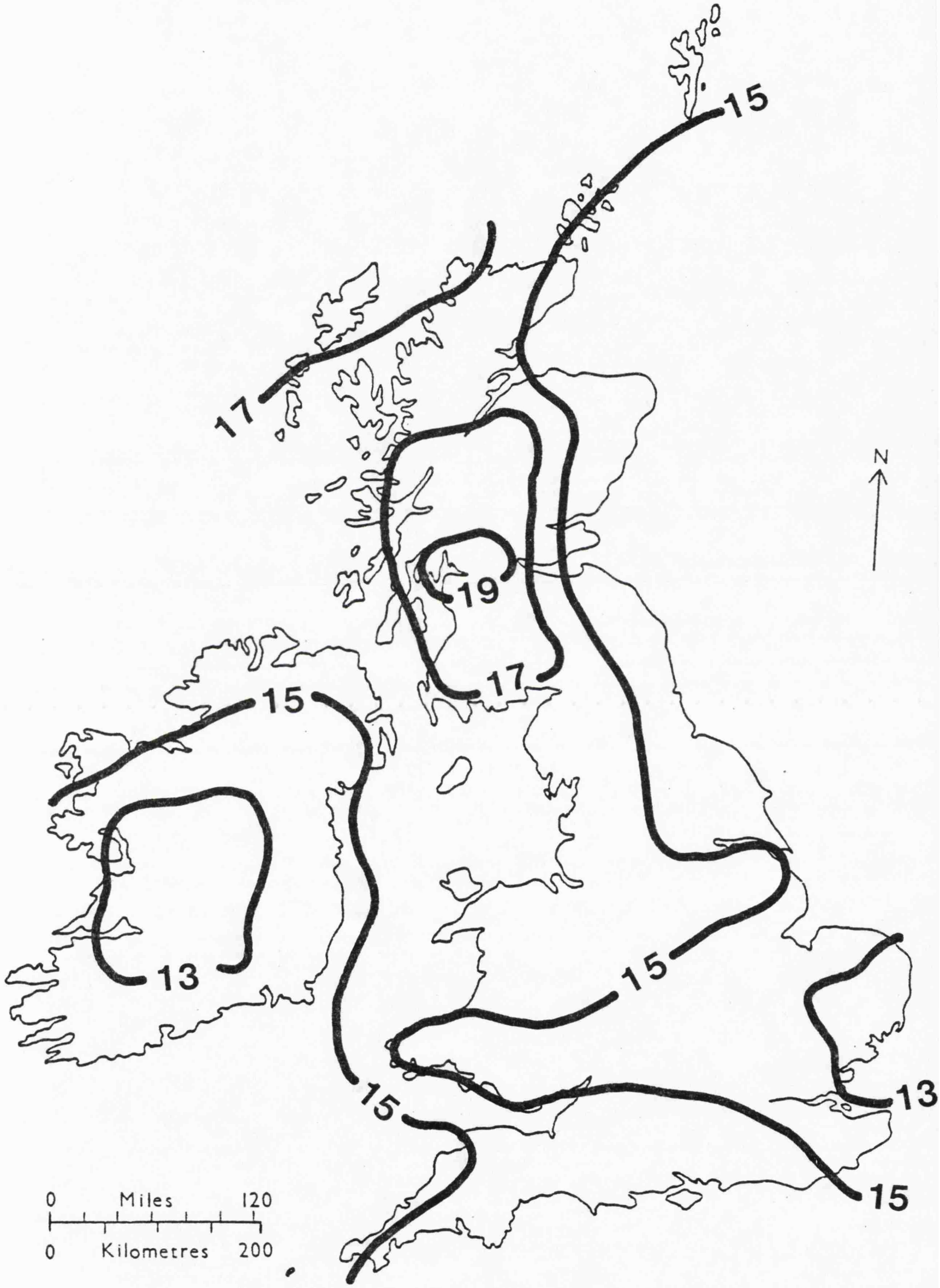


FIGURE 6.3 . The coefficient of variation (%) for the High Summer Human Comfort Index.

HUMAN COMFORT INDEX

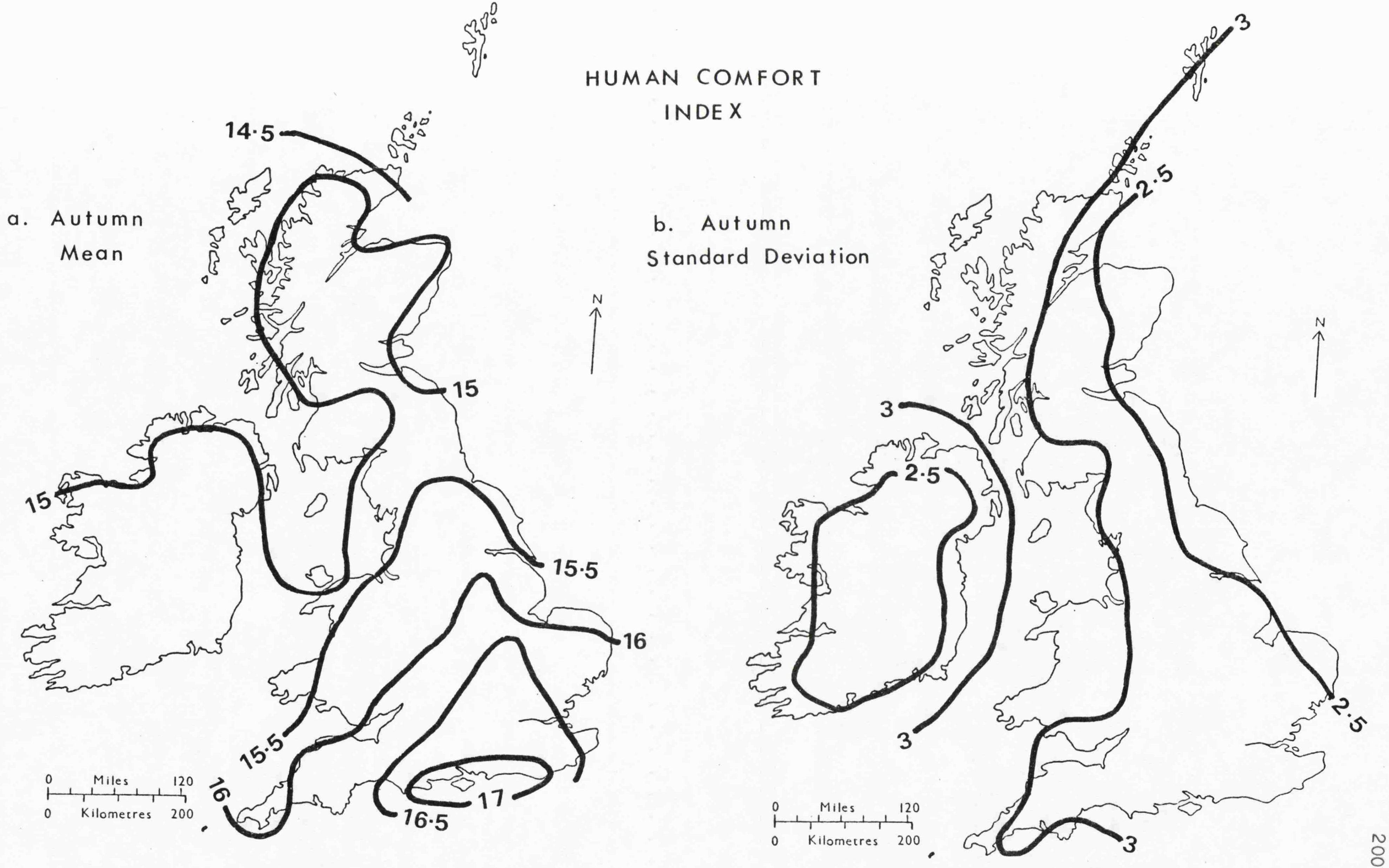


FIGURE 6.4.

Hurn has the highest mean of 17.03. It is of interest to note that these Autumn values are higher than the Spring ones particularly along the east coast of England, although the Midlands of England have similar values to those in Spring because of the greater inland increase in the Index in Autumn. The most favourable human comfort climate in Autumn is found on the south and south east coasts of the mainland where the values are slightly higher than those in Spring (Figure 6.1(a)). In Spring the west coast was preferable to the east coast, however in Autumn this pattern appears to be reversed but is not as marked. The distribution of human comfort for Autumn in Ireland shows little variation. The lowest indices are found on the north coast with the rest of Ireland having human comfort levels similar to those in northern England.

The variation, as shown by the standard deviation, and its associated range are the lowest after High Summer with the maximum value of the standard deviation being 3.5 at Stornoway and the minimum 2.2 at Leeming giving a range of 1.3. The distribution shown in Figure 6.4(b) reveals a west to east decrease in the standard deviation, the west coast being considerably less favourable in Autumn than in the other two seasons already discussed. The mean values on the west coast tend to be relatively low and the human comfort climate is also very variable relative to the rest of the area under study.

(iv) Early Winter (Figure 6.5). There is a marked decline in the mean human comfort index between Autumn and Early Winter. The maximum mean value in Early Winter is 15.45 at Ross-on-Wye and the minimum is 11.43 at Lerwick giving the largest seasonal absolute range of 4.02 units. The distribution shown in Figure 6.5(a) reflects this greater range with the isolines being closer together than on the other seasonal mean maps. A north to south trend is still evident but is not as dominant as in the

