A PRELIMINARY STUDY OF ASPECTS OF JOHANNESBURG'S URBAN CLIMATE

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THIS IS TO DECLARE:

i). that this thesis is my own unaided work; and,

ii). no part has been submitted previously for a degree in any university.

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PREFACE

Few studies on urban climate have been carried out in the Southern Hemisphere and particularly in the Republic of South Africa. Despite overseas investigation much work still remains to be done before urban modification of climate is understood. More precisely a quantitative understanding of relationship between a city environment and its local climate is necessary.

The thesis has been divided into three parts. Part I deals with details of physiography and urban features of Johannesburg, the mobile unit and description of the routes. This is followed by a discussion and description of the technique of analysis. Part II presents the temperature and humidity distribution and considers the use of the multiple regression coefficient to isolate the urban and topographic factors influencing the city climate. In Part III the most important results of the investigation are summarised.

In order to prevent confusion the term city in this study means the central business district (C.B.D.) while the whole built-up area is called the town. Unless otherwise stated all units used are C.G.S. The statistical level of significance is 95% unless other levels are mentioned. Observations were taken at the times of maximum and minimum temperature during the months of December 1966 and June 1967.

It is a pleasure to acknowledge the assistance I have received from many people and organisations; in particular, the staff and senior students of the Geography Department of the University of the Witwatersrand, especially Mr. I. Dickie

and Mr. R. Haswell, for acting as co-workers in the Mobile Unit. To Mr. and Mrs. L. Williams, I am especially indebted for helping me in the construction of the Mobile Unit instrumentation.

I am very grateful to the staff of the C.S.I.R. for their generous loan of the Askania recorder and also to the programmers of the N.I.P.R. for their useful guidance.

Others to whom thanks must be given are the staff of the Israeli Weather Bureau. In particular I wish to acknowledge the help of Mr. M. Thaller, Mr. D. H. Elbashan, and the statistician Mr. Y. Sha'ashua. Also I should like to thank the owners of the premises where the Stevenson Screens were erected; the committee of the Parkhurst Bowling Club, Mr. and Mrs. S. Louis, and Mr. and Mrs. M. Glazer. To my wife I am likewise indebted.

Finally, it is with much pleasure that I express my gratitude to my supervisors, Dr. S. P. Jackson, the Deputy Vice-Chancellor and formerly Head of the Department of Geography and Environmental Studies; Professor P. D. Tyson, Head of the Department of Geography and Environmental Studies, both from the University of the Witwatersrand; Mr. N. Rosenan, Deputy Director of the Israeli Weather Bureau and Head of its Climatology Department for all the assistance, guidance and encouragement they have so willingly given me throughout the investigation.

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PART I

BACKGROUND TO INVESTIGATION

CHAPTER 1

INTRODUCTION

1.1. OBJECTIVE.

Urban climatology is concerned with the effect of urban environment on local climates. Previous studies carried out in various towns in the world have examined some of the relationships between city environment and its local climate.* Not all these studies reach the same conclusions. In particular disagreement on the magnitude of the urban climatic rural discontinuity and intensity of the heat island is obvious.

The aim of this study is to present a new method of isolating the urban factor, i.e. the numerical contribution a city makes to the modification of the mesoclimate. In particular it is intended to determine the causes and state quantitatively the urban factor associated with the town of Johannesburg. At the same time an attempt will be made to isolate Johannesburg's urban heat and humidity islands using the technique of temperature traversing at different times of day and year.

1.2. TOPOGRAPHY OF JOHANNESBURG.

Johannesburg is the largest town in the Republic of South Africa with a population of more than half a million inhabitants.** Its area is about 243 sq. kilometres (94 sq. miles) and the municipal boundaries extend between 26°06' -- 26°16'S and 27°57' -- 28°08' E.

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* Chandler (e.g. 1961, 1962, 1965, 1967a, 1967b), Dockworth and Sandberg (1954), Garnett and Bach (1967), Hutcheon (1967), Kawamura (1965), Kratzer (1956), Landsberg (1956), Lowry (1967, 1968), Mitchell (1953), Parry (1967), Sekiguti (1964), Sundborg (1951) etc.

** Within municipal border only.

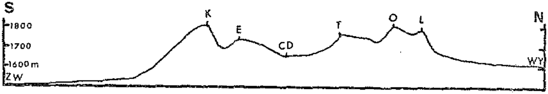

Figure 1 Traverse section across the central Rand (after Wellington 1924). Vertical scale about ten times the horizontal scale. ZW - Zwartkoppies. K - Klipsriversberg. E - Elsberg Ridge. CD - City Deep. T - Troyeville. O - Observatory. L - Linksfield Ridge. WY - Wynberg.

The town has been built over a series of E-W parallel ranges which rise above the surrounding area and which are known as the Witwatersrand. The rand, with Johannesburg in the centre, is in the shape of an arc and extends north west, in the direction of Krugersdorp and east towards Springs. The ranges and the depth of the valleys between them are very variable. In fact the recognition of five parallel ranges (Wellington 1924) from north to south is not possible everywhere. Nevertheless, it is possible to differentiate between a southern and northern complex of ridges, with a well defined wide valley cut by lateral streams between them. This valley includes the gold mining areas, and mine dumps which symbolise the town and add to the topographic complexity. These dumps are between 20 - 100 metres high and about 600 metres long and may significantly influence Johannesburg's local climate by virtue of the dustpollution to which they give rise with strong winds.

1.2.1. THE AREAS NORTH OF THE RIDGES.

Beyond the steep drop northwards from the most northerly Linksfield Ridge and its continuation, the ground slopes gently towards Wynberg (WY in Fig.1) and reaches its lowest point in Johannesburg along the Klein Jukskei River on the boundaries of the suburb of Craighall (contour 5000 feet). This slope is dissected by a close stream network giving rise to moderate relief.

It can be said that on the whole the town is situated in an area of marked relief which has a maximum range of nearly 300 metres. The linear configuration of the east west ridges may act as a barrier to the advection of cold air from the south.

1.2.2. NORTHERN RIDGES.

The Orange Grove escarpment diminishes westward with the exception of the Northcliff Ridges which rises to 1807 metres, the second highest point in Johannesburg. In the central city area the ridges coalesce to form an undulating region with occasional high points. Further eastwards separation occurs to form three distinct ridges with marked topographic effect. The main Northern ridges are:

a). Linksfield Ridge (L in Fig.1). This has a marked northern escarpment and dips steeply to the south rising to a maximum height of 1790 m. with an average relative relief of 160 m.

b). Observatory - Yeoville Ridge (O in Fig.1). This is on the whole less prominent than the Linksfield Ridge except for its southern dip slope and where it reaches its highest point in Johannesburg (1808 m.). Between these two ranges the narrow and shallow valley of the Observatory Golf Course is found.

c). Troyeville Ridge (T in Fig.1) lacks prominence except for the steep hill (1789 m.) to the south of Kensington. Westwards it merges with the Northern range beyond Bezuidenhout-Doornfontein valley. Eastwards it extends towards Germiston.

1.2.3. SOUTHERN RIDGES.

The southern ridge consists of two ranges: the Elsberg (E in Fig. 1) and the southern Klipriviersberg (K in Fig.1). They are more dissected than the northern ridges especially the line of isolated hills forming the Klipriviersberg. The municipal boundary follows the southern slope of the Elsberg Ridge and occasionally reaches the watershed. The slopes of the latter ridge are relatively gentle in comparison to both the northern ridges and Klipriviersberg lying completely outside the municipal area of Johannesburg. Southward the slope descends steeply to a height of 1520 m. and thence continues sloping slightly towards Zwartkopjes (ZW in Fig.1). Owing to its dissection its effect as a climatic barrier is slight compared to that of the other ranges. Thus the Elsberg Ridge is the most southerly of the Witwatersrand ridges which need be considered in terms of its climatic influence.

1.3. THE URBAN CHARACTER OF JOHANNESBURG.

The topography is well connected with the development of the town. The southern suburbs are built on the Elsberg Range. The industrial area lies in the wide valley of the gold mines north to this range. On the northern ranges the city and also the earliest housing areas of Johannesburg are situated. On part of the two northern ranges and past them in the north are the high class residences.

The city (C.B.D.) is almost in the centre of the municipal area (see map in flap of back cover) and is not easy to define exactly. Roughly, one can say that the southern border is the gold mining area and the northern - the railway, the western - West Street and to the east - End Street. The city consists of high rise and high density buildings.

Almost all the industrial area is in the vicinity of the main railway line north of the gold mining area and surrounds the city on all its sides except for the north. Industria forms another important industrial area.

The main residential area of Johannesburg lies to the north of the city with older suburbs forming southern residential areas. The residential areas can be divided into three kinds:

i). low class,
ii). flatland,
iii). high class.

Low class residential areas are defined as areas of single storey houses on ground of less than 5,000 sq. ft. (500 sq.m.) in area and are generally to be found along the gold mining strip and the periphery of industrial areas, e.g. Mayfair and Jeppe. Almost all these suburbs were the first residential areas of Johannesburg.

Flatland areas are found in the Hillbrow/Bellevue area, Killarney, Rosebank, Corlett Drive. Of these areas the most important and densely populated is Hillbrow.

In the high class residential area, houses of one or two storeys and with grounds of more than 5000 sq. ft. are found; in some suburbs the plots are one or more acres. This area together with the empty stands and open spaces represents most of the town. The sparse population is not only the result of the size of the stands, but also due to the number of parks and golf courses, largely confined to valleys. In the southern suburbs the average stands are smaller than the northern suburbs and are situated on the northern slope of the Elsberg Range and only slightly beyond the watershed. Most of the Northern suburbs are situated on the northern slope of the Linksfield/Houghton escarpment and many are to be found beyond the municipal boundary e.g. the new towns of Randburg and Sandton. Thus the northern boundary of Johannesburg has no climatological significance. Towards East and West, Johannesburg merges with the general conurbation of the Witwatersrand.

Within Johannesburg non-White residential areas are not found. Exceptions are the Western and Eastern Townships in which population and housing are dense. Houses are small and with low heat capacities.

The greatest single artificial heat source in Johannesburg is that of buildings and large concrete structures. Of considerably less importance is the heat contributed by vehicular traffic and railway locomotives. Domestic heating is necessary in Winter and was until very recently based entirely on open hearth fires.

Apart from advection and evapourtransporation the major source of humidity in the Johannesburg region is the numerous artificial lakes in the town.

1.4. MACROCLIMATE.

Johannesburg is situated on the Highveld and its climate is warm temperate with a summer rainfall maximum and is classified according to Köppen as Cwb.

1.4.1. PRESSURE SYSTEMS.

Seasonal pressure maps at the height of 2,000 metres showed that there is no great difference between summer and winter systems. In both cases the circulation is anticyclonic, stronger in Winter, weaker in Summer (Jackson 1952). Departures from the mean circulation pattern occur throughout the year, mainly as disturbances from the south which produce cold snaps and rainy spells.

1.4.2. WEATHER TYPES.

The most recent and reliable classification of weather types is that of Vowinckle who shows that fair weather anticyclones occur on 79% of the days of June and July. This anticyclonic circulation produces very frequent subsidence inversions and highly stable air in Winter. In Summer the weakening of the anticyclone is accompanied by a corresponding decrease in the stability of the air over the Southern Transvaal.

In Winter, weather is fair, characterised by stable air, lack of clouds and at night a strong inversion near the ground (Vowinckle 1956). The mean maximum temperature for the month of June in Joubert Park is 16°C. At night radiation frost occurs frequently. The minimum mean temperatures is 5.4°C and at Jan Smuts Airport 4.4°C. This mild weather is often disturbed by cold snaps accompanied by strong winds which last two or three days at a time. These can also be accompanied by rains and infrequently snow.

Summer weather is characterised by high intensity rain showers which contribute considerably to the total precipitation of 818 mm. over Johannesburg. These showers are mainly caused by convergence within the tropical air mass (Jackson 1951). Frequently rain is associated with violent thunderstorms and hail occuring in the afternoon and early evening. The maximum and minimum temperatures in Johannesburg in Summer are 24.6°C and 14.1°C respectively.

1.4.3. THE WINDS.

Wind data refer to the Jan Smuts anemograph (*Schulze 1965, p.253*). *In January the wind direction* from midnight until 08.00 is NE. The direction changes gradually to N until 15.00 then a quick change to ENE occurs and slowly changes back to NE. The mean maximum speed is recorded at 09.00 and the minimum speed at 18.00.

In July the picture is different. From midnight to 08.00 the direction is W changing to NW in the morning. So it stays until 14.00 and then changes slowly back to W. The minimum speed is during the night (less than three kilometres per hour) and at 09.00 the wind gets stronger and reaches its maximum at 13.00 Gales are very seldom in the Johannesburg area even though tornados have been reported on occasions.

1.4.4. HUMIDITY.

According to the humidity measurements taken in Germiston the following picture was obtained. Table 1 gives mean vapour pressure at Germiston, about 12.Km. from the city of Johannesburg.

TABLE 1.

MEAN VAPOUR PRESSURE IN GERMISTON, mb
(after Schulze 1965 p.200)

TIME MONTH	08.00	14.00
JANUARY	15.4	15.1
JUNE	6.7	6.0
JULY	6.6	5.9
DECEMBER	14.5	14.1

Winter is dry, with winds producing dry and well-mixed air which is probably descended from the upper air (Jackson 1951, p.12). The diurnal variation of vapour pressure in Summer (and the humidity mixing ratio) shows a distinct double wave usually with the main minimum in the afternoon and the secondary minimum is near the minimum temperature time. The drop in humidity in the afternoon is explained by turbulence due to wind and convection which uplifts the moisture to the upper air. The secondary minimum results from dew formation and in Winter is not as prominent as in Summer (Schulze, 1965 Fig.107).

The daily process of the relative humidity is more connected with the temperature than with the vapour pressure. In January, the maximum (above 90%) is at the minimum time of the temperature and the minimum is at noon (50%). This is most noticeable on days when there is afternoon precipitation where the humidity goes up all at once. In July the maximum is later and is near 08.00 (72%) due to the late sunrise. The minimum is near 14.00 (32%).

CHAPTER 2

THE MEASUREMENTS

2.1. INSTRUMENTATION.

2.1.1. THE MOBILE UNIT. Insufficient meteorological stations are available in Johannesburg for detailed mesoclimatological work. Much of the available data relates only to short observation periods and the stations are irregularly distributed.

The establishment of a network of static weather stations is limited to the number of screens and instruments available. The research done in Pretoria, using fixed screens, (Shumann 1942) was done when the city was still small but it would not be suitable for larger towns like Johannesburg. A successful solution to the problem of the shortage of instrumentation and screens was found by Sharon (1964) who measured the areal distribution of maximum and minimum temperatures only. This was done by moving a few of the screens from the network of stations, from place to place, at fixed intervals; the duration of these intervals was determined statistically after a short period of measurements, during a pilot project; by a series of reductions, a uniform picture was achieved. The Sharon method is also adequate for a small area, such as a cross section of a valley but not for a wide area with varied topographic and urban features. There was no choice other than the use of a mobile unit in which there is no limit to the number of measuring points.

When planning the mobile unit for this research three instruments built in the past for similar purposes *were considered*:-

1). Stationary instruments (Blount 1966).
2). The mobile unit of the Israel Meteorological Service *(Goldreich, 1965; Meterologia BeIsrael, 1966)*.
3). The mobile unit which was used in London (Chandler, 1962(a), 1965).

2.1.1.1. THE MEASURING UNITS AND RECORDER. In this survey it was decided to use miniature thermistors type F23, manufactured by Standard Telephones and Cables Ltd. (S.T.C.). This thermistor is 8cm. in length and has a resistance of 2,000Ω (± 20%) at a temperature of 20°C, and was designed as a rapid acting thermistor for use in either straight or bridged circuits. It has a large temperature coefficient which provides great sensitivity, allowing the use of a simple bridge without an amplifier; it is therefore cheaper to use a thermistor than the platinum resistance thermometer. The change of the resistance of the thermistor is not linear with the change of temperature. The relationship of resistance and temperature is usually approximate to an exponential form (Phillips 1963, p.8). This relationship can be improved almost to a linear function by shunting the thermistor with a fixed resistor (Scarr, 1960, p.87)*.

The lag coefficient (time recovery) of this termistor is 5 seconds (63%). This means that the recovery time to reach 63% is the resistance in ambient temperature, if the thermistor has been operating for some time at the maximum permitted current while cooling down in still air. Obviously, in ventilated air the lag coefficient is much shorter.

In the wet bulb thermistor the lag coefficient is larger than in the ordinary thermistor (Goldwater, 1960, p.9) because of its small size, although the lag coefficient is shorter in the ordinary wet bulb thermometer than in the dry bulb.

The Askania Recorder (Berlin, Western Germany) was chosen for this research- it was borrowed from the C.S.I.R. This recorder works on the following principles; instead of a moving coil galvanometer or a cross coil there is a flat metal sheet placed between two coils heated by electricity. These two coils form

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* For Winter nights where the temperature range along the route was great, the temperatures were corrected by the aid of a calibrating table.

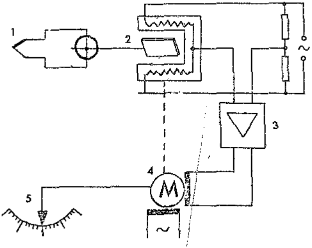

Figure 2.1 The Askania Recorder Circuit

1 Thermistor
2 Heated Coils
3 Amplifier
4 Ferrarismotor
5 Pen

the two arms of an electric bridge (Wheatstone Bridge). The movement of the sheet towards one of these arms cools the arm and unbalances the bridge (see fig. No.2.1). This movement is caused by another bridge when the thermistor is one of its arms. The unbalancement of the two coils bridge is increased by means of an amplifier (A.C.) and transferred to a Ferrarismotor (Askania OFM 0.2)., to which the pens are connected. The Ferrarismotor then rebalances the recorder Wheatstone Bridge (see Askania, 1959. The main advantage of this recorder is that the thermistor bridge and the recorder bridge are separate and thus enable a very low current to pass through the thermistor, as a high current heats the thermistor and changes its resistance in addition to the change in resistance with temperature. (See handbook of Met. 1956 p.130). Some of the characteristics of the Askania recorder are listed below.

1). It takes 14 seconds for the pen to move from one end to the other (it is possible to order one of 7 seconds).

2). The maximum standard chart speed is 12 cm. per hour. With the help of a synchronomotor the movement of the chart is linear with time.

3). The recording is made by two pens filled with coloured ink which span the width of the whole chart. (see fig. 3.2).

2.1.1.2. ELECTRIC SUPPLY FOR INSTRUMENTATION. Three parts of the apparatus have to be supplied with electricity. The thermistor resistance circuit, the recorder and the ventilation system. In order to supply electricity to the thermistor resistance circuit, two mercury batteries were used. These Direct Current cells (ZM - 12 Mallory, U.S.A.) have a voltage of 1.4 V and 3,600 mA hours. Mercury batteries are the simplest

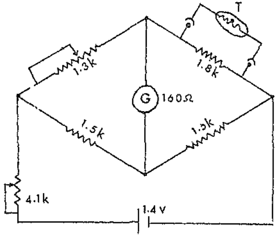

Figure 2.2 The Thermistor's Circuit (Summe

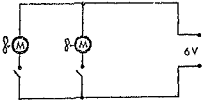

Figure 2.3 The Fan's Circuit

solution to the problem of keeping the voltage stable. It is well known that there is a declination in voltage with time in the usual battery.

The termistor's electric circuit can be very simple, for example, one resistant parallel to the thermistor along with one in a series. In order to gain the maximum sensitivity it is advisable to use a Wheatstone Bridge (see fig.2.2). All the arms of the most sensitive Wheatstone Bridge are equal; the two fixed arms that were chosen therefore have a resistance of 1.5 K (panclimatic 5% N.L.)

$$\frac{1}{x} = \frac{1}{6200} + \frac{1}{1800}$$

$$x = 1395\Omega$$

where x is the sum of the two resistances. (The thermistor at $-10^{\circ}c$ + shunt). The shunt chosen was the same as the one used by Pein (1964, p.4) who used Philips thermistors with the same resistance and size similar to those chosen in this research. The third arm was a potentiometer which was used as a rheostat. This 'Helipot' potentiometer (the large potentiometer) was manufactured by Backman (Scotland), had a nominal resistance of 10 K, with an exactness of dialling to 1 Ohm (lin.Tol.± 0.25%, Res. Tol. ± 3%). After calibration the potentiometer can be locked and a fixed resistance secured.

For zero setting another Rheostat was used (the small potentiometer). It is manufactured by the Canadian division of the same firm; it is called 'Hellibrine' and has the same nominal resistance.

This Rheostat was placed not in a series with the galvanometer (Scarr,fig.3p88) but in a series with the Wheatstone Bridge so as to reduce the current through the thermistor.

If one computes the maximum power which passes through the thermistor it will be found that it does not come to more than 13.1μW !! and a voltage of 0.13V. This will be the case in

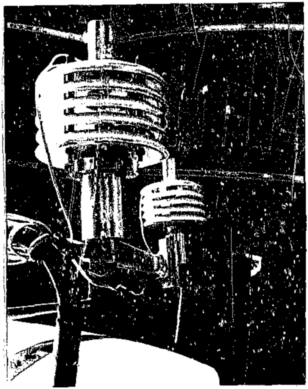

Figure 2.4. The Mobile Unit Screens

Summer at the maximum temperature (30^{o}C) when the resistance of the thermistor is 1.3K, and the resistance of the small potentiometer in the Summer calibration is 4.1 K and the large potentiometer is 1.3K.

Since there is no electric connection between the thermistor circuit and the recorder bridge, it is naturally possible to use alternate current for the recorder, which is important for keeping the linearity of the chart speed. This current (50 H.Z. 220 V) (i) operates the Wheatstone Bridge of the recorder, (ii) supplies additional current directly to the Ferraris motor, (iii) operates the synchronomotor of the chart. In order to gain an E.M.F. of 220 V a convertor from 6 V. D.C. heavy duty battery to 220 A.C. (60 V.A. 50 H.Z.) was used and was made by Kupfer Asbest Co. (Heilbronn, Germany).

The current for the fans was supplied by the same heavy duty battery and was used without the convertor (see fig. 2.3). By selecting the suitable polarity the fans were made to aspirate the temperature sensing elements (as against blowing).

2.1.1.3. THE SCREENS. The construction of the screens was based on the construction of screens by Blount (1966). Instead of the big aluminium flat discs, five plastic saucer shaped covers were used (see fig.2.4). Besides the plastic covers which were painted with a white illuminated paint, the thermistor was protected against radiation by a perforated brass tube. For ventilation at time of stopping, a fan consisting of a boat propellor attached to a battery driven motor, was constructed at the top of the screen.

A small container for distilled water was fixed in the wet bulb thermistor screen (see fig 2.7). The upper cover was separated from the others for filling the container with water, for changing the wick etc. The top cover was easily removed by opening the four nuts on the top cover manually.

The resistance box was made from a plastic pipe with a

Figure 2.5. The convertor, resistance box, and fan switches.

Figure 2.6. The equipment inside the car.

15 c.m. diameter and height 13.4 cm. Above the box on the perspex disc were eight plug connections; four for the thermistor terminal and four for connecting the recorder. Also above the box were the upper parts of the two big potentiometers, and two holes for a miniature screwdriver to adjust the small potentiometers. These small potentiometers were attached to a perspex board connected to the disc in the centre of the pipe. Two mercury cells were attached to one side of this board and the printed circuit to the other (see fig.2.5). The resistances to both thermistor circuits (including the shunts) were attached to the printed circuit (5.9 x 3.3cm) which was easily replaced by another printed circuit with different resistances. This made the resistance box multi-purpose.

The height of standard thermometers in South Africa is 133 cm. (4'5") and for the purpose of comparison and reduction to fixed stations it is preferable to use a similar height. This height is above the limit of the micro climatic influences as the scale of this research is Local rather than Micro.

The screens were mounted on the front of the carrier of the car, 1.8 m. from the ground. As the car moves, however, the air rises in front of the car and so one is in fact measuring the temperature of the same layer of air as the standard screen.

2.1.1.4. MOUNTING THE EQUIPMENT FOR TRAVERSING.

The recorder had to be mounted on a specially constructed spring seat (see fig.2.6). A thick sheet of foam rubber was placed on this seat and the recorder was tightened to the upper board of the seat with a thick strap which kept the recorder's window open. The spring seat was fastened to the floor of the car. A special box seat was made for the co-worker to sit on, the heavy duty battery was kept inside it. (see fig.2,6). All the other equipment, namely a convertor, control switches of the fan and the resistance box (figs. 2.5 and 2.6), were placed on the floor in front of the recorder on top of layers of foam rubber.

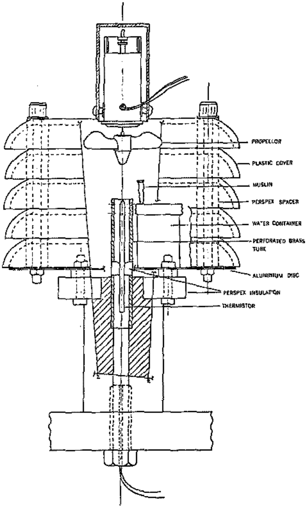

Figure 2.7 Section through shelter

2.1.1.5. THE QUALITY OF THE MOBILE UNIT. There are a few important disadvantages in this mobile unit which should be mentioned. The recorder is not made as a portable one:

a). It marks with ink and one has to blot it from time to time.

b). The gear speed is not fast enough.

c). The recovery time (of the recorder) is not quick enough.

When ordering the recorder the last two points can be improved. As this recorder was borrowed it was not possible to do so.

In spite of these disadvantages the recording was satisfactory. If one takes into consideration an adequate degree of accuracy, results were of a satisfactory standard and could be analysed.*

2.1.2. ADDITIONAL INSTRUMENTATION.

For reduction purposes it was necessary to use data from fixed stations in addition to the mobile unit.

2.1.2.1. WEATHER BUREAU SCREENS. In Johannesburg and its environs 17 climatological stations were erected at different periods, but never more than nine stations worked simultaneously. Today four stations are operating, two in Johannesburg - Joubert Park and City Deep - and two outside the town - Jan Smuts and Swartkopjes.

Jan Smuts Airport station is a Grade A station (Synoptic Station) with 24 hourly observations a day. This station was moved recently from the Air Terminal to the Air Field (1964 m. above M.S.L.). There is an anemograph next to this station which was established in 1953.

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* As an indication of the stability of the shelters and all the *instruments the latter were undamaged in a motor accident on* 2.6.67, during recording. The car was hit in the front, pushed back five meters and the front of the car was badly damaged, but none of the instruments including the thermistor(!) the

Joubert Park station (1,753 m.) is the oldest station (established 1893) and 'represents' the city (next to station 92 in. fig.2.8). It is a Grade B station and has no anemograph or hygrograph. Three readings are taken daily - 6, 9 and 12hrs. G.M.T. (8, 11 and 14 hours local time).

City Deep station is situated next to the City Deep Gold Mine offices, at a height of 1,680 m. This station (next to Station 22 on the southern route) is Grade C and the reading is taken once a day (6 hours G.M.T.). The station has been operating since 1935.

Swartkopjes station is outside the town, south of the southern ridges. This is a Grade B station and has been operating since 1916.

In all those stations there are thermographs, maximum, minimum, wet and dry bulb thermometers.

2.1.2.2. ESTABLISHMENT OF OTHER STATIONS. It was decided to erect two temporary stations for this research, which along with the other two fixed stations would make three stations along each route (see fig. 2.8). One spot was chosen on the combined route, which in the Winter was also the first and terminal station of the route in Observatory, and the second in the lowest spot on the Northern Route in Parkhurst. Both stations were constructed of standard height Stevenson Screens mounted on stands. The stations were equipped with thermo-hygrographs, maximum, minimum, wet and dry bulb thermometers.

Observatory station was placed at a height of 1,737 m., first in Frances Street between Innes and Steyn Streets (next to station 7 in fig 2.8). For the June measurements the screen was moved to 4, Observatory Street (see fig.2.8). This station is about a meter above the road level (height 1,760 m.).

Parkhurst station was erected in front of the Parkhurst Bowling Club (next to Station 47 on the northern route). The

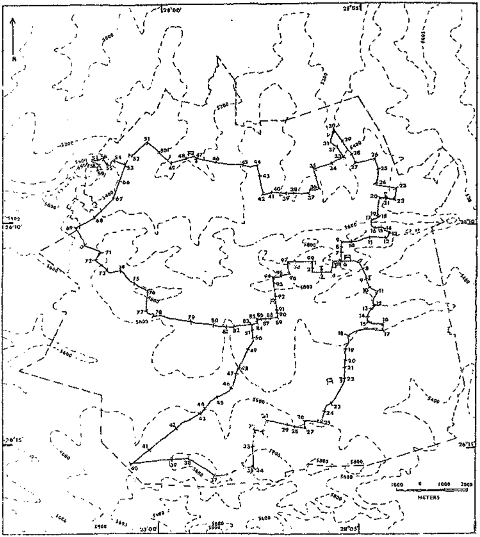

Figure 2.8 Johannesburg traverse routes. Stations are numbered. ⌂ - Climatological Screen. T - pressure reading spots. Contours in feet.

height of the station is 1,575 m.

Besides this equipment, for the summer month of measurements a hygrograph was placed in Joubert Park. The anemograph (Dynes) of the University above the Geography Department in the main block, was also used.

2.3. THE ROUTE.

A mobile unit may be used in two ways:-

1). Following a circular route.

2). Following a U-type route. (A route on which one returns along the same road).

The latter route is popular with many investigators (see Chandler 1962, 1965, Dockworth and Sandberg 1954, Goldreich 1965) because by this method it is easy to reduce the data to a standard time. The main advantage of the circular route is that it saves time. For this method one thermograph is required for reducing the values to standard time (Schnelle 1963).

The conditions of the two possible routes were checked. Since Johannesburg covers such a large area, it was decided to use the circular route method.

It was decided to establish two routes in the form of a figure eight in order to cover most of Johannesburg in a limited time. Route 1 would cover the Northern Suburbs, and Route 2 the Southern Suburbs. The connection of the two circles of the figure eight would be an overlapping section included in both traverses (see fig.2.8). This common section would help to reduce the two routes to one composition of temperature and humidity distribution.

The selected routes traversed different types of urban and physical terrain. The length of Route 1 was 54.1 Km (33.7 miles) and of Route 2 38.6 Km. (24.0 miles). The length of the overlapping portion was 7.7 Km. (4.8 miles).

From Northcliff(station 59, Route 1) the same road was used on the inward journey as on the outward journey. This was the only portion in the traverse that the U-type route was used. There was another exit out of Northcliff, but the road was not tarred, and there was a possibility of the dust damaging the wet-bulb readings.

99 stations on Route 1 (and 68 on Route 2) were marked on the recorder's chart (fig.2.8). Becuase of the low speed of the recorder's chart the average distance between stations was 500 meters. The stations were selected so that they represented the environment. On the other hand they should be easily located while driving even under adverse weather conditions. Therefore, most of the stations were located at turns and corners of streets. Stations were also next to the weather stations, places of pressure reading in the centre of the city, corner Pritchard and Eloff Streets (Lipworth 1961 p.7).

Station No. 1 and Station No.99 which were at the corner of Kenmere and Raleigh Streets in Summer were transferred for Winter to Station No.5 opposite the house at 4, Observatory Road where in the Winter the screen was set (see 2.1.2.2.). In the Winter, Stations No's 1 and 99 were called Station No. 5. This exchange was done so that the stationary screen was next to the beginning and ending point of the route. In Summer where this was not so, there was a difference in temperature between stations 99 and 1 inspite of the standardization to one time.

On each route the pressure was read four times using an Aneroid Barometer. Each pair of pressure readings was taken at the highest and lowest altitudes over a short distance (see.fig.2.8). The second pair of pressure readings in each route was used to check the accuracy of the first pair of readings.

2.3 DURATION AND TIME OF OBSERVATION.

2.3.1. THE LENGTH OF OBSERVATION PERIOD.

Lately the conception that one needs years of observation to obtain representative means was rejected (Sharon 1964). In some climatological elements it is possible to obtain a good sample representative of the population on a certain level of significance even during a short period of observation. The period depends on three factors:

1). The variability (with time) of the parameter.

2). The expected degree of accuracy of the resulting mean data (the error interval).

3). The desired level of significance.

The first factor depends on the character of the climatological element itself - for instance to obtain good means for rainfall, much more time is required than for temperature. The weight of this factor can only be fixed after preliminary research on the parameters chosen for investigation. The second factor depends on the accuracy of the instrumentation.

Plotting these three factors in one equation will give the size of the sample, that is the number of days required for observation (see 3.5.2). Because of the different character of this research from that of Sharon (see 2.1.1) it was not possible, for technical reasons, to have a preliminary research. On checking the variability of temperature of the four existing stations in Johannesburg and vicinity, the following conclusions were reached:

a). The number of days of observation in summer would be considerably greater than the number necessary in the Winter.

b). For the maximum temperature fewer days are needed than for the minimum.

The months of December and June were chosen, even though the average data of the maximum and minimum temperatures are more extreme in January and July. From the point of view of uniformity July is preferable firstly, as the possibility of 'cold snaps' is lower than in June (Jackson 1933) and secondly as the humidity in July is much lower (more like Winter). The decisive point was the angle of elevation of the sunrays which are extreme and smaller in range in these months.

2.3.2. <u>TIMES OF MEASUREMENT.</u> The choice of the hour depended on three points.

1). It was recommended that there be linearity between the changing of temperature and the time.

2). There is a slight change in temperature near the maximum and minimum time.

3). After testing in the mobile unit it was decided to drive at a speed of 20 M.P.H. (32Km.P.H.).

The time of sunrise in the months of measurement must also be considered, as after sunrise, when the sun is just above the horizon, it might penetrate between the covers of the screen and could cause serious error in the measurements.

The decision was made after the thermograms for the *months of measurement over the past two years in Joubert* Park and City Deep stations were checked, and the frequency distribution of the hours of linearity were tabulated. The lag of the thermograph was taken into account. The results of this tabulation show the following:

a). In some hours there is no compatibility between the stations, but if the thermograms are superimposed, their records are parallel near sunrise.

b). The duration of linearity is higher in Winter than in Summer and higher at night than in daytime.

c). The linearity next to the time of minimum temperature is similar to the linearity at midnight.

Taking the above results into account the time of observation was as shown in the following table.

TABLE 2.

TIME OF OBSERVATION

	DAY		NIGHT	
MONTH	ROUTE 1	ROUTE 2	ROUTE 1	ROUTE 2
JUNE	13 - 15	$13 - 14^{30}$	$4^{45} - 6^{45}$	$5^{15} - 6^{45}$
DECEMBER	13 - 15	$13 - 14^{30}$	$3^{30} - 5^{30}$	$4 - 5^{30}$

2.4. WEATHER DURING THE MONTHS OF MEASUREMENT.

The data in this paragraph deals with the monthly means for the whole month and not only for the 24 days of measurement (12 in each route).

