F.T.B.M. 13

METEOROLOGICAL OFFICE

FORECASTING TECHNIQUES BRANCH MEMORANDUM No. 13

TECHNIQUES IN USE AT METEOROLOGICAL OFFICE OUTSTATIONS FOR FORECASTING LOCAL COOLING AT NIGHT

by

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October, 1966

Techniques in use at Meteorological Office outstations for forecasting local cooling at night

TECHNIQUES IN USE AT METEOROLOGICAL OFFICE OUTSTATIONS FOR FORECASTING LOCAL COOLING AT NIGHT

1. Introduction

At many meteorological offices the forecasting of overnight temperatures at screen level is important either as an end in itself (e.g. in forecasts for public services and in frost forecasts) or as a step in the forecasting of some other element (e.g. fog or low stratus). The importance is indicated by the number of published articles on the subject. Most techniques described in such articles are for forecasting the night minimum temperature but some also give forecasts of the temperatures at other times of night. Most of the prediction diagrams or formulae given in these articles are applicable for one place (a point sometimes stressed) but it is stated or implied that the technique could be applied elsewhere if local data were processed in the same way.

During 1964 Meteorological Office outstations in the United Kingdom and in Germany were asked to supply details of work done in evolving or adapting such techniques for local application. As a result a considerable amount of information on local work was received. The present report is mainly a summary of this but also incorporates information more recently received in the Forecasting Techniques Branch.

2. Information sought

The information requested from outstations in 1964 was:

(1) Whether any work on night cooling was being done, or had been completed, specifically for the station?

(2) Whether such work was based on any published technique, such as those summarized in the Handbook of Weather Forecasting (Ref. 1) - section 14.7.2.1.? If so, which technique?

(3) If not, what parameters were used and what was the general approach to the problem? (The usefulness was stressed of information about parameters which had been found locally significant but were not incorporated in the more commonly used techniques.)

(4) What was the period of the data used?

3. Extent of work on local night cooling

It is known that techniques for forecasting the local cooling at night have been or are being derived or adapted for at least 39 outstations in the United Kingdom and Germany, i.e. nearly one half of the forecasting offices. For some places more than one technique has been adapted. No distinction has been made in this note between work completed and work being done. Such distinction was not always clear from the information received and it was often apparent that uncompleted work was nevertheless far enough advanced to form a useful forecasting aid (in some cases completion was merely awaiting examples of the most uncommon combinations of parameters).

It is difficult to assess the extent to which this work satisfies local forecasting requirements because these must vary greatly from office to office.

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Local work on night cooling would clearly be valuable for the detailed forecasting for an aerodrome. On the other hand at Weather Centres (for instance) a forecast of night cooling might be required for any place within a large area and a technique for forecasting for the station itself is not likely to go far towards meeting the requirement.

It should be appreciated that work on local cooling at night is not practicable at some stations because adequate observational data for the night periods are not available.

4. Local work based on published techniques

So that practical considerations in locally adapting some of the commonly used techniques can be appreciated, brief notes on each technique are given in the following before summarizing local work based on that technique. Most of the techniques use as parameters temperature and some function of moisture of the air at screen level during the preceding daytime period. To make plain similarities between different techniques the following notation will be used here, regardless of notation used in the original articles:

T_n : forecast minimum temperature (screen)

T_{hh}: screen temperature at hour hh GMT
T_x : maximum screen temperature
D_{hh}: screen dew point at hour hh GMT
D_x : screen dew point at the time of maximum temperature
} during the preceding daytime

C : value as given by the author of the technique.

For a parameter which is peculiar to a particular technique any notation will be given when the technique is described.

4.1. Saunders' technique

This is the technique most commonly adapted for local use. Saunders (Ref. 2) described means of forecasting temperatures at Northolt on nights with clear skies. First a temperature, T_r (i.e. the temperature at a specified time in the evening at which a discontinuity occurs in the rate of cooling), is forecast using an equation $T_r = \frac{1}{2}(T_x+D_x) + C$. Different values of C are given according to whether or not during the afternoon there was an inversion with base below 900 mb. From prediction diagrams T_n is obtained according to the calculated value of T_r, the mean speed of gradient wind expected during the night and the time of year. In some circumstances special provision is made if there was an inversion based below 900 mb during the preceding afternoon or if the top soil was moist.

