CONDENSED WEATHER DATA FOR HEATING CALCULATION

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Two methods for reducing weather data are assessed and compared with respect to use for heating calculations. Degree days for calendar months, utility bill periods and without weekends were calculated and compared along with temperature 'bins' of various sizes using the CIBSE Example Weather Year. Wind velocity and solar radiation are also analised with respect to degree days.
Both methods, degree days and the bin method, are found to represent the actual weather conditions adequately for use in heating calculations.

INTRODUCTION

Degree days were originally used by the American gas industry and it was not until about 1934 that British engineers began to use degree days of a slightly different form to the American version. (The British degree days made no account of internal gains). Current degree day practice is based upon the analysis of Billington (1) in 1966.

The Department of Energy Fuel Efficiency booklet (2) gives degree days as the difference in °between a base temperature and the 24 hour mean of maximum and minimum outside air temperatur (when less than the base temperature). The base temperature for a building is the interna temperature above which space heating is not required. Early investigation of building performanc has shown that a base temperature of 15.5°C was acceptable in this country. (The Fuel Efficienc booklet quotes that a further 2.8°C can be realised from gains due to people, lights and machiner etc, giving an internal temperature of 18.3°C, a rather low temperature for present day design).

Degree days are used in the analysis of space heating fuel consumption as detailed in the CIBS Guide (3). A linear relationship is assumed between degree days for monthly periods and th corresponding fuel consumption. This relationship can be a possible indication of how efficientl the heating plant is performing. Degree day theory is quite simple and is of practical use t Energy Managers in monitoring and targeting consumption. However, many question its accuracy i this use as it does not represent all the variables contributing to energy consumption.
Wind speed, solar radiation and occupancy hours may well have a significant effect on heatin consumption, as well as the heating controls.

The bin method, mostly used in America (4), is a histogram of hourly occurances of temperatur within certain values or "bins". It contains more information about the outside air temperatur than degree days but the time factor is absent, i.e there is no relationship between a particula temperature occurance and when during the year it occured. Time is an important factor fo modelling buildings consumptions.

Variable base degree days (5) are now popular in the U.S.A where each buildings base or balanc temperature (above which no heating is required) is calculated individually.
Energy signatures and performance lines are becoming popular in Europe, which are basically degree day or straight temperature analysis of consumption data.

NOTE. Linear regression analysis is applied to a set of variables to determine if any relationshi exists between them. Here we are considering two variables in each case. The analysis is carrie out by using the method of least squares to determine the equation of the 'best fit' straight lin to represent the two sets of data. A statistic can be calculated from the sets of data, th coefficient of determination, which indicates how well the straight line can be said to represen

the data. This statistic varies in value from 0.0 for extreme scatter of points about the 'best fit' line to 1.0 for most or all points close to or on the 'best fit' line.
For all regression analyses dealt with here we consider seven data sets each one corresponding to a month of the heating season, October to April inclusive.

WEATHER AND CONTROL INFLUENCES

The analysis of fuel consumption using degree days is thought to be erroneous by some because of other weather influences. Using data from the CIBSE Example Weather Year for Kew 1964 it is interesting to see that monthly average wind speed does correlate with calendar month degree days, FIG 1, the coefficient of determination for the linear regression analysis, r^2, being 0.6854 corresponding to a probability of a linear relationship being due to chance of I in 50.
Analysis of average monthly solar radiation data (6) reveals that there is no correlation between global radiation and monthly degree days, FIG 2, r^2 being 0.3550. However sunny days often have clear, cloudless, skies at night and the solar gains can be offset by losses at night which indicates that net radiation should be used. A linear regression analysis between net radiation and monthly degree days shows that there is no correlation here either, FIG 3, r^2 being 0.2620.

It is interesting that in the heating season some months have negative net radiation values although the argument in section A2 of the Guide (7) leading to the assumption that the environmental temperature is assumed approximately equal to the air temperature for heating calculations may be slightly generous as regards the Example Weather Year.

Owens (8) however has demonstrated that monthly solar radiation can be correlated with the air temperature of the following month. With the Example Weather Year this is also demonstrated, the coefficient of determination, r^2, for global radiation being 0.9190 and for net radiation 0.8567.

So although it is difficult to modify degree days for other influences as Hitchin has shown (9) the monthly correlation with wind and the month offset correlation with solar radiation suggest that degree days, monthly anyway, are not grossly bad comparators for consumption.