2.4.1. DECEMBER, 1966. According to the monthly weather report (Weat' [illegible] eau 1966) for Joubert Park, it seems that December 1: [illegible] fairly normal month. While the amount of precipitati [illegible] little lower than the normal for this month (130.0 mm. against 141.1 mm.) the number of rainy days was higher (18 compared to 15). The mean maximum temperature was 24.4°C. which was lower by 0.2°C than the normal, and the mean minimum was 14.1°C (Jan Smuts Airport, the minimum temperature of Joubert Park does not appear) and 0.5°C higher than the normal. That means that the daily mean temperature was higher than the normal and the amplitude was smaller. On the 26th December, 1966 in spite of the temperature being similar to that of Summer, the weather conditions were like Winter (type 1 after Vowinckel, see 1.4.2). At night a strong inversion developed similar to those which were measured in Winter. This phenomenon is not abnormal as the relative frequency of type 1 in the month of December is 3% (which means one day).

2.4.2. <u>JUNE 1967.</u> In this month there was no precipitation in Johannesburg, while the normal is 6.5 mm. and the number of rainy days is one. The mean minimum and maximum temperature (4.5°C and 15.0°C) were 1°C lower than the normal. The mean maximum temperature at Jan Smuts was lower by 1.5°C than the normal, while the minimum temperature deviated from normal by equal amounts at both stations.

There were two cold snaps in June 1967. The worse was between the 11th and the 14th, when the temperature dropped to 5°C below the normal. Twice during the traverses the water froze on the wick (on the 12th and 13th June) and the water at the Parkhurst screen also froze. In both cases the freezing occurred a short while after passing the coldest places on the traverse. This was found by the jumping of the wet-bulb temperature pen back to 0°C and after a while all the water changed into ice and the pen returned again to below zero (see also Wile 1944). During the month of June, too, the number of days of type 1 (fair weather) was similar to the average of the month.

While in Summer average wind speed at the time of the temperature minima and maxima was almost the same (8 knots) in Winter it was lower at night (5 knots) than at daytime (8 knots). At night, however, the windspeed never exceeded 10 knots. Generally, the cloudiness was nil, but during some nights at the time of the minimum temperature, the fog in the valleys lifted with the increase of wind and changed into a stratus cloud above the town.

CHAPTER 3

TECHNIQUES OF ANALYSIS

3.1. STANDARDIZATION OF TIME.

Differences in temperature due to change of temperature with time were discarded by reducing the temperature to one time with the help of the thermographs at the fixed standard screen.

3.1.1. CHECKING THE THERMOGRAM AND PLOTTING IT ON THE CHART.

The thermograph chart, (only daily one) which was in the screen at the Observatory Station, was used as a basis for the reduction. The thermogram curve was compared first with the other thermograms at the other stations. The curve was divided into small portions that were nearly linear, so that instead of a curve a series of straight lines was obtained. These lines were plotted on the recorder charts. At daytime, especially in Summer, when the turbulence and cloudy patches caused a curve of a wavy pattern, it was difficult to find similarity between thermograms that were far one from another. It was decided to smooth this wavy curve by means of a straight line. These fluctuations did not exceed more than $\frac{1}{2}^{o}C$ so that for an average of 12 days of measurements the error would be negligible.

3.1.2. STANDARDIZATION OF TEMPERATURE. The reduction equation which was worked out actually included three reductions:-

a). To the minimum temperature (or the maximum).

b). To the time of the minimum temperature (or to the maximum).

c). To a standard screen condition.

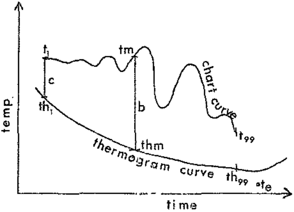

Figure 3.1 Schematic Graph showing the temperature reduction

The reduction to screen conditions meant reducing the height of the thermistor to screen level, and taking into account the differences caused by exposure on lawn or on asphalt surface, etc. Measuring temperature on grass in towns does not represent city conditions; but for the use of reduction to normal conditions and to compare with the other permanent screens there is no other way but to reduce to standard climatological screen conditions. As far as measurements in the town are concerned, it seems impossible to overcome one difficulty, which is the lag of the time of the maximum (minimum) temperature in the city (Mitchell 1961 b).

The reduction equation reads:-

$$t_{R_m} = \overbrace{t_e}^{a} + \overbrace{(t_m - th_m)}^{b} - \overbrace{(t_1 - th_1)}^{c} \quad \text{........(3.1)}$$

where:

t_{R_m} is the reduced temperature for station number m.

t_e is the extreme temperature (maximum or minimum) as it was read from the maximum (or minimum) thermometer at the Observatory screen. (see fig.3.1)

t_m is the temperature on recorder chart at station m.

th_m is the temperature of the thermogram at the time when the mobile unit passed station number m.

t_1, th_1 is the temperature of the chart and the thermogram at the beginning of the measurements, that is next to the station number 1 (in winter, or t_7, th_7 next to the summer screen which was located in another place (see 2.2)).

Specific case- calculation of t_{R_m} of station 1 (or station 7 in summer).

In this case:-

$$t_m = t_1$$

$$th_m = th_1$$

following equation 3.1:

$$t_{R_1} = t_e + b - c$$

as: $b = c$

$$\therefore \quad t_{R_1} = t_e \quad \dots\dots\dots\dots\dots\dots\dots (3.2.)$$

From equation 3.2. one can see that t_R at station number 1 in Winter (station number 7 in Summer) is the minimum or maximum temperature in the Observatory screen.

Second specific case, where the thermogram shows no change in temperature. If one substitutes in equation 3.1. th_1 instead of th_m it will read:

$$t_{R_m} = t_e + (t_m - th_1) - (t_1 - th_1)$$

or:-

$$t_{R_m} = t_e + t_m - t_1$$

As t_e and t_1 are constant for that individual date it will yield the following equation:-

$$t_{R_m} = t_m + \text{constant} \quad \dots\dots\dots\dots\dots\dots\dots (3.3)$$

In all the other cases when there is a change of the temperature with the time one will obtain:-

$$t_{R_m} = t_m - th_m + \text{constant} \quad \dots\dots\dots\dots\dots\dots (3.4)$$

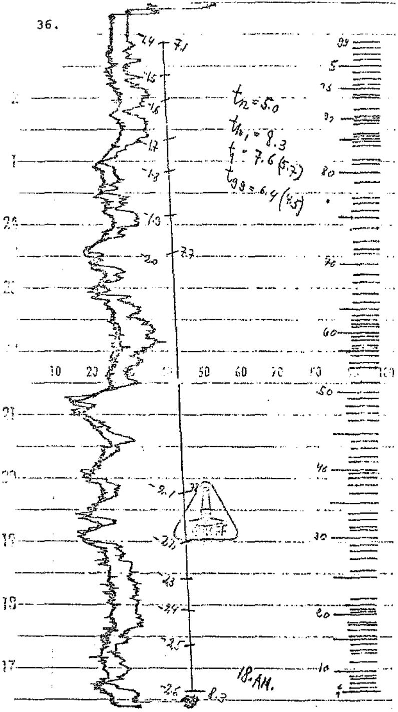

Figure 3.2 The Chart for 18.6.67 night.

In other words one has to calculate for each individual traverse the expression $t_e + th_1 - t_1$ which is constant for this date, to subtract the th_m at every angle on the thermogram and to write the result on the chart (see fig.3.2). The number that is written on the graph will be called k. If one inserts it in equation 3.4. the following will be obtained:

$$t_{R_m} = t_m + k_m \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

One now has to divide the portions of the thermogram that were plotted on the chart into portions equal to 0.1°C and write next to every portion the value k for the point. To obtain the t_{R_m} value one has to read t_m and to add the k_m value. In practice, to obtain the t_{R_1} value one has to apply the following procedure demonstrated with an example (station 30, date - 18.06, night, see fig.3.2):

1). The minimum temperature is written on the chart. (t_e = +5.0 at the Observatory screen).

2). The time of traverse on the thermogram is indicated.

3). One checks whether the difference in temperature of the chart graph stations number 1 and 99 is equal to the difference of the corresponding temperature on the thermograms. (The difference between t_1 and t_{99} = 7.6 - 6.4 which is equal to the difference on the thermogram).

4). If the difference of (3) is not equal one has to compare the graph with other thermograms along the route. (The differences are equal).

5). The thermogram curve is transformed to short linear lines which are drawn on the thermogram. (There were three portions, (1) a drop in temperature, (2) a very slight drop in temperature, (3) a drop in temperature).

6). The thermogram in its new linear from is drawn on the chart and to mark the temperature on every turning point. (7.7, 7.[illegible]).

7). The th_1 (th_7) and t_1 (t_7) are marked at the side of the graph. (th_1 = 8.3, t_1 = 7.6).

8). The constant value of equation 3.4 is computed ($t_e + th_1 - t_1$ = const. - 5.0 + 8.3 - 7.6 = 5.7).

9). The k_m value every 0.[illegible]°C is written on the thermogram (which was drawn on the chart). (const. - $th_{30} = k_{30}$, 5.7 - 7.9 = -2.2).

10). The t_m is read from chart (t_{30} = 1.7).

11). (For winter only). The unlinearity of the thermistor (t_m) is corrected by aid of a table. (t_{30} = -0.9 (=$T_{(2)}$) see 3.4.1.).

12). Equation 3.5 is calculated:

$$(t_{R_{30}} = t_{30} + k_{30}$$

$$t_{R_{30}} = -3.1^{\circ}C. \quad (T(3))$$

For the portion of Northcliff where the U-type route was used (see 2.2), at every station an arithmetical mean was calculated for the dry and wet-bulb temperatures, and only then reduced to the t_R values.

3.1.3. REJECTING THE REDUCTION OF THE WET-BULB TEMPERATURE.

Reduction for tw following the t_R, will not improve the standardization of wet-bulb temperature for the following reasons:-

a). The hygrograph is not reliable.

b). There is a severe lag in the hygrograph reaction.

c). The Stevenson screen is not ventilated, and the difference in wind speed will harm the quality of the recording.

d). It would be impossible to compute correct humidity values in a ventilated screen for wet and dry-bulb temperatures even if an electric recorder, similar to those in the mobile unit were available; the assumption that the change with time is linear in every place is not correct for the differences between the wet and dry-bulb temperature. In fact, as the temperature is lower, the changing of the wet-bulb temperature with time is smaller, i.e. it is not linear with that of the basic screen.

There was therefore no alternative but to use the wet-bulb temperature as it was. Since it was impossible to use the reduced dry-bulb temperature for computing the humidity on the base of the unreduced wet-bulb temperature, two dry-bulb temperatures were given. One not reduced ($T_{(2)}$, see 3.4.1) and the other reduced ($T_{(3)}$). In winter in cases where the water froze on the wick (see 2.42) a reduction to vapour pressure above water was done before correcting the two by the aid of a table.

3.1.4. REDUCTION FOR MISSING DATA. In cases where data was missing, as in the case of the accident on the 2.6.67 (see 2.1.8. footnote) where the traverse was stopped after station 70, data were interpolated for the missing stations. This was done by the conventional method with the aid of the means for the missing stations. The reduction was done separately for dry-bulb temperature, wet-bulb temperature and t_R.

3.2. CALCULATING THE MEAN AIR PRESSURE.

3.2.1. CALCULATING MEAN AIR PRESSURE FOR SUMMER.

The pressure reading was taken at a few stations (see 2.2.) and only once in each month and route was the reading of pressure taken at all the stations. The daily pressure data were tabulated and the differences between the pairs of stations computed. The means were calculated for each station and for the differences between the stations. The data of the two days when all stations were measured were standardized by means of the barogram of City Deep station. On the two days in summer, when the pressure was read at every station, the differences between the stations where the pressure was taken every day was almost equal to the mean differences between those stations. There was, therefore, no need to make a reduction to the fixed station from the common section of the two routes to obtain the monthly mean of the stations. The difference in pressure between the day and night is negligible, as in the pressure level between 800 and 850 mb. an error of 1 mb. can cause an error of $0.1^{O}K$ in potentional temperature or an error of 10 gpm.

3.2.2. CALCULATING MEAN AIR PRESSURE FOR WINTER.

In Winter the pressure reading was taken at station number 1 (and 99) instead of station No. 3. After calculating the mean as it was done for Summer, it was found that the mean pressure was about 1.7 mb. higher than in Summer. The computer was used to adapt the pressure data for Winter (see App Prog.8.).

3.3. COMPUTING PARAMETERS.

The following paragraphs describe briefly the formulae and the theoretical background to the calculations; the practical computing, i.e. the programing for the computer is represented in an Appendix. Not all the parameters computed were used in this study. The capital letters in parentheses are the variables which were used in the program.

3.3.1. SIMPLE CORRELATIONS. Programs 4 and 5 computed the variances, standard deviations and coefficients of variations for every station.

$$\text{Variance} = \sigma^2 = \frac{\sum (a_i - \bar{a})^2}{n} = \frac{\sum a_i^2}{n} - \bar{a}^2 \quad \ldots (3.6)$$

Where:

a_i - the individual value in the series.
$\bar{a}$ - the average of that series.
n - the number of values in the series.

$$\text{Standard Deviation} = \sigma = \sqrt{\frac{\sum (a_i - \bar{a})^2}{n}} = \sqrt{\frac{\sum a_i^2}{n} - \bar{a}^2} \quad \ldots (3.7)$$

$$\text{Coefficient of variations} = \frac{\sigma}{\bar{a}} .100$$

For the coefficient of variation $\bar{a}$ was computed in $^{\circ}$K. At the end of each route the averages for all above parameters were computed and the correlation between the averages and their standard deviations calculated.

Programs No. 6 and 7 dealt with correlations. The formula of the correlation coefficient (RR in the program) is the following:

$$r = \frac{\frac{1}{n}\sum (x-\bar{x})\ (y-\bar{y})}{\sigma_x \sigma_y} = \frac{\text{covariance}}{\sigma_x \sigma_y} \quad \ldots\ldots\ldots\ldots (3.8)$$

for every r a t-test (TT) was computed:

$$t = \frac{r\sqrt{n-2}}{1-r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

where: n-2 - degrees of freedom.
Together with the correlation coefficients the regression equations were computed. The general formula of the regression is:

$$y = b_o + bX \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

y in formula 3.10 was computed as follows:

$$y = r\frac{\sigma_y}{\sigma_x}\cdot(x - \bar{x}) + \bar{y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.11)$$

if x is the unknown (the dependant variable) the formula is:

$$x = r\frac{\sigma_x}{\sigma_y}\ (y-\bar{y}) + \bar{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

the coefficient b in formula 3.10 is derived from (3.11)

$$b(B) = r\frac{\sigma_y}{\sigma_x}$$

and b_o is:

$$b_o(C) = -r\frac{\sigma_y}{\sigma_x}\cdot\bar{x} + \bar{y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

For the two regression equations the confidence limit for 95% — 2 standard errors (SA,SB) was computed:

$$2S = 2\sigma_{y.x} = 2\,\sigma_y\sqrt{1-r^2}$$

3.3.2. COMPUTING HUMIDITY PARAMETERS. The formula for computing the humidity mixing ratio (RR in program No. 8) was established according to the following formula (Brunt 1939)

$$(C_p + XC'_p)\ (T-T') = L'\ (X' - X) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

where: C_p - The specific heat at constant pressure of dry air = 0.2396.

C'_p(CPV) - The specific heat at constant pressure of water-vapour.

T-T'(Y) - The wet bulb depression.

X (RR) - The humidity mixing ratio.

X' (RW) - The humidity mixing ratio of air saturated at the wet-bulb temperature (T').

L' (YL) - Latent heat of water-vapour at the wet-bulb temperature.

If one isolates the X value one attains the following equation:

$$X = \frac{X'L' - C_p(T-T')}{L' + C_p'(T-T')} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.15)$$

Formula 3.14 can be written in a shorter way but is less accurate. (Brunt 1939).

$$C_p(T - T') = L'(X' - X) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.16)$$

The humidity mixing ratio for group card No. 3 (see 3.4.3.) was computed according to formula 3.16.

The computing of the X' in equation 3.15 was done according to the formula in the Smithonian Tables (List 1951 p.302).

$$X' = \frac{0.62197.f_w.e_w}{p - f_w e_w} 10^3 \, g/Kg \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.17)$$

where:

e_w(WE) - The saturation vapour pressure over water in pure phases in mb.

f_w(WE) - Correction factor for the departure of the mixture of air and water vapour from the ideal gas laws.

P(PRE) - total pressure in mb.

The correction factor (WF) and C_p' (CPV) were not obtained from equations but from close values (according to tables 89 and 91, List 1951) with the aid of IF statement to three temperature groups ($>15^{\circ}$C, 5 - 15°C, $< 5^{\circ}$C). It was possible to do this as the error would be noticeable only after a few decimal places.

There remained for the computing of X' in formula 3.17, the saturation vapour pressure (e_w). This equation was [illegible] from Goff and Gratch (1946) and reads as follows:

$$\log_{10} e_w = -7.90298(Ts/T-1)+5.02808 \log_{10} (Ts/T)$$
$$-1.3816 \cdot 10^{-7} \cdot (10^{11.334(1-T/Ts)}-1)$$
$$+8.1328 \cdot 10^{-3} \cdot (10^{-3.49149(Ts/T-1)}-1)+\log_{10} e_{ws} \; \ldots\ldots (3.18)$$

where:

T - Absolute temperature ($^{\circ}$K)

Ts - Steam point temperature (373.16°K)

e_{ws} - Saturation pressure of pure ordinary liquid water at steam point temperature (1 standard atmosphere = 1013.246mb.)*

For the equation of the relative humidity (RH) one had to use X' for dry-bulb temperature (PW) and not for the wet-bulb temperature (RW). While computing the humidity parameters a further three parameters were computed.

$$\text{Potential temperature (TP)} = T\left(\frac{1000}{p}\right)^{2/7} \; \ldots\ldots\ldots\ldots (3.19)$$

$$\text{Equivalent temperature (TE)} = t_w + \frac{L'X'}{C_p} \; \ldots\ldots\ldots\ldots (3.20)$$

$$\text{Potential equivalent temperature (TPE)} = (TE+273.16) \cdot \left(\frac{1000}{p}\right)^{2/7} \; \ldots\ldots\ldots\ldots (3.21)$$

The result of formulae 3.19 and 3.21 were printed and punched in $^{\circ}$C.

---

* The same equation which is quoted also by List (1951 p.350), and, at first, was punched according to List. After running the programme it was found that this equation was copied from Goff and Gratch (1946) incorrectly: in the 3rd row of equation (1) one had to multiply the factor 8.1328 by 10^{-3}.

3.3.3. MULTIPLE LINEAR REGRESSION. Multiple regression is used for the data analysis, to obtain the best fit of a set of observations of independent and dependent variables by a formula which is an extension of the simple regression one (3.10) of the form:

$$y + b_o+b_1X_1+b_2X_2 \; \ldots . b_KX_K \; \ldots\ldots\ldots\ldots\ldots\ldots (3.22)$$

where:

y - dependent variable

X_1, X_2 - independent variables

b_o, b_1 - regression coefficients

There are different methods of computing this regression formula, and the results differ. Draper and Smith (1967) who discussed the various methods believed that the stepwise procedure is the best of the variable selection procedures. In this study this method was used for isolating the urban and topographic factors. In order to allow comparison of the results with other cities, the simultaneous method was chosen for evaluating the weather element influence on the heat island (Chapter 8).

3.3.3.1. THE STEPWISE PROCEDURE.

This procedure starts with a simple correlation matrix. The X variable, most highly correlated with Y enters into regression. *The result is formula 3.10. Using the partial* correlation coefficients (formula 3.24) it now selects the X variable whose partial correlation with the response is highest. The result is the following formula:

$$y = b_o' + b_1'X_1 + b_2'X_2 \qquad \ldots\ldots\ldots\ldots\ldots (3.23)$$

The partial correlation at this stage reads:

$$r_{yx_1 \cdot x_2} = \frac{r_{yx_1} - r_{yx_2} r_{x_1x_2}}{\sqrt{1 - r^2_{yx_2}}\sqrt{1 - r^2_{x_1x_2}}} \qquad \ldots\ldots\ldots\ldots\ldots (3.24)$$

where r_{yx_1} is the correlation coefficient between y and x_1, r_{yx_2} is the same for y and x_2 etc.

After adding the second independent variable the contribution of the first selected variable is examined. It might be removed or kept. This procedure is continued until all the variables which can contribute to the equation are included and it still remains above a certain F-level defined at the beginning of the programme. A flow chart for this procedure can be found in Efroymson's study (1967). The matrix operation differed to that of the simultaneous method, even though the definition and result of the statistic parameters, except for the F-level, are the same; these are given in the following paragraph. The F-level in the stepwise method is to test whether the additional of K+1 variable makes a significant reduction in the residual sum of squares.

The F-level is:

$$F = \frac{(Sy^2_{k} - Sy^2_{k+1}) \quad (N-(K+1)-1)}{Sy^2_{k+1}.} \quad \ldots\ldots\ldots\ldots (3.25)$$

where:

Sy is the standard error of y (3.29).

The F-level value is negative at the step where a variable is removed from the regression equation.

3.3.3.2. THE SIMULTANEOUS METHOD.

This method does not choose variables but computes the regression and correlation for all the variables regardless of their contribution to the regression.

The following computations are carried out. Beta weights are calculated using the following formula:

$$\beta_j = \sum_{i=1}^{k} r_{x_i \cdot y} \quad . \quad r_{x_i x_j}^{-1}$$

where $r_{x_i x_j}^{-1}$ - the inverse of correlation $r_{x_i x_j}$

$$x_i = x_j = x_1, x_2 \ldots\ldots\ldots\ldots x_K$$

The regression coefficients are calculated as follows:-

$$b_j = \beta_j \quad . \frac{\sigma_y}{\sigma_{x_j}} \ldots\ldots\ldots\ldots\ldots\ldots (3.26)$$

The constant is found by the following formula:

$$b_o = \bar{y} - \sum b_j \; . \; \bar{x}_j \ldots\ldots\ldots\ldots\ldots\ldots (3.27)$$

The multiple correlation coefficient is:

$$R = \sqrt{\sum \beta_i r_{x_{iy}}} \ldots\ldots\ldots\ldots\ldots\ldots (3.28)$$

The standard error of y is the following:

$$Sy = \sqrt{\frac{(1-R)^2 \sum (y-\bar{y})^2}{N - K - 1}} \ldots\ldots\ldots\ldots\ldots\ldots (3.29)$$

Standard error of regression coefficients:

$$Sb_j = Sy \sqrt{\frac{r_{x_j x_j}^{-1}}{(x_j - \bar{x}_j)^2}} \ldots\ldots\ldots\ldots\ldots\ldots (3.30)$$

Unbiased estimate of population is calculated as follows:

$$R' \quad (RU) = \sqrt{\frac{n.R^2}{n-K-1}}$$

and the estimate R in future sample:

$$R''(RF) = \frac{n.R^2}{n-K-1(\sqrt{R})} \ldots\ldots\ldots\ldots\ldots\ldots (3.31)$$

The F-test is: $F = \frac{R^2(N-K-1)}{(1-R^2)\;K}$ .... (3.32)

3.4. PREPARING DATA FOR THE ELECTRONIC COMPUTER.

Three groups of data cards were punched:

Group No. 1 ... The measurements (3 4.1)
Group No. 2 ... Physical description of the station (3.4.2)
Group No. 3 ... Details of weather during the measurement (3.4.3).

3.4.1. GROUP CARD NUMBER 1. THE MEASUREMENT.

Group number 1 is punched for every station and every measurement, i.e. 24(68+93) = 3864 cards for each month. These cards included the route, (1 for northern and 2 for the southern route), the number of the station, the date (T(1)) the time (1 for minimum temperature time and 2 for the maximum one), and the three temperatures (t, t_R, tw) which are coded T(2), T(3), T(4) respectively.

3.4.2. GROUP CARDS NUMBER 2: *PHYSICAL DESCRIPTION OF THE* STATIONS.

Group number 2 contained 161 cards. A card for every station in each route. The parameters in these cards were used as the independent variables in the stepwise regression method in order to isolate the urban and topographic influences.

3.4.2.1. CODES FOR ELEVATION AND RELATIVE HEIGHTS.

In order to obtain equal weight in each factor for the purpose of computing multiple regression coefficients, the number code was *from 0 to 9 (except for* the pressure which was punched for a different purpose). Table number 3.1 gives the codes for the elevation and relative heights.

TABLE NO. 3.1

CODES FOR THE ELEVATION AND RELATIVE HEIGHTS OF THE STATION

CODE	HEIGHT (in feet)	RELATIVE HEIGHT (in feet)
1	5100 - 5200	0 - 100
2	5200 - 5300	100 - 200
3	5300 - 5400	200 - 300
4	5400 - 5500	300 - 400
5	5500 - 5600	400 - 500
6	5600 - 5700	500 - 600
7	5700 - 5800	
8	5800 - 5900	
9	5900 - 6000	

The determination of the relative height caused many problems, and it was not easy to decide in each case, which valley and at what level in that valley, the basis for the relative height would be. Generally, the basis chosen was the bottom of the valley below the station. If the longitudinal line of the valley below the station was too steep so that the cold air drainage on inversion nights would continue to flow almost at the same speed, a lower level was chosen as a basis. For this purpose the air photos (1959) were of great use.

3.4.2.2. CODES FOR THE EXPOSITION AND STEEPNESS OF SLOPE.

The steepness codes for Winter were different to those of Summer as, their exposures to insolation was different. They were punched for Summer conditions and changed using the computer to Winter conditions (See App. Programme 8). The exposure was punched without considering the insolation intensity on these exposures but, was changed by the computer in such a way that the insolation intensity would drop with the rising of the code number.

TABLE NO. 3.2.

CODES FOR THE EXPOSURE OF SLOPES

PUNCHING CODE	EXPOSURE	CODE AS CHANGED BY COMPUTER
0	flat	-
1	N	N
2	NE	NE.NW
3	E	flat
4	SE	E.W.
5	S	SE.SW
6	SW	S
7	W	-
8	NW	-

For Summer this order of symbols has no meaning.

In the program for Summer the different specifications of 'flat' were changed into code number 3.

For Winter when the sun angle is low, the order of the codes was changed according to the intensity of the different slope. On southern aspects special series of codes were used as shown in table No. 3.3.

3.4.2.3. CODES FOR THE ROAD DIRECTION. A code was made for the direction of the road to check the possibility that the road direction might influence the temperature distribution i.e. that the buildings will shade the East-West road and not the South-North road. The order of the numbers is meaningless.

TABLE NO. 3.3

CODES OF THE SLOPE STEEPNESS

[illegible]	STEEPNESS IN SUMMER	RATE OF STEEPNESS in degrees	STEEPNESS IN WINTER Adjusted for elevation of sun	
			FOR 1 - 4 Slope	FOR 5 - 6 Slope
1	flat in valley	<15°	3	3
2 } 3	flat on range			
3	flat on bend			
4	slight slope	15 - 35°	4	2
5	medium slope	35 - 55°	5	2
6	steep slope	55 - 70°	4	1
7	very steep slope	>70°	3	0

TABLE NO. 3.4

CODES FOR THE ROAD DIRECTION

CODE	ROAD DIRECTION
1	E - W
2	S - N
3	SW - NE
4	NW - SE

3.4.2.4. CODES FOR THE DENSITY OF URBANISATION AND HEIGHT OF BUILDINGS.

The codes for urbanisation density were also changed into *graded form*.

TABLE NO. 3.5

CODES FOR DENSITY

DESCRIPTION	EXAMPLE	PUNCHED CODE	GRADED CODE
Very dense	Hillbrow and Western township	0	0
Dense	Berea	1	1
Medium density	Highlands North	2	2
Low density	Houghton	3	3
Empty in town	-	4	4
Empty outside town	-	5	5
City	-	6	0
Industrial area	-	7	1

The density of *dwelling areas* was determined according to the town planning maps and tables for the size of plots and percentage of building per plot. The code was not done arbitrarily according to maps, but according to the practical density. For instance, if there were open plots next to the station in one of the zones coded as dense, the density was defined by a lower density code number. The code for the height of buildings was determined by the average number of floors in the near vicinity of the station and not by the height of the whole suburb.

TABLE NO. 3.6.

CODES FOR HEIGHT OF BUILDING

0	empty plots
1	one floor
2	two floors
3	three - four floors
4	five floors and more

3.4.2.5. CODES FOR THE RIDGES. To determine the influence of ridges on climate i.e. to discover whether ridges behave as a climatic barrier, codes for the areas between ridges were fixed (see also 1.2.).

TABLE NO. 3.7.

CODES FOR THE AREA BETWEEN RIDGES

CODE	SIDE OF RIDGE
1	North to Linksfield Ridge
2	Between Linksfield Ridge and Observatory/ Yeoville Ridge
3	Between Observatory/Yeoville and Troyeville
4	Between Troyeville and Elsburg Ridge
5	South to Elsburg Ridge
6	On a ridge

The stations on a ridge (6) were not used.

3.4.2.6. CODES FOR MISCELLANEOUS. For symbolising the specific conditions that might influence the spot climate, another column was added. Obviously, there is no grading in the code.

TABLE NO. 3.8

CODES FOR MISCELLANEOUS

1	Near railway
2	Near garden
3	Avenue
4	Heavy traffic
5	Heavy traffic and near railway.

3.4.3. GROUP CARDS NUMBER THREE: DETAILS OF WEATHER.

The Group Cards number three contain a description of weather for every traverse (48 cards for each month). These cards included the date, route, time, cloudiness (in oktas) windspeed (in Knots), wind direction (in code), the difference in temperature between Parkhurst and Observatory, the minimum (or maximum) temperature in Station 87, H.M.R. for Station 6, temperature range for Station 87 and temperature range for Jan Smuts Airport.

3.5. RELIABILITY OF THE SAMPLES.

As preliminary research was not possible, the checking of the statistical meaning of the sample is possible in the present study only after the measurements have been taken. Schnelle (1963, p.426) suggests taking observations in a net-work of stations during 15 to 20 nocturnal inversions, regardless of their strength before deciding on how many more observations are necessary to achieve the required accuracy. This depends on the variability of the studied element. Sharon (1964) shows, with the aid of a preliminary study that under certain circumstances eight nights were enough to represent differences of minimum and maximum temperatures along slopes. Averages obtained from samples of this size were within 0.33°C of the true temperature differences, at a confidence level of 95%.

3.5.1. THE PROBLEM OF RANDOMNESS OF THE SAMPLE'S AVERAGE.

The formula for determining the sample size discussed later (3.5.2.), i.e. the relation between the factors defined in 2.3.1., is based on assumptions which had to be checked:

a). That the distribution of the sample is normal.

b). That the sample is a random one.

The first assumption can be assumed even if the population is not normally distributed. The central limit theorem states that the distribution of sample means obtained from the population approaches the normal distribution (e.g. Fraser 1958., p.121).

The second assumption is problematic. Values obtained from successive observations cannot often be regarded as a random sample when analysing climatiological data (Panofsky 1958, p.47), as data from one day are partly dependent on the conditions of the previous day. Sharon (1966) solved this problem in two simultaneously applicable ways. Firstly, he carried out the investigation of a climatic element separately for sets of specified external conditions only (weather-types); within each of these sets variations between successive observations can be regarded as random. Secondly, he analysed directly the differences between the stations (Δt) rather than the values themselves. These differences are less influenced by weather variations than the climatic elements themselves. In this study the problem was even less serious, as the observations were not carried out successively but alternately in each route. Even though the mapping was done in absolute values, the study of the urban influence on the elements and parameters done separately for each route was based on the differences between the stations and not on the values themselves.

3.5.2. CALCULATING THE ERROR INTERVAL.

The error interval discussed earlier is determined by two factors:

1). the rate of accuracy of the instrumentation (which in this study also includes the accuracy of the reduction),

2). the size of the average values.

In other words the error interval should be equal to or greater than the effective rate of accuracy, which can be obtained by the instrumentation, and smaller than the differences between the stations. For instance, if one *decides on an error interval of* ± 1.0°C and the difference between two stations is less, i.e. - +0.7°C, then the difference can even be a negative one - -0.3°C.

The calculation of the sample size after the preliminary study is the following:-

$$n = \left(\frac{t.\hat{\sigma}}{d}\right)^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.33)$$

where:

n — is the sample size (the number of days of observations).

t or $t_{1-\frac{\alpha}{2}}$ (n-1) is the fractile of the t distribution with (n-1) degrees of freedom corresponding to a probability of $1-\frac{\alpha}{2}$ (α–the 5% level of significance).

$\hat{\sigma}$ — is the best estimate of the standard deviation $= \sigma\sqrt{\frac{n}{n-1}}$.

d — is the error interval.

Because of the small samples at value was used instead of the standardised normal distribution. In this study where *n is known* but the d value is missing, equation 3.33 can be converted as follows:-

$$d = \frac{t\hat{\sigma}}{\sqrt{n}} \qquad \text{.............}(3.34)$$

or

$$d = \frac{t\,\sigma}{\sqrt{n-1}} \qquad \text{.............}(3.35)$$

As n and the mean values for σ are different for day and night and summer and winter (and for each route, see Table 3.9) d values will also be calculated for each route, time and season.

TABLE NO. 3.9.

ERROR INTERVALS VALUES FOR WINTER

TIME	ROUTE	n-1	t-test	d	ELEMENT	$\bar{\sigma}$	$\bar{d}$	$\overline{\Delta t}^{o}_{c}$
INVERSION NIGHT	I	6	2.447	1.00σ	t^{o}_{c}	1.67	1.67	
					Δt^{o}_{c}	0.75	0.75	1.21
	II	5	2.571	1.15σ	t	2.52	2.9	
					Δt	0.71	0.8	0.72
DAY	I	11	2.201	0.66σ	t	3.15	2.1	
					Δt	0.33	0.22	0.18
	II	11	2.201	0.66σ	t	2.98	2.0	
					Δt	0.53	0.35	0.16

$\bar{\sigma}$, $\bar{d}$ and $\Delta\bar{t}$ are the means for the route.

These values correspond to the elements t^{o} or Δt, which are the actual temperatures and the temperature differences between nearby stations. For each time and route the n, t-test and d values (for a given standard deviation) are equal but are different if one distinguishes between the averages of the standard deviation ($\bar{\sigma}$) for t^{o} (program No.4) and for Δt (App. program No.5).

From Table 3.9 it seems that it would be difficult to use the t^{o}_{c} values, as the error interval is too high, especially in inversion nights where the differences in d values between the two routes is high. It would be better to investigate the differences between successive stations (Δt) where the mean standard deviation and the error interval are equal for the two routes. Using the differences between stations helps to solve the problem of the randomness of the sample (see 3.5.1.) yet, using the Δt also presents problems as the standard deviations vary considerably due to the fact that the vertical distance between the stations was not uniform. $\bar{d}$ thus becomes less meaningful. Computing the d value for every successive two stations reduced to one level (average height for each route, prog. No.5) did not improve the homogeneity of the standard deviations but made it worse. The effect is heightened as there are cases where the Δt is $0^{o}C$, or where the differences are great while the vertical differences are low. The $\bar{d}$ value can therefore be regarded only as a qualitative conception and a base for examining the error interval for every two stations; thus the error interval obtained in regard to its Δt may be reasonable in some cases but not in others. In other words, in cases where it is possible to use the error interval (i.e. where it is smaller than Δt) the sample represents the population satisfactorily (in the given error interval and level of significance), and in cases where the error interval is not reasonable, the sample is too small to determine the differences between the stations.