It will be noticed that local adaptation of this technique involves not only data which can be extracted from Daily Registers (temperatures, dew points, etc.) but also data which has to be obtained from other sources (e.g. inversion details from tephigrams, gradient winds from synoptic charts). Therefore the extraction of back data could be a large task and not readily done at offices where the plotted charts and

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tephigrams are retained for only a limited period. Local adaptation can be carried out more easily by logging relevant data day by day as part of the office routine.

Notable among work based on Saunders' technique is a comprehensive investigation at Bomber Command where night cooling characteristics are being determined for 13 aerodromes. Diagrams to the form suggested by Barthram (Ref. 3) - to facilitate the quick drawing of a forecast curve of local cooling - have been prepared for each aerodrome for use during the winter half-year; work proceeds in preparing diagrams for use during the summer half-year. The scope of this investigation extends beyond that of Saunders' technique in that cooling under cloudy skies is considered as well as cooling under clear skies. Also being investigated are the differences between screen and grass minimum temperatures and the effect of fog formation on night cooling.

The technique due to Saunders has been, or is being, adapted for use at 10 stations other than those participating in the Bomber Command investigation.

4.2. McKenzie's technique

The technique due to McKenzie (Ref. 4) is for forecasting night minimum temperatures at Aberdeen (Dyce) Airport under various conditions of cloud cover and surface wind. As with Saunders' technique, maximum temperature and a dew point value are used as parameters; the dew point value (which will be referred to as D) chosen by McKenzie is "the dew point of the air mass, which is assumed to remain constant or almost so" and consequently the data he used to derive his table for Dyce were restricted to occasions when the dew point from 1300 GMT one day to 0700 GMT the following day remained "constant to within two or three degrees" (Fahrenheit), i.e. about $1\frac{1}{2}^{\circ}$C. The minimum temperature is forecast using the formula $T_n = \frac{1}{2}(T_X+D_X)+C$. Values of C vary according to the average low-cloud cover and average speed of surface wind between 1800 GMT and 0700 GMT.

Adaptation of this technique is relatively simple because parametric values can be readily extracted from back data, referring only to local records (Daily Registers). Local constants (values of C for different conditions of surface wind and cloud cover) for use in McKenzie's formula have, in fact, been calculated for 10 stations. At most of these stations, though, the dew point parameter used has been the value at time of maximum temperature without regard to subsequent changes during the night so long as such changes were not due to advection (i.e. D_x has been used, not D).

McKenzie's assumption that so long as no change of air mass occurs the dew point at screen level remains constant, or almost so, seems open to criticism; in particular, significant variations of dew point from day to night might be expected when skies are clear and winds light -

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the conditions under which forecasts of minimum temperature are of greatest importance. Indeed Ritchie (Ref. 5) has quoted details of a radiation night at Dyce itself when the temperature fell considerably lower than the minimum which would have been forecast from afternoon values using McKenzie's technique - the discrepancy being mainly accounted for by the progressive lowering of the dew point through the night. Some support for the objection to McKenzie's assumption is also given by a check carried out in the Forecasting Techniques Branch and summarized in Table I. The figures given are, however, based on data from only one year.

From a survey by McCaffery and Harrower (Ref. 6) of forecasting techniques, McKenzie's technique is used at 49 Meteorological Office outstations in the United Kingdom and Germany. Since local constants have been calculated for only 10 of the stations it must be assumed that McKenzie's constants for Dyce are often used for forecasting for other locations. As part of work at Mildenhall in comparing techniques for forecasting night cooling, locally derived constants for use in McKenzie's technique were examined. This ~~lead~~ led to the conclusion that "by fortuitous accident McKenzie's constants are roughly the average of all constants which have been calculated for other stations".