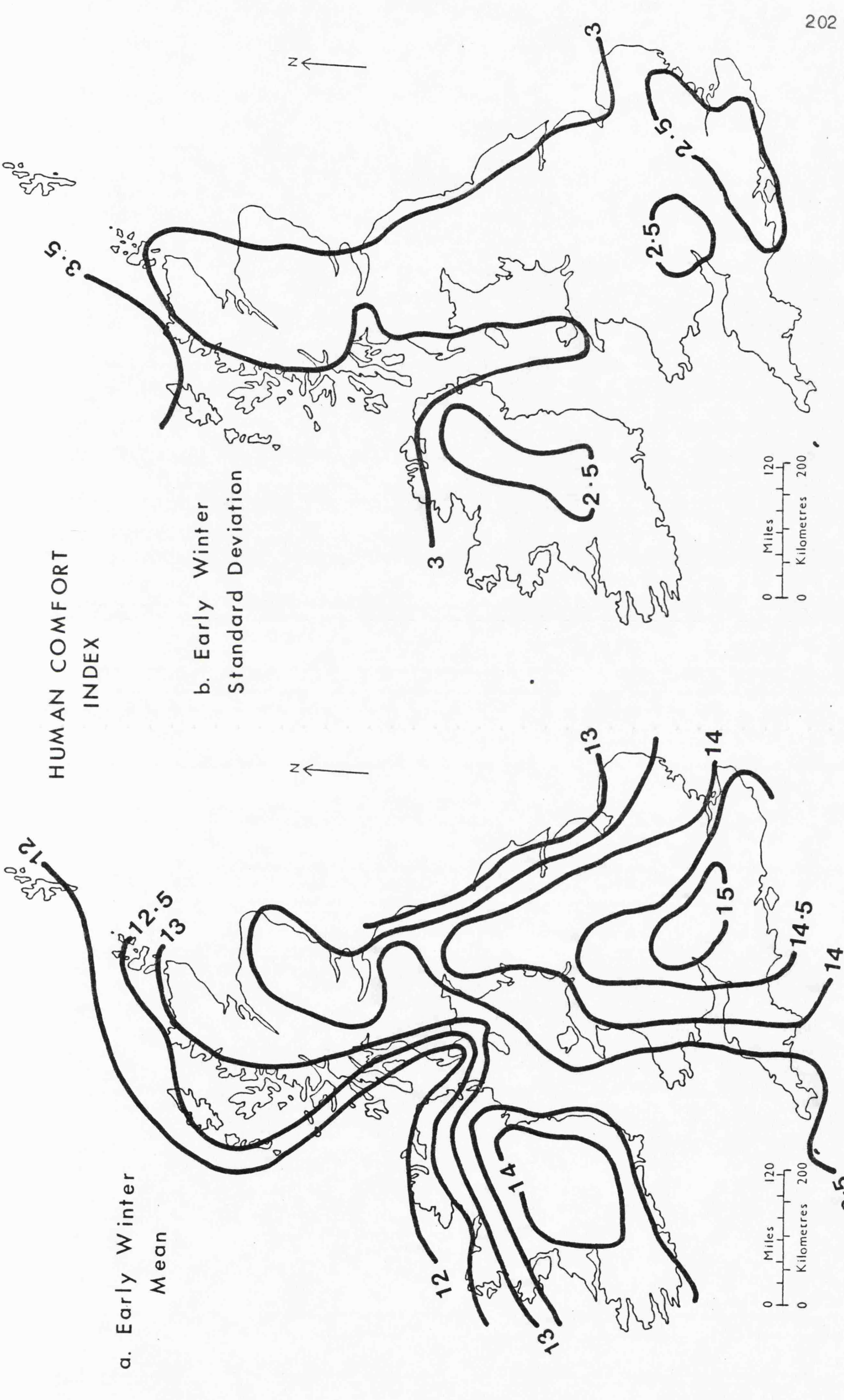

HUMAN COMFORT
INDEX
a. Early Winter
Mean
b. Early Winter
Standard Deviation
N
N
12
12·5
13
13
14
14
14·5
15
14
13·5
14
12
13
3·5
3
2·5
2·5
2·5
3
0 Miles 120
0 Kilometres 200
0 Miles 120
0 Kilometres 200

FIGURE 6.5.

other seasons. A coast to inland increase is the most marked trend in Early Winter, with the Midlands and south of England having the most favoured human comfort climate. A similar tendency for an inland maximum is found in Ireland together with a marked reduction of human comfort towards the north coast in particular.

The distribution of the standard deviation of the Human Comfort Index in Early Winter reflects the unsettled weather along both east and west coasts (Figure 6.5(b)). The range of the standard deviation is not large at 1.6 units and varies from 3.7 at Sule Skerry to 2.1 at Wattisham. The least variation in human comfort is found in the south east of England, the area around Ross-on-Wye and central Ireland which are also the areas with the highest mean values.

(v) Late Winter (Figure 6.6). In Late Winter the distribution of the mean Index (Figure 6.6(a)) shows a trend similar to that found in Early Winter with a north to south and a marked coast to inland increase. The seasonal range of mean values is the lowest varying by only 2.61 from 14.83 at Ross-on-Wye to 12.22 at Lerwick. In England and Wales these Late Winter values are the lowest of the year but over the north western coastal margins of the British Isles the values are lower in Early Winter. The most favourable human comfort climate of this season is in the English Midlands, the Home Counties, Gloucestershire, Wiltshire, Hampshire and Sussex with a maximum in Gloucestershire.

The general trend in the distribution of the standard deviation (Figure 6.6(b)) is a north west to south east one and varies from 3.9 at Malin Head to 2.1 at Ross-on-Wye, this maximum value being the maximum for the year. The variation, as measured by the standard deviation, shows similar values along the north coast of Devon and Cornwall as are found in south east England. Overall, the South Midlands and the Home

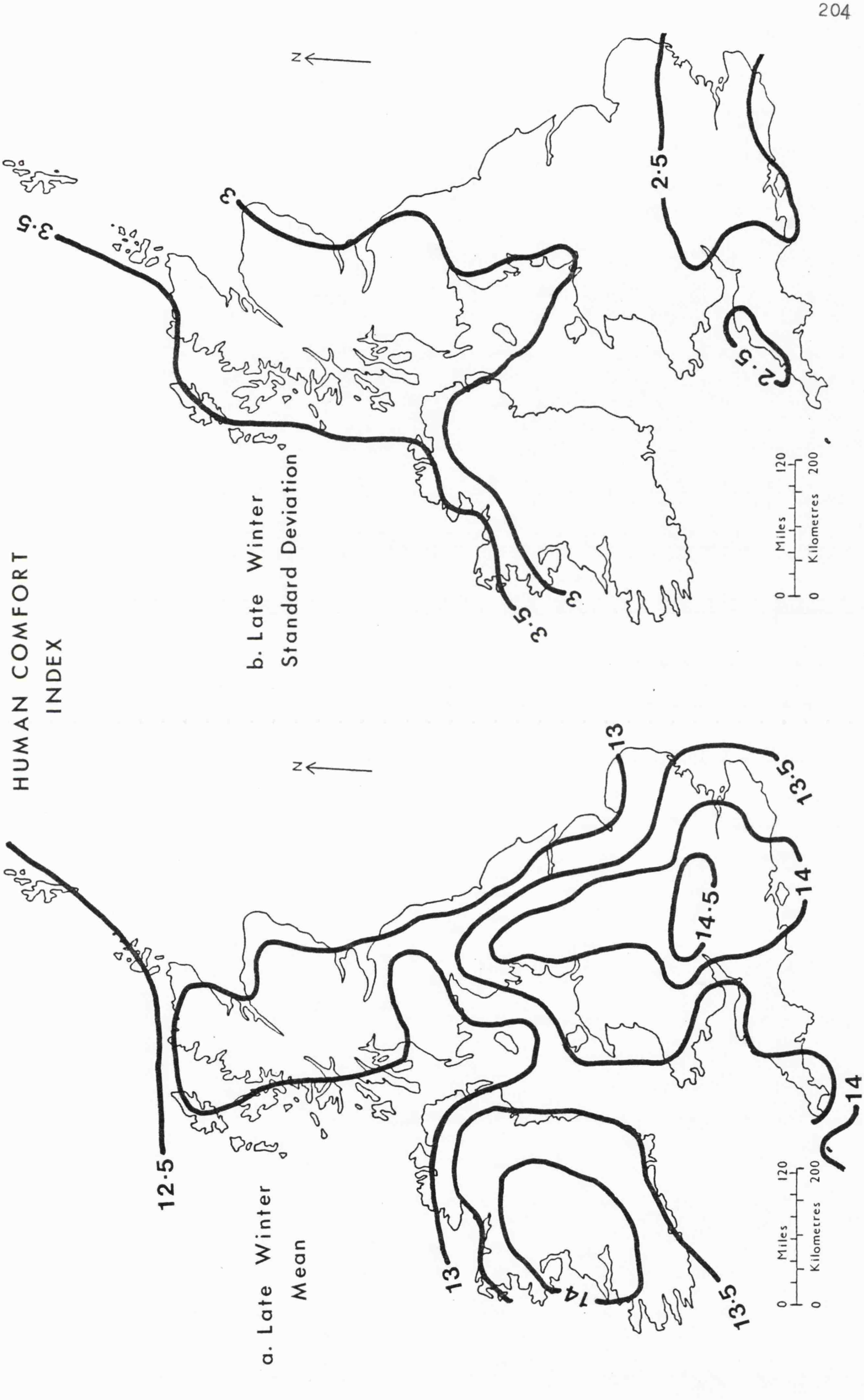

HUMAN COMFORT INDEX
a. Late Winter Mean
12·5
13
13·5
14
14·5
b. Late Winter Standard Deviation
3·5
3
2·5
N
Miles
Kilometres
0 120
0 200

FIGURE 6.6.

Counties of England appear to have the most favourable human comfort climate in the Late Winter season which, in general, is the least favourable season in the context of human comfort.

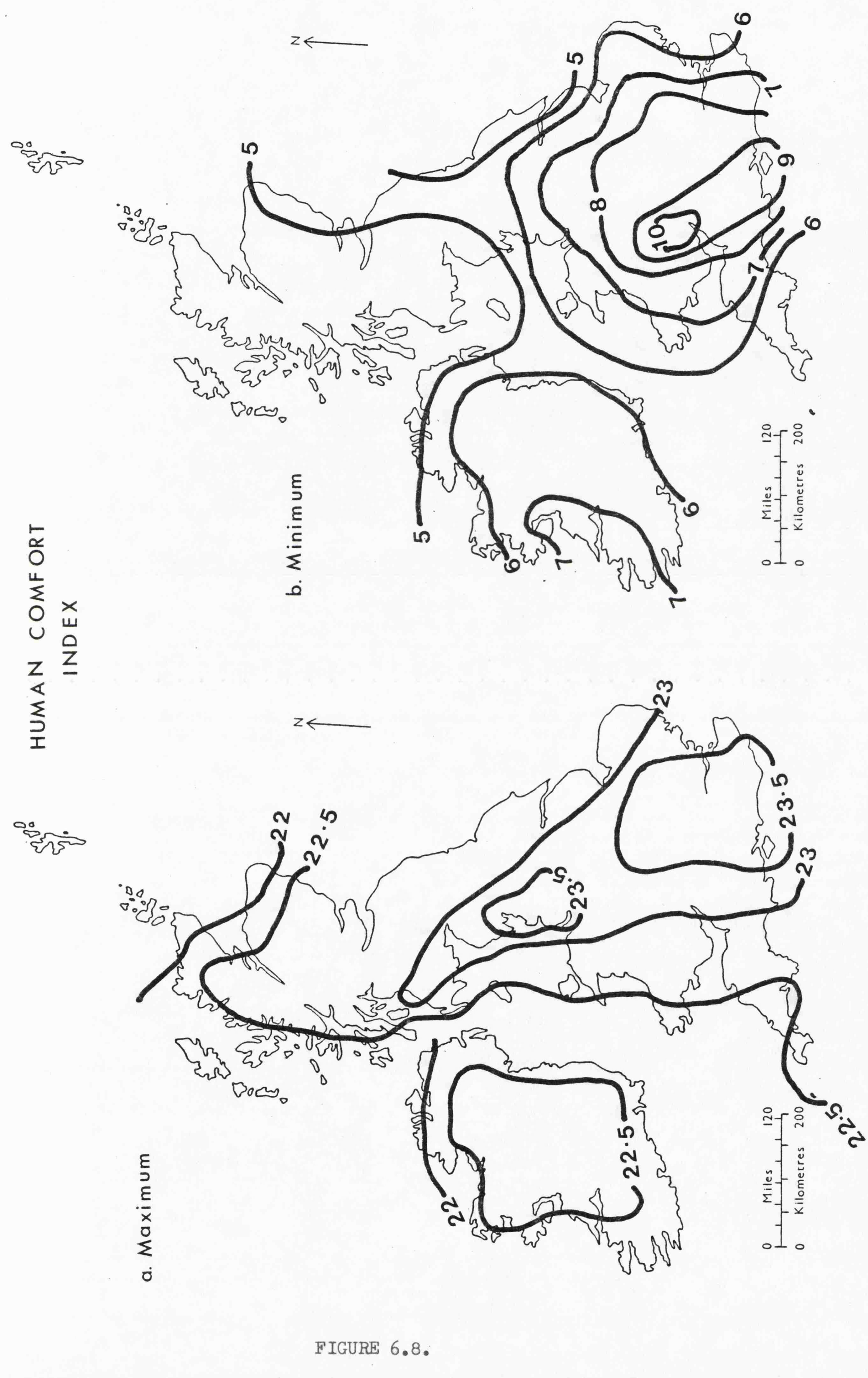
Having carried out a seasonal analysis of comfort using mean values it is important to also consider the annual mean and the range of the instantaneous values which is afforded by the use of the DWR data. The distributions of these variables are mapped in Figures 6.7 to 6.9.