Degree day theory assumes that the daily variation in temperature is sinusoidal. Using the condensed statistics (IO), FIG 4, shows that the hourly mean temperature variation for each month is not a sine wave, the curves show that the monthly mean is not equal to $^1/2(t_{max} + t_{min})$ which will affect the accuracy of the degree day equaitons in (2).

An often forgotten but very important influence on energy analysis using degree days or bins is that due to the heating controls. The internal temperature is assumed constant. With degree days this is taken as the base temperature plus an increment due to gains. However, it has been shown that with many compensator controls the internal temperature can rise with outside temperature (11) as indeed it does to a greater extent with thermostats. Thermostatic radiator valves, being proportional control devices, will also suffer from some offset.

DEGREE DAYS

Area accuracy. Energy managers, when analysing heating plant performance, use published degree day data (12) to a 15.5 C base temperature. Craddock (13) has shown, FIG 5, 6 that there can be a significant difference between degree days calculated for the actual site and published degree days for the appropriate degree day region, the difference being as much as 10%.

Occupancy time. For lightweight buildings with very short thermal memories, weekend weather is of limited influence so using the CIBSE Example Weather Year a comparison was made between actual calendar month degree days and degree days calculated for each month but excluding any contributions made by weekends, FIG 7,. A linear regression analysis shows that by omitting weekends from the degree day calculations the monthly degree day totals are reduced by upto 25%.

Weekly data. Fuel consumption data as extracted from utility bills are not always from exact calendar months but are to the nearest weeks of the calendar months. Monthly degree day figures were calculated from the CIBSE Example Weather Year for sets of whole weeks to represent the calendar months, FIG 8, a linear regression analysis shows that there is little difference between exact calendar month degree days and "nearest week" degree days. The coefficient of determination, r^2, is 0.8296.

BIN DATA

Using Lethermans (10) frequency distribution for hourly mean outside temperatures for the Exam Weather Year various bins can be obtained. Various width temperature bins can be derived and are considered 1°,2°,5°,10° bins. These data can be presented in the form of percentage cumulat frequency of hours and plotted against the mean temperature of each individual bin, FIG 9. graph shows a significant difference between a 1°bin, 5°bin and 10°bin

Because we are interested in space heating fuel consumption the heating season is considered temperature bins for each month and the whole heating season have been calculated and a percent cumulative frequency graph plotted, FIG 10.
For half of the duration of the heating season the outside temperature is below 6°C according the 1°C bin. A 10° bin shows that the outside temperature is below 6° C for 80% of the time of heating season. This means that the 10°C bin has represented 30% of the heating season as un 6°C when it is infact over 6°C.

FIG 10 shows that the bin curves are nearly parallel in the temperature range -4°C to indicating that the error in this region will remain fairly constant at about 30% between a 1°C and a 10°C.

A plot of the 1°C bin on probability paper, FIG 11, shows that the whole heating season ha Gaussian distribution and each individual month can also be represented by a Gaussian distribut with December showing the greatest deviation from a straight line.

COMPARISON OF DEGREE DAYS AND BINS

In order to compare the two methods it is necessary to convert the data into quantities wi similar units. A quantity here called "temperature hours" are considered. True temperature hour TTH, are obtained by adding the hourly temperatures for every hour in the month, TABLE 1.

TABLE 1

MONTH	TRUE TEMPERATURE HOURS	1°C BIN TEMPERATURE HOURS	DEGREE DAYS TEMPERATURE HOURS
OCTOBER	7001	6915	6982
NOVEMBER	6235	6190	6252
DECEMBER	3608	3558	3480
JANUARY	3296	3253	3194
FEBRUARY	2728	2711	2633
MARCH	4784	4753	4870
APRIL	6516	6453	6578
YEAR TOTAL	34169	33833	33989

Conversion of bin data. The temperature hours for each heating season bin is the sum of t frequency of temperature for each bin width multiplied by the mean teemperature of that bin widt These are shown in TABLE 1 for the Example Weather Year.