TABLE I - CHANGES IN DEW POINT (°C) AT LONDON (HEATHROW) AIRPORT FROM 1200 GMT ON ONE DAY TO 0600 GMT ON THE NEXT FOR GIVEN CONDITIONS OF CLOUDINESS AND SURFACE WIND DURING THE NIGHT

Mean* speed of surface wind (knots)	Mean* cloudiness									
	Sky obscured		0 - 2/8		3/8 - 4/8		5/8 - 6/8		7/8 - 8/8	
	Mean change	Standard deviation of change	Mean change	Standard deviation of change	Mean change	Standard deviation of change	Mean change	Standard deviation of change	Mean change	Standard deviation of change
0-3	-2.2	3.0	-2.3	2.3	-0.9	2.3	-0.7	1.5	+0.4	2.7
4-6	-2.7	2.0	-1.9	2.0	-0.5	1.9	-0.6	2.0	+0.2	2.2
7-10	-	-	-1.1	2.3	-0.5	2.7	0.0	3.4	-0.2	2.6

This table was prepared from data for the year 1964. The data used were limited to occasions when no front marked on the Daily Weather Reports passed through Heathrow during the period 1200-0600 GMT.

*Cloudiness (total amount of cloud) and wind speed were in general the values averaged from 0000 and 0600 GMT observations. However, nights were listed as "sky obscured" if this was reported at 0600 and/or 0000 GMT.

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4.3. <u>Technique due to Craddock and Pritchard</u>

Unlike most of the techniques for forecasting night cooling, that due to Craddock and Pritchard (Ref. 7) is not for a specific place but for general application at inland places in England. Data for sixteen inland stations during one year were used to obtain the regression equation for predicting night minimum temperature, i.e. $T_n = 0.316\ T_{12} + 0.548\ D_{12} + 2.12 + C$. (This is for temperatures in degrees Fahrenheit.) Values of "C" vary according to mean cloud amount and mean gradient-wind speed during the night. (Another equation is given for forecasting the temperature at which fog would form.) The authors say: "Since data from several stations are lumped together, the prediction formulae depend on the atmospheric processes which act alike at all the stations (i.e. on those connections between parameters and quantities predicted which are the same at all stations) and ignores those which operate differently at different stations."

The technique is therefore useful for forecasting the most typical value of minimum temperature to be expected over an area but should be open to improvement by some form of local adaptation when the problem is to forecast the minimum temperature for a particular place. Adaptation could take one of several forms, for instance:

(1) A single value might be calculated as a local correction to the minimum forecast by means of the equation.

(2) A table for local values of "C" might be prepared.

(3) The regression equation and values of "C" might be re-calculated from local data.

Craddock and Pritchard have given the means and standard deviations of residual errors in forecasting minimum temperatures at different places using their equations. From these results it would appear that a single value correction for locality would not greatly improve the technique for purely local application. This is perhaps to be expected because the magnitude of local differences would vary according to conditions of wind speed and cloud cover during the night.

Thus the second and third forms of adaptation seem more satisfactory than the first though, being more complex, the work involved would be greater and it would be necessary to examine a greater amount of local data.

Local work in adapting this technique has been done at three stations. Details are unknown for one of the stations. For Hurn local values of "C" have been calculated. For London (Gatwick) Airport the regression equation and values of "C" have been re-calculated from local data.

/Gatwick

Gatwick is subject to particularly low temperatures on radiation nights, hence the departure of the derived equation from that given by Craddock and Pritchard is of interest. The equation for Gatwick is $T_n = 0.17\ T_{12} + 0.61\ D_{12} - 0.94 + C$. (This is for temperatures in degrees Celsius whereas the equation due to Craddock and Pritchard is for temperatures in degrees Fahrenheit; only the last two terms on the ~~left~~ right hand side are altered by conversion, however.) For nights with mean cloud amount 0-2 oktas and gradient wind 0-12 knots values of T_n obtained from the Gatwick equation are lower than those from the equation due to Craddock and Pritchard by about $(0.15\ T_{12} - 0.06\ D_{12} + 2)^{\circ}C$. With temperature and dew point at the preceding noon in the range of the more common values this difference is roughly $3^{\circ}C$; with high temperature and low dew point at noon the difference might amount to as much as $5^{\circ}C$.