(i) <u>Annual Mean Human Comfort Index</u> (Figure 6.7). The general trends which have been seen on the seasonal distribution of the Index are also revealed clearly on this map. The major trend is a north to south increase in the mean Human Comfort Index which ranges from 13.4 at Lerwick to 16.3 at Ross-on-Wye and superimposed on the distribution is a less well marked trend for a coast to inland increase. There is little variation in annual mean over the Midlands and North of England although the Index increases southwards towards south east England, Gloucestershire and the Scilly Isles which have the most favourable mean conditions. The central and western parts of Ireland are to be preferred to the rest of this country for human comfort which have values similar to those found in Scotland.

The annual standard deviation of the Index showed little variation or trend and is therefore not presented.

(ii) <u>Absolute Maximum Index</u> (Figure 6.8(a)). The distribution of the absolute maximum index shows, again, a north to south and coast to inland increase in human comfort with the highest value recorded being 23.9 at Cardington, London Airport, Kew and Gatwick and the lowest 21.3

FIGURE 6.7. The annual mean Human Comfort Index.



HUMAN COMFORT INDEX
a. Maximum
b. Minimum
N
22
22·5
23
23·5
5
6
7
8
9
10
Miles
Kilometres
0
120
200

FIGURE 6.8.

at Wick. A further feature revealed by the distribution is that the east coast of Scotland and England show a tendency for higher maxima than do western coastal areas at the same latitude. The maximum values recorded for the sample never exceeded the maximum value of the attitude scale which was 30 suggesting that the attitude scale is capable of measuring the upper extremes of human comfort which are experienced in the British Isles.

(iii) Absolute Minimum Index (Figure 6.8(b)). The distribution of this facet of the Human Comfort Index shows that, by contrast, the Index falls below the minimum scale value of six with an absolute minimum value of 4.1 being calculated for Sule Skerry. It is impossible to judge whether the scale can be extended to measure such conditions although the extension is not far below the limits of the attitude scale and is perhaps not relevant to the human comfort of the majority of people living in the British Isles who live some considerable distance from Sule Skerry. The problems of measuring the response to extremes of poor weather for human comfort is considered in the final chapter, and at this stage it seems reasonable to state that the northern peripheries of Scotland are the least favourable areas in the British Isles for human comfort although there is uncertainty as to the exact level of minimum comfort given the range of the attitude scale. The distribution shown in Figure 6.8(b) again reveals a north to south and coast to inland increase in human comfort with a highest minimum value of 10.4 at Ross-on-Wye. There is little difference between the east and west coasts in the minimum values of the Index. The range of the absolute minimum Index is 5.4 which is considerably higher than the range of the absolute maximum Index which was 2.6. The absolute minimum value of the Index gives an indication of the potential discomfort which may be experienced and shows marked spatial variation.

(iv) The Range of Values (Figure 6.9). The final facet of the human comfort climate to be considered here is the range of the comfort climate and the distribution of the absolute maximum less the absolute minimum Index of Human Comfort is shown in Figure 6.9. The lower this value is, the less the Index varies between extremes. The most variation is found in the coastal areas of Scotland and northern England with the Midlands and south coast of England having the least. This distribution emphasises the favourable weather in the Midlands and south of England which does not vary very much about a relatively high mean Index.

6.4 Conclusions

The main purpose of this research was to obtain an index which defined human comfort and this was achieved by conducting a questionnaire which calibrated people's attitudes to the weather which was measured at the same time. A basic concept of this research was that the attitude to the weather could be defined as 'some function' of the weather, this function being found by a multivariate analysis to produce an equation which has the general form:

$$\text{Attitude} = aX_1 + bX_2 + \ldots\ldots\ldots X_n \qquad (6.1)$$

where the X values are respondent and/or weather variables and the values a, b, etc. are the coefficients of the variables. Most other examples of indices of overall comfort have chosen the 'X' values arbitrarily and have invariably chosen the coefficients by examining the range of the weather variables and using the standard deviations to obtain coefficients (Davis, 1968) or by categorising the variable across its range (Maunder, 1962). The experiment described in this thesis aimed to obtain both the weather (X) variables and the coefficients (a, b, etc.) using relatively objective methods which have been described in the preceding

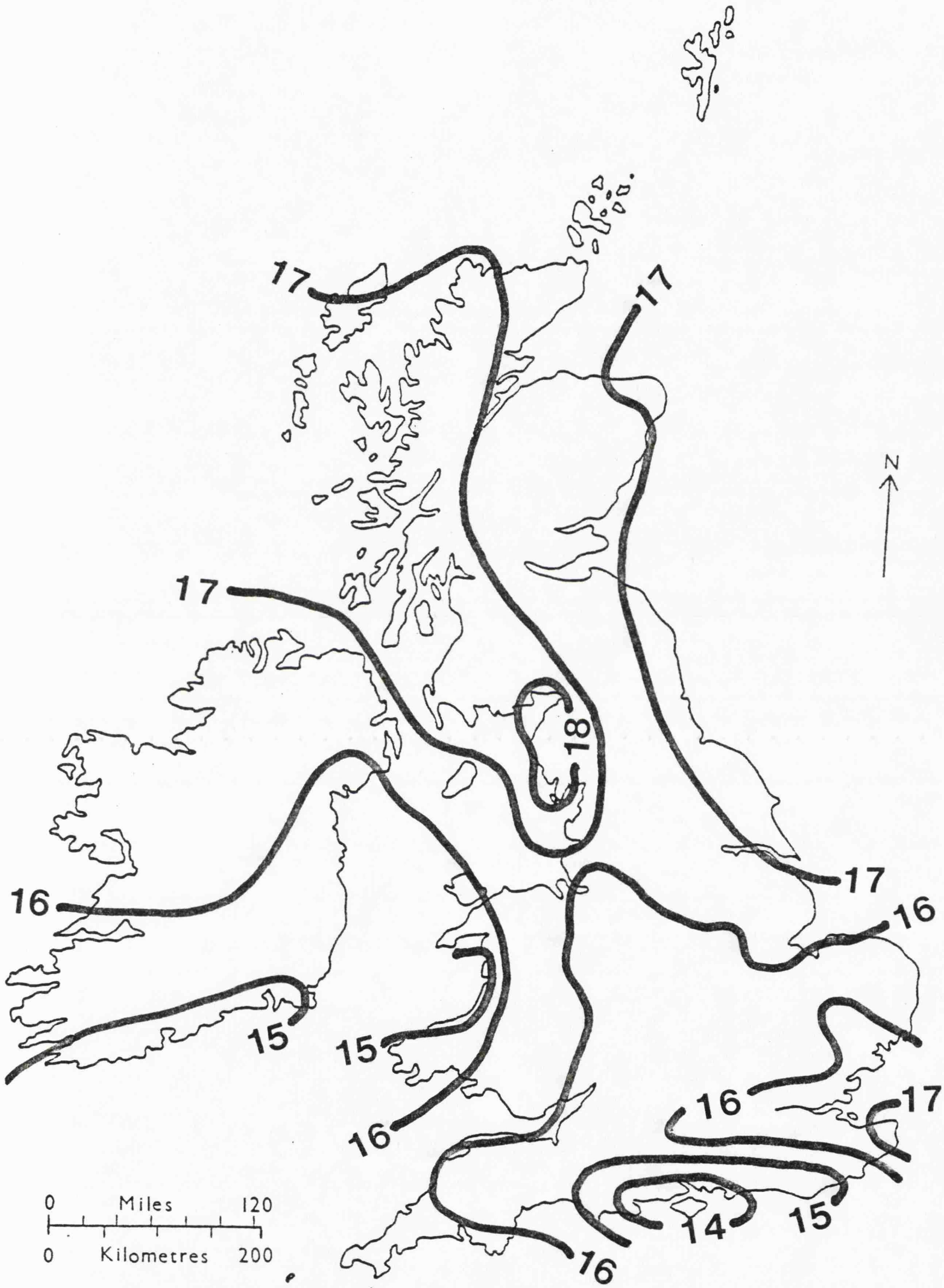


FIGURE 6.9. The range of the Human Comfort Index for the sample period.

chapters. The resulting Index and the subsequent mapping of the results represent a considerable innovation in the study of human comfort climatology.

The distributions of human comfort, both seasonally and annually, considered in this chapter present the first comprehensive study of a human comfort climatology and reveal that there are considerable spatial and temporal variations in human comfort. These variations show many features which are similar to those of the component variables whose distributions were examined in Chapter 5 and which showed a correspondence to the weather types on which the Lamb Natural Seasons are based (Lamb, 1950). Latitude and proximity to the coast are major controls on all the distributions of the human comfort climate presented in this chapter. The use of instantaneous data allowed an examination of the extremes of the Human Comfort Index and the resulting distributions present an indication of potential comfort and stress over the British Isles which appears to be related to latitude and distance from the coast with southern inland areas being the most favoured for human comfort.

One possibly surprising result is that the Midlands of England are found, in general, to be more favourable than the west coast at the same latitude. This runs contrary to the usual notion of an 'equable' maritime climate but is consistent with the combination of high wind speeds and high rainfall probability in west coast areas. It may, therefore, be cooler in the Midlands of England but it is probably pleasanter!

Chapter Seven

Retrospect and Prospect

7.1 Introduction

The research described in this thesis has been concerned with the relationship between man and his environment and has concentrated specifically on the weather which forms just a part of man's total environmental experience. Previous work in the field was reviewed in Chapter 1 which suggested that three major models have been adopted in the study of the relationship between man and weather. These models are summarized in Figure 7.1. A large number of environmental factors impinge on man's life, and energy balance studies have tried to incorporate as many weather elements as possible into a single energy balance equation. In contrast, laboratory experiments have involved isolating individual aspects of the environment, such as temperature, and assessing man's response to this variable. These two methods are concerned with relating man's physical and mental responses to the climate, be it indoor or outdoor. A third and very different approach, which was adopted for the current research is concerned with discovering the respondent's perception of the weather and from this to develop an index which is related to the weather as measured at the time of the response. The diagram shown in Figure 7.1(c) is based on Downs' (1970) schema for the study of geographical space perception and it can be seen that the current research was based on defining the weather and the image of that weather and was not concerned with the rest of the schema. This chapter discusses the need to expand the study of human comfort climatology and concludes with some recommendations as to the ways in which Downs' schema could be developed within this field.