Conversion of degree day data. The average daily temperature for each month was calculated fr the degree day equation and was multiplied by the number of hours in the month.

$$\text{Temperature hours} = N*24*(t_b - DD/N)$$

Temperature hours from degree days are shown in TABLE 1

Camparison of degree day and bin temperature hours

TABLE 2

MONTH	BIN TEMP HOURS% TTH	DEGREE DAY TEMP HOURS% TTH
OCTOBER	98.77	99.73
NOVEMBER	99.28	100.27
DECEMBER	98.60	96.44
JANUARY	98.70	96.91
FEBRUARY	99.37	96.51
MARCH	99.35	101.80
APRIL	99.03	100.95
YEAR TOTAL	99.02	99.47

TABLE 2 shows the bin method temperature hours and the degree day temperature hours as a percentage of the True temperature hours. The bin method is closest to the true temperature hours, the deviation being under 2% in December and the degree day deviation being under 4%, again in December.

Both methods compare favourably with the True temperature hours . Given 1°C bin data in a monthly format it should be possible to convert this data into degree day, monthly, data and vice versa without introducing large errors.
FIG 12, 13 show temperature hours for various bin widths as a percentage of the True temperature hours and it can be seen that a 10°C bin width will introduce large errors in temperature hours and that data should not be condensed further than a 3°C bin width.

CONCLUSION

Bin data and degree day values have been calculated for the CIBSE Example Weather Year. It is found that both methods of condensing the weather data do not introduce significant deviations from the true temperature hours on a monthly basis, with the bin method giving more information than degree days but lacking the important time factor. The latter is important for consumption modelling. However, bins with a width greater than 3°C are likely to introduce significant differences with respect to the original data which will give rise to errors in heating consumption calculations.

Degree days are found to be surprisingly accurate for monthly data representation in the heating season. It is also found that wind speed correleates with degree days but solar radiation does not, although the introduction of a one month set back (after Owens work) of radiation values does improve correlation.

Degree days for months taken to the nearest whole week do not differ significantly from calendar month data. However if weekend data is not required, as for a very lightweight building not heated at weekends, then complete monthly degree days can be erroneous by upto 25%.
Bin representation can be further simplified by assuming a Gaussian distribution for each month or indeed the whole heating season.

SYMBOLS USED

DD	=	degree days.
N	=	number of days in month.
r	=	correlation coefficient
r^2	=	coefficient of determination.
t_b	=	base temperature (°C).
t_{max}	=	maximum daily outside air temperature (°C).
t_{min}	=	minimum daily outside air temperature (°C).

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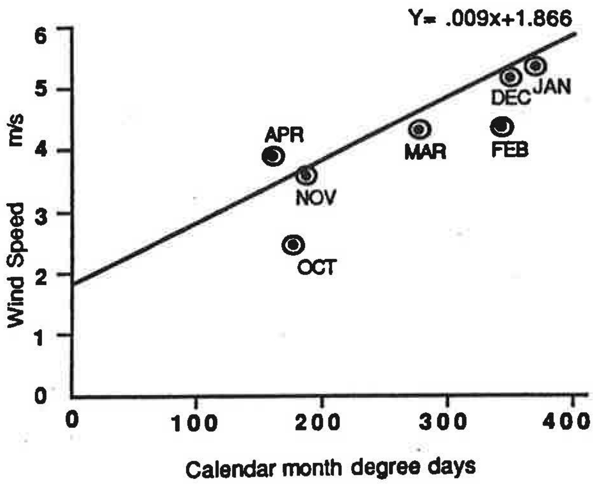

FIGURE 1 Average monthly wind speed vs Calendar month degree days.

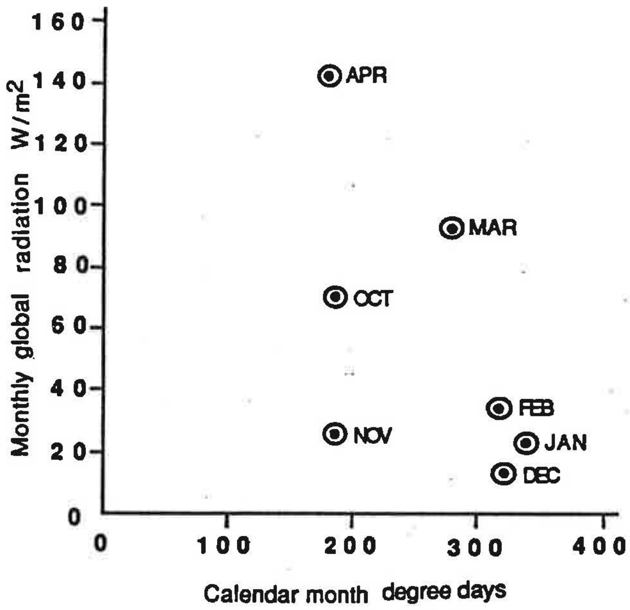

FIGURE 2 Monthly global radiation vs Calendar month degree days.