According to the Winter in inversion nights the small sample (n = 6 or 7) is sufficient in most of the cases. The difficulty occurs mainly along the slopes near the thermal belt (see 4.4.3.), where the d value will be greater than

Δt. The mean error interval of ±0.8°C is not high if one takes into account the tendancy today to report only in whole degrees celsius, except for the measurement of humidity and lapse rates in micro-climatology (Sutton 1963). On the other hand, in spite of the d values being lower for the day in Winter and Summer, (see tables No. 3.9 and 3.10) they are generally not adequate as they are still higher than the Δt value. It does not help to increase the sample size, as the number of observations would have to increase drastically in a position where $\Delta t > \bar{d}$. The d value would still be meaningless; it is meaningless in mobile unit measurements where d is lower than 0.2°C. As in the night, it is also possible to state here that in part of the differences in temperature between successive stations, the sample is large enough to represent the population.

TABLE 3.10

ANALYSIS OF THE ERROR INTERVAL FOR Δt SUMMER DAYS

$d = 0.69\sigma$
$n-1 = 11$
t-test = 2.201

ROUTE	σ	$\bar{d}$	Δt
I	0.42	0.29	0.19
II	0.41	0.28	0.19

3.5.3. COMPARISON WITH THE NORMALS FOR PERMANENT STATIONS.

It was possible to check if the data from the months of measurement are similar to the normal, if only in a qualitative form, by using the data of the stations Zwartkoppies, which is still used, and Observatory, which was used during 1904 - 1940 (Shumann 1942). These two stations are similar in height to the extreme stations on the routes. Zwartkoppies is about 70 meters lower than Station 49 in Route 1, while Observatory station is next to Station 4.

TABLE 3.11

COMPARISON OF DECEMBER 1966 TO THE DECEMBER NORMALS (°C)

TEMPERATURE	ZWARTKOPPIES		STATION No.4.	OBSERVATORY
	1966*	1906-1940	1966	1904-1940
Min.	14.7	13.7	14.7	13.1
Max.	27.4	27.8	24.5	24.8
Mean	21.0	20.7	19.6	18.9

* For the days of the observation only.

Table No. 3.12 shows that the temperature slope lapse rate between Observatory and Zwartkoppies was equal to the normal in the day, but not at night, because of the great variability of inversion conditions.

TABLE 3.12

TEMPERATURE COMPARISON OF JUNE 1967 TO THE JUNE NORMALS (°C)

TEMPERATURE	ZWARTKOPPIES		STATION No.4.	OBSERVATORY
	1967	1906-1940	1967	1904-1940
Min.	-0.6	-1.4	4.4	4.5
Max.	17.2	18.3	14.2	15.8

Table No. 3.12 shows that in both places the maximum temperature in June 1967 was lower than the normal, i.e. the number of 'cold snaps' days (see 1.3) was greater than the average. A 'cold snap' lasts two to three days. During 28 years there was only one year with two 'cold snaps' and three years with three 'cold snaps' (Jackson 1933), i.e. the average is one per year in the month of June.

In June 1967 there were two 'cold snaps'. During a 'cold snap' the development of inversion conditions is weak. It is possible to come to the conclusion -- at least from a qualitative point of view, -- that inversion strength for the month of June 1967 is reasonable and similar to the normal, and there is no reason to suspect that the enormous negative slope lapse rate that was measured at lower stations (see 4.4.1.) occurred only by chance.

PART II

THE OBSERVATIONS, THEIR DISCUSSION AND ANALYSIS

CHAPTER 4

MINIMUM TEMPERATURE DISTRIBUTION IN WINTER*

In analysing temperature distribution the minimum temperatures in winter (June) were stressed. The reasons for preferring the winter nights were as follows:-

a) The relatively great uniformity of the weather (only nights of strong inversion were chosen).

b) The great range of temperatures that facilitated determination of the error interval (see 3.5.2.).

c) The highest multiple correlation coefficient values were obtained.

4.1. APPLICATION OF THE MULTIPLE REGRESSION EQUATIONS.

The general formula of the multiple regression (3.22) and the procedure of the stepwise method were discussed in 3.3.3. In this study the dependent variable (Y) is the average temperature of every station (output of program 8 and plotted in Fig.4.1) and the independent variables are the descriptions of the station (see 3.4.2.), as follows:-

1). Elevation.
2). Relative height.
3). Slope aspect.
4). Steepness of slope.
5). Density of urbanisation.
6). Height of buildings.

---

* When referring to the measurements taken in this study the terms day and night, and Summer and Winter, refers to times of maximum and minimum temperature during December and June.

These independent variables are actually not variable but fixed if the structural features of the town do not vary greatly; they were the same for day and night, Winter and Summer, and will be the same for another sample. The output of program 9 (the stepwise procedure) is the result of the statistic parameters which were discussed in 3.3.3.2. after every step. Only the table of residuals is given after the stepwise series is completed.

So far, the fluctuations of climatological correlation coefficients have not been studied sufficiently in theory or by experiment (Panofsky 1958). It seems likely that the multiple correlation coefficient (R) and the coefficients in the regression equation will differ in another set of data even for the same independent variables. Indeed, when computing the multiple regression on separate routes, the same variables and coefficients did not always appear in the regression equation. The advantage of this study, as already explained, is that the independent variables are actually not variable but fixed.

The multiple correlation coefficient always appears with a positive sign. The stability of the multiple correlation coefficient (R) and of the regression equation is also dependent on the number of variables. Although every additional variable increases the R value and decreases the scattering around the regression line, i.e. reduces the standard error of Y, (S_y - *equation* 3.29), such addition also decreases the stability of the equation for the next sample. Moreover, the significance values of R (at the different levels of confidence) rise with an increase in the number of variables. There is therefore little point in adding a variable which has little effect on the R values but decreases the significance and the stability. Computing the multiple correlation coefficient by the stepwise method allows one both to determine the F level and to cut the stepped series after the suitable step is reached. If the regression coefficient (b_j) does not pass the test, or if the physical relation between the variable and the dependent value is unclear, it may be omitted. The test which will be used for the regression coefficients is twice the standard error of the regression coefficient ($2S_{b_j}$). In other words, if $2S_{b_j} > b_j$, with a confidence limit of 95%, the regression coefficient might appear with an opposite sign. Applying a one tailed normal distribution test, (i.e. instead of twice S_{b_j} ($1.96S_{b_j}$) multiplying S_{b_j} by 1.64) will be too biased, as the regression coefficients can appear with both signs even in the same variable at different times and parameters.

There was no disadvantage in computing the multiple correlation for each route separately. It was possible to standardise the procedure, so that only one route had to be computed. The combined multiple correlation coefficient could also be computed with the aid of Fisher's Z' transformation (Brooks & Carruthers 1953, p.222).

Fig.4.1 shows the mean minimum temperatures on Winter inversion nights only (t_R); it was made by interpolation between the stations, with due regard to the coefficients given by the multiple regression equation.

Isotherms are shown by full lines, even for areas with insufficient data. Every small park, open space etc. could not be taken into account. The reliability of the interpolation would be decreased further away from the routes. It is possible to compute the temperature value for each spot by means of the multiple regression equation. Then, with a significance of 95%, the predicted temperature would be $Y \pm 1.96S_Y$.

4.2. CHOOSING INVERSION NIGHTS AND STANDARDISING THE ROUTES TO ONE MAP.

When examining the differences between the minimum temperatures recorded at the fixed stations -- at Observatory and at Parkhurst -- it was found that out of 24 nights on which measurements were taken in June 1967, 19 were inversion nights. In attempting to single out the nights on which the inversions were particularly strong, it was found hard to determine their strength from the measurements at these two stations alone. On comparing the various temperature cross-sections in Fig.4.2 one can see that the cross-section for 28.6.67 does not show strong inversion conditions along the whole section. This case can be explained by the fact that the development of inversion conditions depends on small changes in conditions, i.e. any air current or turbulence is able to disturb the inversional distribution. Another case in point is represented by the measurements taken on the southern route on 25.6.67. The sky was cloudy at the time, but the difference between the screens nevertheless reached 5°C. This could be explained here too by the fact that during the night the inversion developed in the normal way, but only became disturbed at the time of measurement. Thus it proved impossible to rely on the stationary screen data

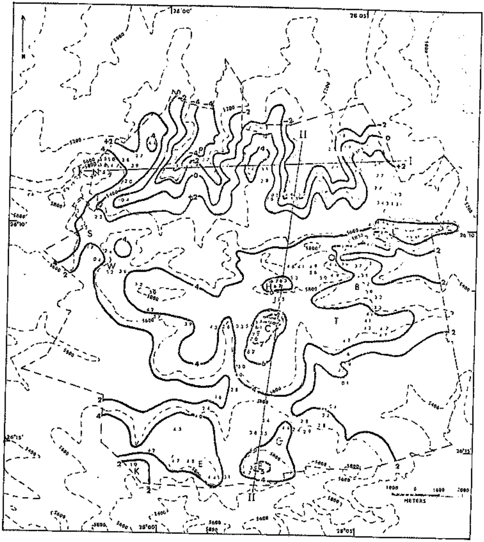

Figure 4.1 Mean minimum temperature distribution for strong inversion nights only (June 1967)

alone (nights where at least a 2.7°C difference between the two fixed stations were chosen); reference had to be made also to the temperature profile of the following portions of the traverse: the section next to Parkhurst (P in Fig.4.1 - Stations 47-49) in the northern traverse, and the section next to K in Fig.4.1 (Station 40) on the southern traverse.

Using this method of selection, data were chosen for only seven nights from Route 1, and for six nights from Route 2.

Difficulties arose while standardizing the two routes. A comparison of the differences between the stations along the common route shows that they are not uniform. The average for Route 2 is higher by 0.5°C than for Route 1, but the difference at the Observatory screen (which represents also Stations 1 and 99 after the reduction) for the days on which only the one route was measured is higher by 0.2°C for Route 1 than for Route 2. It seems that the reliability of either the measurements or of the reduction method is low. But if one compares the stationary screens in Johannesburg and vicinity for the nights when one route was measured, to those of the other route, one finds no uniformity of the mean differences between the minimum temperatures.

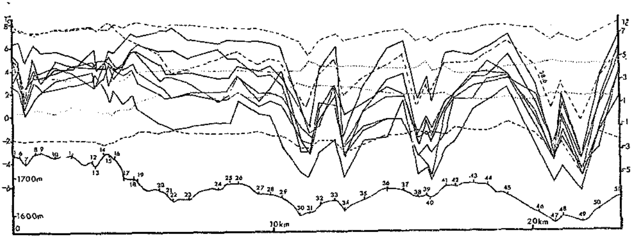

Figure 4.2 Minimum temperature cross-sections for June 1967. Broken lines for weak inversion. Dotted line for no inversion

TABLE 4.1.

THE MEAN MINIMUM TEMPERATURE IN STATIONARY SCREENS

STATION	ROUTE 1. NIGHTS	ROUTE 2. NIGHTS	DIFFERENCES
OBSERVATORY	4.4	4.2	+0.2
JOUBERT PARK	4.9	5.9	-1.0
JAN SMUTS	4.2	4.0	+0.2
PARKHURST	-0.6*	-0.1	-0.5
ZWARTKOPPIES	-2.3	-1.7	-0.6

* One observation is missing.

Table 4.1 indicates that for the stations situated at lower elevations (except for Joubert Park) the temperature differences between the two routes are greater than for the higher stations. It is therefore possible to assume that the inversion strength during nights was greater on Route 1 than on Route 2. Furthermore, the data for the city show a thermal gradient on Route 1 but not on Route 2. Nevertheless, it is possible to prove that the inversion conditions were stronger on Route 2. For instance, the differences between Jan Smuts Airport and Station 87 (C in fig.4.1) was greater on Route 2 (3.7°C compared to 2.8°C). This contradiction can be explained by the fact that the inversions are affected by small changes in conditions as was mentioned above.

It was finally decided to use Route 1 (in its entirety) for the purpose of mapping and to add the data from Route 2 (excluding the section common to both) unchanged. As the isotherms are drawn for two degrees Centigrade intervals, the error is negligible, especially since the additional portion of Route 2 does not include the city or any particularly low locations.

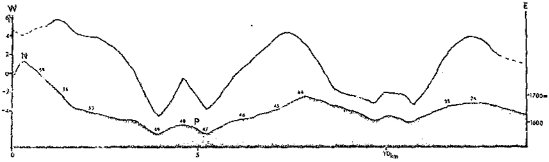

Figure 4.3 Winter minimum temperature profile across the northern valleys (Section I in Fig.4.1). N - Northcliff. P - Parkhurst screen. Stations are numbered.

4.3. RESULTS OF MULTIPLE REGRESSION COEFFICIENTS.

The qualitative correlation between the topography and the urban distribution on the one hand and the temperature distribution on the other hand is quite prominent in this map. Combined with the fact that the R (multiple correlation coefficient) values are very high, this makes it possible to improve and direct the interpolation and to give some quantitative data for analysing the map.

TABLE 4.2

ANALYSIS OF MULTIPLE REGRESSION FOR WINTER INVERSION NIGHTS

VARIABLE	ROUTE 1.		ROUTE 2.		COMBINED	
	R= 0.85		R= 0.94		R= 0.86	
	COEFFICIENT (b_j)	STD. ERROR (S_{b_j})	COEFFICIENT (b_j)	STD. ERROR (S_{b_j})	COEFFICIENT (b_j)	STD. ERROR (S_{b_j})
ELEVATION (1)	0.62	0.10	0.46	0.14	0.69	0.07
RELATIVE HEIGHT (2)	0.49	0.14	0.26	0.16	0.36	0.10
ASPECT (3)	0.19	0.09	0.30	0.08	0.12	0.06
STEEPNESS (4)	-	-	0.32	0.14	-	-
BUILDING DENSITY (5)	-0.52	0.21	-0.61	0.11	-0.57	0.13
HEIGHT OF (6) BUILDINGS	0.33	0.22	0.50	0.12	0.47	0.15
CONSTANT (b_o)	-1.21		-0.68		-0.87	
STD. ERROR OF y(Sy)	±1.39		±0.71		±1.23	

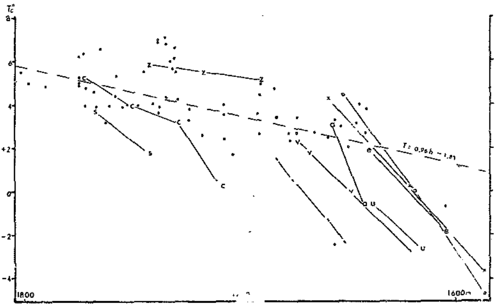

Figure 4.4 The regression line of mean temperature on elevation (route 1)

Table 4.2. stresses the influence of elevation relative height and of urbanisation. The high R value for Route 2 (0.94) is not due only to the fact that the number of stations (cases) on this route was smaller. If that were the reason, then the R value for the combined route (138 cases) would be much smaller. It is possible to explain the high R value for Route 2 by the lack of stations at low elevations in comparison to Route 1. In the table of residuals (see Table 4.6) these stations on Route 1 showed a greater difference between the predicted and the actual temperatures, i.e. at the low spots the temperature distribution is not linear (see 4.4. and Fig. 4.4).

In order to improve the multiple correlation coefficient the mean temperature was replaced by mean potential temperature (see Garnett and Bach (1967)). Despite the reduction to a datum level no improvement was achieved, also for the day the multiple correlation was not improved.*

4.4. TOPOGRAPHICAL INFLUENCE.

4.4.1. RATE OF INVERSION IN VALLEYS.

The difference between the warmest and the coldest place on the map (Fig.4.1) is 11.7°C (-4.6°C)- at P in Fig. 4.1 (Station 49, Route 1), and +7.1°C - at C (Station 89), common to both routes). This great difference which might represent the normals (see 3.5.3.), or the mean temperature gradient measured at P (between Stations 49 - 51) on Route 1

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* The same was computed for humidity; instead of H.M.R., mean equivalent temperature and potential equivalent temperature were inserted but without improvement.

(about 60 m. level difference), with a temperature difference of 9°C (!) and a standard deviation of $\pm 1.2^{\circ}$C, is not known from any other investigation in the world.* The record for one single night at P was 11°C on the 18.6.67. Even if all the 12 nights are taken, including those without inversions, the difference between Stations 49 and 51 (P) is 6.1°C, and for the whole town 8.3°C. In two different studies in Pretoria one using fixed stations (Schumann 1942) and another using a mobile unit and readings of a standard thermometer (Louw and Meyer 1965) differences of up to 5°C were found between valley and hill (for a level difference, according to Schumann, of 120 m.). The fact that there are inversions in the highveld is not new, but the rate measured in Johannesburg is exceptional. Even though Johannesburg is higher than Pretoria the air is less dense and less humid and there are better conditions for nocturnal ground radiation, one must check the area at P in Fig.4.1 (Station 49) for its mesoclimatology, and mainly the direction and strength of the air drainage system in the area. The temperature slope lapse rate is strong not only at the bottom of valleys but in the whole town. If one divides the mean temperature difference between successive stations by the average level difference (App Program 5) and considers

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* Except, of course, the classical case of the Gstettneralm sinkhole where a 27°C difference per 100 m. was measured (Geiger 1965 p. 399). It is not clear at what height above ground the temperature was taken. Geiger quotes another case where, according to E. Bylund and A. Sundborg, a difference of 8 to [illegible]C was recorded at a level difference of less than 100 m. but at an intervening distance of 2-3 Km. in Lapland (p.437). Where slopes are covered with snow it is

the quotient representing the slope lapse rate per 100 m., the rates would be 8.0° per 100 m. on Route 1 and 6.5° per 100 meters on Route 2.

4.4.2. BEZ VALLEY PARADOX.

Bez Valley (B in Fig 4.1) is noted for its strong relief. In comparison with the top of the valley and with the valley next to Linden, (P in Fig.4.1 - Station 49, Route 1) no low temperatures were recorded (the average being 2.2°C) at the bottom of the valley (Station 9, Route 2)). Moreover, at O in Fig.4.1 (Station 7) on Route 1, in a shallow valley situated not far from Bez Valley, lower temperatures (1.8°C) were measured. That means that the relative height played an important part. From a quantitative point of view, one has to distinguish between the two routes according to the weight of their regression coefficients: elevation and relative height (see 4.3). The distinction is necessary since the valleys on Route 2 are on a higher elevation than on Route one and most of them are at the same elevation. This fact explains the high correlation coefficient (+0.86) between the relative height and elevation on Route 2, in comparison to the lower correlation coefficient (+0.60) for Route 1 (See Table 4.3.).

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possible to get higher slope lapse rates, as were measured by Middleton (1936) in Toronto, where, at 68 cm. above ground a lapse of 15°C for a level difference of 45 m. was determined. When he repeated these measurements in the Summer and Autumn, the lapse did not reach 5°C, while in Johannesburg even during one Summer night with strong inversion the temperature lapse was similar to the Winter one (4.5). Sharon (1964 p.94), for comparison with his own research, quotes a number of cases dealing with the minimum temperature slope lapse rate, where

The regression coefficient of the relative height on Route 2 does not pass the twice standard error test ($2S_{b_2}$), because of the high interrelation between these two variables.

TABLE 4.3.

CORRELATION COEFFICIENT MATRIX FOR THE DESCRIPTION OF STATIONS FOR SUMMER (PROGRAMME 6)*

VARIABLE	1.	2.	3.	4.	5.	6.
1. ELEVATION	R	0.60	-0.10	-0.07	-0.28	+0.44
2. RELATIVE HEIGHT	0.86	O U	-0.29	0.26	-0.07	+0.16
3. SLOPE ASPECT	0.04	0.02	T R E	-0.19	-0.11	0.01
4. SLOPE STEEPNESS	0.05	0.08	-0.20	O 1 U	0.11	-0.12
5. DENSITY	-0.00	-0.10	-0.22	0.06	T E	-0.76
6. HEIGHT OF BUILDINGS	0.32	0.35	0.12	-0.06	-0.71	2

* For Winter variables 3 and 4 were not the same (see 3.4.2.2.).

Since there is a lack of data on the wind flow, its strength and directions in the various valleys, only theoretically plausible explanations will be given here. Firstly, if one checks the table of

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the extreme case was 3.3°C per hundred meters. In his research the extreme slope lapse rate was 8.5°C per 220 m. as established over a much longer period than the 12 nights on which measurements were taken in the present case, at a height of 1 m. above ground (which increases the slope lapse rate).

residuals (Table 4.6), one will find that at *Station 9, (B in Fig 4.1) the actual temperature* is higher by 0.4°C than the predicted one, in comparison with the difference of 3.1°C and 2.5°C at P in Fig. 4.1 (Stations 47 and 49 in Route 1, re this difference see 4.4.3.). This fact can be explained by physical considerations. During radiation nights, on a steep slope, one may expect a strong thermal gradient towards the bottom of the valley, caused by the strong sliding of cold air downwards. On the other hand, on a gradual slope the condition will be more isothermal. On a steep slope, however, it is possible, according to Weise (Koch 1961), that the air drainage will be strong enough to cause great turbulence (which the urban pattern may intensify) that will interfere with the stratification of cold air at the bottom of the valley.

Another explanation for this phenomenon is that the *Bez Valley adjoins the city and lies* leeward of the city (C in Fig.4.1) and Hillbrow (h), both of which are the warmest places in Johannesburg. It is possible that the warm air which receives heat radiation from the buildings at night advects towards this valley. This might also explain the lack of clearness of the temperature distribution in the valley south-east of the city (towards Heidelberg Road).

4.4.3. THE THERMAL BELT.

The inversion profile at night does not cover the whole slope, but terminates at certain levels, beyond which the usual lapse rates become apparent.

The zone of this transition is called the thermal belt which corresponds to the top of the inversion in the free atmosphere of the valley and is the warmest place along the slope. Such a zone on the slope is explained as a boundary between the lower part of the valley, where inversion conditions exist, and the upper part where the inversion is disturbed by turbulence.

The location of the thermal belt depends on the weather, i.e. the rate of development of the inversion; therefore, its height above the valley is not the same every night and may not be constant during the same night. Opinions differ as to how long the process of establishing the thermal belt takes. According to Baumgartner (Sharon 1964) the maximum height of the thermal belt is already reached at the beginning of the evening and remains almost constant until the morning. Geiger (1959 p.207) speaks of the upward migration of the thermal belt to certain elevation over a number of hours, settling at an average level at the end of the night. While Baumgartner and Geiger speak of a fixed position, Mano (1956) speaks of a vertical migration of the thermal belt along the slope backwards and forwards. Mano connects this migration with the movement of the surface of wind discontinuity at the base of the general westerlies above Japan. In other words, the thermal belt depends also on dynamic factors. Following Mano, Geiger corrects himself in his 1965 edition (p.436) and states that during the course of any individual night the thermal belt does not always remain at the same elevation on the hillside.

According to Mano's research, it appears that it is impossible to find the position of the thermal belt with the aid of a mobile unit and there is no particular value in standardization for one point in time in the vicinity of the estimated position of the thermal belt.

A different opinion in connection with the thermal belt is put forward in the study by Koch (1961). Contrary to the conventional idea of one thermal belt being established by stratification of the air according to its density and temperature, Koch maintains that the distribution of temperature along the slope is determined by the topographic features of each portion of the slope by itself, and not by the topography of the valley as a whole. The determining factor is the steepness of each portion of the slope and the resulting differences in the draining speed of the cold air (see also 4.4.2.).

In recent works published after Koch's research, (*e.g.* Sharon (1964) who also quotes Koch) no support can be found for Koch's ideas. Sharon states that certain importance has to be attached to the steepness, but it is certainly not [illegible]in cause of the appearance of the thermal be[illegible]e present study, made in a town where the slopes [illegible]vered by houses, fences, walls and belts of trees, it is hard to prove or disprove Koch's views (see also 4.4.4.). Anyhow no evidence was found to support them.

In Johannesburg the thermal belt was not found in every valley at the same height (neither relative nor absolute). The thermal belt oscillate generally between the elevations of 1670 and 1750 m. In the northern valleys (such as Waverley or Linden, P. in Fig.4.1) the thermal belt is found at an elevation of about 1670 m., while in Northcliff (N) it lies at about 1750 m. (see Fig. 4.3), which is some 50 m. below the highest point of Northcliff. As to its relative height, the thermal belt in Waverley and Linden is found about 75 m. above the bottom of the valley, and in Northcliff about 120 m. As for Linksfield Ridge (L in Fig. 4.1. Station 13-19 Route 1), it is difficult to locate the position of the thermal belt on both its flanks, as it varies from night to night (see Fig.4.2). If its average position is taken, the thermal belt is found to lie next to Station 18, which corresponds to an elevation of 1670 m. and at a relative height of 75 m. above the bottom of the valley. This fact is probably connected with the great steepness of Linksfield Ridge, but is certainly not the only factor, since in Northcliff which is as steep, the deviations from the mean elevation of the thermal belt are small. The answer to this problem will probably be found after checking the windflow pattern above Johannesburg during inversion. As to the southern route, the thermal belt in Bez Valley, (B in Fig.4.1), lies between [illegible]vations 1700 and 1770 m. and at the Elsburg Ridge (E) at about 1770 m.

The fact that the thermal belt appears at varying heights in different places, makes the analysis of the urban influence on it more difficult, especially where the city (C in Fig. 4.1) itself is situated within the range of thermal belt distribution. On plotting temperature against elevation (see Fig.4.4) a rapid increase the elevations of 1670 and 1750 m. In the northern valleys (such as Waverley or Linden, P. in Fig.4.1) the thermal belt is found at an elevation of about 1670 m., while in Northcliff (N) it lies at about 1750 m. (see Fig. 4.3), which is some 50 m. below the highest point of Northcliff. As to its relative height, the thermal belt in Waverley and Linden is found about 75 m. above the bottom of the valley, and in Northcliff about 120 m. As for Linksfield Ridge (L in Fig. 4.1. Station 13-19 Route 1), it is difficult to locate the position of the thermal belt on both its flanks, as it varies from night to night (see Fig.4.2). If its average position is taken, the thermal belt is found to lie next to Station 18, which corresponds to an elevation of 1670 m. and at a relative height of 75 m. above the bottom of the valley. This fact is probably connected with the great steepness of Linksfield Ridge, but is certainly not the only factor, since in Northcliff which is as steep, the deviations from the mean elevation of the thermal belt are small. The answer to this problem will probably be found after checking the windflow pattern above Johannesburg during inversion. As to the southern route, the thermal belt in Bez Valley, (B in Fig.4.1), lies between elevations 1700 and 1770 m. and at the Elsburg Ridge (E) at about 1770 m.

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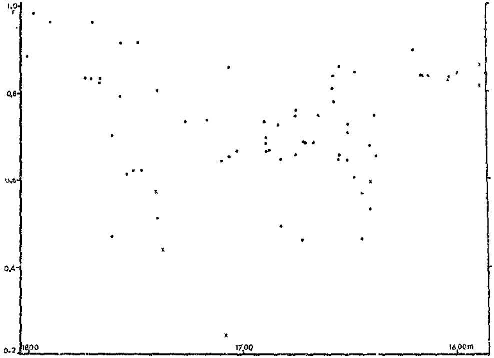

Figure 4.5 Graph of correlation coefficients (r) between Station 87 and every other station against elevation.

in the temperature for elevations is observed up to a certain level, and from there on a slight increase in temperature, and in some places even isothermal conditions. The group of stations with high temperatures is the one representing the city. For certain slopes the stations are plotted on the graph (4.4) in letters to show their thermal gradient. In Fig. 4.5, where the correlation coefficients (r) between Station 87 (C in Fig. 4.1, the centre of the city) and every other station are plotted against elevation, one can discern a parabolic regression trend. In this graph, the lowest and highest stations show high correlation values whereas for the other stations (near the thermal belt) the trend is not clear. In this figure, the deviation of the stations at the bottom of the valleys is prominent (x in Fig.4.5). As the correlation between Stations 87 and 1 (O in Fig.4.1) is high (r = 0.91), one can say that, in fact, the whole series of correlations is applicable also to Station 1. The graph at Fig. 4.5. will change its shape if one takes all the nights into account and on the regression line will show more linearity where the place is lower and the r value will be lower. Even in this case the rate of change will be different above and below the thermal belt.

Contrary to the positive correlation between Station 87 and other stations in Winter (when the temperature drops at Station 87, it corresponds to decreases at the other stations), Summer conditions are different. Examining the correlation between Station 87 and the other stations for inversion nights without sorting them according to their strength (App, Program 7), the correlations are alternately positive and negative. For instance, on Route 1, the correlation of Stations 87 with Station 49 (P in Fig.4.1) is -0.97 and with Station 51 +0.80; with Station 53 it is -0.70 and with Station 54, +0.27. This fact shows the extreme variations of the inversion strength or, in other words, the considerable fluctuations of the thermal belt.

4.4.4. INFLUENCE OF SLOPE ASPECT.

In contrast to its effect on the temperature distribution during the day, the slope aspect has almost no influence on the temperature distribution at the time of minimum temperature. A slope having a northern aspect (in the southern hemisphere), which will be heated during the day more than a slope with a southern aspect, according to Stefan - Boltzmann's law, will lose its heat more rapidly than a southern slope. As the radiation loss according to this law is not linear with time, the difference in temperature between these slopes at the time of minimum temperature will be smaller than during the day and will almost reach zero. The above law refers to the total heat emission of a body which, in this case, is the ground surface. But at a height of 1.2 m. above ground, which is the height of measurement, the temperature difference between the slopes will be even smaller.

This theory does not agree with the surprising results obtained in a study made in Pretoria (Louw and Mayer 1965). In that study temperatures were taken along a traverse at a height of 1.2 m. above ground, near the time of minimum temperatures in nocturnal inversions, with the aid of an ordinary thermometer which was affixed to the front of a car. The results show that on a slope with a northern aspect, such as the Magaliesberg Range, the temperature was higher than on the southern aspect.

Following these findings, it was decided to add the *aspect of the slope* and its steepness in computing the multiple correlation coefficient for the nights too. The results obtained from the present study, as presented in Section 4.3., show an influence of the slope's aspect but in the opposite direction, i.e. the southern has a higher temperature than the northern. These results appear in each route by itself and also in the combined route. *The regression coefficient* (b_3) of this influence is low, but in all cases it passes the test of twice the standard error ($2S_{b_3}$). The most prominent instance is found on Route 2, where b_3 is 0.26, which means that the difference in temperature between the northern aspect (which is the multiplication of the b_3 and code 1 -- see Table 3.2), and the southern aspect (which is the multiplication of the b_3 and code 5) reaches 1°C. As the results do not fit the theory and oppose the Pretoria findings, a further check was made in this case. The correlation coefficient between the *minimum temperature* and the slope aspect for the southern route was first computed and found to be +0.25, thus indicating that, as the slope changes from north to south, the temperature rises. This correlation passed the t test with a confidence limit of 95% (66 degrees of freedom). The fact that there is a significant correlation does not explain why this relationship exists. It is possible that *one of the other factors* is inter-correlated with the slope aspect. Therefore, the correlations between the slope aspect (Variable 3) and the other variables were checked (see Table 4.3.). In Route 1 the correlation between the elevation and the slope aspect is -0.10; between the density and the slope aspect is -0.11. In

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TABLE 4.4.

THE STEP-WISE REGRESSION PROCESS FOR WINTER INVERSION NIGHTS - ROUTE 1.

Step No. 1. Variable 1 included

R - 0.77
F-level - 128.6
Sy - 1.65
Constant - -1.83

Variable	b	S_b
1	0.96	0.08

Step No. 2. Variable 5 included

R - 0.82
F-level - 22.4
Sy - 1.48
Constant - 0.22

Variable	b	S_b
1	0.85	0.08
5	-0.73	0.15

Step No. 3. Variable 2 included

R - 0.84
F-level - 8.5
Sy - 1.42
Constant - 0.31

Variable	b	Sb
1	0.68	0.10
2	0.40	0.14
5	-0.78	0.15

Step No. 4. Variable 3 included

R - 0.84
F-level - 3.7
Sy - 1.40
Constant - -0.45

Variable	b	S_b
1	0.67	0.09
2	0.47	0.14
3	0.17	0.09
5	-0.74	0.15

Step No. 5. Variable 6 included

R - 0.85
F-level - 2.2
Sy - 1.39
Constant- -1.21

Variable	b	S_b
1	0.62	0.10
2	0.49	0.14
3	0.19	0.09
5	-0.52	0.21
6	0.33	0.22

TABLE 4.5.

THE STEP-WISE REGRESSION PROCESS FOR WINTER INVERSION NIGHTS - ROUTE 2

Step No. 1. Variable 6 included

R - 0.83
F-level - 141.7
Sy - 1.07
Constant - 2.49

Variable	b	S_b
6	1.20	0.10

Step No. 2. Variable 2 included

R - 0.88
F-level - 25.97
Sy - 0.91
Constant - 1.65

Variable	b	S_b
2	0.54	0.10
6	1.04	0.09

Step No. 3. Variable 5 included

R - 0.91
F-level - 18.6
Sy - 0.81
Constant - 2.99

Variable	b	S_b
2	0.63	0.10
5	-0.49	0.11
6	0.66	0.12

Step No. 4. Variable 1 incl.

R - 0.92
F-level - 10.3
Sy - 0.76
Constant - 1.06

Variable	b	S_b
1	0.49	0.15
2	0.19	0.17
5	-0.60	0.11
6	0.57	0.12

Step No. 5. Variable 2 removed

R - 0.92
F-level - -1.21
Sy - 0.77
Constant - 0.53

Variable	b	S_b
1	0.64	0.08
5	-0.62	0.4
6	0.57	0.12

TABLE 4.5

THE STEP-WISE REGRESSION PROCESS FOR WINTER INVERSION NIGHTS - ROUTE 2

Continued:

Step No. 6 Variable 3 included

R - 0.93
F-level - 7.0
Sy - 0.74
Constant - 0.09

Variable	b	S_b
1	0.62	0.08
3	0.14	0.05
5	-0.55	0.11
6	0.60	0.11

Step No. 7 Variable 4 included

R - 0.93
F-level - 4.66
Sy - 0.72
Constant - -1.28

Variable	b	S_b
1	0.66	0.08
3	0.27	0.08
4	0.29	0.14
5	-0.63	0.11
6	0.50	0.12

Step No. 8 Variable 2 included

R - 0.94
F-level - 2.8
Sy - 0.71
Constant - -0.68

Variable	b	S_b
1	0.46	0.14
2	0.26	0.16
3	0.30	0.08
4	-0.32	0.14
5	-0.61	0.11
6	0.50	0.12

Route 2 a relative high correlation can only be found between the density and the slope aspect (-0.22). This correlation, which is on the border of significance, means that places where the density is higher (like the city) are likely to be facing South. In other words, some of the city heat is incorporated in variable 3. This circumstance might cause the appearance of the slope aspect factor in the multiple regression equation. There is also a high negative correlation between the slope aspect and steepness in the Winter data (-0.75) on Route 2. Such a correlation is expected, since the coding of the steepness depends on the slope aspect.