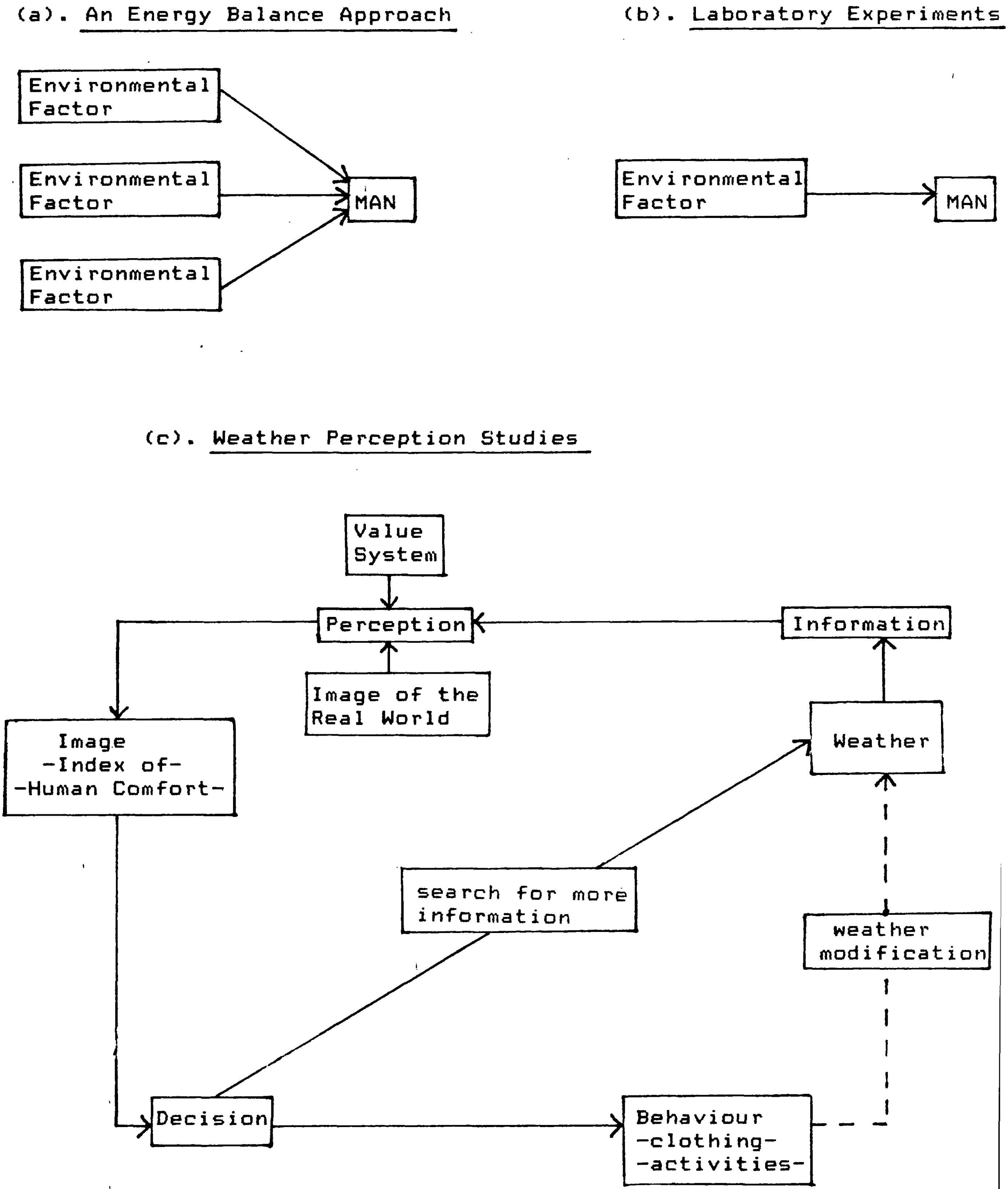


FIGURE 7.1. Three models which have been used in the study of the relationship between man and the weather.

The deficiencies in the previous work led to the setting up of the experiment with the methodology described in Chapter 2 and the results in Chapters 3 to 6. Essentially the experiment attempted to use social survey methods to elicit people's weather perception and then to synthesise a perceived 'climate' from the integration of these results into a Human Comfort Index. The climatologies of the component variables, such as the Windchill Index and the T.H.I. were useful and original by-products.

The study which has been described in this thesis was therefore in areas in which there was little published previous research experience to draw on. There are perhaps two other areas within climatology which have adopted social survey methods.

(i) In the examination of the value of weather forecasts (Maunder, 1969) where the major concern was to establish the frequency with which people watched or listened to the weather forecast and which item was of most interest. Sunshine and the related cloud cover were found to be the most important items to the 60% of the respondents who watched or listened to a weather forecast. The questions asked by Maunder were, however, ones of fact rather than opinion or cognition and as such his research does not have major parallels with the current work.

(ii) In natural hazard research, much of which to date has been concerned with climatic extremes, such as hurricanes, floods and snow, and the state of this field of research is summarized in Burton, Kates and White (1979). This research is arguably (Gold, 1980) the best research area within behavioural man-environment studies and is concerned with finding the image of a particular extreme weather situation (Figure 7.1(c)). At first sight, therefore, the natural hazard research field seems to hold useful analogies with the current work.

7.2 The Analogy with Natural Hazard Research

On closer inspection this analogy is less well marked because of the following four characteristics of hazards which differentiate them from the 'normal' weather events considered in the present work:

(i) Hazards are sharply defined in both time and space and the study of perception of hazards is therefore 'object' perception rather than 'environmental' perception (Ittelson, 1973). This distinction has been discussed for perception of landscapes by Unwin (1975) who noted that objects are observed from an outside position whereas the respondent is a participator in an environment.

(ii) The image of a hazard is probably univariate. A hurricane may involve combinations of weather elements, but the word most probably conjures up a single image.

(iii) The 'at risk' population is relatively well defined and in many studies is restricted to a particular class such as farmers, river and resource managers.

(iv) Adaptation to the hazard is usually social and long term, for example flood alleviation. The human body does not make any physiological adjustments to, say, hurricanes or avalanches.

These characteristics mean that although hazard perception studies may have the usual problems associated with the selection of an appropriate methodology (Chapter 2) they tend to work well. They are made simpler in that sampling the 'object' - the hazard - is not necessary or can be done by using its spatial variation as a way of selecting people at different levels of risk. For example, Saarinen (1966) considered farmers' attitudes to drought across a gradient of aridity in the Great Plains. Hazard research is further simplified by the fact that there is no need to elicit opinions as the hazard occurs and thus the research can rely on recall. There are also no complications due to short term adjustments such as clothing or sweating.

Weather perception is environmental perception and presents a considerable contrast in the range of problems experienced by the researcher in this field compared to those in natural hazard research. The weather is continuous and ongoing and hence there is a need to sample both it and the people as it occurs in order to obtain valid opinions. Simply obtaining a representative population presents sufficient problems in any social survey (Moser and Kalton, 1971) but is insufficient for weather perception research where recall is almost certainly inadequate. An attractive alternative is to use panel interviews in weather perception studies but, as discussed in Chapter 2, this is difficult to administer. The sampling unit is not a person's idea of an unvarying object, but is his idea of a continuously varying environmental phenomenon. The researcher attempting to measure weather perception has three sampling alternatives.

(i) Ideally, both the people and the weather should be sampled simultaneously. For the reasons discussed in Chapter 2 this is very difficult.

(ii) Control can be exerted over just the sample population whose perception is measured over a single weather event. As the pilot survey described in Chapter 2 showed, this reveals changes in perception by people, but not how perception varies with different weather conditions, unless a large number of surveys are carried out. The pilot survey indicated that it was reasonable to assume a normal distribution about a standard for any weather event.

(iii) Control can be exerted over the sample weather with a less well sampled population. If a normal distribution of responses for a given weather event can be assumed then this third alternative is a considerable improvement on the second and this was the method used in the experiment which has been described in this thesis.

An additional sampling problem for weather perception studies is that of spatial variation because of the possibility that perception may vary between places because of different experiences. This can be seen on Figure 7.1(c) as the effect of people's image of the real world which may affect their perception. The experiment described in Chapters 2 to 6 assumed that this spatial variation is not important although future research is required to test this.

Although natural hazard research is the best example of behavioural man-environment studies to date the foregoing discussion reveals that the analogy with weather perception studies is weak because of the differences between studying perception of an 'object', such as a hazard, and an 'environment', such as the weather in which the respondent is a participant rather than an observer. Weather perception studies therefore encounter peculiar problems compared to previous studies of man-environment relationships in the field of natural hazard research.

7.3 The Synthesis to Climate

Weather perception by itself is of interest, but to the geographer interested in spatial variation it is of more importance to look at the climate. The idea of climate involves the synthesis of the statistics of the weather including not only mean conditions but also variability and co-variation. For example it would be of interest to examine the variation in comfort over a day and to build up a synoptic climatology of comfort. The climatology has been referred to as the 'human comfort climate' in this thesis and there are at least two ways of producing this comfort climatology.

(i) The first begins by developing an index of comfort using either arbitrary variables and weightings (Maunder, 1962; Poulter, 1962) or by using more objective methods such as those used in this thesis and then examining the spatial and temporal variation of this index. The discussion in Chapter 1 revealed that although a number of indices have been developed only rarely have the resulting distributions been examined.

(ii) The second method approaches the problem of producing a climatology directly by eliciting respondents' perceptions of the climate as compared to the first method which develops an index for the instantaneous weather and then synthesises to the climate. This second approach is very different from that used in the experiment described in Chapters 2 to 6 and is considered in the next section.

7.4 Perception of Climate

The experiment described in this thesis approached the initial problems discussed in Chapter 1 by discovering people's attitudes to the weather in order to produce an Index of Human Comfort which was then mapped. The alternative approach, described in the last section, is to directly elicit the respondents' perception of the climate. This approach was also of interest to the present author for two reasons, first, as an additional methodology in a field which is lacking in standard methodologies and second, as a possible comparison for the results of the major experiment described in Chapters 2 to 6. An experiment was therefore conducted to examine the potential of such an approach and this is now described.

The experiment involved designing a methodology to extract people's information about the climatology of the British Isles. The survey which was carried out used maps of the British Isles which the respondent was asked to shade in. This experiment was not concerned with the respondents' knowledge of the exact location of the land and sea areas or the cities and towns and therefore there was little value in presenting the respondent with a blank sheet of paper on which to draw his climatology. A major problem in the experimental design was therefore concerned with the nature of the spatial 'clues' which should be given on the response map and, unfortunately, the literature to date gives no help regarding this matter. As a result it was decided to present the respondent with a clear, well drawn map of the study area on which was marked a number of major towns and cities to give some location clues and the land over 1000 feet was also marked, the final map being shown in Figure 7.2. The respondents were presented with two copies of this map and asked to shade in on the first map where they thought were the warmest area(s) and also where they thought were the coldest area(s); on the second map respondents shaded where they thought were the rainiest and driest areas. It was hoped that these maps would give an indication of the respondents' perception of the climatology of the British Isles. As in the first experiment, a street survey was adopted but, unlike the first experiment, it also involved quota sampling (Moser and Kalton, 1971) using the percentages in sex and age groups for the Leicestershire population as a base. Using this method 200 respondents were interviewed giving a total of 400 maps for analysis. The mapping exercise was found interesting by most respondents and no respondent was unable to attempt the questionnaire once it had been explained.

Conducting the questionnaire proved to be the simplest part of this experiment. In order to produce a composite map from the 400 individual maps a grid was laid over each map and the shading of each grid square examined. Various methods of examining the composite picture were

FIGURE 7.2. The response map used in the questionnaires.

considered, including mapping the distribution of the proportion of respondents who had shaded in squares in a particular way but this did not allow an examination of all the different shadings into a single map. The best method was found to be a coding scheme similar to that adopted by the present author in an undergraduate dissertation (Gaskell, 1976) for a similar problem and to that used independently by Green (1976) for examining businessmen's ideas of the business environment in England. The scheme is described in Appendix 7 and the resulting distribution of the respondents' perception of the climate of the British Isles is mapped in Figure 7.3 with five ordinally scaled groups being used for the map shading.