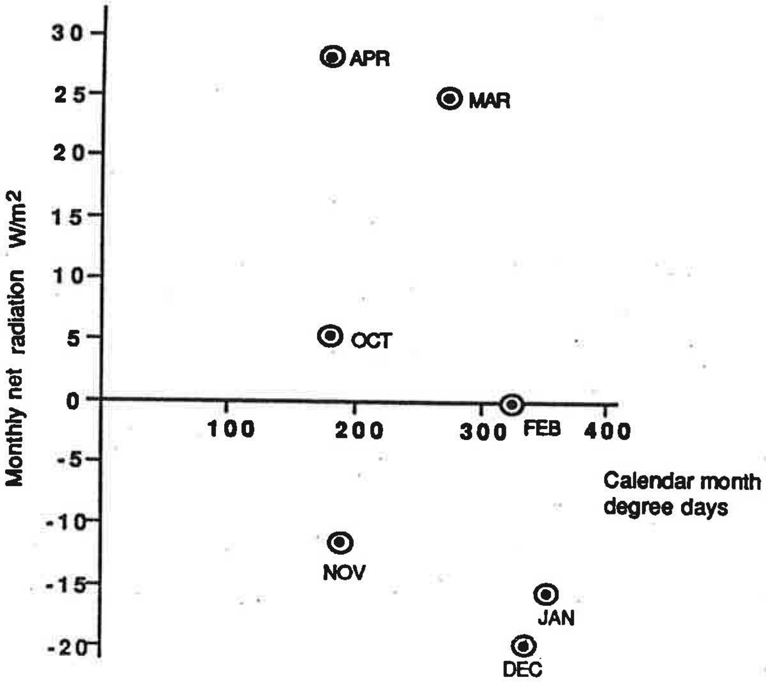

FIGURE 3 Monthly net radiation vs Calendar month degree days.