Prediction formulae of the type given by Craddock and Pritchard have been calculated for London (Heathrow) Airport by a vacation student working temporarily in the Forecasting Techniques Branch. The formulae apply only to nights with little or no cloud; separate formulae have been prepared for different ranges of wind speed. A summary of this work is given in Annex A.

4.4. Schmidt's technique

Schmidt (Ref. 8) investigated cooling on nights with little cloud at Warnemunde (on the Baltic coast of Germany). Because of the economic importance of making a forecast of night minimum temperature early on the previous day his technique uses as parameters values at 1000 Central European Time. He gives graphs showing the variation of ΔT (the mean depression of the minimum temperature below the temperature at 1000 CET the previous day) according to one or more of the following (up to three of the factors are considered in combination):

(1) the temperature at 1000 CET,
(2) the vapour pressure at 1000 CET,
(3) the month,
(4) the season,
(5) the mean speed of the surface wind during the night,
(6) the mean direction of the surface wind during the night,
(7) the minimum temperature of the night before.

Schmidt compared the accuracy of the different graphs when used to forecast minimum temperature at Warnemunde. In the test actual values for (5) and (6) were used, though in practice these values would necessarily be forecast. The test showed that the method which gave the best forecast during one season did not do so during another; for instance the best forecasts for Warnemunde in winter were from mean monthly values of ΔT for each of two ranges of wind speed but in

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the summer were from a graph relating ΔT with temperature and vapour pressure at 1000 GMT. Thus Schmidt's approach consists not of deriving a single technique but of choosing from several derived techniques the one which has been found best for the appropriate season and location.

At several meteorological offices in the United Kingdom Schmidt's methods are being tested. Details are known of some preliminary results from Heathrow and Watnall.

At Heathrow the local relationships examined were the mean monthly values of ΔT (taken as the depression of the minimum temperature below the preceding 1000 GMT temperature), the variation of ΔT according to the temperature at 1000 GMT, and the variation of ΔT according to the vapour pressure at 1000 GMT. The relationships on the whole gave better forecasts than similar relationships at Warnemunde (as quoted by Schmidt). The tests in each case were made from the data used to derive the relationships, not from independent data. The better results from Heathrow may have been due to some extent to the exclusion of data for occasions when a change of air mass occurred between 1000 GMT and the time of minimum temperature and when the temperature at 1000 GMT may not have been representative on account of fog or heavy low cloud. The relationships determined for Heathrow were only for nights with little cloud and a mean wind speed of 6 knots or less.

At Watnall diagrams similar to one of those given by Schmidt were prepared from local data to give a forecast of the minimum temperature from the values of temperature and dew point at 0900 GMT on the preceding day. Separate diagrams were prepared for the ranges of wind speed (mean for the night) 6 knots or less and 7-15 knots. A test in operational use showed that the former diagram gave rather better results than the subjectively made forecast but the latter diagram gave rather worse results.

4.5. Boyden's technique

Boyden (Ref. 9) ~~have~~ has given the following formula for predicting the night minimum temperature at Kew Observatory:

$$T_n = \tfrac{1}{2}(T' + D_x) + C$$

In this formula T' is the wet-bulb temperature at the time of maximum temperature and values given for C vary according to cloud amount and surface-wind speed expected during the night.

Boyden's technique has been locally adapted at one outstation - Gutersloh, in Germany. In addition to the table of local values of "C" for use under normal conditions, a table has been derived for use when the ground is at least half-covered with snow.

5. Local work not based on published techniques

Techniques evolved at Coltishall, Leconfield, Liverpool Airport and West Raynham are rather similar in that use is made of mean cooling curves

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for each of several different conditions (e.g. time of year, surface-wind speed and cloud cover overnight). Sometimes for the same condition two or more mean curves are given, from data grouped according to the level of the afternoon temperature. At Coltishall and West Raynham separate curves have been prepared for winds off the sea and for winds off the land.