There is another possible explanation of the slightly higher temperature on slopes with a southern aspect. The wind direction during Winter nights is from the north-west until midnight, later changing to westerly (see 1.4.). That means that the south-east slope is on the lee-side of the wind. In studies made in other locations, London (Chandler 1961), Japan (Sekiguti 1964), it was found that the heat island (see 4.4.2.) migrates to the leeward. Therefore the slopes with a southern (leeward) aspect will be slightly warmer than those with a northern aspect.

In the analysis of the values of the multiple regression coefficient, before and after the step which included variable 3 (slope aspect), the contribution of the slope aspect is very slight and does not exceed 1%. (Table 4.4). It would, therefore, be avisable to cut the process of computing the multiple correlation coefficient after Step 3 in Route 1. The difference in the R value is from 0.85 to 0.84. Variable 6 (height of buildings) does not, in any case, exceed the twice standard error test. Use of the regression after Step 3 will reduce the regression coefficient of the urban factor (Variable 5), but that will be compensated for by improving the result of the standard error test.

In Route 2 it would also be advisable to cut the procedure after Step 3 (Table 4.5), despite Variable 1 (elevation) not appearing in the equation, being part of Variable 2 -- relative height (as mentioned above, there is a high correlation between the elevation and the relative height in the route). On cutting the computing process after Step 5 the F level will be found below the chosen level. After Step 4 the relative height does not pass the twice standard error test. The drop in R value resulting from this shortcut will be greater. In the combined route it would be advisable to cut the computing process after Step 4, when the weight of the urban factors would be greater. The R value remains 0.86 (the influence of the slopes exposure does not pass the twice standard error test).

Taking the Pretoria study (see above) into account, it is probable that the results might change if the study were extended to some other slopes in the vicinity of Pretoria. This is especially likely, as according to Fig. 1 (Louw and Mayer 1965, p.50), the results in Voortrekker Hill were pointing in the opposite direction to those of Magaliesberg. It seems that the higher temperature on the northern aspect of the Magaliesberg Range is probably associated with local air circulation. it might have been recorded at the elevation of the thermal belt, and be unrelated to the heat balance. The same condition can be found in Johannesburg at S in Fig. 4.1 -- Stations 68 and 70 on Route 1. But Station 70 which is colder, is situated on a slight slope at a low relative height in comparison to Station 68, which faces north.

4.4.5. INFLUENCE OF SLOPE STEEPNESS.

The influence of steepness on the minimum temperature distribution during nocturnal inversion has already been discussed above and the theoretical conclusions indicated. On a steep slope the temperature will be slightly higher than on a gradual slope, owing to the more rapid drainage of the cold air down the steeper slope. On a steep slope drainage may cause general turbulence sufficient to disturb the inversional stratification, a case in point being the Bez Valley paradox discussed earlier. If one compares B in Fig.4.1 (on Route 2, Station 9, at the bottom of Bez Valley) and K (Station 40, on Route 2), which lies at almost the same elevation, one finds that K is colder by 1.2°C. While B lies at the bottom of a valley with steep slopes, the slope down to K is slight and continues further southwards.

In this context no individual portions of the slope will be discussed as these would form a subject for microclimatology. In an urban area, specially in a city, the street level is influenced more by the fact that it is situated at the bottom of the canyon created by the tall buildings, than by the effect of the slight slope on which the city is built.

In computing the multiple regression coefficient, the slope steepness factor was included in the Winter coding, (see Table 3.2), even though for the night it should have been included in the Summer coding, i.e. according to their actual steepness. The Winter form which is dependent on the angle of incidence of the sun's rays in Winter, was used only with reference to the Pretoria study. The influence of steepness appears only in the multiple regression coefficients for Route 2; it has no physical meaning and contradicts the slope aspect factor, (both appear with positive signs, while their code setting is reversed (see Tables 3.1. and 3.2)), it was not taken into account and the computing process was cut after Step 3.

4.4.6. INFLUENCE OF RIDGES.

One of the popular notions in Johannesburg is that north of Linksfield Ridge, - L in Fig.4.1 (see 1.2.) the temperature is higher than in the southern suburbs, which are more open to colder advection from the south. To check this notion another factor (Variable 7, see Table 3.7) was introduced in computing the multiple regression coefficient. Two computations were made for the night. In the first test the stations of Route 2 were used. No influence of the ranges was found, perhaps due to the fact that Route 2 does not cross all the ridges. In order to overcome this drawback, 62 stations were taken from both routes in the eastern part of the town, where the topography is more prominent. (On Route 1, Stations 1-34 were taken and on Route 2, Stations 1-37, 98 and 99). The stations located at the peak of the ridges (code 6 in Table 3.7) were excluded. The following regression equation was obtained.

$$t_n = 0.98 + 0.88X_1 - 0.93X_5 - 0.21X_7 \quad \ldots \quad (4.1)$$

where

t_n - minimum temperature

X_1, X_5, X_7 are the elevations, the urban density, the ridges and their standard errors are 0.08, 0.15 and 0.098 respectively.

The multiple correlation coefficient is 0.84. Assuming that b_o, b_1X_1 and b_5X_5 are constant, only $0.21X_7$ in equation 4.1 remains. According to Table 3.7 codes 1 and 5 are the extreme cases, north of Linksfield Ridge and South of Elsberg Ridge respectively. Multiplying these extreme cases by this coefficient (b_5) gives $1 \cdot (-0.21)$ and $5 \cdot (-0.21)$ *and the difference between the two places* is 0.84°C. At first glance it would seem that this is a considerable difference, but in practice it is of no significance for such purposes as planning of gardens, industries etc., since the difference will disappear if one raises the planned object by about 10 m. Obviously, one has to keep in mind that these results are suitable only for inversion nights at the time of minimum temperature and at a certain height.

Besides determining the influence of the ridges, one other important conclusion can be deduced from equation 4.1. This particular set of stations, does not include the city or the very dense area next to it. The fact that the slope aspect and the steepness factors do not appear in the above regression equation reinforces the assumption that the influence of the slope aspect determined in the ordinary computing process (see 4.4.4. and 4.4.5.) is connected to the southern aspect of the city.

TABLE 4.6.

TABLE OF RESIDUALS AFTER STEP No. 3 (ROUTE 1)

STATION	PREDICTED	ACTUAL	RESIDUAL
1	4.62	4.37	-0.25
2	6.50	5.56	-0.95
3	6.50	5.03	-1.48
4	5.69	4.93	-0.76
5	5.43	4.92	-0.50
6	3.16	3.93	0.77

TABLE 4.6. (Continued)

STATION	PREDICTED	ACTUAL	RESIDUAL
7	1.27	1.81	0.54
8	3.55	3.79	0.24
9	5.10	3.19	-1.92
10	3.55	4.00	0.44
11	3.94	3.97	0.04
12	3.94	4.03	0.09
13	2.08	3.67	1.59
14	3.16	4.06	0.90
15	4.33	3.99	-0.34
16	4.33	3.91	-0.41
17	3.38	4.03	0.64
18	3.38	4.91	1.53
19	3.38	4.44	1.06
20	2.31	3.44	1.14
21	2.31	3.27	0.96
22	1.23	3.16	1.92
23	1.23	3.00	1.77
24	2.31	2.67	0.36
25	3.38	2.67	-0.71
26	2.99	3.66	0,67
27	2.31	2.49	0.18
28	2,31	2.70	0.39
29	0.81	1.90	1.09
30	-0.26	-1.83	-1.56
31	-0.26	-2.71	-2.45
32	0.42	0.33	-0.09
33	1.23	2.01	0.78
34	0.16	-2.87	-3.03
35	0.81	-0.04	-0.86
36	1.49	1.77	0.28
37	1.49	2.31	0.82
38	0.03	-2.46	-2.49
39	1.10	-1.26	-2.36
40	0.03	-2.40	-2.43
41	1.10	0.25	-0.60
42	1.49	1.64	0.15
43	2.31	2.77	0.47
44	2.70	3.47	0.78
45	2.31	4.23	1.92
46	0.94	0.24	-0.67
47	-0.53	-3.66	-3.13
48	0.55	-0.73	-1.28
49	-2.15	-4.61	-2.47
50	0.55	0.11	-0.43
51	1.62	4.41	2.79
52	1.62	2.66	1.04
53	1.62	3.96	2.34
54	0.81	3.81	3.00

TABLE 4.6. (Continued)

STATION	PREDICTED	ACTUAL	RESIDUAL
55	1.88	4.73	2.84
56	2.96	5.01	2.06
57	4.03	5.58	1.54
58	5.10	5.81	0.71
59	5.10	5.37	0.27
66	0.42	3.04	2.62
67	-0.78	-0.41	0.37
68	3.12	2.33	-0.79
69	3.38	3.59	0.21
70	4.19	1.70	-2.49
71	3.38	2.40	-0.98
72	3.38	0.44	-2.94
73	6.07	3.24	-2.83
74	5.26	3.93	-1.34
75	5.43	5.27	-0.16
76	5.43	5.01	-0.42
77	4.10	4.20	0.10
78	3.28	3.74	0.46
79	4.10	3.91	-0.18
80	4.10	4.33	0.23
81	3.41	2.57	-0.84
82	4.91	3.29	-1.62
83	4.91	5.56	0.65
84	5.98	6.13	0.15
85	5.98	6.44	0.46
86	5.98	6.84	0.86
87	5.98	7.04	1.06
88	5.98	6.99	1.00
89	5.30	7.17	1.87
90	5.30	7.06	1.76
91	5.30	6.69	1.39
92	5.56	5.54	-0.02
93.	7.44	6.69	-0.76
94	7.44	6.66	-0.79
95	6.63	6.33	-0.30
96	6.63	5.39	-1.25
97	5.82	4.67	-1.15
98	5.82	4.80	-1.02
99	4.62	4.37	-0.25

The influence of topography on the minimum temperature distribution in Johannesburg has been discussed. At this stage it is possible to analyse the tables of residuals (Table 4.6) before discussing the integration of the urban features in the distribution.

4.4.7. ANALYSIS OF THF RESIDUALS.

The residuals are the differences between the expected values (computed from the regression equation) and the actual observed values for every station. In this analysis, the tables of residuals computed after the chosen step in the stepwise procedure have been used. For the purpose of the analysis only cases where the difference between the actual and the expected value was greater than 2°C, irrespective of the plus or minus sign, have been taken. The most significant finding is that on Route 2 there was no such case. This can be explained by the much lower value of the standard error of y (Sy) than on Route 1, owing to the lack of stations at low elevation in this route (see 4.3.). On the other hand, there are several such cases on Route 1.

All the stations which are located at the bottom of the lower valleys in the northern suburbs (Stations 31, 34, 38, 40, 47 and 49), have negative residuals. The lower the valley the greater the difference. This is caused by the lack of linearity in the change of temperature with elevation (see Fig. 4.3). As most of the stations are not located at these low elevations, the regression line shows a lower temperature gradient, causing greater residuals in the lower places. Hence there are negative differences .+ S (in Fig. 4.1 Stations 70 and 72). Even where these stations are at a high elevation, their relative height is low, or, more precisely, their slope is so slight that (~~it can be said that~~) their relative height above the base of the valley to the south does not express the real position from the air drainage point of view. The opposite effect can be found in Station 30, which is in a valley in the northern suburbs (it lies a little lower than Station 31 which is mentioned above) and its residual does not exceed $-2.0^{\circ}C$. Here too, it is possible that the air drainage is better than could be expected from the relative height. The high negative residual in W (Station 73) will be discussed in 4.5.1.

There remains a group of stations on the way from Linden (P) to Northcliff (N) and around the cliff i.e. Stations 51, 53, 54, 55, 56 and 66. Regarding Station 51, it is possible to state that the high negative residual at P, which was explained above, is compensated for by the high positive residual at Station 51, which is located at the top of the slope west of P. (being situated near to the steep Northcliff Hill (N) which probably increases the turbulence (see 4.4.4.). Stations 53, 54 and 66 are probably again influenced by better drainage and open spaces. This is probably also the reason for the high positive residuals at Station 55 and 56 on the Northcliff Hill slope. From Station 56 to the top of the hill the difference decreases until it becomes minimal at the top (Station 59) which is situated above the thermal belt.

4.5. URBAN INFLUENCE.

Fig. 4.1. shows a conformity between the contours and the isotherms, except for the city (C in Fig.4.1) and its vicinity, with its extensions along the ranges branching out from it. A heat island covers the city, the industrial area south of the city and Hillbrow (H) in the north. The heat island is confined to the west by a valley starting at the central bus garage (Station 81) and where the temperatures are about $4.5^{\circ}C$ lower than at the centre of the town (topography effect). The eastern branch of the heat island continues along Troyeville Range (T) which is limited on both sides by valleys. The one to the north is Bez Valley (B) and the one to the south towards

Heidelberg Road. Extension of the isotherms of the heat island southwards is based not on measurement but on two assumptions:

a) that this is the leeward side of the wind (see 4.4.4.) and that the heat island migrates towards this side; and

b) that the corner of Pritchard and Eloff Streets, is the centre of the city, not only geographically, but also climatologically.

The steep thermal gradient next to the margin of the city is not always as prominent here as in other cities. Owing to specific topographical features, there is not a distinct boundary everywhere between the city and its environment.

4.5.1. ISOLATION OF THE URBAN FACTOR.

Isolation of the urban factor, as a factor influencing temperature distribution is complicated. One has to keep in mind that besides primary factors such as density, height of buildings, combustion of fuel etc., there are also secondary factors caused by the primary ones, like smog above the city, sluggish air drainage,difference in humidity, etc.

With regard to minimum temperatures, two intercorrelatedfactors (Table 4.3) were taken into account: density and height of buildings. As for the night, there is no need to add the effect of traffic, which is mentioned by some investigators (e.g. Chandler 1961), since at night the volume of traffic is low. The effect of domestic heating will be expressed by the above two factors.

The conventional method of isolating the urban factor in various investigations (Kratzer 1956, Mitchell 1961c, Landsberg 1956, etc.,) is applied by comparing the data for the central city with those of the reference station set up outside the city. This method has many disadvantages, especially in places where inversion conditions are well developed as in the present case. Some of the disadvantages are:-

a). A climatological station in the city is generally sited in a park and is not fully representative of the central city. Even outside the town, the reference station does not always represent outside conditions as it is not always situated exactly at the same elevation or relative height as the one in the city. This is especially so in strong inversion conditions, when every metre of altitude makes a difference. This view is supported by Chandler (1965 p.155) who states that in London, which has numerous climatological stations, there is not a single pair of stations (in or outside the town) which may be regarded as perfect for the purpose of measuring the strength of the heat island effect. Landsberg (1956 p. 597) refers to this problem and states that topographical and other micro-climatic factors may cause similar temperature differences even without the existence of a town in that place. For that reason, Sundborg (1951 p.87 footnote) did not always take only two stations, but an average of several stations, in and outside the town so as to obtain a reliable representation of the temperature variations. (See also Geiger 1965, P.489).

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b). Even if the warmest place in the city is found (by a preliminary study), its temperature could be due to an accidental heat source (e.g. a bakery) or because of special topographical conditions (thermal belt). Parry (1967) also states that screens in town do not properly represent the environment because of the different amount of walls around the screen.

c). The heat island is not found in the same place at the same time of day and in all kinds of weather. Isotherm maps of London (Chandler 1965) show different sites of the heat island for different weather conditions.

For the above reasons, it seems that one cannot compare data for one pair of stations; a large group of stations must be investigated along the routes. Using a large number of stations the influence of the city can be measured by isolating the urban factors from the other variables. The isolation is done by computing the regression coefficients. For instance, in the combined route (after Step 4, see 4.4.4.) the equation takes the following form:

$$t_n = -0.87 + 0.69x_1 + 0.34x_2 - 0.61x_5 + 0.45x_6 \quad \ldots(4.2)$$

where t_n is the predicted minimum temperature. The negative sign of the coefficient b_5 caused by the inverse coding for the density, in the city - 0 and outside the town - 5. The extreme case in the city for the urban influence arises when x_5 (density) = 0 and x_6 (height of buildings) = 4 which are the two variable which express the urbanity. Outside the city, the extreme case occurs when $x_5 = 5$ and $x_6 = 0$ (see Tables 3.5 and 3.6). All the other parts of the equation remain constant. On substituting these values in Equation 4.2, two equations are obtained, one for the city, (t_{n_1}) and one for outside the town (t_{n_2}). *The difference between* them (Δt_n) is the urban factor (UF_t) as follows:

$$\begin{array}{lllll}
\underline{Y} & & \underline{b_5(X_5)} & \underline{b_6(X_6)} & \\
t_{n_1} & = \text{const.} & -0.61\cdot(0) & +\ 0.45\cdot(4) & \dots\ (4.3) \\
-\ t_{n_2} & = \text{const.} & -0.61\cdot(5) & +\ 0.45\cdot(0) & \dots\ (4.4) \\
\hline
\Delta t_n & = & 3.05 & +\ 1.80 & \\
UF_t & = & \Delta t_n & = 4.85^{\circ}\text{C} & \dots\ (4.5)
\end{array}$$

Table 4.7 presents the isolation of the urban factor for all the routes after all the steps (final), and also after restricting the number of variables, i.e. cutting off the stepwise procedure after the desired step (see 4.4.4.).

TABLE 4.7.

ISOLATION OF THE URBAN FACTOR

ITEM	ROUTE 1.		ROUTE 2.		ROUTES 1 AND 2	
	FINAL	CUT	FINAL	CUT	FINAL	CUT
R	0.85	0.84	0.94	0.91	0.86	0.86
IN THE CITY (t_{n_1})	1.32	0	2.00	2.64	1.88	1.80
OUTSIDE TOWN (t_{n_2})	-2.60	-3.90	-3.05	-2.45	-2.85	-3.05
UF_t °C	+3.92	+3.90	+5.05	+5.09	+4.73	+4.85

From Table 4.7. it is possible to observe the small difference if the R and UF values are taken either after the final step or after the desired step (Cut). On the other hand, it can be seen that despite the high R values, the two routes do not represent the same population at a significance level of 95%. Only by slightly reducing the level, can they represent the same population. This may be checked by using the 95% confidence intervals, which were also computed (Prog.9). For computing the confidence interval see Brooks and Carruthers 1953, p.223, and also Kendal and Stuart 1958, p.396). If the R value of Route 2 is in the range interval of Route 1, they do represent the same population. In the present case the R value of Route 2 is greater by 0.01 than the upper limit of the confidence interval of Route 1. The reason for this is, perhaps, the different inversion conditions for the two routes and the fact that on Route 1 the distribution of temperature with elevation is not linear as it is on Route 2 (4.4.3.).

One can add to Table 4.7 the computation made for the influence of the ranges (4.4.6.) where $R = 0.84$ and the density coefficient is -0.93, i.e. $UF_t = 4.65$. The similarity of the UF value, obtained from the influence of the ranges, to those in Table 4.7 is most important, especially as in the computation of the influence of the ranges, no stations in the city or in other areas of high density were taken into account. This fact leads to an important implication, namely that the urban influence can not only be measured in the city (CBD), by this method, but exists and can be measured anywhere in town. Moreover, this fact proves that the models of density and height of buildings were chosen properly, where the average for certain nights gives a linear or nearly linear influence.

If one does not consider other factors, the thirteen stations in the town area which are at almost the same elevation as the city yield an average difference of 3.1°C in favour of the city on Route 1 and 3.7°C on Route 2. Eight of these stations are on Route 1 and five on Route 2. The extreme cases will be: the difference of 1.3°C in comparison with similar elevations in Northcliff (N in Fig. 4.1 - between Stations 57 and 58), where the reason for the high temperature in Northcliff has already been explained in

4.4.3. The second case is at O (Station 7 on Route 1), where the relative height is nil and the difference recorded was 5.3°C. If, for instance, there was a meterological station in the vicinity of Station 57, and a comparison were made between this station and another station in the city the results of the influence of the city would be, of course, extremely under-estimated.

The warmest point in the city is Station 89 on Route 1, and 86, 87 on Route 2, but the differences between them do not exceed 0.2°C. There are a few places besides the city where a rise in temperature due to the urban factor is found: (a) at the entrance to the city from the south (Station 50 on Route 2). (b) at G - the important junction at Station 29 on Route 2, where the temperature is more than 1.2°C higher than in its environment. On the other hand it is worth mentioning the low temperature at W (Station 73), which was found to be 3.2°C as compared to the predicted temperature of 6.0°C (residual of 2.8°C, see Table 4.6). This station is located in the centre of the Western Township, where the density code is the maximum one (0); the height of buildings is Code 1, and, during the traverse made at about 6 a.m., when the residents begin to get up and the heating is on in most houses, the temperature still remained below the predicted value. This is proof that the heat source in certain towns may originate primarily from the radiation at night from buildings with a great heat absorption rate, like the skyscrapers in the city, rather than from the density of population or house heating in small structures with a poor heat absorption capacity.

4.5.2. ISOLATING THE URBAN FACTOR FOR ALL WINTER NIGHTS.

Taking into account all the 12 passes taken on each route, including the nights when the inversion was not well developed or did not exist, less extreme values will be obtained for the differences between the warmest and coldest points along the route. In comparison with the seven nights on Route 1 when there was a strong inversion, only two nights had no inversion (according to the differences in temperature between Parkhurst (P in Fig 4.1) and Observatory (O) stations) and on Route 2 three nights. The lowest average temperature which was measured on Route 1 was at P - Station 49, (-2.15°C), and the highest at Station 89 in the city, ($+6.11^{\circ}$C). The difference was 8.26°C. On Route 2 the difference was 5.05°C. As the multiple regression was not computed for all the nights, it is only possible to evaluate the influence of the urban factor with the aid of a station at a similar elevation to that of the city as was done in 4.5.1. for inversion nights only. For these stations, values which were only 0.2°C lower than those for the inversion nights were obtained. In the city, the temperature caused by cold snaps which occured at night without inversion was lower by about 1°C than those obtained for the inversion nights. Altogether, the difference between the average temperature in the city and temperature at stations lying at the same elevation beyond the city was lower by 0.8°C than those obtained for inversion nights. If (using Table 4.7), a reduction is made for all the nights, the UF_t value will be about 1°C lower than in the table. Such values for the influence of the city are not known in anywhere in the world. With the aid of two standard stations in and outside the town, where the station outside the town is located at a special topographical position, these differences can obviously be reached. In London the extreme occurs in summer, where the difference reaches 2.1°C (Chandler 1965, p.149).

In contrast to London, Johannesburg summer values are not as high as those reached in winter owing to the lack of strong inversion nights in summer.

CHAPTER 5

MAXIMUM TEMPERATURE DISTRIBUTION IN WINTER

In contrast to the winter night and the summer day, the day weather throughout June was characterised by consistent lack of precipitation and a small measure of cloudiness. During one day only was the sky fully overcast. On most of the days there was little or no cloud and as opposed to summer the weather remained almost constant (See 6.1). On the other hand, there was considerable inter-diurnal changes in the maximum temperature due to cold spells. The difference between the extreme maximum daily temperatures for this month at Jan Smuts Airport was 10.9°C.

5.1. STANDARDISING THE TWO ROUTES INTO ONE.

Determining the difference between the maximum temperatures recorded in the common section of the two routes presented no real problem. The temperature was 0.8°C (standard deviation ± 0.12°C) higher on Route 1. In both the Observatory Station (O in Fig.5.) and in Station 92, next to Joubert Park (J), the difference was 0.7°C. But, if one takes the permanent station of the Weather Bureau, the picture is different. At Jan Smuts Airport the mean maximum temperature for the days when Route 1 was taken was 15.0°C and when Route 2 was taken, 14.5°C, and the mean value 14.8°C. At Joubert Park, on days when Route 1 was taken, the corresponding value was 15°C and for Route 2, 15.1°C. Even though the mean difference for all the days in Joubert Park, which was higher than at the Jan Smuts Airport, fitted the normal difference between the stations, it was decided to check another permanent station - Zwartkoppies (the only station in the vicinity which had all the data). This station shows a difference of 1.3°C in favour of Route 1. As a result of this considerable discrepancy, it was decided to accept the difference of 0.8°C, which was found for the common section of both routes. Fig. 5 was accordingly plotted using the data of Route 1 for that section.

5.2. *RESULTS OF THE MULTIPLE REGRESSION COEFFICIENTS*.

At the time of maximum temperature, one does not expect extreme temperature variations from place to place, as on inversion nights. The mean temperature difference between the extreme cases was 2.2°C (Route 1) compared to 11.7°C at night. The low coefficients obtained from the multiple regression equation express this small difference.

TABLE 5.1.

ANALYSIS OF THE MULTIPLE CORRELATION AND REGRESSION *COEFFICIENTS FOR MAXIMUM* WINTER TEMPERATURE

	ROUTE 1		ROUTE 2	
	R = 0.85		R = 0.73	
FACTORS	COEFFICIENT b_j	STANDARD ERROR S_{b_j}	COEFFICIENT b_j	STANDARD ERROR S_{b_j}
ELEVATION (1)	-0.22	0.017	-0.15	0.024
RELATIVE HEIGHT (2)	+0.046	0.024	-	-
SLOPE ASPECT (3)	-	-	+0.054	0.028
SLOPE STEEPNESS (4)	-	-	+0.058	0.044
URBAN DENSITY (5)	-0.094	0.025	-0.12	0.024
CONSTANT (b_o)	16.55		15.06	
STD.ERROR OF Y(S_y)	± 0.25		±0.25	

The factor of the slope aspect and steepness which appears only on Route 2 has an opposite sign to the expected one i.e. the slope facing south is warmer than that facing north. This is probably connected with the correlation between the urban density and slope aspect (see 4.4.4.). In both cases the standard error is high and the coefficient does not pass the twice standard error tests, or in other words, the probability that the coefficient value will have an opposite sign is greater than 5%. By cutting the regression process after Step 2, all the cases which fail the significance test, and do not have a physical basis, are eliminated and only two variables remain: the elevation (1) and the urban density (5).

TABLE 5.2

THE MULTIPLE REGRESSION COEFFICIENTS CUT AFTER THE SECOND STEP

FACTOR	ROUTE 1. R = 0.84		ROUTE 2. R = 0.71	
	b_j	S_{b_j}	b_j	S_{b_j}
ELEVATION (1)	-0.20	0.014	-0.15	0.024
URBAN DENSITY (5)	-0.088	0.026	-0.13	0.024
CONSTANT (b_o)	16.54		15.43	
STD.ERROR OF Y (S_y)	± 0.25		± 0.25	

The difference of 1.1°C. between the constant for the two routes (Table 5.2) is mainly due to the higher average temperature in Route 1 (see 5.1). There is no change in magnitude of the constant in Route 1 between Table 5.1 and

5.2. By omitting the relative height (Variable 2) in Table 5.2, which has a different sign to that of the elevation in Table 5.1, the regression coefficient of elevation (Variable 1) is decreased.

5.3. TOPOGRAPHICAL INFLUENCE.

The factors which determine the temperature distribution at the time of maximum temperature are different to those for the time of minimum temperature. Daytime dominates the transfer of heat from the lower layers next to the ground, to the upper layers, mainly by turbulence and convection, so that at noon a negative slope lapse rate of temperature with height might be obtained.

5.3.1. INFLUENCE OF ELEVATION.

If one computes the temperature lapse rate along the slope by means of the coefficient of elevation (b_1 - after the second step), the slope lapse rate will be $0.67^{o}C$ per hundred metres for Route 1, and $0.5^{o}C$ for Route 2. This slope lapse rate is similar to the lapse rate of the lower layer of the free atmosphere. This similarity was ascertained also in other studies. Sharon (1964 p.100) measured the maximum temperature at the height of 1 m. above ground in summer and found a difference in the lapse rate of $0.5 - 0.9^{o}C$ per hundred metres. If one computes the temperature range for the whole range of elevations according to the regression coefficient (Codes 1 - 9, see Table 3.1), the value will be $1.6^{o}C$, but as the extreme difference in Johannesburg was $2.2^{o}C$ then, the difference in elevation accounts for more than

2/3 of it. Therefore, the warmest spot in Johannesburg is not in the city but at the lowest point - P in Fig.5. (Station 49, Route 1). Consequently, this point has the greatest mean daily amplitude, which is 18.8°C for all the days, or 21.2°C when the night had a strong inversion, i.e. after a night with a strong inversion the maximum temperature of the following day at P was 21.2°C higher than the minimum temperature.

5.3.2. *INFLUENCE OF SLOPE ASPECT.*

Contrary to expectation, the influence of the slope aspect was not expressed in the temperature distribution on Route 1 (see Table 5.1) and appeared with an opposite sign on Route 2 (as happened also during inversion nights). In the Soreq Valley, near Jerusalem, differences of 1.0 - 1.5°C were found between the south and the north aspects (Sharon 1964]. These measurements, taken 1 m. above ground, are thought to be lower than expected, especially, where the slope with a southern aspect was barren, while the northern aspect was covered with low Meditteranean bushes. At the height at which the measurements were taken in the present study, no such differences were expected. In measurements during June (month of winter solstice), however, the difference in temperature between the northern and southern slopes is expected to be greater (Sharon took his measurements in summer).

For a traverse which took more than two hours, the chosen coding of the slope aspect could not be accurate. Obviously at 1 p.m. the NE slope is warmer than the SW slope, but it is doubtful if it is the same at 3 p.m. Therefore, it was decided to check the extreme aspects: the southern and the northern slopes. The table of residuals for Route 1 was used without taking account of the fact that the relative height was also included, thus eliminating the urban and the elevation influences. It was impossible to do this for Route 2 because of Steps 3 and 4 which were cut off, had higher regression coefficients than that of the relative height on Route 1. It is possible, of course to compute a new table of residuals for use after Step 2, using the regression equation, as was done for winter nights.

Nineteen stations on Route 1 face north (not including stations in the city, where the influence could not be measured) and 12 stations face south. The slope with the northern aspect (without considering the steepness) had an average deviation of $+0.02^{\circ}C$ and the southern aspect slope of $-0.13^{\circ}C$, i.e. the temperature difference between the two slopes is $0.15^{\circ}C$. A t-test was done and the t value found to be 1.5 (29 degrees of freedom). In other words, the difference in temperature between the northern and the southern aspects is not significant.

Assuming that an accurate code could be defined for the slope aspect from 1 to 6, where 1 is north and 6 is south, when one divides the difference between the southern and the northern slope into 5, while assuming that those residuals are due only to the slope aspect, one obtains $0.025^{\circ}C$, which is the regression coefficient for the slope aspect. This value is very low and will probably not stand the F level, i.e. it would not appear in the regression equation.

The only explanation which can be offered is that by day the urban complex changes the sloping surface almost into a succession of flat and vertical surfaces. This fact is pronounced in the southern aspect, where walls of houses, fences and even garden hedges, receive more insolation than the slope. The influence of the slope lessens with a rise in the density of buildings (for the influence of the road direction see 5.4.1). One has to remember that the present discussion relates to measurements at a standard height above ground, and not of course to the temperature of the ground, measured in a garden facing north or south. One must also remember that the discussion relates to the afternoon where the micro-convection and the urban turbulence are relatively strong and it is certain that conditions change in the late afternoon. The practical implication is that the general slope aspect of the suburbs is less important than the micro-climatic conditions of the gardens, the wall aspect and especially, the area of windows in the northern walls, which produce the greenhouse effect.

5.3.3. THE INFLUENCE OF SLOPE STEEPNESS.

Outside the town the slope angle exerts a certain influence on the temperature distribution. This was observed on a slope with a northern aspect. On a slope with an opposite aspect, the effect of steepness on the intensity of insolation is different. Obviously if there is no meaning to the slope aspect in a town, the steepness of the slope will also have no meaning. In the town the steepness will be broken completely by walls and artificial garden terraces. The road can only reach a certain limiting steepness, and the gardens must be flat to prevent soil erosion. The steepness factor appears in the regression equation of Route 2 only, (Table 5.1) and does not pass the twice the standard error tests. Here too, as with the slope aspect, one cannot learn of the influence of slope steepness on temperature distribution near the ground or of the ground temperature itself.

5.3.4. INFLUENCE OF RIDGES.

Using the same method of computation carried out for winter nights (see 4.4.6.), the influence of the ridges on winter days was checked. With the same 62 stations, standardized to one time (following 5.1) and with the seventh independent variable (the ridges) added, the influence of the ridges did not appear in the regression equation. Therefore, even if there is an influence of the ridges on temperature distribution on winter days, it is not significant (under 1.5 F-level). Once again one has to keep in mind that this result is suitable only for the time of maximum temperature and at a certain height.

5.4. URBAN INFLUENCE.

The influence of urbanization on temperature is less by day than by night and less in winter than in summer (Mitchell 1961a). In Johannesburg this difference in the urban influence between winter days and nights is more pronounced because of the strong inversion during the winter nights, as against the slight thermal gradient over the town during the day. In the

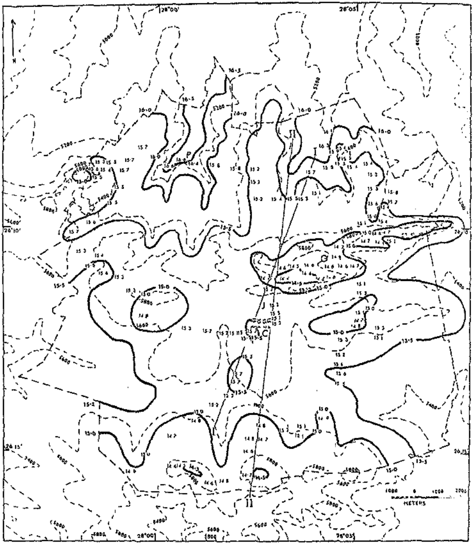

Figure 5 Mean maximum temperature distribution (June 1967)

map of maximum winter temperatures (Fig.5) where the isotherms interval is 0.5°C, the city is separated from the suburbs by only one isotherm. The main reason for this shallow heat island is that the city is at a relatively high elevation. Thus the elevation of the city, which leads to increased temperature differences between the city and the coldest places at night, reduces the range in the daytime.