The distribution shown in Figure 7.3 reveals a general north west to south east improvement in the perceived climate of the British Isles. The Highlands and Islands of Scotland are seen as having the poorest climate with northern England and Wales being the next group. Eastern areas are, in general, seen to be more favourable than western areas at the same latitude with the exception of the south of England which is considered to be the most favourable area climatically in the British Isles. Although Ireland also has a west to east improvement in the perceived climate, the climate in Ireland appears to be considered more favourable than on the mainland at the same latitude. One of the reasons for conducting this experiment was as a comparison with the major experiment described in Chapters 2 to 6 especially the final map of comfort (Figure 6.7). Although the problems involved in the comparison of maps must be common experience in geography, little is written on the subject (Cliff and Ord, 1973; Taylor, 1977). A major problem in the comparison being described here is that the data from the main experiment are based on point information from the synoptic stations whilst the data in the second experiment are area based. In order to make the data comparable

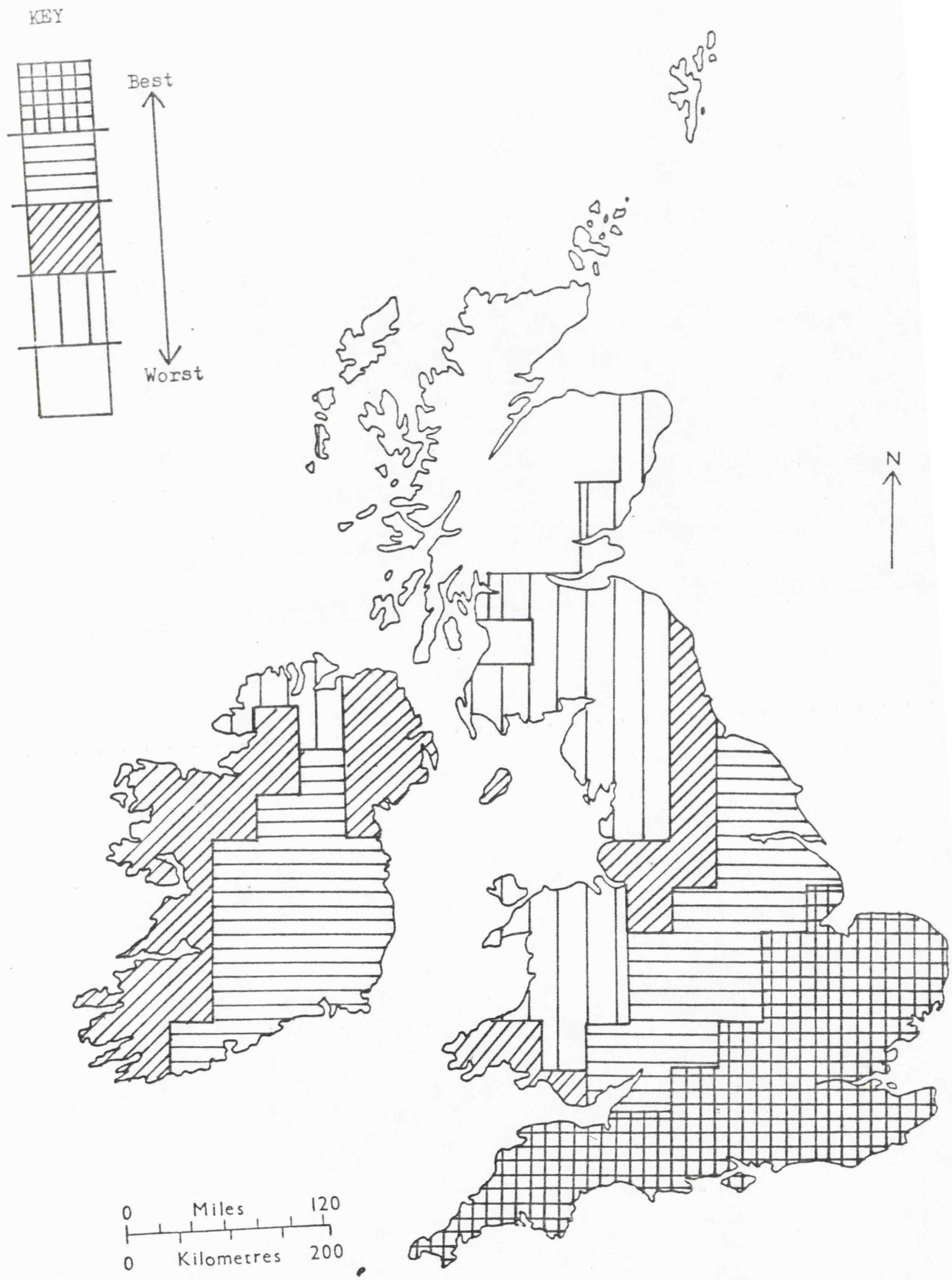


FIGURE 7.3. The composite map for the respondents perception of the climate.

the point based data were converted into data based on the grid squares used in the coding of the response maps by the FORTRAN programme shown in Appendix 8. The programme calculated the value of the Human Comfort Index for the centre of each square from the mean values for the six nearest synoptic stations weighted according to the inverse distance squared.

The grid square data for the Human Comfort Index (Figure 6.7) and for the perceived climatology (Figure 7.1) were compared using two methods. The first involved a regression analysis (Taylor, 1977) which produced a correlation coefficient of 0.785 indicating some similarity between the two distributions. The distribution of the residuals from this regression is shown in Figure 7.4 and reveals a number of points which are worthy of comment. The higher areas of Scotland, England and Wales are picked out markedly on this map as having large negative residuals. This is probably due to the synoptic data giving an inadequate cover of the higher areas and therefore reducing the validity of any analysis in these areas, a point which was noted in Chapter 5. Parts of Ireland and the Shetland Islands have been overestimated by the respondents, a feature which could be due to the coding method used (Appendix 7), for example these areas, which are peripheral to the mainland, were often left unshaded and this increased the coding compared to the mainland areas at the same latitude which were often shaded as being unfavourable. Some of the area south of a line joining the Wash and the Severn also shows an overestimation by the respondents, which is a result of the large proportion of people who shaded in the whole of the south of England as being 'warm' and 'dry'. As indicated by the correlation coefficient, the fit is in general a good one with 157 of the 245 squares falling within the residual range of plus and minus one standard deviation from zero.

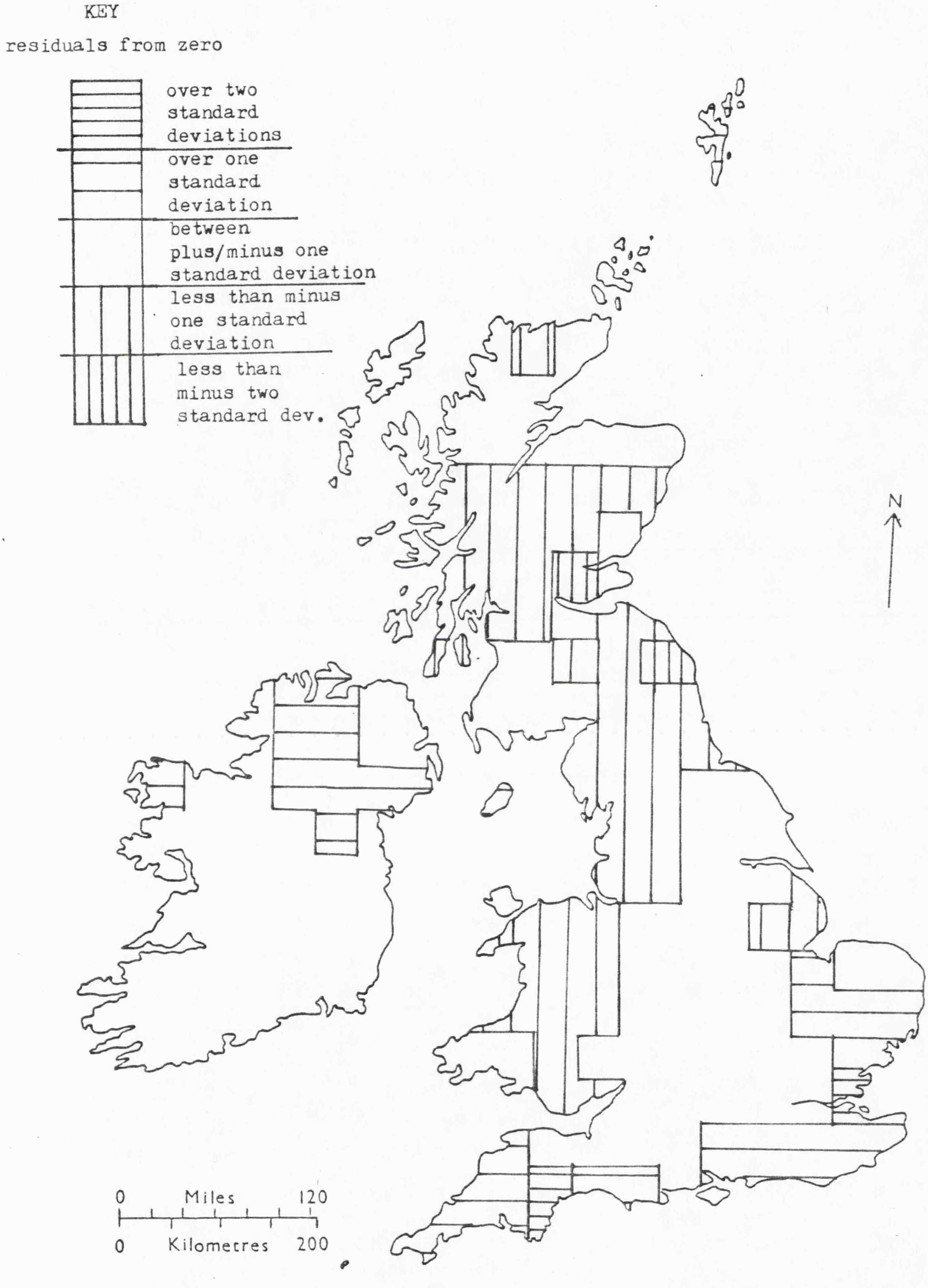


FIGURE 7.4. The residuals from the regression of the composite response map (Figure 7.3) with the Human Comfort Index map (Figure 6.7).

The second method of map comparison involved an examination of the differences between the spatial distributions of the Human Comfort Index and that of the composite perceived climatology. In order to do this the values of the Human Comfort Index for each square were divided into five equal ordinal groups and the distribution mapped in a manner similar to the perceived climate (Figure 7.3). A map was then drawn showing, for each grid square, whether that square was shaded in the same group on the two maps, or whether the respondent had under- or over-estimated the value of the Human Comfort Index. The resulting distribution was very similar to that shown in Figure 7.4 for the residuals, although there were more differences due to the nature of the technique which does not allow any measurement of the extent of the difference, the squares are either in the same group or they are not. This is a considerable disadvantage of this method in that there is no allowance for error which probably needs to be made when questionnaire maps are being analysed. The use of the Cliff and Ord (1973) joins count test for spatial autocorrelation revealed that the pattern of mismatches was not random. The reasons for this most probably have more to do with the techniques adopted than to real misperception, for example, the marking of the high land on the response maps resulted in the respondents making allowance for altitude in contrast to the mapping of the distribution of the Human Comfort Index (Figure 6.7) in which the higher areas were, in general, unrepresented by the data. As formulated the experiment cannot distinguish between the possible reasons for the difference between the results of the two experiments and the use of the differences maps and the associated joins count test tend to exaggerate the problems by their inflexibility. It can be concluded that the use of correlation coefficients presents a better methodology for such a study.