The separate consideration of nights with winds off the sea is also a feature of work done at Stradishall. For different ranges of surface-wind speed, regression equations have been calculated to give the night minimum temperature from the preceding maximum temperature and dew point at time of maximum temperature; in the equations for use with winds off the sea, afternoon temperatures from an upwind coastal station have been included as additional parameters.

At Valley a technique has been derived for forecasting minimum temperatures on nights with winds off the sea. The mean monthly sea temperature and expected surface-wind speed and cloud amount are used as parameters.

At Little Rissington the direction of the surface wind is taken into account because of the way this affects the drainage of cold air into adjacent valleys. (Cooling effects peculiar to places above the general level of the surrounding countryside have been noted at Waddington (Ref 10) Binbrook and Stradishall.) Apart from the wind direction, the parameters used in forecasting night minimum temperatures at Little Rissington are the wind speed, the temperature at 1500 GMT and the amount of cloud. The technique gives lower forecast minimum temperatures with winds from the east (other factors being constant) than with winds from the west. For surface winds of up to 12 knots the effect of wind direction seems more significant than that of wind speed.

At Gutersloh some work has been done on a method of forecasting night minimum temperatures using as parameters the temperatures and dew point at 1500 GMT and the wet-bulb potential temperature the at the level where the pressure is 50 millibars less than the station level pressure.

6. Parameters considered significant but not included in conventional techniques

6.1. Direction of the surface wind

In letters from outstations to the Forecasting Techniques Branch mention has often been made of the direction of surface wind as having an important influence on night cooling. Wind direction is not used as a parameter in most of the published techniques though Saunders has given a modification of his technique for use on nights with winds off the sea (Refs. 11 and 12).

The direction of surface wind has been considered important at various places for such reasons as:

(1) its effect in impeding or assisting drainage of cold air from higher ground,

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(2) the movement of air from over a nearby city decreasing the cooling ("heat island" effect),

(3) the different thermal influences with winds off the sea and off the land.

6.2. Sea surface temperature

At places near the sea the sea surface temperature must be an important parameter on the nights with winds off the sea. There is evidence that even 30 or 40 miles inland the effect of sea surface temperature can still be important (Ref. 13). It would be useful to know how far inland sea surface temperature exerts a significant influence on local cooling during nights with winds off the sea; the critical distance probably varies according to wind speed.

6.3. Presence of snow cover

It is well appreciated that minimum temperatures on nights when the ground is covered by snow are often substantially lower than on nights when the ground is free from snow but other factors are similar. At Aldergrove it is said that on nights with snow cover the temperature has fallen to as much as 6°C (10°F) below the value forecast using conventional techniques which take no account of snow cover. (It may be noted that Müldner (Ref. 14) has suggested that minimum temperatures at Nuremberg as forecast from his formulae should be reduced by values ranging up to 10°C for nights when the ground is covered by snow - the actual value depending on the nature of the snow surface.)

7. Periods of data on which local techniques have been based

Information received on the amounts of data which formed the bases of local works on night cooling has not been complete - sometimes there was no record of what data were used in investigations made several years ago. The other investigations were made using very varied periods of data, periods of between two and five years being most common.

8. Accuracy with which parameters can be forecast

A general characteristic of the techniques for forecasting night cooling is that some of the predictors used have themselves to be forecast. Consequently errors in forecasting night cooling arise not only from any inadequacy of the particular technique used but from the inaccuracy in forecasting the predictors. All too often the forecast of night cooling is badly in error because of the unexpected presence (or absence) of strato-cumulus during the night or the behaviour of surface wind in an unexpected manner. In the opinion of some forecasters, indeed, the errors in forecasting the predictors well outweigh the errors intrinsic to different techniques and even the errors due to local variations (i.e. when the technique has not been adapted for the place for which it is applied). This opinion, though perhaps extreme, does usefully

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emphasize the need to consider errors in forecasting the predictors used in any technique as well as the errors which would remain had the predictors been correctly forecast. Analyses of errors in forecasting the predictors are being made at Mildenhall and at the Glasgow Weather Centre. Some preliminary results are given in Annex B.