5.4.1. ISOLATION OF URBAN FACTOR.

The urban factor which causes an increase in the maximum temperatures in towns, has different effects by day and by night. The most important difference is due to reradiation of heat from houses, roads and pavements and to a smaller extent also to artificial heating in the houses, and heavier traffic on the roads and railways during the day. In computing the multiple correlation coefficient for the day, contrary to the one for the night, the urban factor appears only in the density and not in the height of the building (see Table 5.1). On cutting the regression process after the second step (Table 5.2), the following equations are obtained:

Route 1 $R = 0.84$ $t_x = 16.54 - 0.20x_1 - 0.09x_5$...(5.1)

Route 2 $R = 0.71$ $t_x = 15.43 - 0.15x_1 - 0.13x_5$...(5.2)

If the urban factor is isolated as it was for the night (4.5.1), its value for Route 1, is $UF_t = 0.45°C$ and for Route 2, $UF_t = 0.65°C$, i.e. the influence of the town is about 0.5°C.

It is hard to explain the differences in R values and in the urban coefficients for the day (as was done for the night), since the weather conditions were almost identical every day. In cold spells, the temperatures were lower, but the windspeed and the cloudiness were not affected. Even the time of crossing the city, which was not the same on the two routes (see 2.3.) did not change the fixed differences in temperature between them (5.1.). Checking the differences in the regression coefficients (b_j) for the two routes from the error interval viewpoint (see 3.5.2.) shows however, that the differences have no meaning.

5.4.2. INFLUENCE OF TRAFFIC.

In order to isolate the traffic influence, the residuals of the stations with heavy traffic (see Table 3.8, codes 4 and 5) were summed for Route 1. The assumption was made that if the traffic does have an influence (e.g. see Chandler 1961), these stations will have a positive residual as the other factors were eliminated by the regression equation. On Route 1 there were 14 cases (excluding the city); in 8 of these the residuals appear with a negative sign and in 6 with a positive one. Quantatively, however, they add up to the same sum (1.2°C). In other words, the mean deviation is equal to 0, i.e. there is no measurable influence of heavy traffic on temperature distribution.

In the city the traffic is, of course, very heavy and the isolation of its influence will be discussed separately (see 7.2).

5.4.3. INFLUENCE OF ROAD DIRECTION.

It seems that another hypothesis which relates to the daytime conditions should be checked. The hypothesis is that on a road running from north to south, where the sun rays fall on the road surface, the temperature will be higher than on a road with an east to west component, where the surface is shaded by houses, fences, etc. This was checked by again using the residual tables for Route 1. The directions were sorted according to the relevant road codes (Codes 1 and 2 in Table 3.4.). For the sake of greater accuracy and despite the lack of significance of slope aspect, roads running on slopes with northern aspects were taken. The hypothesis could not be proved, even in the city where tall buildings shaded the EW roads. The same check was done for other parts of the town (for all slope aspects) and the same negative results found. The well developed turbulence near the ground during the day probably prevented any temperature differences appearing as a result of the road direction.

CHAPTER 6

MAXIMUM TEMPERATURE DISTRIBUTION IN SUMMER

As already stated (1.4, 3.5.2.), the summer weather conditions are highly variable. At night there is great variation in the temperature lapse rate and in the precipitation; during the day, even when there was no rain, the sky was partly cloudy in the afternoon.

6.1. STANDARDISING THE TWO ROUTES TO ONE MAP.

From a technical point of view it is possible to standardise the two routes, but not satisfactorily. The mean difference between the two routes in the common section was 0.56°C in favour of Route 1. The difference at Observatory Stations was 0.5°C and at Jan Smuts Airport 0.6°C. (At Joubert Park station the maximum thermometer was damaged and so no data was available for the last few days of the month). The disadvantage of this reduction to one route is that the standard deviation of the difference between the two routes in the common section is 0.32°C on summer days, while in winter it is only 0.12°C. This is caused by the great difference between Stations 1 and 99 (on Route 2 a difference of 1°C) which were located in different positions in the summer (see 2.2.). The difference between the first and last station was caused by the varying amounts of cloud and precipitation on different portions of the route, which the thermograph was not always sensitive enough to trace.

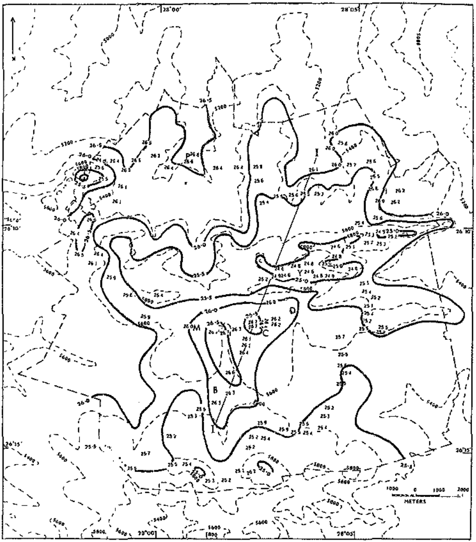

Figure 6.1 Mean maximum temperature distribution (December 1966)

6.2. RESULTS OF THE MULTIPLE REGRESSION COEFFICIENTS FOR SUMMER DAYS.

The difference in mean temperature between the warmest and coldest stations on Route 1 was the same in the summer as in the winter. One could therefore expect that the regression coefficients would be the same. An inspection of Tables 5.1 and 6.1, shows that this is not so. While the regression coefficient of the elevation (b_1) shows the same slope lapse rate as in the winter, the regression coefficient for the urban density (b_5) is much higher in the summer. This fact is not new (e.g. Chandler 1962b). The explanation for this misfit is the following:

In winter the highest temperature in the city is $1^{\circ}C$ less than in the warmest place determined outside it, but in summer, both temperatures are equal. (See Fig.6.1). Moreover, the deviation from the mean in the summer is greater than in the winter. While in winter the standard deviation of the mean temperature (App. Program 4) on route 1 is $0.47^{\circ}C$ ($0.35^{\circ}C$ on Route 2) in summer it is higher - $0.60^{\circ}C$ ($0.56^{\circ}C$ on Route 2).

TABLE 6.1

RESULTS OF THE MULTIPLE CORRELATION AND REGRESSION EQUATION FOR MAXIMUM TEMPERATURES FOR SUMMER

	ROUTE 1.		ROUTE 2.	
	R = 0.84		R = 0.70	
FACTOR	COEFFICIENT b_j	STD. ERROR S_{b_j}	COEFFICIENT b_j	STD. ERROR S_{b_j}
ELEVATION (1)	-0.218	0.0180	-0.168	0.0466
SLOPE ASPECT (3)	+0.0344	0.0205	+0.057	0.0307
SLOPE STEEPNESS (4)	-	-	-0.121	0.0487
URBAN DENSITY (5)	-0.334	0.0341	-0.140	0.0632
HEIGHT OF BUILDING (6)	-	-	+0.0938	0.0643
CONSTANT (b_0)	27.47		26.58	
STANDARD ERROR OF Y (Sy)	± 0.33		± 0.42	

The appearance of the slope aspect coefficient (Variable 3) in an illogical form has already been discussed (see 5.3.2.). In the summer, in December (month of the summer solstice) when the angles of incidence of the sun rays are different, the slope aspect also appears showing that it is interrelated with another factor. Here again the variable does not pass the twice standard error test. The height of the buildings also fails to pass this test. The innovation is the appearance of Variable 4 (steepness) on Route 2 which does pass the twice standard error test. This will be discussed in the following paragraph.

6.3. *TOPOGRAPHICAL INFLUENCE.*

After cutting the regression equation after the suitable step to eliminate the variables which do not pass the twice standard error test, a comparison with winter day data was made.

TABLE 6.2.

COMPARISON BETWEEN THE REGRESSION COEFFICIENTS FOR WINTER AND SUMMER DAY

	SUMMER			WINTER	
	ROUTE 1	ROUTE 2		ROUTE 1	ROUTE 2
		After Step 3	After Step 2		
	R=0.83	R=0.67	R=0.61	R=0.84	R=0.71
VARIABLES					
ELEVATION (1)	-0.22	-0.13	-0.14	-0.20	-0.15
SLOPE STEEPNESS (4)	-	-0.14	-	-	-
URBAN DENSITY (5)	-0.34	-0.23	-0.23	-0.088	-0.13

Table 6.2 shows the similarity in temperature slope lapse rate for each route. In summer the difference between the routes is greater than in the winter. There is no satisfactory explanation for this difference, other than the great variability in summer's weather.

An interesting phenomenon is the appearance of the slope steepness factor (Variable 3) on Route 2, which passes the twice the standard error test and increases the R value from 0.61 to 0.67. If the seemingly logical possibility is accepted that with a steeper slope the insolation and the temperature are lower - why does

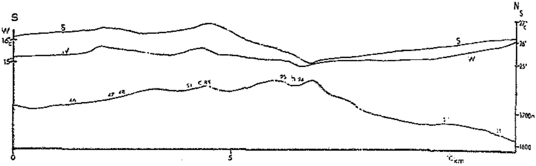

Figure 6.2 Maximum temperature profiles (Section I in fig. 5 and 6.1). Right temperature scale - summer. Left temperature scale - Winter. C - city. H - Hillbrow. Stations are numbered.

not the same effect appear on Route 1 or in winter? It is possible to reject this one isolated case out of four and to argue that it appears on a route that shows a considerable temperature difference between Stations 1 and 99 (1^{o}C in favour of Station 99, see 6.1). A careful study of this case shows, however, that between the first and last stations there is a connection in the reduced temperature (t_R) with the appearance of this variable in the regression equation as follows: the average of all the stations for the slope steepness variable ($\bar{x}_3$) in Route 2 is 4.57, whereas for the first half of the stations (from No.1 to No.34) it is 4.8. Moreover, in the first 15 stations the average is 5.0. This means that the area with great slope steepness (and low temperatures) is concentrated at the beginning of a route, while at the end of the route the steepness is slight and the temperature higher with time. The appearance of this variable is caused by the simultaneous decrease of slope steepness and the increase in temperature. On the other hand, the influence of the steepness cannot be ignored but possibly its F level is below the required value (<1.5).

6.4. URBAN INFLUENCE.

During summer days the great influence of urbanisation is also prominent in the isotherm map (Fig.6.1). In contrast to the winter, the thermal gradient towards the centre of the city in summer is quite prominent (Fig.6.2). Inside the closed isotherm of 26^{o}C, from Mayfair (M in Fig.6.1) in the west, to Doornfontein (D) in the east and south of Booysens (B), there were two heat centres. One was in the mid-west of the city and included the eastern part of Fordsburg (F); it was connected to the industrial part in the south (B - Stations 47 and 48) through the narrow valley between Fordsburg and the city (C). The other heat centre was in the centre of the town, where it had a strong gradient of 2°C towards the higher places of Berea and Yeoville (Y). In other parts of the town the isotherms followed the topographical contours as shown in the winter maps.

On isolating the urban factor, as was done for winter, the following equations are obtained:

For Route 1: $t_1 - t_2 = 0-(-0.34\cdot(5))$

$UF_t = +1.70$

For Route 2: $t_1 - t_2 = 0-(-0.23\cdot(5))$

$UF_t = +1.15$

The influence of traffic on temperature was checked for summer too (on Route 1 only), yielding a rise of 0.1°C at stations where the traffic was heavy. As for the residuals of the city (Stations 82 - 91) the average was 0.2°C; their values were negative at the outskirts of the city and changed to positive values with a maximum near the centre of the city. As there was no marked difference in the traffic between the different part of the city, it had to be attributed to the heat island intensity (see 7.1.). It is worth mentioning here that during the month of December, traffic in the city was very heavy and there were traffic jams at nearly every robot, at the time of traversing.

6.5. SOME REMARKS ON SUMMER NIGHTS.

For summer nights the multiple regression coefficient for the description of stations was not computed and no maps were drawn. It was impossible to obtain any suitable sample, even a small one, which would have some meaning. For instance, if one took only the inversion nights, as was done for winter, there were 8 cases of inversion according to the differences between Parkhurst and Observatory stations, and another two cases where the temperature was equal. Also in cases where the temperature at Parkhurst was a little higher than at Observatory there were cases of inversion. The problem lay not in the number of inversion nights, but in the uniqueness of their inversion strength. During all night measurements there was only one night where there was no wind or cloudiness. On that night (26.12.66) the difference between the two stations was 5.5°C, and the inversion was well developed in a manner typical of winter nights, but not rare in summer (see 2.4.1.). The difference between the warmest and coldest point was 10.8°C (in comparison to an average difference of 11.7°C in strong winter inversion nights on the same route, see 4.4.1.). There were also nights where the inversion was of medium strength, but on most of the inversion nights the inversion was rather weak. On the other hand, taking nights without inversion, the sample would include six instances on Route 1 and four on Route 2. In these cases, the differences in temperature were much smaller [illegible] an in the day, and the weather was also not ur [illegible] it of these ten nights three had no precipitation [illegible] .. During one night there was precipitation just before the traverse started, and on three other nights, about six hours before the traverse started. Out of those ten nights only three nights had fine weather, four nights were foggy in the higher locations and one in the lower locations. During two nights there was fog throughout the town. On the other hand, the great variability in wind speed and cloudiness etc. helped in computing the multiple correlation coefficient for the influence of the weather on the heat island intensity (see Chap.8). The warmest place is the city, where the temperature difference between its boundary and its centre was 0.38°C for Route 1 and 0.40°C for Route 2.

CHAPTER 7

INTENSITY OF JOHANNESBURG'S HEAT ISLAND

The analysis of temperature distribution during the various seasons, at different times of day, and the analysis of the multiple regression coefficients showed differences in the intensity of the heat island in Johannesburg. The urban factor is most pronounced in strong inversion nights. The maximum difference in temperature between the centre of the city and its environs was reached during such nights. Einarson & Lowe (1965) who measured temperature during inversion nights in Winnipeg speaks of a maximum difference of 12.5°C. This value exceeds the average value of 11.7°C found in Johannesburg between Stations 49 (P in Fig.4.1) and 89 (in the city) on Route 1. On summer days the urban factor is stronger than on summer nights or on winter days. This fact is discussed later (7.4.).

7.1. INFLUENCE OF SIZE OF TOWN ON HEAT ISLAND.

In checking the influence of traffic (6.4.) in the city during summer days, high positive residual values were found. Such residuals are found during both summer and winter, day and night. They can not be connected with traffic for the following reasons:

a) In the centre of the city the residual is much higher than at its edges, (in locations like Market, Troye/Twist Streets), where the traffic is as heavy as at the centre.

b) During winter nights when traffic is very light, the residuals are relatively high and reach more than 1°C in the centre of the city.

Towards the centre of the city the temperatures (or residuals) increase; this is shown in all the measurements, and is also known from several studies of the urban climate. Existence of a strong thermal gradient towards the centre of the city raises the problem of the linearity of the multiple regression coefficient that was used, since the stations in town were coded with the same rate of density and same height of building, without taking the factor of 'centrality' into account. Changing the codes of the urban factor was impossible, as they were defined in definite quantitative terms. The height of buildings in the centre of the city does not exceed their height at its edges or in Hillbrow (H in Fig. 4.1), and yet in Hillbrow the residuals are generally negative (Stations 93-95). The influence of centrality is explained by the stagnation of warm air, discharged from the buildings, and retained in the lower layer in the canyons of the city. Should such a location be removed intact from the centre of the city to its outskirts without the surrounding houses, the temperature in it will not be as high. In open spaces the heat will not be retained but will spread.

This fact forced some climatologists to add another parameter, one that will express the size of the city or its radius. Mitchell (1953), who developed a climatological index for the influence of the increase of population on the heat island (the difference in temperature between the centre of the city and outside the town), chose the value of $P^{\frac{1}{2}}$ (P = population) where $\Delta P^{\frac{1}{2}}$ (difference in population) plus a coefficient expresses linearly the Δt value for several periods in the history of the town. This equation is correct only under certain conditions, for instance, where the urban area is proportional to the number of inhabitants, when an increase of the area is proportional to an increase of the population, where the weather station is in the geometrical centre of a town of a circular shape and where the rate of the town's rise in temperature is proportional and linear along the air trajectory above the urban area.

Dockworth and Sandberg (1954), who checked the influence of a town's size on temperature during evening hours in several towns in western U.S.A., used some conventional parameters such as population, urban area and density. In addition, they used some special parameters, like the difference between the maximum and minimum observed temperatures in the traverse area, the least distance along which a 1°F temperature change might be observed from the heat island centre to a point on a circle, where the radius is the same as that of the built up area (p.202). Another parameter used by them was the contiguous area about the urban centre whose temperature is more than 2°F higher than the mean (although on their maps they use the 'median' and not the 'mean') of their chart (p.203).

Landsberg (1962, p.323) too states that as the town size increases so does the Δt increase. This opinion is not accepted today. It has been proved that a heat island of appreciable size can be created above a village or at the commercial centre of a suburb (Chandler 1962b). This was also proved by the Leicester study (Chandler 1967b) and by the Corvallis (Hutcheon 1967) data. Moreover, the size of the heat island is dependent on local geographical features (e.g. topography) more than on the urban complex (Chandler 1964). The method used by Mitchell and Duckworth for the municipal area or the urban area cannot be used for a town like Johannesburg, where most of the area is not densely built and includes many open spaces, like golf courses, etc.

One cannot assume that the heat island in the city would increase if more suburbs were added next to Mondeor, south of the southern suburbs, or if Randburg and Bryanston were included in the calculation. On the other hand, additional high buildings on the margin of the city or blocks of flats filling in the mine area, south of the city probably would strengthen the heat island.

Also, the special parameters of Docksworth and Sandberg cannot be taken into account in a town where there are open spaces (mining areas) 1 kilometre from its centre. The temperature in those areas (according to the residuals) does not exceed those for example at Rosebank, which is far from the city, and the temperature in Parktown is no higher than in Yeoville or Bellevue. Moreover, the fact that the continuity of the tall houses is interrupted between the city and Hillbrow by Joubert Park etc., causes the residual in Hillbrow to be negative.

The above is not intended to under estimate the influence of the structures in the suburbs on the temperature, proportional or nearly proportional to the density of building as defined. The temperature in the suburbs, however, is not correlated to the distance from the city; even the centrality factor of the city in inversion nights in winter, as expressed in Map 4.1, is imaginative, because the city lies near the elevation of the thermal belt.

7.2. ANALYSIS OF CITY AREA RESIDUALS.

The existence of a centrality factor in the inner city and the impossibility of applying it to the whole town, makes it necessary to adopt a specific parameter for the distance from the city centre to its edges only. It seems possible to incorporate this parameter in the following form: the effect of the distance from the centre will be linear down to the margin of the city, and from there on the effect will be constant. A similar method was used for coding the height of buildings where all the buildings higher than four storeys had the same code. In order to check this approach, the residuals were computed further than the desired step in the stepwise procedure for all the city stations from Station 82 (No.51 on Route 2) to Station 91, a total of ten stations. Residuals computed for standard elevations ($X_{1i} = 7$) and relative heights ($X_{2i} = 2$) appear in Table 7.1. This table shows that Station 87 does not have the highest temperature in the city, except for one case (summer day, on Route 2). On the other hand, on winter days, the warmest point on both routes is Station 84. Even on inversion nights, in spite of Station 87 being at the highest elevation, the warmest place is in the leeward, at Station 89. Cases where the residual is negative occur only on the margin of the city, at Stations 82, 83, 90 and 91, becoming more prominent at Station 92 next to Joubert Park. On winter nights, where the 'heat island' spreads towards the leeward side, even at Station 91 (Route 1) its residuals are relatively high. The lower residual at Station 82 is due to its low elevation.

7.3. CORRECTION OF THE MAGNITUDE OF THE URBAN FACTOR.

As the centre of the heat island is not located in one spot (see Table 7.1) it is impossible to use the centrality factor, unless it conforms with the heat centre. It would be biased to compute each case and route from a different centre. This will change the code in the city station while the other stations remain the same. Therefore instead of adding another variable to the multiple regression computation, it was decided to add the centrality factor, with the aid of the residuals to the urban factor (UF) defined previously. The residuals for Station No. 87 will not be taken, nor those for the station with the highest residuals. One has to take into account the fact that the residual values include more than the centrality factor, namely a possible error or accidental deviation etc. which is included in the error interval (3.5). Therefore, it was decided arbitrarily to define the additional centrality as the mean of the three highest residuals which appear successively in the city. These triplets are blocked in Table 7.1 and their mean values given at the bottom of the table (A). The highest residual in every column is encircled. An analysis of this table shows a similar trend in the urban factor values: as the urban factor increases, so does the centrality factor. This rule holds good for every time and season. Comparison of the two routes shows in every case that the relationship between the central addition (which will be called the centrality factor - CF) and the UF value is inverted. That means that the CF value is greater where the UF is smaller, or, in other words, CF climplements the UF value. The sum of UF and CF gives a new value which will be called UF' (see Table 7.2). As for the UF' values, there is a surprisingly great similarity between the two routes for the day. The great difference in the winter nights is probably due to a different inversion strength. On winter days, where the weather was uniform, the UF' values are very similar for the two routes and the boxed in figures are almost identical.

TABLE 7.1.

CONCENTRATION OF THE RESIDUALS FOR STANDARDISED CONDITIONS

STATION	WINTER NIGHT I	WINTER NIGHT II	WINTER DAY I	WINTER DAY II	SUMMER DAY I	SUMMER DAY II	$\bar{x}$	y	y'
82(51)	*-2.75	+0.28	-0.03	+0.37	+0.26	+0.26	+0.10	3.9	770
83	-0.48	+0.60	+0.16	+0.14	+0.66	+0.11	+0.20	2.5	590
84	+0.10	+0.62	+0.52	+0.47	+0.63	+0.40	+0.45	1.7	400
85	+0.41	+0.65	+0.40	+0.38	+0.43	+0.11	+0.40	1.5	350
86	+0.85	+0.78	+0.27	+0.26	+0.38	+0.46	+0.49	0.8	190
87	+1.03	0.77	+0.07	+0.20	+0.41	+0.68	+0.52	0	0
88	+0.9	+0.62	+0.22	+0.06	+0.18	+0.59	+0.44	1.5	350
89	+1.1	+0.58	+0.08	-0.10	+0.12	+0.52	+0.39	2.2	520
90	0.90	+0.31	-0.04	+0.01	+0.14	+0.28	+0.27	2.3	540
91	+0.65	+0.27	+0.16	+0.05	-0.03	+0.09	+0.20	2.5	590
A	+1.03	+0.73	+0.40	+0.37	+0.57	+0.60	$\bar{A}$ =0.62		
σ							±0.14	±1.01	

* This value was not standardised to one height. It was corrected for $\bar{x}$ value.

A - The mean of the three highest successive values (in the blocks).

y - The distance from Station No. 87 (in centimetres on the map).

y'- The distance from Station No. 87 (in metres on ground).

To obtain the new values their standard error values are added; these relate to the UF and not to the UF'. The standard error can be computed with the aid of Equation 7.1 (worked out according to Graybill 1961, pp.122 - 124).

$$S^2_{UF} = 2S^2_y \left(1+\frac{1}{n}\right) + S^2_y \left[\frac{(x_5-\bar{x}_5)^2}{\Sigma(x_{i5}-\bar{x}_5)^2} + \frac{(x'_5-\bar{x}_5)^2}{\Sigma(x'_{i5}-\bar{x}_5)^2}\right] \ldots (7.1)$$

where:

$x_5 = 0$, $x'_5 = 5$ - the extreme cases of density.

$\bar{x}_i$ - mean of the series x_{ij} (j the order within series i)

Sy - standard error (of estimate) of y (see 3.3.3.2).

as

$$\Sigma(x'_{i5} - \bar{x}_5) = \Sigma(x_{i5} - \bar{x}_5) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.2)$$

therefore

$$S^2_{UF} = 2S^2_y \left(1 + \frac{1}{n}\right) + S^2_y \frac{(x_5 - \bar{x}_5)^2 + (x'_5 - \bar{x}_5)^2}{\Sigma(x_{i5} - \bar{x}_5)^2} \ldots (7.3)$$

where the standard error has to be computed for two variables (density and height of buildings) the following formula is obtained (it is an approximation, taking the covariance between $(b_5, b_6) = 0$):

$$S'^2_{UF} = 2S^2_y \left(1+\frac{1}{n}\right) + (x_5-\bar{x}_5)^2 S^2_{b_5} + (x_6-\bar{x}_6)^2 S^2_{b_6} + (x'_5-\bar{x}_5)^2 S^2_{b_5} + (x'_6-\bar{x}_6)^2 S^2_{b_6}$$

$$\ldots\ldots (7.4)$$

where:

x_5 - density

x_6 - height of buildings

S_{b_5} - *standard error of the coefficient of* x_5

s_{b_6} - standard error of the coefficient of x_6

TABLE 7.2

ISOLATION OF THE URBAN FACTOR - CONCLUSION

SEASON AND TIME	WINTER NIGHT		WINTER DAY		SUMMER DAY	
ROUTE	I	II	I	II	I	II
UF	3.90	5.09	0.45	0.65	1.70	1.15
CF	1.03	0.73	0.40	0.37	0.57	0.60
SE of UF (S_{UF})	2.04	1.26	0.36	0.36	0.39	0.66
UF'	4.93	5.82	0.85	1.02	2.27	1.75
THEORETICAL UF	5°		0° - 1°		1°	

Table 7.2. concludes the isolation of the urban factor by adding the centrality factor (CF). On Route 1 during winter nights twice the standard error is greater than the UF value. This is due to the deviation from the multiple regression equation, also expressed by the high residual values. The factor $2S^2_y$ which is the determining size of the *standard error (in Equation 8.4)* is dependent on the standard deviation of y (and the R value); in this case σ_y is very high and so also $2S^2_y$ is high. It seems that the urban factor can be expressed in the following way (for winter nights, Route 2):

$$UF'_{tn} = 5.82 \pm 1.26$$

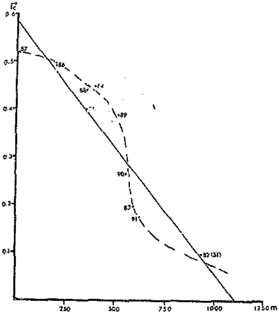

Figure 7 The regression line of mean temperature's residuals on distance from the centre of city.

It is permissable to express the S_{UF} for UF + CF together as CF is based on the Table of Residuals, that is it reduces the residual values. This means that the S_y will be smaller and so also the S_{UF}. This done, the UF' of Route 1 will pass the twice standard error test.

In order to obtain a uniform picture of the influence of centrality (CF), the mean residuals for each station were computed and entered in column $\bar{x}$ in Table 7.1 (for Station 82 a value reduced for the elevation of the city was taken for winter nights).

The most interesting inference from this column is that the highest mean residual is at Station No. 87 - the heart of the city. Moreover, this value is only 0.1°C lower than the mean value of the CF. This column indicates clearly a drop in the residual value with distance from the centre. In order to check the influence of the distance, a correlation was computed between the mean residual value ($\bar{x}$) and the direct distance from the centre (column y, table 7.1). For Stations Nos. 51 and 82 the mean distances from the centre were taken. In column y the distance is given in centimetres on the map and the actual value, in metres on the ground, appears in column y' in the same table. The correlation coefficient is - 0.89 (8 degrees of freedom) which is significant at the 0.01 level. The regression equation is $y = 0.582 - 0.124x$ and $Sy = 0.066$ (see fig.7). For station No. 87 where the distance $x = 0$, the mean residual predicted is 0.582. <u>This value for Station No. 87 is very near to the mean value of the centrality factor which was chosen arbitrarily (0.62)</u>. This fact gives more meaning to the centrality factor. According to this regression equation the residual will be 0 at a distance of 1,100 metres from the centre. All the cases are in the confidence limit of 2σ. A curve plotted through the relevant points (see Fig.7) shows a strong thermal gradient about 600 metres from the centre.

It should be noted that this regression equation cannot represent conditions for a certain season or time. Correlations were calculated for each route and for every season; the r values were found to be lower than those for the mean values. For each set of measurements one has to compute the CF value, as was done here, and which was confirmed by the similarity of its value to the mean coefficients obtained from the above regression equation.

In conclusion, it is worth mentioning the theoretical urban factor (or the temperature difference between the centre of the city and its edges - Δt), which is similar to those determined in this study. Lowry (1968) computed the Δt value relying upon the study of Suomi and Tanner (1958) on the heat balance under conditions of a 'canopy'. For night conditions, with polluted air and calm wind, corresponding to winter night inversion in Johannesburg, $\Delta t = 5^{o}C$ (Lowry, 1968, Table 14-4). The other value appears at the bottom of Table 7.2. Lowry states that even now there is no agreement between the theory and practice as the "observation sites are too seldom comparable". It appears that the method chosen for computing Δt (UF'), which suited the theoretical research, was the correct one.

7.4. COMPARISON WITH OTHER TOWNS.

The isolation of the urban factor, enables one to distinguish between the urban influence in summer and in winter on minimum and maximum temperatures and so to compare the effects with those found in other towns overseas. The same effect of the urban factor on the minimum and maximum temperatures has been found consistently by the various investigators. They found that at the time of the minimum temperature, the centre of the city is warmer than the outlying parts of the town particularly on inversion nights. The same effect was found in Johannesburg on inversion nights. But taking all the summer nights together, one finds that the men Δt value (the difference between Jan Smuts and Station 87, see 8.1) is a little smaller than on summer days (1.58 and 1.76°C respectively). On the other hand, there is considerable disagreement over the influence of the urban factor during the two seasons at the time of minimum and maximum temperatures. Table 7.3 shows examples from some other towns in the Northern Hemisphere.

TABLE 7.3

RELATION BETWEEN THE VALUES OF Δt BETWEEN WINTER (W) AND SUMMER (S)

TOWN	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	REFERENCE
VIENNA	$W < S$	$W > S$	Mitchell (1961b) assumes that the same is also correct for towns in the U.S.A.
LINCOLN (NEBRASKA)	$W \backsim S$	$W > S$	Landsberg (1956)
LONDON	$W < S$	$W < S$	Chandler (1962c)
JOHANNES-BURG	$W > S$	$W < S$	

The great variation brought out in Table 7.3 proves that even with the same climate it is inadmissable to apply data from one town to another. There is a simple explanation of the phenomenon of the exceptional winter nights in

Johannesburg - winter in Johannesburg is the strong inversion season. (Even taking the data for all the nights in the relevant month, the Δt value (UF) will be much greater than in summer). In Europe and the U.S.A. winter is a rainy season with greater instability than in summer. On the other hand, there are prominent differences in maximum temperature, between the towns. Landsberg (1956 p.598) stated that some investigators are of the opinion that convection above the town in summer reduces the maximum temperature, i.e. the air pollution from fuel combustion, dust and smoke keeps the heat near the ground and therefore in winter it will be warmer during the day. Convection also aspirates cold air from outside the town and mixes it, and prevents the town to get warmer. On the other hand, Chandler (1962b) who obtained opposite results to Landsberg, explains that the main cause of the heat island is the high heat capacity of the city, and therefore in summer Δt value will be higher during the day. This effect is heightened by freedom from air pollution both winter and summer. Mitchell (1961b) explains that the influence of the town in summer is smaller due to the dust which decreases insolation. On the other hand, in winter the Δt will be higher because of domestic heating and smoke from chimneys.

The contribution of the present study to this problem is clear and definite, for the following reasons:

(a) the Δt values were not determined from a few stations in and outside the town, but from the urban factor which was isolated from observations on a great number of stations. The differences between the two methods has already been discussed (see 4.5). One can assume that the diversity of the various opinions quoted is due to the use of only two stations. Landsberg (1956) demonstrates this problem from the data for Cleveland (p.600) which is situated on the shore of a lake.

(b) During the month of June (1967) weather conditions were uniform - fine weather without precipitation and strong winds, so that the degree of air pollution was constant for the whole month. The grey/white sky above Johannesburg bore out this fact.

On summer days usual convection conditions dominated, mainly in the late afternoon accompanied by showers (18 days during December 1966). The air was clear and the sky was bright during the maximum temperature period. As to conditions on winter days, one cannot argue that the lower data for the city were recorded, because measurements were not taken at peak temperatures; there is a lag in the maximum temperature compared with places outside the town. On Route 2 higher values were obtained than on Route 1, in spite of travelling across the city half an hour earlier than Route 1 (see 2.3.). The results for Johannesburg show that the high significant UF and UF' values of summer-days were obtained under conditions of convection and lack of air pollution. The fact that the angle of incidence of the sun's rays was at its peak (nearly 90° at this latitude) does not cause the high UF value, as the vertical walls in the city in winter tend to reflect solar radiation towards the ground rather than the sky (Lowry 1967). One should mention that in the southern hemisphere, the summer solar constant is higher than in the northern hemisphere. Also the high elevation of Johannesburg intensifies insolation in the bright morning hours. This fact is in contrast to the assumption made by Sundborg (1951, p.103) that there should be a negative Δt in lower latitudes. Despite the convection, which might eliminate the heat, the city remained warmer due to its great heat capacity. The rocklike material of the city's buildings and streets can conduct heat about three times as fast as it is conducted by wet, sandy soil. On the other hand, in winter, the air is stable and polluted. The insolation which is weaker in the city strikes the top of the buildings but is reflected down to ground level. In this connection one may recall the opposite opinion that the peak temperature is at the top of the buildings similar to that under forest conditions (Landsberg 1956). If this opinion were correct then the height of buildings (Variable 6) would appear in the winter regression equation with an opposite sign (see 5.4.1.). Moreover, there should be an influence of road direction (see 5.4.3.). The heating of the air after the break in the night inversion started with a considerable lag in the city, and at the maximum temperature, Δt was very low. Probably, without the credit of the night heat island, the Δt would never be positive at the time of maximum temperature.

CHAPTER 8

WEATHER INFLUENCE ON THE HEAT ISLAND

8.1. CHOICE OF PARAMETERS AND COMPUTING METHODS.

Sundborg (1951) in Uppsala was the first to compute the influence of the climatic elements on the difference in temperature (Δt) between the city and its rural environment. The regression equation evolved by him and its simplified formula (p.103) are quoted in almost every general study on the subject of urban climate. Sundborg used the equation of the partial regression, where the dependent variable is Δt (D) and the independent variables are cloudiness (N), wind velocity (U), temperature (θ) and absolute himidity (e). The general formula is:

$$D = b_o + b_1 N + b_2 U + b_3 \theta + b_4 e \qquad \text{..........(8.1)}$$

where

b_o - represents the urban factor.

The computation was done separately for day and night. Presentation of the results does not include the R value or the standard error of the coefficients (S_{b_j}). The equations for Uppsala were:

$$D \text{ day} = 1.4^{o} - 0.01\ N - 0.09\ U - 0.01\theta - 0.04\ e\ (^{o}C) \quad \text{...(8.2)}$$

$$D \text{ night} = 2.8^{o} - 0.10N - 0.38U - 0.02\theta - 0.03e\ (^{o}C) \quad \text{...(8.3)}$$

Sundborg states that the sample does not represent the numerical size of the population but the order of magnitude which, however, is probably correct. He also explains the inaccuracy caused by the lack of linearity in the wind effect at high and low velocities.