This discussion of the methodological problems involved in the study of the perceived climatology of the British Isles considers many problems which are common to any study of spatial perception which take such a direct approach to the problem and indicates that this method of deriving a human comfort climatology is no simpler than the indirect approach used in the experiment which has been described in Chapters 2 to 6. One contrast, not mentioned so far, is that the climate is not so great a stimulus as the weather except for long term decision and this may have affected the results. There are also considerable problems in producing a composite map with the results being constrained by the scoring methods used. A comparison of some form of 'objective' map with a 'perceptual' map is not an uncommon task and it is hoped that the discussion has highlighted areas in which problems can occur and where further research is needed.

The methodological problems in this second, trial experiment were clearly numerous but, in retrospect, it can be seen that there is a more fundamental problem which is concerned with the exact nature of what was being measured by the survey. The initial intention had been to examine people's perception of the climatology of the British Isles but it is more probable that the survey measured people's knowledge of this climatology, which is just a part of their total perception. This does not invalidate the comparisons but puts a different complexion on them, with areas of discrepancy being due to poor knowledge rather than to an incorrect perception of that particular area. This problem is fundamental in all similar studies and researchers should take care to ensure that their initial problem definition is valid before tackling the problems involved in the selection of a methodology.

7.5 Recommendations for Future Research

This chapter has been concerned with the lessons learned from the research described in this thesis with particular reference to the methodological problems involved. In the light of the experiment discussed in Chapters 2 to 6 and the comments made in this chapter it is appropriate to conclude this thesis with some recommendations for future research within the field of human comfort climatology. The eight recommendations are made with particular reference to the schema shown in Figure 7.1 and suggest ways of strengthening the field of human comfort climatology within this schema which is adapted from Downs (1972).

(i) This first recommendation concerns the need to measure the total weather fully to ensure that the information received by the respondent is represented as accurately as possible. Despite the fact that a considerable number of weather measurements were made at the time of each response it is possible that further variables may be more appropriate, for example an improved sunshine variable, although, as was noted in Chapter 3, sunshine is not incorporated in standard daily meteorological information which presents problems for examining spatial and temporal variations of this variable. Increasing the number of variables and the sophistication of measurement also presents practical problems at the time of the questionnaire when the measurements need to be made quickly to ensure compatibility with the questionnaire response.

(ii) There is a need for further examination of the physiological effect of the total weather and not just parts of the weather such as windspeed and temperature. The inclusion of improved physiological indices in any analysis of weather perception would increase knowledge about the information received by respondents about the weather.

(iii) The Index of Human Comfort, which has been described in this thesis, was derived using multiple regression analysis and left 40% of unexplained variance. More research is needed to discover whether this is a result of inadequate measurement of the information or whether it is due to respondent variation because of varying value systems and images of the real world.

(iv) The future prospects for the field of human comfort climatology clearly involve the development of more suitable and standard methodologies for the measurement of the perception of weather and climate. There is also a requirement for greater clarity in the aims and uses of particular methodologies and there needs to be a consideration of how the individual responses can be related to general patterns in both time and space.

(v) Alternative methodologies may be required for the wider range of climatic conditions which are experienced, and considered to be normal, in the British Isles, or even on a global scale. The weather which occurred during the survey was never sufficiently poor to dissuade 25 people from responding to the questionnaire. Problems may be evident, however, if particularly bad, yet 'normal', weather occurs, for example snow or low winter temperatures, and methodologies other than a street questionnaire survey may be required in such circumstances. It is impossible to simulate weather in laboratory conditions but it may be possible to suggest a wide range of weather conditions by using photographs or films and Saarinen (1966) and Saarinen and Sims (1969), for example, described the use of the Thematic Apperception Test in natural hazard work. They presented farmers with a picture and asked them to tell a story about the picture. One of their most famous pictures is of a Great Plains farmer harvesting his crop with a large storm cloud developing above him. Because responses vary considerably in such an open-ended questionnaire the coding up and generalisation can present problems. Films could also be appropriate and may be more effective in that sound could also be used, stereoscopic films could be even more valuable although expensive, and it is believed that these techniques have not been used to date. The problem of using films and photographs is that it is difficult to ascertain what the respondent is responding to; it may be the effectiveness of the photography rather than to the weather being depicted. Although problems will exist when these techniques are used it is difficult to suggest any other methodologies which could be used for measuring attitudes to relatively extreme weather. One particularly interesting development could be the use of stereoscopic films in a climatic chamber which simulated the temperature associated with the film. The whole field of measuring instantaneous response to the weather for the wide range of weather conditions which can be considered 'normal' where they occur presents a large potential field for future research.

(vi) There is a need to examine the relationship between the image, that is the Index of Human Comfort, and behaviour. The experiment described in Chapters 2 to 6 was only concerned with behaviour in that the estimated clo unit was included in the analysis, although it was excluded from the final index because of its close relationship with temperature. The weather clearly does affect behaviour with activities being changed as a result of the weather conditions. A wide range of weather conditions have an effect on behaviour although it is not always possible to assess this using a street survey as used for the experiment described in Chapters 2 to 6, if, for example, snow is falling. It is probable that a diary survey would be an appropriate methodology for studying the relationship between the weather and behaviour.

(vii) There is a requirement for more research to be conducted into the ways in which a climatology can be derived from an index of human comfort. This climatology may have important implications for holidays and fuel consumption, for example.

(viii) The climate may have longer term influences on behaviour, although no work exists on this topic. The experiment on perception of climate described in this chapter revealed that considerable problems exist in the discovery of the nature of this perception.

The recommended avenues for research would strengthen the field of human comfort climatology and develop it along the lines suggested in the schema adapted from Downs (1972) (Figure 7.1). Doornkamp and Warren (1980) see work in fields such as human comfort climatology as leading to a closer co-operation between physical and human geography in the 1980s and it is hoped that the research described in this thesis has shown the potential of such a study. In addition to intra-disciplinary links studies in human comfort climatology in particular and man-environment studies in general give the researcher the impetus to encourage fruitful links between geography and other disciplines and to develop common links of interest by combining differing expertises to the solution of problems along a common frontier.

APPENDICES AND BIBLIOGRAPHY

APPENDIX I

```
COMMENT          PROGRAMME USED TO ANALYSE THE QUESTIONNAIRE DATA
COMMENT          USING A MULTIPLE REGRESSION WITH DUMMY VARIABLES
COMMENT
RUN NAME         ANALYSIS OF QUESTIONNAIRE DATA
FILE NAME        QUESTIONNAIRE DATA
COMMENT
COMMENT          LIST THE INPUT DATA AND THEIR FORMAT
COMMENT
VARIABLE LIST    DAYNO,QUENO,INDEX,SEX,AGE,FOR,CLO,TD,TW,VEL,RAIN,
                 SUN,CLOUD,RH,THI,WCH,PRES,TD1,TD2,TD3,SUN1,SUN2,SUN3,PWC
INPUT FORMAT     (1X,9F8.3/1X,9F8.3/1X,6F8.3)
COMMENT
N OF CASES       750
INPUT MEDIUM     DISK
COMMENT
COMMENT          SET UP THE DUMMY VARIABLES FOR THE CATEGORICAL DATA
COMMENT
IF               (SEX EQ 1) D1=1
IF               (AGE EQ 25) D2=1
IF               (AGE EQ 35) D3=1
IF               (AGE EQ 45) D4=1
IF               (AGE EQ 55) D5=1
IF               (AGE EQ 65) D6=1
IF               (FOR EQ 1) D7=1
COMMENT
IF               (RAIN EQ 1) D8=1
IF               (SUN EQ 1) D9=1
IF               (SUN EQ 2) D10=1
IF               (SUN EQ 3) D11=1
IF               (SUN EQ 4) D12=1
IF               (CLOUD EQ 3) D13=1
IF               (CLOUD EQ 4) D13=1
IF               (CLOUD EQ 5) D13=1
IF               (CLOUD EQ 6) D14=1
IF               (CLOUD EQ 7) D14=1
IF               (CLOUD EQ 8) D14=1
IF               (SUN1 EQ 1) D15=1
IF               (SUN1 EQ 2) D16=1
IF               (SUN1 EQ 3) D17=1
IF               (SUN1 EQ 4) D18=1
IF               (SUN2 EQ 1) D19=1
IF               (SUN2 EQ 2) D20=1
IF               (SUN2 EQ 3) D21=1
IF               (SUN2 EQ 4) D22=1
IF               (SUN3 EQ 1) D23=1
IF               (SUN3 EQ 2) D24=1
IF               (SUN3 EQ 3) D25=1
IF               (SUN3 EQ 4) D26=1
COMMENT
COMMENT          SET UP DUMMY VARIABLES FOR THE SEASONS
COMMENT
IF               (DAYNO GT 6 AND LT 13) D27=1
IF               (DAYNO GT 12 AND LT 19) D28=1
IF               (DAYNO GT 18 AND LT 25) D29=1
IF               (DAYNO GT 24) D30=1
COMMENT
COMMENT          SET UP VARIABLES FOR EXPECTED TEMPERATURES FOR THE
COMMENT          SEASON=TEMP.-MEAN SEASONAL TEMP.
COMMENT
IF               (DAYNO LT 7) MTP=TD-5.087
IF               (D27 EQ 1) MTP=TD-12.68
IF               (D28 EQ 1) MTP=TD-17.633
IF               (D29 EQ 1) MTP=TD-13.487
IF               (D30 EQ 1) MTP=TD-5.77
COMMENT
COMMENT          PRODUCE ONE-DIMENSIONAL HISTOGRAMS AND ASSOCIATED STATISTICS
COMMENT
FREQUENCIES      GENERAL=ALL
OPTIONS          6,8,9
STATISTICS       ALL
COMMENT
COMMENT          PRODUCE 2-DIMENSIONAL SCATTERGRAMS AND ASSOCIATED STATISTICS
COMMENT
SCATTERGRAM      INDEX WITH SEX TO PWC/
STATISTICS       ALL
COMMENT
COMMENT          CARRY OUT MULTIPLE REGRESSION FOR INDEX WITH ALL
COMMENT          THE VARIABLES
COMMENT
REGRESSION       VARIABLES=INDEX,D1 TO D7,CLO TO VEL,D8 TO D14,RH TO TD3,
                 D15 TO D30,MTP/
                 REGRESSION=INDEX WITH D1 TO MTP (2)/
COMMENT
COMMENT          CARRY OUT FINAL MULTIPLE REGRESSION
COMMENT
                 REGRESSION=INDEX WITH D8,D13,D14,THI,WCH,PRES (2)/
STATISTICS       2,4,6,7
FINISH
```

The SPSS programme used to analyse the questionnaires.