9. Local differences of temperature at night

It has already been remarked that at some offices the forecaster may be called on to predict night temperature at any place within an extensive area. A technique for forecasting for a single place within the area is only a start to solving his problem; knowledge of local differences in night cooling characteristics is of great importance. The forecaster needs some sort of yardstick as to differences in temperature at night between various types of site under the general conditions to be expected on the night in question.

Some such guidance is available from published work. For instance Chandler (Ref. 15) has given much information about the "heat island" effect of London under various conditions and, in fact, gives regression equations for estimating the extent to which the minimum temperature in central London (Kensington) will exceed that outside London (Wisley, Surrey) according to cloudiness, wind speed and temperature at London (Heathrow) Airport. Other authors have compared night minimum temperatures in certain frost hollows with the values elsewhere (see for instance Refs. 16 and 17).

Some work in examining local differences of night minimum temperature has been carried out at outstations - for instance the minima at the London Weather Centre and Heathrow have been compared (Ref. 18). In the Forecasting Techniques Branch a simple comparison of values at a selection of places in eastern and southern England was found useful in verifying that one of the stations was subject to especially low minimum temperatures (Annex C). Such an analysis could be expanded for the benefit of the forecaster by examining the differences according to pressure gradients and cloud amounts and by incorporating results from more widely varied sites, including sites for which observations are not normally available to the forecaster in his day-to-day work.

The results of mobile meteorological surveys over limited areas on individual nights can be helpful to the forecaster. Lawrence (Ref. 19) has given details of temperature variations according to height above sea level and slope of ground during three radiation nights in May. It is known that rather similar investigations are being made by at least two outstation forecasters: Mr. A.A. Harrison is observing temperature distribution according to topography in parts of Kent on radiation nights; Mr. D.J. George is making similar observations in the vicinity of Shawbury. Such work, carried out by enthusiastic individuals during off-duty hours, may be rather slow to yield results which are of immediate use in forecasting practice. However, the efforts seem likely to be valuable in

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giving a better appreciation of the problem and of factors which were important on particular nights.

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ANNEX A

Summary of work by Mr. I.G. MacKenzie on minimum temperatures at Heathrow on nights with little or no cloud

Nights with "little or no cloud" were taken as those on which the total cloud amount did not exceed 2 oktas at 1800, 2100, 0000, 0300 and 0600 GMT. For each of these nights during the years 1949-1965 the appropriate values were recorded of T_n, T_{12}, D_{12}, T_x, D_x and the mean speed of the surface wind (the mean of the values at 1800, 0000 and 0600 GMT). Synoptic situations were not examined for these nights so that on some of the occasions selected there may have been a change of air mass between midday (or the time of maximum temperature) and the time of minimum temperature. However, the conditions imposed with regard to cloud probably precluded most of the occasions when an active front passed through Heathrow between 1800 and 0600 GMT.

Data from about two thirds of the occasions selected were used to calculate the prediction equations by the method of least squares. The results, as given below, suggest that there is little to be gained by forecasting from the later data, i.e. the parameters for the time of maximum temperature, instead of from data for 1200 GMT.

EQUATIONS FOR PREDICTING MINIMUM TEMPERATURES AT HEATHROW ON NIGHTS WITH LITTLE OR NO CLOUD

Mean wind speed (kt)	From dependent data		From independent data	
	Prediction equation T_n =	No. of nights	R.M.S. error	No. of nights
	Using parameters at 1200 GMT			
0-3	$0.58\ T_{12} + 0.38\ D_{12} - 6.3$	80	2.12°C	30
4-6	$0.52\ T_{12} + 0.31\ D_{12} - 4.7$	100	1.74°C	50
7-10	$0.67\ T_{12} + 0.09\ D_{12} - 5.0$	70	1.59°C	20
≥11	$0.69\ T_{12} + 0.01\ D_{12} - 3.7$	20	1.03°C	12
	Using parameters at the time of maximum temperature			
0-3	$0.64\ T_x + 0.29\ D_x - 8.1$	80	2.17°C	30
4-6	$0.54\ T_x + 0.26\ D_x - 5.9$	100	1.63°C	50
7-10	$0.55\ T_x + 0.26\ D_x - 4.8$	70	1.55°C	20
≥11	$0.69\ T_x + 0.05\ D_x - 4.7$	20	1.41°C	12