Chandler (1965 pp. 177 - 8) changed Sundborg's formula (8.1), in respect of one independent variable. Instead of the humidity factor, which did not show any relationship to the intensity of the heat island in London, Uppsala or

San Fransisco (Dockworth and Sandberg 1954), he inserted the temperature range of the 12 hours preceding the time of measurement. The data, which referred to midnight and midday (12.00, and 0.00 G.M.T.), were measured over a period of two years and were divided into winter (October - March) and summer (April - September). Thus, the total number of days recorded in summer was n = 366 and in winter n = 365. The regression was computed in British units, but also given in c.g.s. units, with the temperature shown in ^{o}C, N - in oktas, Um - wind speed in metres per second. The relevant equations in c.g.s. units are as follows:

$$D\ \mathrm{min}/S = 1.72 - 0.12N - 0.17Um + 0.1Tc + 0.15Rc \ldots (8.4)$$

$$D\ \mathrm{min}/N = 1.69 - 0.13N - 0.10Um + 0.04Tc + 0.08Rc \ldots (8.5)$$

$$D\ \mathrm{max}/S = 0.83 + 0.03N - 0.00Um + 0.06Tc + 0.00Rc \ldots (8.6)$$

$$D\ \mathrm{max}/W = 0.73 - 0.03N - 0.01Um - 0.00Tc + 0.00Rc \ldots (8.7)$$

where:

Tc - temperature
Tc - temperature range

In order to compare these results with the Johannesburg data, the D-dependent value for Johannesburg was computed separately for each month and for times of minimum and maximum temperature of the day (in every case n = 24). The parameters were as follows:

D - the difference between Station No. 87 (in the city) and Jan Smuts Airport (the dependent variable), cloudiness (N) in Oktas, wind velocity (U) converted to metres per second for comparison with London results, Tc - the minimum (or maximum) temperature at Jan Smuts Airport and Rc - the range between the maximum and minimum before Tc.

The humidity and humidity mixing ratio was expressed in its simplified form (Equation 3.16). The wind velocity and the cloudiness values were determined as the average for the time of the traverse. For computing the D value the simultaneous rather than the stepwise method was used, (3.3.3.2, program No. 10) allow comparison with the London and Uppsala results. Another variable expressing the slope lapse rate which was the difference in temperature between the Observatory and Parkhurst stations was taken into account.

8.2. CHECKING THE SIMPLE CORRELATIONS BETWEEN THE VARIABLES.

Before computing the multiple regression coefficients, the variables (Card 3, see 3.4.3.) were checked to ensure that they were not inter-related. This was done by computing the correlation between them. The variables checked were:

1). Cloudiness
2). Wind velocity
3). Δt (Parkhurst minus Observatory)
4). Δt (Jan Smuts Airport minus Station 87)
5). Humidity mixing ratio (of Station 6, O in Fig, 5.1)

TABLE 8.1

CORRELATION COEFFICIENTS (r) MATRIX FOR WINTER

(App, Program No.6)

	VARIABLE	1.	2.	3.	4.	5.
1.	CLOUDINESS	NIGHT DAY	0.19	0.33	0.21	0.26
2.	WIND VELOCITY	-0.07	NIGHT DAY	0.58	0.36	-0.30
3.	PARKHURST - OBSERVATORY	0.18	-0.08	NIGHT DAY	0.23	-0.32
4.	JAN SMUTS AIRPORT STATION No. 87	0.15	0.12	0.36	NIGHT DAY	0.20
5.	H.M.R. (STATION No. 6)	0.01	-0.42	0.19	0.04	NIGHT DAY

The data below the diagonal line in Table 8.1 refer to day values and above it to night values. The numbers encircled are correlation coefficients which passed the t test at a significance level of 95%. It should be noted that Variable 4 is negative, being the value for the station outside the town (J.S.A.) minus that for the station inside the city (Station No. 87). In summer, when the data are more varied, the correlations are higher, especially for the night. The similarity between summer and winter is mainly due to the influence of cloudiness. In winter the correlation between wind velocity and lack of inversion at night is prominent, and the influence of wind on humidity is stronger, where the wind carries well-mixed air of lower humidity.

TABLE 8.2.

CORRELATION COEFFICIENTS (r) MATRIX FOR SUMMER

VARIABLE	1.	2.	3.	4.	5.
1. CLOUDINESS	NIGHT DAY	0.16	0.39	0.61	0.23
2. WIND VELOCITY	-0.46	NIGHT DAY	0.55	0.15	0.56
3. PARKHURST --OBSERVATORY	0.07	0.24	NIGHT DAY	0.44	0.76
4. JAN SMUTS AIRPORT -- STATION No. 87	0.14	-0.13	0.19	NIGHT DAY	0.46
5. H.M.R. (STATION No.6)	0.45	-0.21	-0.09	0.13	NIGHT DAY

In summer nights the connection between humidity and the other variables is prominent. On the other hand, this is the only case where the correlation between wind velocity and humidity is positive. This can be explained by the fact that windy nights are connected with precipitation. For that reason, humidity is also correlated with the lack of inversion (in contrast to the winter).

It would be hard to compare Tables 8.1 and 8.2. with Uppsala results (Sundborg, 1951, p.84) as these tables have been computed for all the data obtained at different hours of the day and in different seasons. Anyhow, the correlations for the nights between cloudiness and the D value are similar to the mean values for winter and summer in Johannesburg. The correlation between D and wind in Uppsala is near that for winter in Johannesburg. On the other hand, the connection between D and humidity is much greater in Johannesburg than in Uppsala. According to the humidity and D values during the day, the correlation coefficients in Johannesburg are low while in Uppsala they are high.

8.3. COMPARISON OF MULTIPLE CORRELATIONS FOR LONDON AND JOHANNESBURG.

The correlation coefficients were computed in the simultaneous form and in a great number of selections. Later only four of these selections were chosen for discussion:

i). the one which corresponds to the Uppsala variables,

ii). the 'London variables',

iii). a combination of these two,

iv). the result of (iii) + the Δt for Parkhurst and Observatory (see tables 8.3 - 8.5).

In order to improve the R value and the significance of the regression coefficients the computation was done also for selected nights in summer with northern wind components. D values might be more homogeneous due to the lee effect on the heat island (see 4.4.4.). The results showed no improvement. The R value (which shows how closely the equation fits the data) for the Johannesburg data, where the variable fits the London parameters, is always higher than the R value for London. As the number of observations in Johannesburg is much smaller, however, one has to check that the R value of London is in the confidence limit of the Johannesburg data (see Brooks and Carruthers, 1953 p.223). In all four cases the values for London are at the 95% confidence limit level, i.e. there is no significant difference between them. If one takes the F test at the value of F = 1.5, as was done for the stepwise computation, it will be found that all the cases for the night passed the test, but not one for the day.

TABLE 8.3.

ANALYSIS OF MULTIPLE REGRESSION RESULTS FOR SUMMER NIGHT

VARIABLE	SELECTION 1		SELECTION 2		SELEC. 3		SELEC. 4	
	Coef. (b_j)	S_{b_j}	b_j	S_{b_j}	b_j	S_{b_j}	b_j	S_{b_j}
1. CLOUDINESS (N)	-0.22	0.06	-0.17	0.07	-0.16	0.06	-0.16	0.06
2. WIND VELOCITY (U)	0.07	0.12	-0.24	0.12	-0.10	0.14	-0.09	0.15
3. Δt (PH - OB)	-	-	-	-	-	-	-0.01	0.23
4. TEMP. (Tc)	-0.19	0.14	-0.37	0.14	-0.31	0.14	-0.31	0.16
5. HMR	-0.27	0.13	-	-	-0.21	0.12	-0.20	0.18
6. R_t	-	-	+0.17	0.07	+0.14	0.07	+0.14	0.07
CONSTANT	8.00		6.76		7.98		7.95	
R	0.74		0.76		0.80		0.80	
STD. ERROR (S_y)	±0.86		±0.13		±0.79		±0.81	
F TEST	5.86		6.64		6.46		5.09	

TABLE 8.4.

ANALYSIS OF MULTIPLE REGRESSION RESULTS FOR SUMMER DAY

VARIABLE	SELECTION 1		SELECTION 2		SELECTION 3		SELECTION 4	
	b_j	S_{b_j}	b_j	S_{b_j}	b_j	S_{b_j}	b_j	S_{b_j}
1. N	-0.12	0.17	-0.17	0.15	-0.15	0.16	-0.11	0.16
2. U	+0.06	0.18	+0.07	0.17	+0.07	0.17	+0.14	0.18
3. Δt	-	-	-	-	-	-	-0.65	0.54
4. Tc	-0.08	0.08	+0.18	0.18	+0.18	0.18	+0.18	0.18
5. HMR	-0.07	0.15	-	-	-0.08	0.14	-0.11	0.14
6. Rt	-	-	-0.33	0.20	-0.34	0.21	-0.34	0.21
CONSTANT	4.95		1.45		2.26		3.12	
R	0.28		0.43		0.44		0.51	
SY	±1.19		±1.12		±1.14		±1.13	
F TEST	0.39		1.05		0.87		0.99	

TABLE 8.5.

ANALYSIS OF MULTIPLE REGRESSION RESULTS FOR WINTER NIGHT

VARIABLE	SELECTION 1		SELECTION 2		SELECTION 3		SELECTION 4	
	b_j	S_{b_j}	b_j	S_{b_j}	b_j	S_{b_j}	b_j	S_{b_j}
1. N.	-0.09	0.09	+0.01	0.09	-0.05	0.09	-0.01	0.09
2. U	-0.19	0.08	-0.24	0.07	-0.20	0.07	-0.12	0.08
3. Δt	-	-	-	-	-	-	-0.20	0.11
4. t_c	-0.48	0.12	-0.18	0.07	-0.37	0.13	-0.49	0.14
5. HMR	+0.73	0.33	-	-	+0.56	0.32	+0.68	0.31
6. Rt	-	-	+0.20	0.09	+0.16	0.09	+0.11	0.08
CONSTANT	0.85		1.79		-0.39		-1.11	
R	0.76		0.77		0.81		0.83	
Sy	±1.00		±0.99		±0.94		±0.88	
F TEST	6.57		6.83		6.67		6.78	

8.4. COMPARISON OF MULTIPLE REGRESSION COEFFICIENTS.

The function of the regression coefficients is more important than the R value, as these coefficients are used to predict the dependent variable. While a comparison of R value is easy from a technical point of view, it is difficult in comparison with various regressions. If one checks the coefficients with the aid of twice the standard error test ($2\ S_{b_j}$), one finds that all the variables for the day do not pass the test, (Table 8.4), as is the case with part of the variables in the London regression (Chandler 1965, pp.178-179). Regarding the night, the position is much better; but in winter the cloudiness does not pass the $2S_b$ test. In summer the wind velocity in three selections out of four fails to pass the test (Table 8.3). The cloudiness during winter nights (Table 8.5) which is an important factor did not contribute to the regression; unfortunately the measurements did not represent the actual cloud conditions as the mean value of cloudiness during the traverse was used. On most days the fog covering the valleys lifted in the early mornings and changed to stratus which disappeared with sunrise. In spite of this amount of cloudiness, these were nevertheless inversion nights and the D values were still high. When this selection was tried in the stepwise method, the variable of cloudiness did not appear at all. For the day (winter) no variable appeared, where at night the correlation coefficient was 0.80 and the F level 2.82. The regression equation was as follows:

$$D = -0.206 - 0.218U - 0.356t_c + 0.493H.M.R. + 0.171R_{t_n} \qquad \ldots\ldots \quad (8.8).$$

All the variables passed the twice standard error test, except for humidity which was, however, close to passing it.

The cloudiness on winter nights and the wind during the summer day have low coefficients and suited the low correlation coefficient between D (Δt, - JSA - Station 87) and those variables (Tables 8.1 and 8.2), even though there need be no connection between these two facts. For instance, the correlation coefficient between D and the temperature in summer nights (t_c) is -0.07. Nevertheless, this variable appears with a high regression coefficient which passes the twice standard error test (except for the selection similar to Uppsala - Selection 1 in Table 8.3). This high coefficient is due to the inter-relation between the variables, which means that, although there is no direct correlation between D and t, together with the other variables this variable makes an important contribution to the regression.

On applying the twice standard error test to determine which selection is preferable for Johannesburg, it was found that the London selection (Selection 2) is more suitable for summer nights as it is the only one among the selections in which all the coefficients pass the test. On the other hand, for winter nights there is no difference between the two of them (London - Selection 2 and Uppsala - Selection 1). But using the R value, Selection 3, which contained the variables of both towns (London and Uppsala) is improved by about 4 - 5%. On the other hand, the variable which represents the slope lapse rate (Variable 3 - Δt PH - OB) increases in a clear manner (but does not pass the $2S_{b_j}$) in winter (even during the day) but not in summer nights. It may be noted that an addition of 3% to the R value, due to the inclusion of another variable, as happened at night, does not increase the significance of R, but does raise the F value.

Comparison of the London regression equations with those of Johannesburg shows that the regression coefficients of the Johannesburg equations are greater than those of the London equation, especially of the tc (temperature) value. Not only is the magnitude of the t_c value different but also the sign is similar to that of Uppsala. The Uppsala value is low, and it is doubtful if it passes the twice standard error tests. This fact can be explained for Johannesburg. The lack of correlation between D and t_c for summer nights has already been discussed. In winter the correlation is significant, being -0.48. This indicates that the low minimum temperature at Jan Smuts Airport generally points to inversion conditions, and therefore D will be greater. Consequently, the location of the station will be the determining factor among the values for the station and the other variables. By taking the t_c value at Station 87 or at Joubert Park, instead of the t_c value at Jan Smuts Airport, the sign will probably be the opposite one. This probably also explains why the regression coefficient for the nocturnal temperature fall (R_t) is lower in Johannesburg than for the actual temperature, in contrast to London.

Quite surprising is the great magnitude of the regression coefficient of Variable 3 (Δt, PH-OB), except for summer nights. Although it nearly passed the twice standard error test only for winter nights, during winter days it is the only variable which is near the significance limit, where it increased the R value from 0.37 to 0.54 and raised the F value from 0.58 to 1.16. This shows the importance of the lapse rate factor, especially at night. But there is a disadvantage in this variable for inversion nights. On comparing Selection 4 with Selection 3 in Table 8.5, one finds that the addition of Variable 3 considerably reduces the magnitude of Variable 2 (wind velocity) and increases its standard error (S_{b_2}) owing to the inter-relation between these variables. Moreover, Variable 3 is not always reliable (see 4.2). For the same reason, the D value did not always represent the real situation. In order to overcome this problem it is preferable to check the influence of the climatic elements not on the D value, but on the urban factor (UF or UF') as has already been explained in connection with isolating the urban factor. For this purpose, one has to compute the UF (or UF') value for every day; the particulars of the station description on Group Card No. 3. which are needed in the computation of the multiple correlation by the simultaneous method have to be punched on the whole series of Group Card No. 1 (see 3.4.1.) (to use the stepwise programme which was used for the isolating of the UF factors it will be necessary to punch new cards, as the dependent variable in this programme should be the last variable in the card).

In conclusion, it can be stated that despite the similarity of the R values in the different selections between summer and winter and minimum and maximum temperature time, as in London also, the regression equation, the coefficients, and their significance are not equal. In contrast to London the humidity element played an important role in Johannesburg at night in both seasons. The same applies to the stability index (see also Chandler 1965 p.177) even it does not pass the twice standard error test. The use of the urban factor instead of D (Δt) will probably contribute a lot to improving our knowledge quantitatively on the climatic elements which dominate the urban factor magnitude.

CHAPTER 9

HUMIDITY DISTRIBUTION IN JOHANNESBURG

Very few intensive studies have been made of the influence of urbanization on humidity distribution in towns and on the differences in this distribution between urban and rural areas, mainly because of the instrumentation problem. First of all, not all the climatological stations are equipped with hygrographs, but only with wet and dry bulb thermometers. The inaccuracy of the hygrograph has already been discussed in 3.1.3. In addition, the readings of the wet-bulb temperature are inaccurate in an unventilated screen. The readings also depend on the diameter of the bulb, cleanliness and quality of the muslin etc. In this study, in which only one instrument was used in recording the wet-bulb temperature, the error can be almost the same at all the stations. This error is removed by concentrating on the difference between stations rather than on the difference between the values themselves. The second problem, is that of reduction to a unit time (see 3.1.3.). Further, the temperature is obtained by direct reading but the humidity parameters are obtained indirectly using the wet and dry-bulb temperatures. In addition, there is a need for air pressure data, as a difference in height between two stations may increase the error. Thus the results of the influence of urbanization on absolute humidity may vary from place to place. Kratzer (1956), who was one of the first to deal with this subject, stated that the humidity in town is a little lower than in the rural area. Chandler (1967a) obtained the opposite results.

In the following paragraphs, the distribution of the humidity mixing ratio and relative humidity will be discussed, using the same methods and assumptions as for temperature distribution.

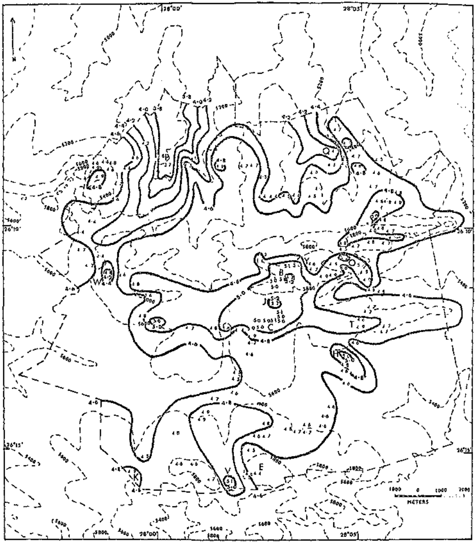

Figure 9.1 Mean Humidity Mixing Ratio distribution at the minimum temperature time for strong inversion night only (June 1967)

9.1. HUMIDITY MIXING RATIO DISTRIBUTION FOR WINTER INVERSION NIGHTS.

As data were not standardised to one time there is a difference between stations 1 and 99 in winter too. Table 9.1 shows the analysis of results for winter nights.

TABLE 9.1.

RESULTS AND ANALYSIS OF THE MULTIPLE REGRESSION COEFFICIENTS FOR WINTER INVERSION NIGHTS (H.M.R.)

ROUTE	DIFFERENCE BETWEEN WETTEST AND DRIEST SPOT	R	MULTIPLE REGRESSION EQUATION	UF_H	S_{UF}
I	1.5 gram/Kg.	0.66	H.M.R.= $4.24+0.066x_1+0.082x_6$	0.33	0.107
II	0.9 gram/Kg.	0.55	H.M.R.= $4.91+0.037x_5+0.10x_6$	(0.24) 0.42	0.059

The mean difference between stations 1 and 99 in Route 1 is 0.132 g/Kg. or about 9% of the whole range of humidity. In Route 2-0.201 g/Kg. which is 22% of the whole range. The mapping (Fig.9.1) was done after the data of Route 2 were reduced by 0.35 g/kg, which is the mean difference for the common section of the two routes. As the common portion is taken from Route 1, Route 2 is shortened and it may be stated that the error due to lack of reduction to one time between the extreme cases is 10%. The isopleths were drawn in intervals of 0.2g/Kg. The humidity map is very complex and has a cellular shape of (+) (-) where most of the town is between the isopleths of 4.6 and 4.8 g/Kg. The complexity is due not only to the urban and topographic features but also to evaporation surfaces, water sources, the rate of the turbulence and the air stream pattern induced by Johannesburg's topography. The R values are much lower than those obtained from temperature distribution for the above reasons. The difference in the inversions is not so important as far as the humidity mixing ratio (H.M.R.) is concerned. Thus in contrast to temperature distribution, even if one cut in Route 2 after step no. 1, both multiple correlation coefficients will include the R of Route 1 in their 95% confidence limits. In both cases the R value is significant at the 99% level. In Route 1 the variable for elevation (1) appears where the height is in proportion to the humidity. On the other hand, in Route 2 the topographic factor does not appear. Here too (as in temperature) it can be explained by the great difference in height in Route 1 where the relative humidity reached 100% in the valleys, and owing to an additional drop in temperature, moisture is precipitated in the form of dew. Generally speaking higher places like Station 14 (T in Fig. 9.1) and the Berea and Yeoville (B and Y) areas are more humid. An exception is Station 34 (E in Fig.9.1) at the southern edge of the southern suburbs which is the driest place on the route.

According to the tables of residuals most of the extreme cases with positive signs are located at a relative height of 0 (i.e. at the bottom of the valleys) like at O in Fig. 9.1 (Station 7) in Route 1 and at H, V and K (Station 19, 36 and 40 respectively) in Route 2. In these cases the relative humidity does not reach 100% and because of the air stagnation the humidity remains constant at one place and does not scatter. These areas are generally open spaces.

Higher values in the city obtained here, are similar to values found in other places. In London, for instance, during one inversion night, the vapour pressure was 3.3 mb (2.0 g/Kg H.M.R.) higher than in the rural area (Chandler 1965 p.201). Although there are no evaporation surfaces in the city and the drainage after rain is good, the high humidity in the city is explained by the cellular morphology of the city which captures hot air bodies, thus retaining the high humidity. This contradiction between high humidity and lack of evaporation source is stressed in an interesting form in Route 2; the urban factor, the density (x_5) and the height of the building (x_6) contradict one another; the code for the density is the opposite to that of the height of buildings. While the height of buildings shows the growth of the humidity, the density shows a decrease in humidity with the increase in density. In other words a built-up area reduces the humidity due to organised drainage and lack of evaporation area. Tall buildings retain humidity by preventing its dispersion. This is the reason for the low humidity in the centre of Western Township, W in fig. 9.1, (Station 73, Routel). The density is high, but the structures are low. The disappearance of the density factor in Route 1 causes this station to have a highly negative residual. Because of the high correlation between the two urban factors it is hard for both of them to appear together in a significant form, the density factor in Route 2 has a low coefficient and does not pass the twice standard error test. Therefore the UF value in Table 9.1 appears once after the first step and in parenthesis after the second one where the UF value is smaller due to the compensation of the density factor. The most humid place during inversion nights in Johannesburg is next to Joubert Park (J) owing to the combination of evaporation areas surrounded by tall buildings.

In the residual analysis the centrality factor is not prominent. As it appears in a very shallow form this factor will not be computed and one can assume that $UF_H = UF'_H$.

Of the other stations in the residual table that were higher than $2S_y$ it is worth mentioning the Linden slope in Route 1 (P in Fig.9.1, Stations 49 - 51). It is hard to explain the negative residuals with the aid of only the lag of the wet-bulb temperature. This occurred in only one other case: in Q (Station 32, residual -0.42). Since in most of those places the relative humidity was 100%, it is possible that super saturation conditions of the wick took a while and caused the lag in the wet-bulb temperature. This is extremely conspicuous at Station 51, the place where the lowest relative humidity was recorded in Route 1. In conclusion it should be said that even with improved technical conditions it would be hard to solve the humidity distribution without intensive knowledge of the wind drainage system of Johannesburg. This is further proof of the importance of the differentiation of the urban factor method expressed in the difference between the height of buildings and the density factors.

9.2. HUMIDITY MIXING RATIO DISTRIBUTION FOR WINTER DAY.

The diurnal change of the H.M.R. in winter according to Germiston data (see 1.4.4.) shows that at the times of maximum and minimum temperature the H.M.R. is almost the same. The means for the two routes for these times show that the day-time values are 1 g/Kg greater than the night values. Obviously, this is not true for every place. While at the base station (Observatory) the difference is 0.4 g/Kg. (5.3gKg. night, 5.7 g./Kg.day), in the city the difference reaches 2 g/Kg. At Station 49, which is very dry at night (in spite of 100% relative humidity) the difference is the great amplitude of temperature in the northern valleys. At night the humidity precipitates in the form of dew while the great warming in the day caused intensive evaporation, especially in the open space of the northern valleys. The additional humidity in the city is explained by small quantities of water vapour, by combustion and enmeshing of warm air between buildings so that it will maintain its high daytime humidity more easily as it is free from excessive mixing (Chandler 1967a). The town breeze which exists according to many investigators, will advect humidity from the suburbs and keep it in the city.

TABLE 9.2.

RESULTS AND ANALYSIS OF THE MULTIPLE REGRESSION COEFFICIENT FOR WINTER DAY (H.M.R.)

ROUTE	DIFFERENCE BETWEEN WETTEST AND DRIEST SPOT	R	MULTIPLE REGRESSION EQUATION	UF_H	S_{UF}	CF	UF'_H
I	1.1g/kg.	0.53	H.M.R. = 6.00 + $0.096x_6$	0.384	0.06	0.406	0.79
II	1.0g/Kg.	0.75	H.M.R.=5.46-$0.041X_5$+$0.095x_6$	0.585	0.053	0.248	0.83

The difference between the first and last station:
in Route 1 - 0.051 g/Kg. is about 4% of the whole difference,
in Route 2 - 0.157g/Kg is about 17% of the whole difference.
The R values are significant even at the 99% level.

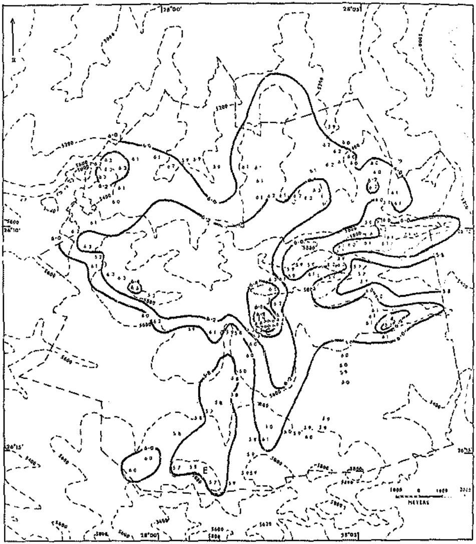

Figure 9.2 Mean Humidity Mixing Ratio distribution at the maximum temperature time (June 1967).

In its final form the multiple regression equation includes three independent variables (Route 1) including also the slope aspect and steepness factors. Slope steepness does not pass the twice standard error tests and slope aspect only passes, if steepness appears too. The slope aspect determines that the slope with the southern aspect will have a greater H.M.R. A similar phenomenon appeared also for winter day temperatures in Route 2, so one can assume that there is a connection between the high temperature of the southern aspect and the high humidity (especially in the city). As the slope aspect factor was not accepted there it cannot be accepted here (5.3.2.). In Route 2 appear the two urban factors and the relative height which always appear instead of the absolute height in this route; this factor does not pass the twice standard error tests.

Fig.9.2 which was drawn at an interval of 0.2g/Kg. was reduced for Route 1 by the addition of 0.5g/Kg. to the values of Route 2. The map clearly illustrates the humidity island of the city (C in Fig.9.2). The appearance of relative height in the negative form shows that there is a tendency for the humidity to decrease with an increase in height. This can be caused by the stronger turbulence at higher altitudes. This effect shows up prominently in the Elsberg Range (E) in the Southern suburbs. But as with the night data, proximity to water sources influence more than the topographic height.

The most important phenomenon in the distribution of H.M.R. in Johannesburg is the appearance of high values in the city, where the UF and UF' are higher during the day than during inversion nights, although the UF_t value is very low during winter days. The phenomenon can be explained by the high stability of the air in the winter. During the night the humidity in the city remains high while the relative

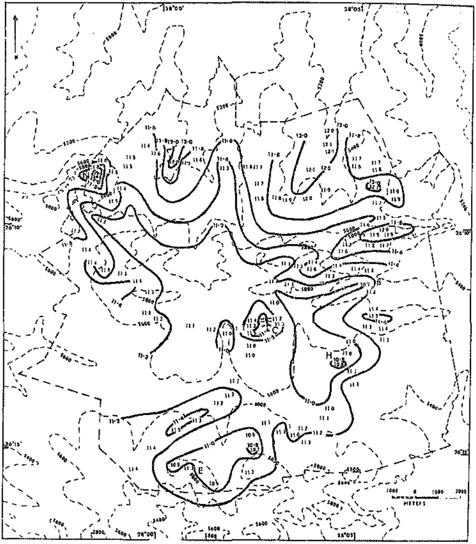

Figure 9.3 Mean Humidity Mixing Ratio distirbution at the maximum temperature time (December 1966).

humidity is quite low (see 9.4), and outside the city where the night cooling is greater, part of the humidity is condensed and precipitated as dew, or rises in the morning hours and changes into low stratus. The city keeps its humidity with the aid of its canyon shape which prevents dispersion by turbulence. In open spaces next to the city, like in Joubert Park, (J in Fig. 9.2) the humidity was highest at night; the humidity is 0.6 g/Kg. lower during the day in comparison to the most humid spot in the city. The fact that tall buildings keep the humid air stagnant in the city necessitates the addition of the centrality factor which does not operate at night. As was found for temperatures the centrality factor (CF) complemented the UF value for the two routes. In both routes the most humid point is at the corner of Rissik and Pritchard Streets (Station 86).

On both routes, the residual is greater than $\pm 2\ S_y$ in only seven cases. Except for the city this phenomenon cannot be explained without detailed inspection of the water sources and other evaporation surfaces.

9.3. HUMIDITY MIXING RATIO DISTRIBUTION FOR SUMMER DAY.

A sample of 12 traverses in each route is too small to understand the humidity distribution of summer days. In 5 cases out of 12 in each route there was precipitation during or just prior to the traverse which makes the obtained map (9.3) and the regression equation very difficult to analyse. Nevertheless, if one regards the analysis in a qualitative form and not in a quantitative one, some implication can be deduced.

TABLE 9.3.

RESULTS AND ANALYSIS OF THE MULTIPLE REGRESSION COEFFICIENT FOR SUMMER DAY (H.M.R.)

ROUTE	DIFFERENCE BETWEEN WETTEST AND DRIEST SPOT	R	MULTIPLE REGRESSION EQUATION	UF_H	SE_{UF}	CF	UF'_H
I	1.3g/Kg.	0.68	$HMR= 11.5-0.044x_1+0.144x_5$	-0.720	0.101	0.264	-0.456
II	1.2g/Kg.	0.41	$HMR= 11.223+0.0664x_6$	0.266	0.079	0.271	+0.537

The difference between the beginning and the end of the routes is less than 0.1 g/Kg, and the percentage from the whole difference of the route (Table 9.3) in Route 1 - 6.5% and Route 2 - 2.1%. The R value shows a difference in population in the two routes, but in both cases it is significant at the 99% level. Fig. 9.3 was drawn at an interval of 0.2 g/Kg. and Route 2 was added after reduction by 0.1g/Kg. The day values are just a little higher than the night values. The northern valley is very *humid but* the most humid spot is the top of Northcliff (N in Fig.9.3) where the relative humidity is also very high. This place, and also Linksfield Ridge (L) stand in contrast to the regression equation, as the coefficient of x_1 is negative *and significant at the 95% level* according to the standard error. It can be understood by the conventional explanation (for instance Landsberg 1962 p.315) of the top of the mountains which have high humidity from being covered by clouds in summer. On the other hand the ranges in the southern suburbs (E) are quite dry. The valleys are not all humid, however, for instance Bez Valley (B) and Stations 18 - 20 (H) in

Route 2 are dry. As this sample is too small to explain the humidity distribution it would be quite ridiculous to try to explain all the humidity islands without increasing the number of measurements and without entering into microclimatic conditions, bodies of water etc.

This complication causes a contradiction in the UF value between the two routes. According to Route 1 the humidity in the city is lower than outside the town. The map illustrates that the northern parts of Johannesburg are wetter than the southern. It can be explained by the northern component of the prevailing wind during the traverse hour bringing humidity from the open spaces. Different distribution of precipitation during the day of measurement is enough to cause a difference of 1 g/Kg. of H.M.R. between the common section of the two routes. It is interesting to see again the difference between the two urban factors (x_5 and x_6) as it appears in Route 2 during winter night (9.1.). While the height of the building increases the humidity, the density decreases it. This effect is well illustrated on the map. The isolines illustrate a decrease in humidity when approaching the city (C in Fig. 9.3) from the North. But inside the city there is again an increase in humidity which creates a humid island above the city, so that the centrality factor in Johannesburg applies only to the city itself and not to the whole town. As was already mentioned one cannot regard the UF and UF' values in a quantitative form. In summer nights too the city is not the most humid place but there is a humid island above the city.

9.4. RELATIVE HUMIDITY DISTRIBUTION FOR WINTER NIGHTS.

The relative humidity (RH) is a function of temperature and H.M.R. is generally more influenced by temperature than by

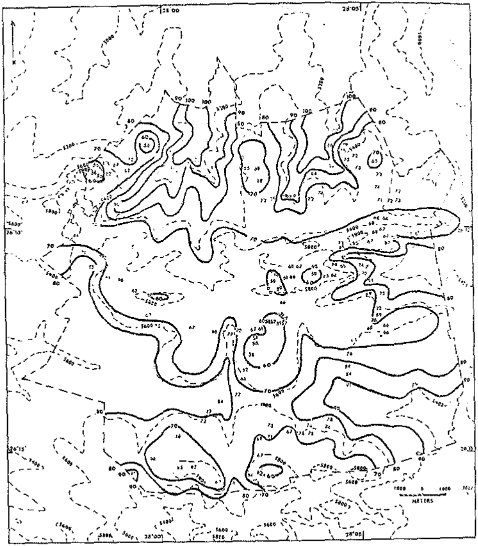

Figure 9.4 Mean relative humidity distribution at the minimum temperature time for strong inversion only (June 1967).

H.M.R. It is very prominent during inversion nights where the difference in temperature and in the RH is great. In the northern route the range is from 100% in the northern valley to 56% in the city. The drawing up of Fig.9.4 was helped by the contours, the relative height and the urban factors. The interval is 10%. The difference between the first and the last station in Route 1 is 1% which is 2.3% of the whole range, and Route 2 is 4.1% which is 11% of the whole range. Route 2 was added to the map after being reduced by 5%.

TABLE 9.4.

RESULTS AND ANALYSIS OF THE MULTIPLE REGRESSION COEFFICIENTS FOR WINTER NIGHT (RH)

ROUTE	DIFFERENCE BETWEEN WETTEST AND DRIEST SPOT	R	MULTIPLE REGRESSION EQUATION	UF_{RH}	SE_{UF}	CF	UF'_{RH}
I	44%	0.77	$RH=82.0-2.3x_1-2.4x_2+3.1x_5$	-15.5%	± [illegible]	-10.41	-25.9
II	36%	0.84	$RH=78-3.9x_2+3.4x_5-1.4x_6$	-22.6%	± > 50%	- 4.83	-27.4

In Route 1 the slope aspect appears in a negative form; it passed the twice the standard error tests i.e. the southern aspect slopes are drier. The dryness is caused by higher temperatures rather than by low absolute humidity. Although in the regression of H.M.R. for winter nights the slope aspect also appears, it does not pass the twice the standard error test. As the high temperature in the southern aspect slope has no physical basis and was rejected there, so it was rejected here too. In Route 2 the regression was cut after the third step for the same reason. The R values represent the same population, at a level of 95%, and are significant at a level of 99%.