APPENDIX 2

A BASIC programme to calculate the Siple and Passel (1945) Windchill Index and the Thom (1959) Temperature Humidity Index.

```
5 REM A PROGRAMME TO CALCULATE THE T.H.I. AND THE
6 REM SIPLE AND PASSEL WINDCHILL INDEX
7 REM
10 PRINT 'INPUT THE TEMP. IN DEG.C.,TO END PROG. TYPE 999';
20 INPUT T
30 IF T=999 GO TO 200
40 PRINT 'INPUT THE WET BULB TEMP. DEG.C.';
50 INPUT W
60 PRINT 'INPUT THE WINDSPEED IN M/S';
70 INPUT F
80 PRINT
90 REM CONVERT TEMP TO DEG.F.
100 LET T1=(T*9)/5+32
110 LET W1=(W*9)/5+32
120 REM CALCULATE THE T.H.I.
130 LET I=0.4*(T1+W1)+15
140 REM CALCULATE THE WINDCHILL INDEX
150 LET I2=(10.45+10*SQR(F)-F)*(33-T)
160 PRINT 'THE THI IS',I
170 PRINT 'THE WINDCHILL INDEX IS',I2
180 PRINT
190 GO TO 10
200 STOP
210 END
```

APPENDIX 3

The sample days on which the survey was conducted

1. Late Winter

26th January 1978
1st February 1978
6th March 1978
8th March 1978
13th March 1978
14th March 1978

2. Spring

12th April 1978
15th April 1978
27th April 1978
23rd May 1978
8th June 1978
14th June 1978

3. High Summer

5th July 1978
10th July 1978
3rd August 1978
10th August 1978
16th August 1978
31st August 1978

4. Autumn

25th September 1978
12th October 1978
18th October 1978
24th October 1978
8th November 1978
15th November 1978

5. Early Winter

5th December 1978
6th December 1978
11th December 1978
18th December 1978
11th January 1979
15th January 1979

A FORTRAN programme to uncode the Daily Weather Report data.

```
C  A PROGRAMME TO READ IN THE DAILY WEATHER REPORT DATA IN ITS CRUDE
C  FORM AND TO PRINT IT OUT IN A MORE READABLE FORM TOGETHER WITH
C  THE SIPLE AND PASSEL WINDCHILL AND THE TEMPERATURE HUMIDITY INDICES
C
C  PROGRAMME WRITTEN BY ANNE MUMFORD IN 1978.
C
      PROGRAM DWR(INPUT,TAPE3,TAPE2,TAPE1=INPUT)
C
C  THE DATA ARE READ IN FROM CARDS WHICH HAVE EITHER ONE OR TWO
C  STATION DAYS PER CARD.THE TOTAL NUMBER OF STATION DAYS IS COUNTED.
C
      DIMENSION LIN1(35),LIN2(35)
      INTEGER A1,A2
      N=0
    5 READ(1,100)A1,LIN1,A2,LIN2
  100 FORMAT(2(I3,35A1))
      IF(A1.EQ.999)GO TO 160
      IF(A1.GT.0)N=N+1
      IF(A2.GT.0)N=N+1
      IF(A2.EQ.0)GO TO 150
      IF(A1.EQ.0)GO TO 151
      WRITE(3,30)A1,LIN1,A2,LIN2
   30 FORMAT(I3,1X,35A1/I3,1X,35A1)
      GO TO 5
  150 WRITE(3,40)A1,LIN1
   40 FORMAT(I3,1X,35A1)
      GO TO 5
  151 WRITE(3,41)A2,LIN2
   41 FORMAT(I3,1X,35A1)
      GO TO 5
  160 REWIND 3
C
C  THE DATA ARE READ FROM TAPE3 IN FIXED FORMAT
C
      DO 10 I=1,N
      READ(3,170)NDY,NST,NC,NFF,NWW,NPP,NT,NTD
  170 FORMAT(I3,1X,I4,1X,I1,2X,I2,3X,I2,2X,I3,I2,7X,I2,4X)
      DY=FLOAT(NDY)
      ST=FLOAT(NST)
      C=FLOAT(NC)
      FF=FLOAT(NFF)
      WW=FLOAT(NWW)
      PP=FLOAT(NPP)
      T=FLOAT(NT)
      TD=FLOAT(NTD)
C
C  CONVERT WINDSPEED TO M/S
C
      F=FF*.5148
C
C  CONVERT PRESSURE FROM CODED FORM TO MB.
C
      IF(PP.GE.501)GO TO 200
      P=(PP/10)+1000
      GO TO 210
  200 P=(PP/10)+900
```

```
C
C  TRANSFORM TEMPERATURES FROM CODED FORM TO DEGREES C.
C
  210 IF(T.LT.50) GO TO 220
      TT=0-(T-50)
      GO TO 230
  220 TT=T
  230 IF(TD.LT.50) GO TO 240
      DP=0-(TD-50)
      GO TO 250
  240 DP=TD
C
C  CALCULATE THE SATURATION VAPOUR PRESSURE FOR AIR TEMPERATURE
C  AND DEW POINT TEMPERATURE USING AN APPROXIMATE POLYNOMIAL.
C
  250 B0=6.107799961
      B1=4.436518521E-01
      B2=1.428945805E-02
      B3=2.650648471E-04
      B4=3.031240369E-06
      B5=2.034080948E-08
      B6=6.136820929E-11
      E=(B0+TT*(B1+TT*(B2+TT*(B3+TT*(B4+TT*(B5+(TT*B6)))))))
      E1=(B0+DP*(B1+DP*(B2+DP*(B3+DP*(B4+DP*(B5+(DP*B6)))))))
C
C  CALCULATE THE RELATIVE HUMIDITY
C
      RH=(E1/E)*100
C
C  CALCULATE THE WINDCHILL INDEX
C
      B=((10*SQRT(F))+10.45-F)*(33-TT)
C
C  CALCULATE THE TEMPERATURE-HUMIDITY INDEX
C
      L=(TT*9)/5+32
      BH=RH/100
      X=L-0.55*(1-0.01*BH)*(L-58)
C
C  EXAMINE THE PRESENT WEATHER CODE TO SEE IF IT IS RAINING
C  IF IT IS R=1,IF NOT R=0
C
      IF(WW.LT.50)GO TO 260
      R=1
      GO TO 270
  260 R=0
C
C  WRITE THE TRANSFORMED DATA TO THE OUTPUT TAPE
C
  270 WRITE(2,300)DY,ST,C,F,WW,P,TT,RH,B,X,R
  300 FORMAT(5F11.5,1F11.4,5F11.5)
   10 CONTINUE
      STOP
      END
```

APPENDIX 5.

A FORTRAN programme to calculate mean values for various weather elements from the Daily Weather Report data.

```
C  A PROGRAMME TO CALCULATE THE MEANS AND STANDARD DEVIATIONS FOR
C  DATA DERIVED FROM A 5% SAMPLE OF DAILY WEATHER REPORTS FOR 1963-1977.
C
C PROGRAM WRITTEN BY ANNE MUMFORD IN JANUARY 1979
C
      PROGRAM DWR(INPUT,OUTPUT,TAPE2=INPUT,TAPE9=OUTPUT)
C
C ARRAY FOR NO. OF DAYS IN EACH SEASON
C
      DIMENSION NDAYS(5)
C
C ARRAY FOR STATION NOS. PRESENT
C
      DIMENSION NSTN(63)
C
C ARRAY FOR ANSWERS
C
      DIMENSION ANS(63,25)
C
      REAL ND,L
C
C NO.OF STATION DAYS IN EACH SEASON
C
      DATA(NDAYS(I),I=1,5)/2791,3235,3375,2787,2518/
C
C STATION NOS.
C
      DATA(NSTN(KI),KI=1,63)/5,10,22,26,49,75,91,100,131,135,140,141,162
     1,171,204,222,244,257,261,262,302,318,334,354,360,395,396,414,462,4
     185,495,497,502,534,559,578,586,590,627,628,703,707,715,746,772,775
     1,776,797,804,809,817,827,862,871,894,917,952,953,962,965,969,976,9
     180/
C
C STATION NOS. PUT IN COLUMN 19 OF ARRAY 'ANS'
C
      DO 1001 I=1,63
      ANS(I,19)=NSTN(I)
 1001 CONTINUE
C
C LOOP FOR EACH OF LAMBS SEASONS,1=LATE WINTER,2=SPRING,3=HIGH SUMMER
C 4=AUTUMN,5=EARLY WINTER
C
      DO 60 NSEA=1,5
C
C ARRAY 'ANS' COLS. 1-18 AND 20 -25 SET TO ZERO
C
      DO 690 I=1,63
      DO 690 J=1,18
      ANS(I,J)=0.0
  690 CONTINUE
      DO 691 I=1,63
      DO 691 J=20,25
      ANS(I,J)=0.0
  691 CONTINUE
C
      NEND=NDAYS(NSEA)
      WRITE(9,1000)NSEA
 1000 FORMAT(1H1,14HSEASON NUMBER ,I2//)
C
C LOOP FOR EACH STATION DAY
C
      DO 70 K=1,NEND
C
C READ THE TRANSFORMED D.W.R DATA FROM TAPE2
C DY= DAY NUMBER IN SAMPLE (TOTAL=274);ST=STATION NO.;C=CLOUD IN OCTAS;
C F=WIND SPEED IN M/S;WW=PRESENT WEATHERCODE;P=PRESSURE IN MB.;TT=TEMP.INDEG.C.;
C RH=REL.HUMIDITY(%);B=SIPLE AND PASSLE WINDCHILL INDEX;X= TEMP.HUMIDITY INDEX;
C R=PRESENCE/ABSENSE OF RAIN(1/0)
C
      READ(2,201)DY,ST,C,F,WW,P,TT,RH,B,X,R
  201 FORMAT(5F11.5,1F11.4,5F11.5)
```

```
C
C CALCULATE WINDCHILL AND CLOTHING REQUIREMENTS USING STEADMAN(1971)
C
C L=TEMP. IN DEG. F.
      L=(TT*9)/5+32
C
C CONVERT WIND SPEED TO M.P.H.
C
      FM=F*2.2369363
C
C CALCULATE WIND VEL. AT GROUND FOR A PERSON MOVING AT 3M.P.H.
C
      IF(FM.GE.6.4) GO TO 721
      FEQ=(FM*FM+10+7*(6.4-FM)**.5)**.5
      GO TO 722
  721 FEQ=(FM*FM+10)**.5
C
C  CALCULATE RADIATIVE HEAT LOSS
C
  722 HR=.0135*(4*((TT+273)/100)**3+.3*((TT+273)/100)**2)
C
C CALCULATE CONVECTIVE HEAT LOSS
C
      HC=(.67-.0008*L)*FEQ**.75
C
C CALCULATE  SURFACE RESISTANCE
C
      RS=1/(HR+HC)
C
C CALCULATE STEADMAN WINDCHILL INDEX
C
      STW=(30-TT)/RS
C
C CALCULATE CLOTHING REQUIREMENTS
C
      A1=.053*(37-TT)+(.03*(30-TT))/RS+(.12*(30-TT))/(.5+RS)
      A2=.85*(30-TT)
      RF=(A2-RS*(41.1-A1))/(41.1-A1)
      DF=1.3*RF
      DF=DF*10
C  CALCULATE THE HUMAN COMFORT INDEX AS OBTAINED FROM MULTIPLE REGRESSION
C
C SET UP DUMMY VARIABLES FOR RAIN AND CLOUD
C
      IF(WW.GE.50) GO TO 965
      DR=0
      GO TO 964
  965 DR=1
  964 IF(C.LT.3) GO TO 966
      IF (C.LT.6) GO TO 967
      DC2=1
      DC1=0
      GO TO 968
  966 DC1=DC2=0
      GO TO 968
  967 DC1=1
      DC2=0
  968 HCM=1.9101112+0.36048472E-01*X-0.41624755E-01*STW-2.0030185*DC1-4.
     13347928*DC2-2.5857233*DR+0.19470314E-01*P
C
      DO 700 I=1,63
C
C ST= STATION NUMBER
      IF(ST.EQ.NSTN(I)) GO TO 705
      GO TO 700
C
C CALCULATE TOTAL SUM AND SUM OF SQUARES FOR EACH VARIABLE FOR EACH STATION
C
  705 NROW=I
      ANS(NROW,1)=ANS(NROW,1)+1
      ANS(NROW,2)=ANS(NROW,2)+C
      ANS(NROW,3)=ANS(NROW,3)+F
      ANS(NROW,4)=ANS(NROW,4)+WW
      ANS(NROW,5)=ANS(NROW,5)+P
      ANS(NROW,6)=ANS(NROW,6)+TT
      ANS(NROW,7)=ANS(NROW,7)+RH
      ANS(NROW,8)=ANS(NROW,8)+B
      ANS(NROW,9)=ANS(NROW,9)+X
      ANS(NROW,10)=ANS(NROW,10)+R
      ANS(NROW,20)=ANS(NROW,20)+STW
      ANS(NROW,21)=ANS(NROW,21)+DF
      ANS(NROW,24)=ANS(NROW,24)+HCM
```

```
      C2=C*C
      ANS(NROW,11)=ANS(NROW,11)+C2
      F2=F*F
      ANS(NROW,12)=ANS(NROW,12)+F2
      WW2=WW*WW
      ANS(NROW,13)=ANS(NROW,13)+WW2
      P2=P*P
      ANS(NROW,14)=ANS(NROW,14)+P2
      TT2=TT*TT
      ANS(NROW,15)=ANS(NROW,15)+TT2
      RH2=RH*RH
      ANS(NROW,16)=ANS(NROW,16)+RH2
      B2=B*B
      ANS(NROW,17)=ANS(NROW,17)+B2
      X2=X*X
      ANS(NROW,18)=ANS(NROW,18)+X2
      STW2=STW*STW
      ANS(NROW,22)=ANS(NROW,22)+STW2
      DF2=DF*DF
      ANS(NROW,23)=ANS(NROW,23)+DF2
      HCM2=HCM*HCM
      ANS(NROW,25)=ANS(NROW,25)+HCM2
  700 CONTINUE
   70 CONTINUE
C
C CALCULATE MEAN FOR EACH VARIABLE FOR EACH STATION
C
      DO 800 I=1,63
      ND=ANS(I,1)
      IF(ND.EQ.0) GO TO 800
      DO 810 J=2,10
      ANS(I,J)=ANS(I,J)/ND
  810 CONTINUE
      DO 811 J=20,21
      ANS(I,J)=ANS(I,J)/ND
  811 CONTINUE
      ANS(I,24)=ANS(I,24)/ND
C
C CALCULATE STANDARD DEVIATION FOR EACH VARIABLE FOR EACH STATION
C
      ANS(I,11)=SQRT(ANS(I,11)/ND-ANS(I,2)*ANS(I,2))
      ANS(I,12)=SQRT(ANS(I,12)/ND-ANS(I,3)*ANS(I,3))
      ANS(I,13)=SQRT(ANS(I,13)/ND-ANS(I,4)*ANS(I,4))
      ANS(I,14)=SQRT(ANS(I,14)/ND-ANS(I,5)*ANS(I,5))
      ANS(I,15)=SQRT(ANS(I,15)/ND-ANS(I,6)*ANS(I,6))
      ANS(I,16)=SQRT(ANS(I,16)/ND-ANS(I,7)*ANS(I,7))
      ANS(I,17)=SQRT(ANS(I,17)/ND-ANS(I,8)*ANS(I,8))
      ANS(I,18)=SQRT(ANS(I,18)/ND-ANS(I,9)*ANS(I,9))
      ANS(I,22)=SQRT(ANS(I,22)/ND-ANS(I,20)*ANS(I,20))
      ANS(I,23)=SQRT(ANS(I,23)/ND-ANS(I,21)*ANS(I,21))
      ANS(I,25)=SQRT(ANS(I,25)/ND-ANS(I,24)*ANS(I,24))
  800 CONTINUE
C
C PRINT THE RESULTS
C
      DO 830 I=1,63
      IF(ND.EQ.0) GO TO 830
      WRITE(9,300)ANS(I,19),ANS(I,1),ANS(I,2),ANS(I,3),ANS(I,4),ANS(I,11
     1),ANS(I,12),ANS(I,13),ANS(I,5),ANS(I,6),ANS(I,7),ANS(I,14),ANS(I,1
     15),ANS(I,16),ANS(I,8),ANS(I,9),ANS(I,17),ANS(I,18),ANS(I,10),ANS(I
     1,20),ANS(I,22),ANS(I,21),ANS(I,23),ANS(I,24),ANS(I,25)
  300 FORMAT(14H STATION NO.  ,F4.0,14H NO.STAT.DAYS ,F3.0,11HMEAN CLOUD
     1 ,F6
     1.3,16H MEAN WIND(M/S) ,F7.3,10H MEAN PWC ,F6.3,/46H
     1                     STDV CLOUD ,F6.3,16H STDV WIND(M/S) ,F7.3,10H
     1STDV PWC ,F6.3//49H                                   MEAN PRESSUR
     1E ,F7.2,11H MEAN TEMP ,F5.2,13H MEAN R.HUM. ,F6.2/49H
     1                     STDV PRESSURE ,F7.2,11H STDV TEMP ,F5.2,13H
     1STDV R.HUM. ,F6.2//50H                                   MEAN WIND
     1CHILL ,F8.3,10H MEAN THI ,F6.3/50H
     1   STDV WINDCHILL ,F8.3,10H STDV THI ,F6.3//61H
     1                  PROPORTION OF RAINDAYS IS ,F7.5//43H THE MEAN OF S
     1TEADMAN'S WINDCHILL INDEX IS ,F10.5,12H CAL M-2 S-1/43H THE STDV O
     1F STEADMAN'S WINDCHILL INDEX IS ,F10.5,12H CAL M-2 S-1//50H THE AV
     1ERAGE CLOTHING THICKNESS REQUIRED IN MM IS ,F7.3/50H THE STANDV. C
     1LOTHING THICKNESS REQUIRED IN MM IS ,F7.3//36H THE MEAN INDEX OF H
     1UMAN COMFORT IS ,F10.5/44H THE STANDARD DEVIATION OF HUMAN COMFORT
     1 IS ,F10.5//////)
  830 CONTINUE
C
   60 CONTINUE
      STOP
      END
```