It was thought that on nights with movement of air from the east local cooling might be offset to some extent by heat released from the buildings of London ("heat island" effect) - more particularly during winter. Consequently for nights when there was a fairly steady wind from between 040° and 120° the errors were examined of predictions of night minimum temperature made from the equations. The results suggest that a small correction (addition) to the value predicted from the equations

/might

might be applied for nights with such winds during October to March.

PREDICTION ERRORS WITH WINDS FROM BETWEEN 040° AND 120°
DURING OCTOBER TO MARCH

Mean wind speed (kt)	Number of cases	Average error of the predicted minimum
1-3	3	+1.5°C
4-6	19	+0.6°C
7-10	8	+0.7°C

In examining effects of wind direction a rather surprising feature came to light: departures from the predicted minimum with winds from the north-west during summer appeared at least as notable as the departures with winds from the direction of London during winter. The results are given below.

PREDICTION ERRORS WITH WINDS FROM BETWEEN 300° and 250°
DURING APRIL TO SEPTEMBER

Mean wind speed (kt)	Number of cases	Average error of the predicted minimum
1-3	8	+1.2°C
4-6	8	+1.2°C

/Annex B

Annex B

Errors in forecasting parameters used in techniques for forecasting night cooling

Test at Mildenhall

The test was of forecasts of parameters used in McKenzie's technique (Ref. 4). The following values were forecast during the afternoon preceding the minimum temperature:

D: the mean dew point for the night (°C) (see section 4.2. over the ambiguity concerning D as defined by McKenzie)

N_1: the mean amount of low cloud during the night (oktas)

ff: the mean speed of the surface wind during the night (knots).

The forecasts were made at six stations in eastern England. Errors (without regard to sign) from 443 forecasts were averaged, giving the following values:

for D: 1.1°C

for N_1: 1.5 oktas

for ff: 2.5 knots

Test at the Glasgow Weather Centre

As at Mildenhall the test was of forecasts of parameters used in McKenzie's technique. The local requirement, however, was for a minimum temperature to be forecast by 1000 GMT on the preceding day and so an additional parameter had to be forecast, T_x (the maximum temperature for the day preceding the appropriate minimum). The values of parameters were forecast to the nearest whole number - °C for maximum temperature and dew point, Beaufort force for speed of surface wind and oktas for cloud amount. A forecast was considered "correct" when the number did not depart by more than 1 from the value actually realised later. The percentage of forecasts correct were:

for T_x : 70%

for D : 66%

for N_1 : 54%

for Beaufort force : 77%

Annex C

Minimum temperatures on radiation nights at Hurn compared with those at other places

This was done as a simple and quick test to verify that Bournemouth (Hurn) Airport is subject to particularly low temperatures on radiation nights - a characteristic described in the entry for Hurn in "Aerodrome weather diagrams and characteristics" (Met. O. 671). Daily Weather Reports for the months October 1960 to March 1961 were examined to select nights with slack pressure gradient and little or no cloud over southern and eastern England. The minimum temperatures for Kew, Mildenhall, London (Heathrow) Airport, London (Gatwick) Airport and Bournemouth (Hurn) Airport were compared for the 28 nights thus selected. The average minimum temperatures for these nights were as follows:

Kew	+2.6°C
Mildenhall	+2.1°C
Heathrow	+1.9°C
Gatwick	-0.5°C
Hurn	-0.7°C

Not only were differences of average minimum temperature noteworthy but the tendency for one station to be warmer or colder than others on radiation nights was maintained with a high consistency. Thus on 18 of the 28 nights the temperature at Hurn fell below or to the same value as the lowest temperature recorded at any of the other stations; on 19 of the nights the minimum at Kew was higher than or as high as the highest minimum recorded at the other stations.