The great dispersion of the relative humidity causes the standard error of UF to be high. The UF values (and UF') are high in comparison with a few other places where the RH distribution was analysed. The great range of temperature on inversion nights produces this effect. Chandler (1967a) found a maximum range of 18% for summer nights in Leicester or 27% (1965) in London. The low relative humidity in the city, despite the high H.M.R. value is due to the high temperatures which have the greater effect on RH values. The centrality factors which are also high appear in a negative form where in the margin of the city the residual is positive. The high residual values are generally identical with the high residual of the temperature.

9.5. RELATIVE HUMIDITY DISTRIBUTION FOR WINTER DAY.

No mapping was done for the relative humidity (RH) during the day (in winter or summer) as the difference between the first and final station was 2½% in Route 1 which is 28% of the whole range. It is possible to map RH after reduction to a standard time as was done in Leicester (Chandler 1967a). For the daytime it is easy to standardise for one time as the difference in temperature is not great and the RH is far from 100%. The analysis of the influence of the urbanisation on the RH distribution is done according to the multiple regression coefficient alone. For the above reason one has to regard the numeric feature as qualitative data only. In Route 2 the difference between the first and final station can be ignored.

TABLE 9.5.

RESULTS AND ANALYSIS OF THE MULTIPLE REGRESSION COEFFICIENTS FOR WINTER DAY (RH)

ROUTE	DIFFERENCE BETWEEN WETTEST AND DRIEST SPOT	R	*MULTIPLE REGRESSION EQUATION*	UF_{RH}	SE_{UF}	CF	UF'_{RH}
I	9%	0.69	$RH+43.2+0.49x_1+0.21x_3+0.54x_5+0.66x_6$	-0.06	3.7	0.84	+0.78
II	8%	0.55	$RH=45.1+0.66x_6$	+2.64	3.59	1.64	+4.28

The R values represent the same population at a significance level of 99%. This is the only case the slope aspect factor (Route 1) is inserted in the regression. It did not appear in the parallel regression for temperatures in this route. On the other hand it appeared contrary to physical and climatological rules in Route 2. But as it passed the twice the standard error test and as it is possible to explain the high RH on slopes which are not facing the sun, this factor was retained. The steepness factor also appeared but it did not pass the twice standard error test.

As occurred with the H.M.R. during summer days the two urban factors (Route 1) appeared with a positive sign, instead of the usual opposing signs; high density reduced relative humidity while high buildings increased it. It appears that these two factors cancel one another out and the relative humidity in the city is higher only because of CF values. If the reductions had been made to one time the UF' value would have been higher by about 2 - 3% in Route 1. In Route 2 where only the height of buildings appear in the equation the UF' value reached 4.28% and that on a route where no difference was found between the first and final stations. Here too, as on winter nights, the standard error (SY) are high owing to the lower R value, which is typical for the humidity in town where the source and evaporation surfaces are varied. Nevertheless, there is no doubt that in a town with a climate similar to that of Johannesburg on a winter day the RH inside the city is higher than its rural vicinity. This is in contrast to all urban climatological studies reported in the literature. The result is connected with the stable air which exists above the Southern African plateau in winter preventing humidity dispersion in the city. It explains the high H.M.R. in the city in contrast to a very small difference in Δt between the centre and outside the town (see 5.4.1 and 9.2). In other words the UF_{RH} value in winter days are determined by the H.M.R. (UF_H) values rather than by the temperature (UF_t). It would be interesting to draw an amplitude map of the RH between the minimum and maximum time of the temperature. Taking only the inversion night the map would show 55% in the northern valleys against 4 - 10% in the city.

9.6. RELATIVE HUMIDITY DISTRIBUTION FOR SUMMER DAY.

The relative humidity distribution for summer days must be regarded in the same way as to the H.M.R. for the same time, due to the precipitation which fell during the traverses. The difference between the first and last station in Route 1 is 1.8% which is 20% of the general range. The regression results for Route 2 were not taken into account as the difference from the beginning to the end exceeded 50%. Standardisation of the RH to one time which would help the analysis of conditions for winter days would not be a great help for summer days. Here too, one has to approach those values in a relative or qualitative form rather than by numeric or quantitative values.

TABLE 9.6.

RESULTS AND ANALYSIS OF THE MULTIPLE REGRESSION COEFFICIENTS FOR SUMMER DAY ROUTE 1 (RH)

R	*DIFFERENCE* BETWEEN WETTEST AND DRIEST SPOT	MULTIPLE REGRESSION EQUATION	UF_{RH}	SE_{UF}	CF	UF'_{RH}
0.81	8.8%	$RH=42.8+0.32x_1+1.62x_5$	-8.1%	3.21	0.054	-8.0%

The relative height also appears in the regression but it does not pass the twice the *standard error test*. In contrast to winter day conditions the UF value is negative, i.e. it is drier in the city than out of town. The value for UF and UF' agrees with the value which Landsberg (1962 p.326) obtained for their urban-rural difference in the summer. The urban factor of the RH is negative in contrast to winter days owing to the increase in temperature and not humidity; the urban factor of temperature (UF_t) is fairly high and is higher than winter days whereas the urban factor *of the H.M.R.* (UF_H) is not clear. In summer when the heat capacity of the city is great and turbulence is caused by the development of convectional conditions in the afternoon, the accumulation of humidity in the city is prevented and the RH is therefore lower.

9.7. THE INFLUENCE OF URBANISATION ON HUMIDITY IN JOHANNESBURG -- CONCLUSION.

Although the humidity standardisation to one time was not carried out, it is possible to draw conclusions on the urban influence of humidity in Johannesburg. The special Highveld climate and the different method of computing the urban factor brought different implications regarding the size of the UF_t value; the value differs also according to the humidity (UF_H and UF_{RH}).

Regarding winter nights there is no difference between H.M.R. and RH results obtained in Johannesburg and from other places, like London and Leicester. Owing to strong inversions the value of the urban factor is much greater. On winter days the high urban factor (UF') of the H.M.R. (due to the stable weather conditions of winter days) causes a positive UF'_{RH}, which is not known in other places. On the other hand, the summer results of the distribution of RH are similar to previous results, while the distribution of the H.M.R. is not clear owing to precipitation during the traverses.

PART III

CONCLUSIONS

CHAPTER 10

SUMMARY OF RESULTS

The results are divided into two parts:

(A) The influence of topography features on the distribution of temperature and humidity.

(B) The influence of the urban factors on the distribution of temperature and humidity.

(A) TOPOGRAPHIC INFLUENCE.

(1) The magnitude of the mean slope lapse rate, measured on strong inversion nights in winter, appears to be greater than lapse rates for similar conditions reported in the literature. These unusually high lapse rates result from strong radiation under clear skies associated with the mean anticyclonic circulation of winter. Also contributing to the occurence of deep surface inversions is the altitude (1700 m.) of Johannesburg.

(2) Valley inversions are most intense in the deepest parts of the northern valleys. Pronounced thermal belts mark the top of the inversion layers and may oscillate in position along the valley slopes from night to night.

(3) Owing to the distribution of buildings in the town, slope aspect and slope angle appear to have little influence on the prevailing temperature field near the ground (1.2 m.) both by day and night.

[illegible] version nights the protective effect of the [illegible] appears to be minimal. Whether this is so during cold snap conditions when inversions are much weak[illegible] r absent has yet to be established. Likewise the influence of the ridges on the distribution of maximum temperature appears to be limited. The popular notion of mild conditions can be explained by the fact that the area lies within the region of an oscillating thermal belt.

(5) Sub-zero temperatures are to be observed within the northern valleys on all strong inversion nights. Valleys to the south of Johannesburg (within the municipal area) tend to be consistently warmer than their northern counterparts.

(6) Despite high relative humidity (often reaching saturation) northern valleys experience the lowest humidity mixing ratios on inversion nights during winter.

(7) On inversion nights topography (together with the urban influence) induces a range of relative humidity extending from 100% in the Northern valleys to 55% in the city.

(B) URBAN INFLUENCE.

(1) Comparing a station inside Johannesburg with one in the rural environment proved to be insufficient to isolate the urban factor. Instead the effect of the city and its suburbs in modifying the local climate of the region was isolated by ascertaining the simultaneous effect of a number of factors on the distribution of temperature and humidity using multiple correlation and regression analysis. The independent variables considered in the regression analysis included both topographic and urban factors. Instead of taking the actual difference between urban and rural temperatures as a measure of the urban influence or factor, the difference between the computed temperatures from the regression equations was used as a more meaningful

and integrated measure of the effect. Addition of a centrality factor based on the analysis of residual temperature improved the reliability of the urban factor i.e. contrast between urban and rural environment.

The successful isolation of the urban factor by regression analysis was to a large extent possible owing to the settled anticyclonic conditions of winter and the uniformity of weather prevailing at this time of year. The justification of choice and coding of urban variables is clearly demonstrated by the results obtained. This was particularly so in the case of the relationship between the urban factor and humidity distribution, where it was seen that an area of high density buildings reduced the humidity (by diminishing the humidity source), while in areas of high rise buildings high humidities prevailed (owing to poor dispersion).

(2) Traffic was shown to have no significant effect on the urban heat island.

(3) By contrast to overseas studies Johannesburg's urban factor tends to be greater by day than by night in summer. Significant high urban factors were obtained despite the clear atmosphere (no air pollution) and the effect of convection.

(4) Summer urban rural contrasts during the day are greater than those in winter due to the high attenuation of radiation when the air is most stable. Consequently indiscriminant use of the terms summer and winter without specifying the actual climatic conditions obtaining is unwise.

(5) The urban rural contrast in minimum temperature in Johannesburg is considerably stronger in winter than in summer -- a result, at complete variance with those of

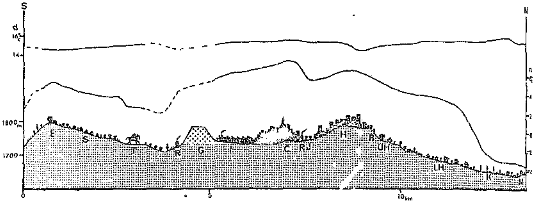

Figure 10 Winter temperature profiles (Section II in fig. 4.1 and 5). Right temperature scale (n) - minimum. Left temperature scale (d) - maximum. E - Elsberg Ridge. S - Southern Suburbs. T - Turffontein Race Course. R - Railway G Gold mine dump. I - Industrial area. C - City. J - Joubert Park. H - Hillbrow. B - Berea. UH - Upper Houghton. LH - Lower Houghton. K - Killarney Golf Course. M - Melrose.

earlier overseas studies and certainly accentuated by the deep inversions that prevail on the clear winter nights of the highveld. The centre of the heat island coincides with the central area of the city, (see fig.10).

(6) In both summer and winter and at both sunrise and the early afternoon there is a distinct humidity island above the city. In summer the humidity mixing ratios are highest in the northern valleys and decrease southwards towards the city where they increase in the central area with the occurence of high rise buildings. In winter the humidity island is most pronounced during the day.

(7) Mapping winter daytime relative humidity instead of humidity mixing ratio in winter day it is apparent that the relative humidity in the city is higher than in the rural surroundings, again a result at variance with the literature. Thus despite the high city temperatures by day the increasing humidity mixing ratio is sufficient to maintain a high relative humidity.

(8) By night relative humidities are lower in the city in winter and as much as a 45% difference might be obtained between the northern valleys and the city centre as has been stated already. Using multiple regression analysis to eliminate the effect of topography the difference is only reduced by half, thus showing the controlling influence the city area exerts on the distribution of relative humidity by night.

(9) Eliminating the effect of topography by reducing temperature and humidity to a datum level (e.g. using potential or equivalent potential temperature) did not improve multiple correlation coefficients.

(10) Centrality was measured not by distance from the centre of the town but by examination of the temperature residuals. Such an analysis seems to indicate that Johannesburg's heat island is controlled by the city area and not the extent of the town.

(11) The magnitude of Johannesburg's urban factor is almost exactly that calculated theoretically for an hypothetical city by Lowry (1968) justifying the use of regression analysis as a means of isolating the modification of the environment by a city.

(12) By night turbulence reduces the value of the urban factor while by day convection and turbulence increase it.

In general the results of this thesis are most valuable as a contribution to the empirical and theoretical study of urban climatology. It has been shown that the climate of Johannesburg is controlled not only by topography but also by the modifications induced as a result of the extent and character of the built environment. Further research into the Johannesburg's heat island might include the examination of the technique of airborne radiation and the measure of vertical temperature gradients above the city. Far more important however is the need to understand the interaction of local air circulations the pollution dome and the heat island over the city.

The most obvious practical application of the temperature and humidity data that has been presented in this thesis is in the field of landscape architecture and in town planning. Together with the aid of the permanent stations in Johannesburg and vicinity, an accumulated temperature map can be drawn for any threshhold for various purposes. Likewise location of certain industries is dependent on temperature and relative humidity thresholds. This study might also be useful as a preliminary study of the thermal belt and determining the height of the top of the ground inversion in Johannesburg. This factor plays an important role in siting industries and determining its stacks' height, in order to minimise air pollution. It is clear that in an urban environment situated in a region that experiences relatively unchanging weather patterns the modifications of climate induced by that urban environment are of paramount importance.

APPENDIX

PROGRAMMING

Data processing was done on electronic computers at the University. While processing the data the computers were changed. Electronic Computer I.B.M. 1620 model 2 was exchanged for I.B.M. 360/50. Most of the work was done on the 1620 model 2 and only the multiple correlation coefficients were computed on the 360. The FORTRAN II language was used for programming. For a few programs the WITGO - 66 system was used. This system compiles rapidly and has comprehensive diagnostics in comparison with the FORTRAN II - D, but has relatively slow execution times. For the new computer FORTRAN IV was used.

A.1. CHECKING GROUP CARD 1 AND RECORDING OF THE DATA.

In the computer centre of the University there was no card verifier, therefore, card number 1 was checked by the computer. The purpose of this check was to ensure that no cards were missing, and if the number of the station, the route, the time symbol and the date were correct, i.e. all the data except for three temperatures.

PROGRAM NO. 1.

CHECKING DATA CARDS (No. 1)

```
   DIMENSION NUMB(2), TOT(2)
   NUMB(1) = 93
   NUMB(2) = 68
   TOT(1) = 4575
   TOT(2) = 2873
10 READ 11, INO,IROUT, ISTAT,IDATE, ITIME
   SUM = ISTAT
   NO =NUMB (IROUT)
   DO 12 I = 2, NO
   READ 13,JNO, JROUT,JSTAT,JDATE,JTIME
   SUM =SUM + JSTAT
   IF(JROUT-IROUT) 14, 15, 14
15 IF (JDATE-IDATE) 18, 16, 18
16 IF(JTIME-ITIME)19, 12, 19
14 PRINT 21,JROUT,JSTAT,JTIME
   GO TO 12
```

```
18 PRINT 22,JDATE,JSTAT,JTIME
   GO TO 12
19 PRINT 23,JTIME, JSTAT, JDATE
12 CONTINUE
   IF (SUM-TOT(IROUT)) 31,32,31
31 PRINT 33,JDATE,JTIME,JSTAT
32 GO TO 10
11 FORMAT (I1, I2, I3, I5, I2)
13 FORMAT (I1, I2, I3, I5, I2)
21 FORMAT(I2,I3,I5,I2)
22 FORMAT(I5,I3,I2)
33 FORMAT(I5,I3,I2,3X,I3)
23 FORMAT(I2,I3,I5)
   END
```

Before recording the data (group card No.1 only), the cards were sorted for each time and route according to the stations, rather than to the date. This sorting was done by the electronic sorter.

PROGRAM NO. 2.

LOADING DATA AND PRINTING AVERAGES FOR EVERY STATION.

```
   DEFINE DISK (10,3500)
   DIMENSION T(4,12),AVT(4),NO(2)
   PAUSE
   JSEC=1751
   NO(1) = 93
   NO(2) = 68
   DO 44 ITI =1,2
   DO 44IRO = 1,2
   N=NO(IRO)
   DO 44  IST =1,N
   AVT(2)=0.
   AVT(3)=0.
   AVT(4)=0.
   DO 41 I=1,12
   READ 40,JRO,JST,T(1,I),JTI,(T(J,I),J=2,4)
   DO 60 J=2,4
60 AVT(J)=AVT(J) +T(J,I)
41 CONTINUE
   AVT(2)=AVT(2)/12.
   AVT(3)=AVT(3)/12.
   AVT(4)=AVT(4)/12.
   PRINT 46,JRO,JTI,JST,AVT(2),AVT(3),AVT(4),JSEC
44 RECORD(JSEC) T
46 FORMAT (I4,I6,I6,3F10.2,15X,I6)
40 FORMAT (1X,I2,I3,F5.0,I2,3F4.1)
   END
```

So as to shorten the punching of cards No. 1 for Winter, a special programme was compiled to punch all the data except dates and temperatures.

PROGRAM NO. 3.

PUNCHING CARD NO.1 FOR WINTER.

```
   DIMENSION NO(2)
   NO(1)=1116
   NO(2)=816
   DO 44 JTI=1,2
   DO 44JRO =1,2
   N=NO(JRO)
   DO 44 JST=1,N
   READ 20,IC,IRO,IST,ITI
44  PUNCH 21,IC,IRO,IST,ITI
20  FORMAT (I1,I2,I3,5X,I2)
21  FORMAT (I1,I2,I3,5X,I2)
   END
```

A.2. COMPUTING THE TEMPERATURE PARAMETERS AND THEIR PRELIMINARY STATISTICAL ANALYSIS.

The temperature average for each station (AVT(3)) or the average differences between each two stations, the variances, standard deviations, and the coefficients of variations were computed. At the end of each route the means of the averages were calculated for the whole route.

PROGRAM NO. 4.

COMPUTING TEMPERATURE AVERAGES FOR SUMMER

```
  DIMENSION T(4,12),NO(2),S(12),AVT(93),VARI(93),TETA(93),COV
 1(93)
  DEFINE DISK (10,3500)
  PAUSE
  JSEC = 1
  NO(1) = 93
  NO(2) =68
  DO 44 JTI=1,2
```

```
    DO 44 JRO =1,2
    N=NO(JRO)
    PRINT 3
    Q=0.
    Z=0.
    AAV=0.
    AVAR=0.
    ATET=0.
    ACO=0.
    DO 43 JST=1,N
    TN=N
    SQ=0.
    AVT(N)=0.
    COUNT= 0.
    FETCH (JSEC) T
    DO 41 I=1,12
    AVT(N)=AVT(N)+T(3,I)
    SQ=SQ+(T(3,I)*T(3,I))
    COUNT=COUNT+1
 41 CONTINUE
    AVT(N)=AVT(N)/COUNT
    SQ=SQ/COUNT
    READ 61,IRO,IST
    VARI(N)=SQ-(AVT(N)*AVT(N))
    TETA(N)=SQRTF(VARI(N))
    Q=Q+(TETA(N)*TETA(N))
    AVT(N)=AVT(N)+273.16
    COV(N)=100.*TETA(N)/AVT(N)
    AVT(N)=AVT(N)-273.16
    AAV=AAV+AVT(N)
    AVAR=AVAR+VARI(N)
    ATET=ATET+TETA(N)
    ACO=ACO+COV(N)
 43 PRINT 98,IRO,IST,AVT(N),VARI(N),TETA(N),COV(N),COUNT
    AAV=AAV/TN
    AVAR=AVAR/TN
    ATET=ATET/TN
    ACO=ACO/TN
    Q=Q/TN
    Y=Q-(ATET*ATET)
    Y=SQRTF(Y)
    DO 20 J=1,N
 20 Z=Z+(AVT(N)-AAV)*(TETA(N)-ATET)
    R=Z/(TN*Y*ATET)
    W=R*SQRTF(TN-2.)/SQRTF(1.-(R*R))
    PRINT 10,IRO,JTI,AAV,AVAR,ATET,ACO,Y
 44 PRINT 11,R,W
  3 FORMAT(69H   ROUTE     STATION AVERAGE   VARIANCE  STAN.DEV.
   1  COEF.VAR.    N          /)
 10 FORMAT(25X,22H * * * * * * * * * * * /25X,23H AVERAGES FOR
   1 THE ROUTE      /25X,23H ---------------------- /5X,56H RO
   2UTE  TIME   AVERAGE   VARIANCE   STAN.DEV.  COEF.VAR./5X,2
   3I5,4F11.2//10X,27H STAN.DEV.OF THE STAN.DEV-  F6.2)
 11 FORMAT(10X,43H CORRELATION BETWEEN AVERAGE AND STAN.DEV.-
```

```
  1  F5.2/ 10X,8H T TEST- F7.2/25X,22H * * * * * * * * * * * |
  2//)
96 FORMAT (I5,I10,4F10.2,I10/)
61 FORMAT (1X,I2,I3)
   END
```

Programme No.5 is similar to No. 4, but instead of temperature data the difference in temperature between two following stations appeared.

PROGRAM NO. 5.

COMPUTING TEMPERATURE DIFFERENCE AVERAGES BETWEEN TWO FOLLOWING STATIONS

```
    DIMENSION T(4,12),NO(2),S(12),AVT(93),VARI(93),TETA(93),CO
   1V (93)
    DIMENSION AXX(93),PRE(93)
    DEFINE DISK (10,3500)
    PAUSE
    JSEC=1
    NO(1) = 93
    NO(2) = 68
    DO 44 JTI=1,2
    DO 44 JRO =1,2
    FETCH(JSEC) T
    N=NO(JRO)
    N=N-1
    PRINT 3
    READ 61,IRO,IST,PRE(N)
    Q=0.
    Z=0.
    AAV=0.
    AVAR=0.
    ATET=0.
    ACO=0.
    APR=0.
    DO 43 JST=1,N
    DO 30 I=1,12
 30 S(I)=T(3,I)
    PRR=PRE(N)
    TN=N
    SQ=0.
    AVT(N)=0.
    COUNT= 0.
    FETCH (JSEC) T
    DO 41 I=1,12
    AVT(N)=AVT(N)+(T(3,I)-S(I))
    SQ=SQ+((T(3,I)-S(I))*(T(3,I)-S(I)))
    COUNT=COUNT+1.
```

```
 41 CONTINUE
    AVT(N)=AVT(N)/COUNT
    IF(AVT(N))81,82,82
 81 AVT(N)=AVT(N)*(-1.)
 82 SQ=SQ/COUNT
    READ 61,IRO,IST,PRE(N)
    IST=IST-1
    K=IST+1
    VARI(N)=SQ-(AVT(N)*AVT(N))
    TETA(N)=SQRTF(VARI(N))
    Q=Q+(TETA(N)*TETA(N))
    AVT(N)=AVT(N)+273.16
    COV(N)=100.*TETA(N)/AVT(N)
    AVT(N)=AVT(N)-273.16
    AAV=AAV+AVT(N)
    AVAR=AVAR+VARI(N)
    ATET=ATET+TETA(N)
    ACO=ACO+COV(N)
    AXX(N)=PRR-PRE(N)
    IF(AXX(N))91,92,92
 91 AXX(N)=AXX(N)*(-1.)
 92 AXX(N)=AXX(N)*10.
    APR=APR+AXX(N)
 43 PRINT 98,IRO,K,IST,AVT(N),VARI(N),TETA(N),COV(N),COUNT
    APR=APR/TN
    AAV=AAV/TN
    AVAR=AVAR/TN
    ATET=ATET/TN
    ACO=ACO/TN
    Q=Q/TN
    Y=Q-(ATET*ATET)
    Y=SQRTF(Y)
    DO 20 J=1,N
 20 Z=Z+(AVT(N)-AAV)*(TETA(N)-ATET)
    R=Z/(TN*Y*ATET)
    W=R*SQRTF(TN-2.)/SQRTF(1.-(R*R))
    PRINT 10,IRO,JTI,AAV,AVAR,ATET,ACO,Y
 44 PRINT 11,R,W,ARP
  3 FORMAT(6    ROUTE  STATION    AVERAGE   VARIANCE  STAN.DEV.
   1  COEF.V.       N              /)
 10 FORMAT(25         * * * * * * * * * * * /25X,23H AVERAGES FOR
   1 THE ROUT          25X,23H ----------------------- /5X,56H RO
   2UTE  TI       AVERAGE   VARIANCE   STAN.DEV.  COEF.VAR./5X,2
   3I5,4F11.2,/10X,27H STAN.DEV.OF THE STAN.DEV-   F6.2)
 11 FORMAT(10X,43H CORRELATION BETWEEN AVERAGE AND STAN.DEV.-
   1  F5.2/10X,8H T TEST- F7.2/10X,30H AVERAGE DIFFERENCE IN H
   2EIGHT-F6.0,2HM.                    /25X,22H * * * * * * * *
   3 * * * //)
 98 FORMAT (I5,I7,1H-I2,4F10.2,I10)
 61 FORMAT(1X,I2,I3,18X,F6.2)
    END
```

```
41 CONTINUE
   AVT(N)=AVT(N)/COUNT
   IF(AVT(N))81,82,82
81 AVT(N)=AVT(N)*(-1.)
82 SQ=SQ/COUNT
   READ 61,IRO,IST,PRE(N)
   IST=IST-1
   K=IST+1
   VARI(N)=SQ-(AVT(N)*AVT(N))
   TETA(N)=SQRTF(VARI(N))
   Q=Q+(TETA(N)*TETA(N))
   AVT(N)=AVT(N)+273.16
   COV(N)=100.*TETA(N)/AVT(N)
   AVT(N)=AVT(N)-273.16
   AAV=AAV+AVT(N)
   AVAR=AVAR+VARI(N)
   ATET=ATET+TETA(N)
   ACO=ACO+COV(N)
   AXX(N)=PRR-PRE(N)
   IF(AXX(N))91,92,92
91 AXX(N)=AXX(N)*(-1.)
92 AXX(N)=AXX(N)*10.
   APR=APR+AXX(N)
43 PRINT 98,IRO,K,IST,AVT(N),VARI(N),TETA(N),COV(N),COUNT
   APR=APR/TN
   AAV=AAV/TN
   AVAR=AVAR/TN
   ATET=ATET/TN
   ACO=ACO/TN
   Q=Q/TN
   Y=Q-(ATET*ATET)
   Y=SQRTF(Y)
   DO 20 J=1,N
20 Z=Z+(AVT(N)-AAV)*(TETA(N)-ATET)
   R=Z/(TN*Y*ATET)
   W=R*SQRTF(TN-2.)/SQRTF(1.-(R*R))
   PRINT 10,IRO,JTI,AAV,AVAR,ATET,ACO,Y
44 PRINT 11,R,W,ARP
 3 FORMAT(69H  ROUTE  STATION    AVERAGE   VARIANCE  STAN.DEV.
  1  COEF.VAR.    N          /)
10 FORMAT(25X,22H * * * * * * * * * * * /25X,23H AVERAGES FOR
  1 THE ROUTE      /25X,23H ----------------------- /5X,56H RO
  2UTE  TIME   AVERAGE   VARIANCE   STAN.DEV.  COEF.VAR./5X,2
  3I5,4F11.2//10X,27H STAN.DEV.OF THE STAN.DEV-   F6.2)
11 FORMAT(10X,43H CORRELATION BETWEEN AVERAGE AND STAN.DEV.-
  1  F5.2/10X,8H T TEST- F7.2/10X,30H AVERAGE DIFFERENCE IN H
  2EIGHT-F6.0,2HM.                  /25X,22H * * * * * * * *
  3 * * * //)
98 FORMAT (I5,I7,1H-I2,4F10.2,I10)
61 FORMAT(1X,I2,I3,18X,F6.2)
   END
```

Program No's. 4 and 5 were used for Winter but a selection for days was done, i.e. nights without inversion (or inversion night). This was done by a series of IF statements for the dates (T(1,I)).

A.3. COMPUTING SIMPLE CORRELATIONS.

Program No. 6 computed correlations between the weather variables with the aid of group card No. 3. The regressions, students t-test value, and the confidence limit for 95% were also computed. Almost the same program was used for correlation between two stations' parameters.

PROGRAM NO. 6.

CORRELATIONS BETWEEN THE WEATHER ELEMENTS

```
      DIMENSION A(7,24)
      DO 11 ITI=1,2
      DO 17 I=1,24
      READ 20,JTI,A(1,I),A(2,I),A(3,I),A(7,I),A(6,I),A(5,I)
   17 A(4,I)=A(7,I)-A(6,I)
      DO 11 II=1,4
      ID=II+1
C CORRELATION
      AW=0.
      DO 12 I=1,24
   12 AW=AW+A(II,I)
      AW=AW/24.
      WS=0.
      DO 15 I=1,24
   15 WS=WS+(A(II,I)*A(II,I))
      WS=WS/24.
      DO 11 IJ=ID,5
      AT=0.
      DO 13 I=1,24
   13 AT=AT+A(IJ,I)
      AT=AT/24.
      TS=0.
      DO 16 I=1,24
   16 TS=TS+(A(IJ,I)*(A(IJ,I))
      TS=TS/24.
      X=0.
      DO 14 I=1,24
   14 X=X+((A(II,I)-AW)*(A(IJ,I)-AT))
      X=X/24.
      R=X/(SQRTF(WS-(AW*AW))*(SQRTF(TS-(AT*AT))))
```

```
   T=R*SQRTF(22.)/SQRTF(1.-(R*R))
   SA=(SQRTF(WS-(AW*AW)))*SQRTF(1.-(R*R))*2.
   SB=(SQRTF(TS-(AT*AT)))*SQRTF(1.-(R*R))*2.
   B=R*WS/TS
   C=(-R*(WS/TS)*AT)+AW
   AX=R*TS/WS
   CX=(-R*(TS/WS)*AW)+AT
11 PRINT 19,JTI,II,IJ,R,AT,AW,TS,WS,X,SA,SB,T,B,C,AX,CX
20 FORMAT (8X,I2,F2.0,F3.0,8X,F4.1,4X,2F4.1,F5.2)
19 FORMAT(12H CORRELATION 3I9,/9F 9.2,/3H A=F8.2,3H*B+F8.2,/3H
  1 B=F8.2,3H*A+F6.2/)
   END
```

A similar program was compiled for the correlation of temperature data for Station 87 with those of the other stations. This was done by comparing the temperatures for the stations from the disk with the minimum (and maximum) temperature of Station 87 in card No. 3. In a similar program, only inversion nights in Summer were taken into account by using the difference (DELTA) between the fixed stations in Observatory and Parkhurst. The correlation of the set of data from Station 87 with itself checked the accuracy of the programming and computing.

PROGRAM NO. 7.

CORRELATION BETWEEN STATION 87 TEMPERATURE AND ALL STATIONS. INVERSION ONLY

```
   DEFINE DISK (10,3500)
   DIMENSION A( 12),T(4,12),NO(2),DATE(12),DELTA(12)
   PAUSE
   PRINT 10
10 FORMAT(52H CORRELATIONS FOR EVERY STATION WITH ST.87INVERSI
  1ON //)
   JSEC=1
   NO(1)=93
   NO(2)=68
   DO 11 IRO=1,2
   N=NO(IRO)
   DO 17 I=1,12
17 READ 20,DATE(I),JRO,DELTA(I),A(I)
C CORRELATION
   AW=0.
   COUNT=0.
   DO 22I=1,12
   IF(DELTA(I))32,32,22
32 AW=AW+A(I)
```

```
      COUNT=COUNT+1.
   22 CONTINUE
      AW=AW/COUNT
      WS=0.
      DO 25 I=1,12
      IF(DELTA(I))35,35,25
   35 WS=WS+(A(I)*A(I))
   25 CONTINUE
      WS=WS/COUNT
      DO 11 IJ=1,N
      FETCH (JSEC) T
      READ 21,JST
      AT=0.
      DO 23 I=1,12
      IF(T(1,I)-(DATE(I)+DELTA(I)))23,33,33
   33 AT=AT+T(3,I)
   23 CONTINUE
      AT=AT/COUNT
      TS=0.
      DO 26 I=1,12
      IF(T(1,I)-(DATE(I)+DELTA(I)))26,36,36
   36 TS=TS+(T(3,I)*T(3,I))
   26 CONTINUE
      TS=TS/COUNT
      X=0.
      DO 24 I=1,12
      IF(T(1,I)-(DATE(I)+DELTA(I)))24,34,34
   34 X=X+((A(I)-AW)*(T(3,I)-AT))
   24 CONTINUE
      X=X/COUNT
      R=X/(SQRTF(WS-(AW*AW))*(SQRTF(TS-(AT*AT))))
      TT=R*SQRTF(COUNT-2.)/SQRTF(1.-(R*R))
      SA=(SQRTF(WS-AW*AW)))*SQRTF(1.-(R*R))*2.
      SB=(SQRTF(TS-AT*AT)))*SQRTF(1.-(R*R))*2.
      B=R*WS/TS
      C=(-R*(WS/TS)*AT)+AW
      AX=R*TS/WS
      CX=(-R*(TS/WS)*AW)+AT
   11 PRINT 19,JST,JRO,R,AT,AW,TS,WS,X,SA,SB,TT,B,C,AX,CX,COUNT
   20 FORMAT(1X,F5.0,I2,15X,F4.1,8X,F4.1)
   19 FORMAT(24H CORRELATION STA 87-STA I2,I9,/9F 8.2,/3H A=F8.2,
     13H*B+F8.2,/wH B=F8.2,3H*A+F6.2,15/)
   21 FORMAT(3X,I3)
      END
```

For Winter all the nights without inversion were removed by the aid of the dates.

A. 4. COMPUTING HUMIDITY PARAMETERS.

Program No. 8 computed and punched output of average temperatures, potential temperatures, humidity mixing ratio, relative humidity, equivalent temperatures, and potential equivalent terms. In addition, this program changed the codes for slope aspect, steepness and density into graded form for Winter and Summer separately.

PROGRAM NO. 8.