APPENDIX 6.

```
STATION NO.   318. NO.STAT.DAYS   52.MEAN CLOUD   6.096 MEAN WIND(M/S)    7.257 MEAN PWC 23.654
                                     STDV CLOUD   2.272 STDV WIND(M/S)    3.564 STDV PWC 28.516

                                     MEAN PRESSURE 1011.83 MEAN TEMP 13.15 MEAN R.HUM.  81.92
                                     STDV PRESSURE   13.79 STDV TEMP  3.10 STDV R.HUM.  10.60

                                     MEAN WINDCHILL  564.563 MEAN THI 55.772
                                     STDV WINDCHILL  114.940 STDV THI  5.175

                                      PROPORTION OF RAINDAYS IS  .30769

THE MEAN OF STEADMAN'S WINDCHILL INDEX IS  107.86040
THE STDV OF STEADMAN'S WINDCHILL INDEX IS   37.51452

THE AVERAGE CLOTHING THICKNESS REQUIRED IN MM IS   3.418
THE STANDV. CLOTHING THICKNESS REQUIRED IN MM IS   1.566

THE MEAN INDEX OF HUMAN COMFORT IS   14.81518
THE STANDARD DEVIATION OF HUMAN COMFORT IS   3.26940
```

<u>An example of the output from the programme shown in Appendix 5.</u>

APPENDIX 7

The Coding of the Response Maps of the Perceived Climatology

To code the maps a grid scheme with 1 cm. squares was adopted to examine whether or not the respondent had shaded in each square and if so in what way. The grid laid over the response map (Figure 7.2) consisted of 245 squares. Each map was coded by examining the square and if a square was shaded favourably, that is 'warm' or 'dry' it was coded plus one; if it was shaded as 'cold' or 'rainy' it was coded minus one; and if it was left unshaded it was coded zero. A square was taken to be shaded in a particular way if more than half of it was shaded in that way. The individual codes were then summed to give a total for each grid square. The distribution of this code, shown in Figure 7.3 was drawn by ranking the grid squares and dividing them into five equal ordinal groups which were then mapped. This coding had the advantage of allowing all four shadings to be brought together into a single composite map.

APPENDIX 8.

A FORTRAN programme to convert the Daily Weather Report data from the synoptic stations to area data on a Icm. grid over the British Isles.

```
C THIS PROGRAMME WAS DESIGNED TO CALCULATE THE MEAN HUMAN
C COMFORT INDEX FOR THE CENTRE OF EACH SQUARE ON A 19*28
C GRIDDED MAP FROM THE MEAN HUMAN COMFORT INDEX VALUES FOR
C THE 63 SYNOPTIC WEATHER STATIONS SHOWN IN FIGURE 5.1.
C
      PROGRAM MAP(INPUT,TAPE3=INPUT,TAPE4)
      DIMENSION DIST(63),AMAP(550)
      DIMENSION ST(63),X1(63),X2(63),HCI(63)
C SET UP A COUNTER
      N=1
C LOOPS FOR SQUARE CENTRES
      DO 300 J=1,28
      DO 300 I=1,19
C READ IN DATA FROM SYNOPTIC STATIONS
      DO 302 K=1,63
      READ(3,201)ST(K),X1(K),X2(K),HCI(K)
  201 FORMAT(4F10.4)
C FIND DISTANCE SQUARED FOR EACH STATION TO THE SQUARE CENTRE
      DIST(K)=(X1(K)-J)**2+(X2(K)-I)**2
  302 CONTINUE
C KN=TOTALNUMBER OF SQUARES
      KN=532
C SET UP COUNTERS FOR SUMMING MEANS
      S1=S2=0.0
C FIND 6 NEAREST STATIONS TO SQUARE CENTRE
      DO 103 K=1,6
      IC=1
      DO 104 L=2,63
      IF(DIST(L).GE.DIST(IC)) GO TO 104
      IC=L
  104 CONTINUE
      D=SQRT(DIST(IC))
      S1=S1+1.0/D
      S2=S2+HCI(IC)/D
      DIST(IC)=9.0E+35
  103 CONTINUE
C FIND MEAN VALUE FOR EACH SQUARE
      AMAP(N)=S2/S1
      N=N+1
      REWIND 3
  301 CONTINUE
  300 CONTINUE
C WRITE OUT THE RESULTS
      DO 333 I=1,KN
      WRITE(4,334)I,AMAP(I)
  334 FORMAT(I5,F10.5)


  333 CONTINUE
      STOP
      END
```

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A Human Comfort Climatology of the British Isles

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Abstract

This thesis describes an attempt to devise a human comfort climatology of the British Isles using social survey methods, and, as such is a departure from previous work which used either controlled experiments or simplified energy balance models. A Likert scale questionnaire was administered to 750 people in a street survey in order to elicit their views of the weather, and its results related to the measured weather. The response was found to be related to a linear combination of the Windchill and Temperature Humidity Indices, cloud cover, pressure and presence or absence of precipitation. This 'Index of Human Comfort' was calculated for the synoptic stations using a sample of U.K. Daily Weather Report data with the data being stratified according to the Lamb Natural Seasons. These data are instantaneous recordings and as such reflected the true covariance of the data unlike mean data which have been used in most earlier work. The examination of the spatial and temporal variation in the mean and standard deviation of the Index of Human Comfort revealed distinct seasonal differences although latitude and proximity to the coast were important controls in all seasons with Southern inland areas being the most favoured for human comfort. The use of instantaneous data also allowed a consideration of the maxima and minima of the Index and its range which again revealed a North to South and coast to inland improvement in human comfort. The thesis concludes with some recommendations for future research which include the need for the development of improved methodologies for the study of the relationship between man and weather and the ways in which a human comfort climatology can be derived, either indirectly by synthesis from an index of comfort, or directly by eliciting people's views on the climate rather than the weather.