COMPUTING PARAMETERS AND PREPARING PUNCHED CARDS FOR MULTIPLE REGRESSION ANALYSIS. WINTER INVERSION ONLY.

```
      DEFINE DISK (10,3500)
      DIMENSION T(4,12),AVT(4),NO(2)
      PAUSE
      JSEC=1751
      MI=1
      MJ=2
      MK=3
      ML=4
      MN=5
      MM=6
      NO(1) =93
      NO(2) = 68
      TENLO=LOG(10.)
      CONV=1./TENLO
      DO 44 ITI =1,2
      DO 44IRO = 1,2
      N=NO(IRO)
      PRINT 10
      DO 44  IST = 1,N
      AVT(3)=O.
      AVT(2)=O.
      AVT(4)=O.
      COUNT= O.
      FETCH (JSEC) T
      DO 41 I=1,12
      IF(ITI-1)101,102,101
  102 IF(T(1,I)-0106.)23,41,23
   23 IF(T(1,I)-0206.)24,41,24
   24 IF(T(1,I)-0606.)25,41,25
   25 IF(T(1,I)-0706.)26,41,26
   26 IF(T(1,I)-1106.)27,41,27
   27 IF(T(1,I)-1206.)28,41,28
```

```
 28 IF(T(1,I)-2606.)29,41,29
 29 IF(T(1,I)-2506.)21,41,21
 21 IF(T(1,I)-0406.)19,41,19
 19 IF(T(1,I)-2306.)18,41,18
 18 IF(T(1,I)-2806.)101,41,101
101 COUNT =COUNT+1.
    AVT(2)=AVT(2)+T(2,I)
    AVT(3)=AVT(3)+T(3,I)
    AVT(4)=AVT(4)+T(4,I)
 41 CONTINUE
    AVT(4)=AVT(4)/COUNT+273.16
    AVT(3)=AVT(3)/COUNT
    AVT(2)=AVT(2)/COUNT+273.16
    READ 61,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE
    PRE=PRE+1.7
    IF(QC)30,30,31
 30 QC=QC+3.
    GO TO 39
 31 IF(QC-3.)39,32,33
 33 IF(QC-5.)32,32,34
 32 QC=QC+1.
    GO TO 39
 34 IF(QC-7.)35,36,37
 35 QC=QC-1.
    GO TO 39
 36 QC=QC-3.
    GO TO 39
 37 QC=QC-6.
 39 IF(QD-2.)11,12,13
 11 QD=QD+2.
    GO TO 13
 12 QD=QD+1.
 13 IF(QR-6.)14,15,15
 15 QR=QR-6.
 14 IF(QC-5.)110,111,111
111 IF(QD-3.)140,140,181
181 IF(QD-5.)120,121,122
120 QD=QD-2.
    GO TO 140
121 QD=QD-3.
    GO TO 140
122 IF(QD-6.)140,130,131
130 QD=QD-5.
    GO TO 140
131 QD=QD-7.
    GO TO 140
110 IF(QD-6.)140,141,142
142 QD=QD-4.
    GO TO 140
141 QD=QD-2.
140 ZZ=5.02808*LOG(373.16/AVT(4))*CONV
```

```
      ZH=5.02808*LOG(373.16/AVT(2))*CONV
      BB=-1.3816E-7*(EXP(11.334*TENLO*(1.-(AVT(4)/373.16)))-1.)
      BH=-1.3816E-7*(EXP(11.334*TENLO*(1.-(AVT(2)/373.16)))-1.)
      CC=8.1328E-3*(EXP(-3.49149*TENLO*(373.16/AVT(4)-1.))-1.)
      CH=8.1328E-3*(EXP(-3.49149*TENLO*(373.16/AVT(2)-1.))-1.)
      DD=LOG(1013.246)*CONV
      AA=-7.90298*(373.16/AVT(4)-1.)+ZZ+BB+CC+DD
      AH=-7.90298*(373.16/AVT(2)-1.)+ZH+BH+CH+DD
C WH=SATURATION VAPOR PRESSURE OF T(AVT(2)) IN ABSOLUTE TEMP.
      WH=EXP(AH*TENLO)
C WE=SATURATION VAPOR PRESSURE OF TW(AVT(4))IN ABSOLUTE TEMP.
      WE=EXP(AA*TENLO)
      AVT(2)=AVT(2)-273.16
      AVT(4)=AVT(4)-273.16
      IF(AVT(4)-25.)71,71,70
C WF=CORRECTION FACTOR FOR THE DEPARTURE OF THE MIXTURE OF THE AIR
C     AND WATER VAPOR FROM IDEAL GAS LAWS (FOR TW)
   70 WF=1.0041
      GO TO 91
   71 IF(AVT(4)-15.)72,72,73
   73 WF=1.0038
      GO TO 91
   72 WF=1.0037
      GO TO 91
   91 IF(AVT(4)-25.)81,81,80
C CPV=CP,-SPECIFIC HEAT OF AQUEOUS VAPOR AT CONSTANT PRESSURE

C     0.4409+DCPV
   80 CPV=0.4456
      GO TO 90
   81 IF(AVT(4)-15.)82.82,83
   83 CPV=0.4450
      GO TO 90
   82 IF(AVT(4)-5.)84,84,85
   85 CPV=0.4445
      GO TO 90
   84 CPV=0.4440
   90 IF(AVT(2)-25.)74,74,75
C WP=CORRECTION FACTOR FOR THE DEPARTURE OF THE MIXTURE OF THE AIR
      AND WATER VAPOR FROM IDEAL GAS LAWS (FOR TW)
   75 WP=1.0041
      GO TO 92
   74 IF(AVT(2)-15.)76,76,77
   77 WP=1.0038
      GO TO 92
   76 WP=1.0037
      GO TO 92
   92 Y=AVT(2)-AVT(4)
C YL=LATENT HEAT OF VAPORIZATION AT TW.(AVT(4))
      YL=594.9-(0.51*AVT(4))
C RW=SATURATION MIXING RATIO OVER WATER FOR TW(AVT(4)).(GR. PER GR)
      RW=0.62197*WF*WE/(PRE-(WF*WE))
C PW=SATURATION MIXING RATIO OVER WATER FOR T (AVT(2)).(GR. PER GR)
      PW=0.62197*WP*WH/(PRE-(WP*WH))
```

```
C RR=MIXING RATIO (GRAM PER KILOGRAM).
      RR=1000.*((0.2396*Y/YL)-RW)/(-(CPV*Y/YL)-1.)
C RH=RELATIVE HUMIDITY.
      RH=RR/(PW*10.)
C TE=EQUIVALENT TEMPERATURE.
      TE=AVT(4)+((YL*RW)/0.2396)
C TPE=POTENTIAL EQUIVALENT TEMPERATURE.
      TPE=(TE+273.16)*((1000./PRE)**(2./7.))-273.16
      TP=(AVT(3)+273.16)*(1000./PRE)**(2./7.)-273.16
      PUNCH 1,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE,AVT(3),MI
      PUNCH 1,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE,TP,MJ
      PUNCH 1,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE,TPE,MK
      PUNCH 1,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE,TE,ML
      PUNCH 1,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE,RR,MN
      PUNCH 1,JRO,JST,QA,QB,QC,QD,QQ,QR,QS,QT,QU,PRE,RH,MM
   44 PRINT 98,JRO,JST,RR,AVT(3),RH,TP,TE,TPE,COUNT
   98 FORMAT(2I5,6F11.3,I5)
   61 FORMAT(1X,I2,I3,9F2.0,F6.2)
   10 FORMAT(/82H   ROUTE STA.   MIXING      TEMP.   RELATIVE  P
     1OTENTIAL EQUIVALENT  POTENTIAL   N    /15X,62H RATIO
     2        HUMIDITY    TEMP.        TEMP.   EQUI.TEMP.      /)
    1 FORMAT(I2,I3,9F4.0,2F8.3,I10)
      END
```

A.5. COMPUTING THE MULTIPLE LINEAR REGRESSION AND THE MULTIPLE CORRELATION COEFFICIENT.

A.5.1. THE STEPWISE METHOD.

For this method the N.I.P.R. kindly granted the use of a programme compiled and recorded on disc by N.I.P.R. programmers.

Besides the data cards, a control card which included direction for output and determination of F-level had to be added. This program used the following subroutines and functions.

Subroutines:

START - Initialising routine which reads title and parameter cards.

IN - Opens a formatted data file for input.

RD - Reads and supplies a case-name and data from a record in a formatted data file.

MRSIG - Computes and prints confidence limits for multiple R.

OUT - Opens a formatted data file for output.

WD - Writes a case-name and its data into a record in a formatted file.

WEF - Closes an output file.

FINISH- Normal terminating routine.

UNCLE - Abnormal-ending routine.

Functions:

INFRVN- Supplies a specified row name of a data set.

INFNV - Supplies the number of variables for a data set.

INFNC - Supplies the number of cases processed from a data set.

INFNE - Supplies the number of incorrect cases read from a data set.

PROGRAM NO. 9.

LINEAR STEPWISE REGRESSION

```
 DOUBLE PRECISION CASE
 DOUBLE PRECISION INFRVN
 DOUBLE PRECISION NAMES(2)
 DATA NAMES(1)/Z40D7D9C5C4C9C3E3/
 DIMENSION DATA(58),AVE(57)
 DIMENSION SIGMA(57),COEN(57)
 DIMENSION INDEX(57),FHI(4)
 INTEGER PARM(8)
 INTEGER D
 DIMENSION IP(8),FHO(4)
 DIMENSION IPO(8),M(8)
 DIMENSION SC(2),VECTOR(58,58)
 EQUIVALENCE (DATA(1),SIGMA(1)),(M(1),NOIN),(K,M(2)),(NOENT,M
1(3)),(M(4),NOMIN),(NOMAX,M(5)),(M(6),NOK),(M(7),NERR),(NWRIT
2,M(8))
 NWTR = 6
 IN1 = 11
 NEW1 = 21
 L = NWTR
 D = IN1
 WRITE(L,6)
```

```
    6 FORMAT('1STEPWISE REGRESSION ERMPR 2 - NR20')
      CALL START(8,PARM)
      CALL IN(D)
      NAMES(2) = INFRVN(D,INFNV(D))
      DO 10 I=1,8
   10 M(I)=0
      VAR=0
      FLEVEL=0.
      IF(PARM(4)) 20,30,20
   20 NOVAR=INFNV(D)-1
      GO TO 40
   30 NOVAR=INFNV(D)
      WHT=1.
   40 TOL=.000001
      NVP1=NOVAR+1
      DO 50 I=1,NVPL
      DO 50 J=1,NVP1
   50 VECTOR(I,J)=0.
      IF(PARM(1)) 51,53,52
   53 EFIN = 1.5
      EFOUT = 1.4
      NRV = 100
      GO TO 60
   52 EFIN= FLOAT(PARM(1))/100.
      EFOUT = FLOAT(PARM(2))/100.
      NRV = 100
      GO TO 60
   51 EFIN=0.02E-60
      EFOUT=0.01E-60
      NRV = -PARM(1)
C     INPUT OF DATA AND COMPUTATION OF CROSS PRODUCTS
   60 CALL RD(D,CASE,DATA)
      IF(CASE) 70,110,70
   70 IF(PARM(4)) 80,90,80
   80 WHT=DATA(NVP1)
   90 DO 100 I=1,NOVAR
      VECTOR(I,NVP1)=VECTOR(I,NVP1)+DATA(I)*WHT
      DO 100 J=I,NOVAR
  100 VECTOR(I,J)=VECTOR(I,J)+DATA(I)*DATA(J)*WHT
      VECTOR(NVP1,NVP1)=VECTOR(NVP1,NVP1)+WHT
      GO TO 60
C     CONVERT CROSS-PRODUCT MATRIX INTO COVARIANCE MATRIX
  110 NOVMI=NOVAR-1
      NOVPL=NVP1
      TOTAL=VECTOR(NOVPL,NOVPL)
      IF (TOTAL)830,830,120
  120 IF(PARM(8)) 145,130,145
  130 DO 140 I=1,NOVAR
      DO 140 J=I,NOVAR
  140 VECTOR(I,J)=VECTOR(I,J)-VECTOR(I,NOVPL)*VECTOR(J,NOVPL)/TOTAL
```

```
C     COMPUTE MEANS
  145 AVY=VECTOR(NOVAR,NOVPL)/TOTAL
  150 DO 160 I=1,NOVMI
  160 AVE(I)=VECTOR(I,NOVPL)/TOTAL
      IF(PARM(6)) 180,165,180
  165 WRITE (L,170)(AVE(I),I=1,NOVMI),AVY
  170 FORMAT (//15H VARIABLE MFANS/ 10(2XE10.3))
  180 NOSTEP=-1
      NUMBER = 1320
      DEFR=TOTAL-1.
      DO 220 I=1,NOVAR
      IF (VECTOR(I,I))850,190,210
  190 WRITE (L,200)I
  200 FORMAT (/9H VARIABLEI3,12H IS CONSTANT)
      SIGMA(I)=1.
      GO TO 220
  210 SIGMA(I)=SQRT(VECTOR(I,I))
  220 VECTOR(I,I)=1.
C     COMPUTE CORRELATION COEFFICIENTS
      DO 230 I=1,NOVMI
      IP1=I+1
      DO 230 J=IP1,NOVAR
      VECTOR(I,J)=VECTOR(I,J)/(SIGMA(I)*SIGMA(J))
  230 VECTOR(J,I)=VECTOR(I,J)
C     START OF TESTING CYCLES
  235 NOSTEP=NOSTEP+1
      SY=VECTOR(NOVAR,NOVAR)
      IF (SY)240,240,260
  240 NSTPM1=NOSTEP-1
      WRITE (L,250)NSTPM1
  250 FORMAT (/'NON-POS SIGMA Y',I5)
      GO TO 1381
  260 SIGY=SIGMA(NOVAR)*SQRT(SY/DEFR)
      IF (1.-SY)280,280,270
C     MULTIPLE R
  270 R=SQRT(1 - SY)
      GO TO 290
  280 R=0.
  290 DEFR=DEFR-1.
      IF (DEFR)300,300,320
  300 WRITE (L,310)NOSTEP
  310 FORMAT (/15H DEFR=0 AT STEPI3)
      GO TO 1381
  320 VMIN=0.
      VMAX=0.
      NOIN=0.
      DO 420 I=1,NOVMI
      IF (VECTOR(I,I))330,420,350
  330 WRITE (L,340)I,NOSTEP
```

```
  340 FORMAT (/22HNEG.SIGMA FOR VARIABLEI3,8H AT STEPI3)
      GO TO 1381
  350 IF (VECTOR(I,I)-TOL)420,360,360
  360 VAR=VECTOR(I,NOVAR)*VECTOR(NOVAR,I)/VECTOR(I,I)
      IF (VAR)370,420,400
  370 NOIN=NOIN+1
      INDEX(NOIN)=I
      COEN(NOIN)=VECTOR(I,NOVAR)*SIGMA(NOVAR)/SIGMA(I)
      VECTOR(NOVPL,NOIN)=(SIGY/SIGMA(I))*SQRT(VECTOR(I,I))
      IF (VMIN)390,380,860
  380 VMIN=VAR
      NOMIN=I
      GO TO 420
  390 IF (VAR-VMIN)420,420,380
  400 IF (VAR-VMAX)420,420,410
  410 VMAX=VAR
      NOMAX=I
  420 CONTINUE
      IF (NOIN)870,430,450
  430 WRITE (L,440)SIGY
  440 FORMAT (10H S.E.OF Y=F12.6)
      GO TO 1350
  450 IF(PARM(8)) 460,470,460
  460 CNST=O.
      GO TO 490
  470 CNST=AVY
      DO 480 I=1,NOIN
      J=INDEX(I)
  480 CNST=CNST-(COEN(I)*AVE(J))
  490 IF(PARM(5)) 1320,500,1320
  500 WRITE(L,501)
  501 FORMAT(1H ,130('-'))
      IF (NOENT)510,510,530
  510 WRITE (L,520)NOSTEP,K
  520 FORMAT (//9H STEP NO.I3/9H VARIABLEI3,8H REMOVED)
      GO TO 550
  530 WRITE (L,540)NOSTEP,K
  540 FORMAT (//9H STEP NO.I3/9H VARIABLEI3,9H INCLUDED)
C     PRINT MULTIPLE R WITH ITS CONFIDENCE LIMITS
  550 NOK1=INFNC(D)
      CALL MRSIG(R,NOK1,NOIN)
      FNOK=NOK1
      FNOIN=NOIN
      RU=  (FNOK*R*R-FNOIN)/(FNOK-FNOIN)
      IF(RU) 552,552,553
  552 RU = O.
      RF = O.
      GO TO 554
  553 RF=RU/SQRT(R)
      RU = SQRT(RU)
  554 CONTINUE
```

```
C      OPTIMUM NUMBER OF PREDICTORS WHEN BATTERY SIZE INDICATOR IS
C      A MINIMUM
       WRITE (L,555)RU,RF
  555 FORMAT (//36H UNBIASSED ESTIMATE OF POPULATION R=F4.2/31H
     1ESTIMATED R IN FUTURE SAMPLES=F4.2//)
       WRITE (L,560)FLEVEL,SIGY,CNST,(INDEX(J),COEN(J),VECTOR(NOVP
     1L,J),J=1,NOIN)
  560 FORMAT (8H F LEVELF12.4/10H S.E.OF Y=F12.4/7H CONST=F13.5//
     19H VARIABLE3X6HWEIGHT5X13HS.E.OF WEIGHT/(I6,2E15.5))
       IF (NUMBER -1320)1589,1320,1589
 1589 IF (NUMBER -1580)899,1580,899
 1320 FLEVEL=VMIN*DEFR/SY
       IF (EFOUT+FLEVEL)1350,1350,580
  580 K=NOMIN
       NOENT=0
       GO TO 615
 1350 FLEVEL=VMAX*DEFR/(SY-VMAX)
       IF (EFIN-FLEVEL)610,600,1380
  600 IF (EFIN)1380,1380,610
C      JUMP OUT FROM TESTING CYCLE
C      REMOVING THE KTH VARIABLE FROM THE MATRIX
  610 K=NOMAX
       NOENT=K
  615 IF (K)890,890,620
  620 DO 660 I=1,NOVAR
       IF (I-K)630,660,630
  630 DO 650 J=1,NOVAR
       IF (J-K)640,650,640
  640 VECTOR(I,J)=VECTOR(I,J)-VECTOR(I,K)*VECTOR(K,J)/VECTOR(K,K)
  650 CONTINUE
  660 CONTINUE
       DO 680 I=1, NOVAR
       IF (I-L)670,680,670
  670 VECTOR(I,K)=-VECTOR(I,K)/VECTOR(K,K)
  680 CONTINUE
       DO 700 J=1, NOVAR
       IF (J-K)690,700,690
  690 VECTOR(K,J)=VECTOR(K,J)/VECTOR(K,K)
  700 CONTINUE
       VECTOR(K,K)=1./VECTOR(K,K)
       IF(NOSTEP - NRV) 235,1380,1380
 1380 WRITE (L,720)NOSTEP
  720 FORMAT (//I3,16H STEPS COMPLETED)
       IF(PARM(1))) 1388,1381,1381
 1388 IF(NOSTEP - NRV) 550,1381,1381
 1381 IF(PARM(5)) 740,1580,740
  740 NUMBER = 1580
       GO TO 550
C      END OF TESTING CYCLE
 1580 CONTINUE
       JUMPA=1
       IF(PARM(7)) 790,770,790
C      COMPUTE PREDICTED VALUES
```

```
 770 JUMPA=2
 790 JUMPB=1
     IF(PARM(3)) 1000,1020,1000
1000 JUMPB=2
     IPO(1)=2
     IPO(2) = INFNC/D) - INFNE(D)
     DO 1010 I=3,8
1010 IPO(I)=0
     CALL OUT(NEW1,IPO,NAMES)
1020 JUMPC=MAXO(JUMPA,JUMPB)
     GO TO (1130,1030),JUMPC
1030 WRITE(L,1031)
1031 FORMAT(1H ,130('*'))
     CALL IN(D)
     GO TO (1037,1038),JUMPA
1038 WRITE(L,780)
 780 FORMAT (//9H CASE NO.3X9HPREDICTED5X6HACTUAL5X10HDIFFERENCE
    1)
1037 CONTINUE
     NOK=0
     NERR=0
     NWRIT=0
1040 CALL RD(D,CASE,DATA)
     IF (CASE) 1050,1110,1050
1050 YPRED=CNST
     DO 1060 I=1,NOIN
     K=INDEX(I)
1060 YPRED=YPRED+COEN(I)*DATA(K)
     DEV=DATA(NOVAR)-YPRED
     GO TO (1085,1070),JUMPA
1070 WRITE(L,1080) CASE,YPRED,DATA(NOVAR),DEV
1080 FORMAT(A9,3F12.5)
1085 GO TO (1100,1090),JUMPB
1090 SC(1)=YPRED
     SC(2)=DATA(NOVAR)
     CALL WD(NEW1,CASE,SC)
1100 GO TO 1040
1110 GO TO (1130,1120),JUMPB
1120 CALL WEF(NEW1)
1130 CALL FINISH
     STOP
 830 WRITE(L,839)
 839 FORMAT('NO DATA')
     CALL UNCLE(110.3)
 850 WRITE(L,859)
 859 FORMAT('NEG.SIGMA')
     CALL UNCLE(180.4)
 860 WRITE(L,869)
 869 FORMAT('POS.VMIN')
     CALL UNCLE(370.4)
 870 WRITE(L,879)
 879 FORMAT('NEG.NOIN')
     CALL UNCLE(420.1)
 890 WRITE(L,896)
```

```
896 FORMAT('ZERO K')
    CALL UNCLE(615,0)
899 WRITE(L,898)
898 FORMAT('''NUMBER'' TAKES UNKNOWN VALUE')
    CALL UNCLE(560,1)
    END
```

A.5.2. THE SIMULTANEOUS METHOD.

This program appeared in I.B.M. (1966) and referred to B. Ostle, ("Statistic in Research", The Iowa State College Press 1954, Chapter 8). In the same program it was possible to compute the correlation and regression in several selections. Section of different sets of independant variables and designation of a dependent variable could be made as many times as desired. It was also possible to compute several problems in one input of the program. This was done by loading a control card after the program (similar to the control card of the stepwise method, but without determining the F level) followed by data cards and then the selection cards. After the selection card it was possible to load another control card, selection card, data card, etc. This program used the following subroutines. (For their listing see I.B.M. 1966):

1. *CORRE* - to find means, standard deviations and correlation matrix.
2. ORDER - to choose a dependent variable and a subject of independent variables from a larger set of variables.
3. MINV - to invert the correlation matrix of the subject selected by ORDER.
4. MULTR - to compute the regression coefficients and various confidence measures.
5. DATA - to read one observation at a time into a work area. This subroutine was called by CORRE.

PROGRAM NO. 10

MULTIPLE LINEAR REGRESSION

```
      DIMENSION XBAR(40),STD(40),D(40),RY(40),ISAVE(40),B(40),
     1          SB(40),T(40),W(40)
      DIMENSION RX(1600),R(820),ANS(10)
      DOUBLE PRECISION XBAR,STD,RX,R,D,B,T,RY,DET,SB,ANS,SUM
    1 FORMAT(A4,A2,I5,2I2)
    2 FORMAT(25H1MULTIPLE REGRESSION.....A4,A2//6X,14HSELECTION..
     1...I2//)
    3 FORMAT(9H0VARIABLE,5X,4HMEAN,6X,8HSTANDARD.6X.11HCORRELATIO
     1N,4X,10HREGRESSION,4X10HSTD. ERROR,5X,8HCOMPUTED/6H   NO.,1
     28X,9HDEVIATION,7X,6HX VS Y,7X,11HCOEFFICIENT,3X,12HOF REG.C
     3OEF.,3X,7HT VALUE)
    4 FORMAT(1H ,I4,6F14.5)
    5 FORMAT(10H DEPENDENT)
    6 FORMAT(1H0/10H INTERCEPT,13X,F13.5//23H MULTIPLE CORRELATIO
     1N  ,F13.5//23H STD. ERROR OF ESTIMATE,F13.5//)
    7 FORMAT(1H0,21X,39HANALYSIS OF VARIABLE FOR THE REGRESSION//
     15X,19HSOURCE OF VARIATION,7X,7HDEGREES,7X,6HSUM OF,10X,4HME
     2AN,12X,7HF VALUE/30X,10HOF FREEDOM,4X,7HSQUARES,9X,7HSQUARE
     3S)
    8 FORMAT(30H ATTRIBUTABLE TO REGRESSION  ,I6,3F16.5/30H DEVIA
     2TION FROM REGRESSION    ,I6,2F16.5)
    9 FORMAT(1H ,5X,5HTOTAL,19X,I6,F16.5)
   10 FORMAT(36I2)
   11 FORMAT(1H ,15X,18HTABLE OF RESIDUALS//9H CASE NO.,5X,7HY VA
     1LUE,5X,10HY ESTIMATE,6X,8HRESIDUAL)
   12 FORMAT(1H ,I6,F15.5,2F14.5)
   13 FORMAT(53H1NUMBER OF SELECTIONS NOT SPECIFIED.  JOB TERMINA
     1TED.)
   14 FORMAT(52H0THE MATRIX IS SINGULAR.  THIS SELECTION IS SKIPP
     1ED.)
C     READ PROBLEM PARAMETER CARD
  100 READ (5,1) PR,PR1,N,M,NS
      REWIND 13
      IO=0
      X=0.0
      CALL CORRE (N,M,IO,X,XBAR,STD,RX,R,D,B,T)
      REWIND 13
      IF(NS)  108, 108,109
  108 WRITE (6,13)
      GO TO 300
  109 DO 200 I=1,NS
      WRITE (6,2) PR,PR1,I
C     READ SUBSET SELECTION CARD
      READ (5,10) NRESI,NDEP,K,(ISAVE(J),J=1,K)
      CALL ORDER (M,R,NDEP,K,ISAVE,RX,RY)
      CALL MINV (RX,K,DET,B,T)
      IF(DET) 112,110,112
```

```
110 WRITE (6,14)
    GO TO 200
112 CALL MULTR (N,K,XBAR,STD,D,RX,RY,ISAVE,B,SB,T,ANS)
    MM=K-1
    WRITE (6,3)
    DO 115 J=1,K
    L=ISAVE(J)
115 WRITE (6,4) L,XBAR(L),STD(L),RY(J),B(J),SB(J),T(J)
    WRITE (6,5)
    L=ISAVE(MM)
    WRITE (6,4) L,XBAR(L),STD(L)
    WRITE (6,6) ANS(2),ANS(3)
    WRITE (6,7)
    L=ANS(8)
    WRITE (6,8) K,ANS(4),ANS(6),L,ANS(10),ANS(7),ANS(9)
    L=N-1
    SUM=ANS(4)+ANS(7)
    WRITE (6,9) L,SUM
    IF(NRESI) 200, 200, 120
120 WRITE (6,2) PR,PR1,I
    WRITE (6,11)
    MM=ISAVE(K+1)
    DO 140 II=1,N
    READ (13) (W(J),J=1,M)
    SUM=ANS(1)
    DO 130 J=1,K
    L=ISAVE(J)
130 SUM=SUM+W(L)*B(J)
    RESI=W(MM)-SUM
140 WRITE (6,12)  II,W(MM),SUM,RESI
    REWIND 13
200 CONTINUE
    GO TO 100
300 CONTINUE
    END
```

REFERENCES

Blount, N.B., 1966 : The Development of Instrumentation for the Measurement of Temperature Gradient near the Ground. (B.A. Honours Thesis, Rand.)

Brooks, C.E.P., & Carruthers, N., 1953 : Handbook of Statistical Methods in Meteorology. H.M.S.O., 412p.

Brundt, D., 1939 : Physical & Dynamical Meteorology. Cambridge, 428p.

Chandler, T.J., 1961 : The Changing Form of London Heat-Island. Geography, 46, pp.295-307.

- " - 1962a: Temperature and Humidity Traverses Across London. Weather, 17, pp.235-242.

- " - 1962b: London Urban Climate. G.J.,78, pp.279-302.

- " - 1962c: Diurnal, Seasonal and Annual Changes in the Intensity of London's Heat Island. Met.Mag.,91, pp.146-53.

- " - 1964 : City Growth & Urban Climate. Weather, 19, pp.170-171.

- " - 1965 : The Climate of London. Hutchinson, London, 250p.

- " - 1967a: Absolute & Relative Humidity in Towns, Bull.Am.Met.Soc., pp.394-399.

- " - 1967b: Night-Time Temperatures in Relation to Leicester's Urban Form. Met.Mag.,96, pp.244-250.

Dockworth, F.S., & Sandberg, J.S., 1954 : The Effect of Cities upon Horizontal and Vertical Temperature Gradients. Bull.Amer.Met.Soc., 35, pp.49-56.

References (Continued).

Draper, N.R., & Smith, H., 1967 : Applied Regression Analysis. John Wiley, 407p.

Efroymson, M.A., 1967 : Multiple Regression Analysis. (In- Mathematical Methods for Digital Computers). Edited by Ralston A., & Wilf, H.S., Vol.1, pp.191-203 John Wiley, Tenth printing.

Einarson, E., & Lowe, A.B., 1955 : A Study of Horizontal Temperature Variations in the Winnipeg Area on Nights Favouring Radiational Cooling. Canada, Met.Div. CIR-2647, TEC-214, 19p.

Fraser, D.A., 1958 : Statistic an Introduction. John Wiley, N.Y., 398p.

Garnett, A., & Bach,W., 1967 : An Investigation of Urban Temperature Variations by Traverses in Sheffield (1962-1963). Biometeorology,Vol.2,part 2 , pp.601-607.

Geiger, R., 1965 : The Climate Near the Ground. Harvard Univ. Press, Massachusetts, 611p.

Goff, J.A., & Gratch, S., 1946 : Low Pressure of Water.. Trans.Amer.Soc. Heat and Vant.Eng., 52, 107p.

Goldreich, Y., 1965 : Topoclimatology Survey in Macabith. Manuscript in Hebrew (available at Climate Dept. Met. Service, Ministry of Transport, Israel), 7p.

Goldwater, F., 1960 : Some Consideration of Instrumentation and Recording Techniques in Micrometeorology. Dept.of Met. the Hebrew U. of Jerusalem, 15p.

Graybill. F.A., 1961 : An Introduction to Linear Statistical Models. Vol.1, Mc.Graw-Hill, pp122-124.

References (Continued).

Hutcheon, R.J., et al 1967 : Observations at the Urban Heat Island in a Small City. Bull.Amer.Met.Soc., 48, pp7-9.

I.B.M., 1966 : I.B.M. Application Program. H20-0205-0. System 130 Scientific Subroutine package (360-CM-03X), Programer's Manual, pp95-101.

Jackson, S.P., 1933 : Notes on the Occurrence of "Cold Snaps" at Johannesburg. S.A.G.J., 16, pp27-38.

- " - 1951 : A Preliminary Study of the Atmosphere Circulation over South Africa. Ph.D. Thesis, Univ. of London.

- " - 1952 : Atmospheric Circulation over South Africa. S.A.G.J., 34, pp48-59.

Kawamura, T., 1965 : Some Considerations on the Cause of City Temperature at Kumagaya City. Tokyo J. of Clim., pp38-40.

Kendall, M.G., & Stuart, A., 1958 : The Advanced Theory of Statistics. Vol.1, Charles Griffin, London, 433p.

Koch, H.G., 1961 : Die Warme Hangzone, Neue Anschauungen Zur Nachtlichen Kaltluftschichtung in Tälern und in Hängen. Zeit. f. Met., 15, pp151-171.

Kratzer, A.P., 1956 : Das Stadtklima. Braunschweig, 184p.

Landsberg, H.E., 1956 : The Climate of Towns. (In-Man's Role in Changing the Face of the Earth). The Univ. of Chicago Press, pp584-606.

- " - 1962 : Physical Climatology. Gray Printing Co., Dubois, Penn., 466p.

Lipworth, M.A., 1961 : An Application of Concepts of Urban Morphology in Studying the Northern Development of Johannesburg. (B.A. Hon. Thesis, Rand) 103p.

References (Continued).

List, R.J., 1951 : Smithsonian Meteorological Tables. 527p.

Louw, W.J., & Meyer, J.A., 1965 : Near Surface Nocturnal Winter Temperatures in Pretoria. Notos, 14, pp49-56.

Lowry, W.P., 1967 : The Climate of Cities. Scien.Amer., 217, No.2, August, pp15-23.

- " - 1968 : Weather and Life. O.S.U. Book Store Inc., Corvallis, Oregon, Lito-U.S.A., 220p.

Mano, H., 1956 : A Study on the Sudden Nocturnal Temperature Rises in the Valley and on the Basin. Geophys.Mag.(Tokyo), 27, No.1, pp.169-204.

Middleton, W.E.K., & Millar, F.G., 1936 : Temperature Profiles in Toronto. J. R. Astron.Soc., Canada, pp265-272.

Mitchell, J.M., Jr. 1953 : On the Cause of Instrumentally Observed Secular Temperature Trend. J. of Met., 10, pp244-264.

- " - 1961a : The Thermal Climate of Cities. In Symposium: Air Over Cities, U.S. Public Health Service, pp131-145.

- " - 1961b : The Temperature of Cities. Weatherwise, 14, pp224-229.

- " - 1961c : The Measurement of Secular Temperature Change in the Eastern U.S. U.S. Weather Bureau, Research Paper No. 43, Washington, D.C., 80p.

Panofsky, H.A., & Brier, G.W., 1958 : Some Application of Statistics to Meteorology. University Park, Pennsylvania, 224p.

References (Continued).

Parry, M., 1967 : The Urban "Heat-Island". Biometeorology, 2, Part 2,pp616-624.

Pein, J., 1964 : A Three-Element N.T.C. Thermometer for Heat-Sink Measurements. EDAC (Pty.) Laboratory Report, 11p.

'Philips' 1963 : N.T.C. Resistors. 43p.

Scarr, R.W.A., 1960 : Thermistor Applications. *Direct Current,* pp87-92.

Schnelle, F., 1963 : Frostschutz in Pflanzenbau. Band I BLV.Verlagsgesellschaft, München, pp215-222, 426-428.

Schulze, B.R., 1965 : Climate of South Africa. Part 8 (General Survey) Weather Bureau Dept. of Transport, Rep. of S.A., 322p.

Sekiguti, T., 1964 : *Local Climate & City Climate. Tokyo J. of Clim.*, 1, No.1 pp1-5.

Sharon, D., 1964 : *Micro-Climatological Studies in the* Soreq Valley near Jerusalem, (in Hebrew) Dept. of Geog. Heb. Univ. Jer., 117p.

- " - 1966 : Sample Size and Reliability of Short-Period Observations. Proc. 1st UNESCO Symp. on Method in Agriclimatology, Reading.

Shumann, T.E.W., 1942 : Temperature. Met.Office Dept. of *Irrigation Union of South Africa,* Various paging.

Sundborg, Å., 1951 : Climatological Studies in Uppsala. *Geographica*, 22, 111p.

Suomi, V.E., & Tanner, C.B., 1958 : Evapotranspiration Estimate from Heat-Budget Measurements over a Field Crop. *Trans.Amer.Geophysical Union,* 39,2,p298-304.

References (Continued).

Sutton, Sir Graham, 1963 : Scales of Temperatures. Weather, 18, pp130-134.

Vowinckel, E., 1956 : *Beitrag Zur Witterungsklimatologie* Südafrikas. Archiv Met. Geophysik Bioklim., Serie B, Band 7, pp11-31.

Weather Bureau 1966 1967 : Monthly Weather Reports. December 1966, June 1967. Ministry of Transport, Rep. of South Africa.

Wellington J.H., 1924 : The Topographic Features of the Witwatersrand with Special Reference to the Evolution of the Present *Witwatersrand Surface.* S.A.G.J., 7, pp17-28.

Wile, D.D., 1944 : Psychrometry in the Frost Zone. Refrig.Eng., October.

——— 1959 : Askania Linienschreiber, B512b.

——— 1956 : Handbook of Meteorological Instruments Part I, M.O. 577, London, Air Ministry, 458p.

——— 1966 : Meteorological Mobile Unit. (in Hebrew) Meteorologia Be-Israel, 3, No.4, p129.

MAPS 1952 : Maps. *Witwatersrand Regional* Topographical Survey.
Sheets: 2627 B8-E8, 2628 B1-E1.

1959 : Airphotograph 438.
13 2789-2793.
14 4432-4438.
15 2872-2878.


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