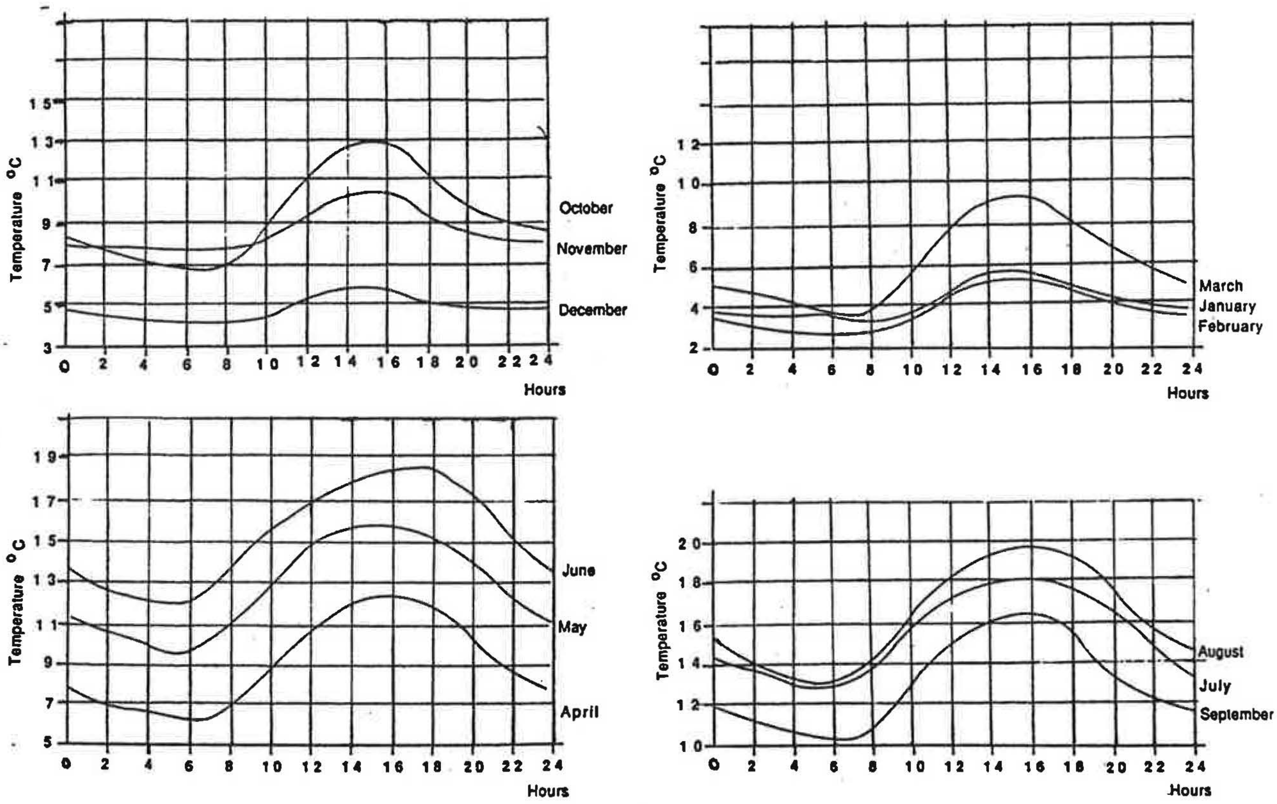

FIGURE 4 Hourly mean temperature versus Hour of the day.

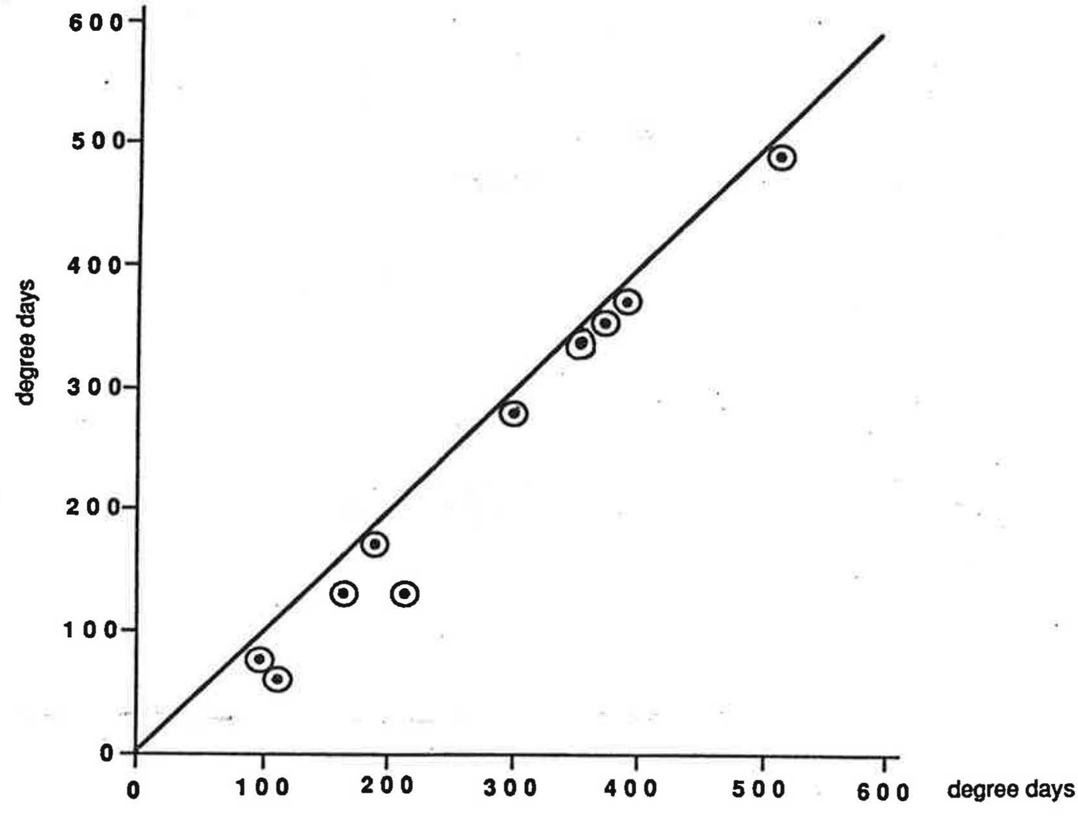

FIGURE 5 Local degree days vs Heathrow degree days.

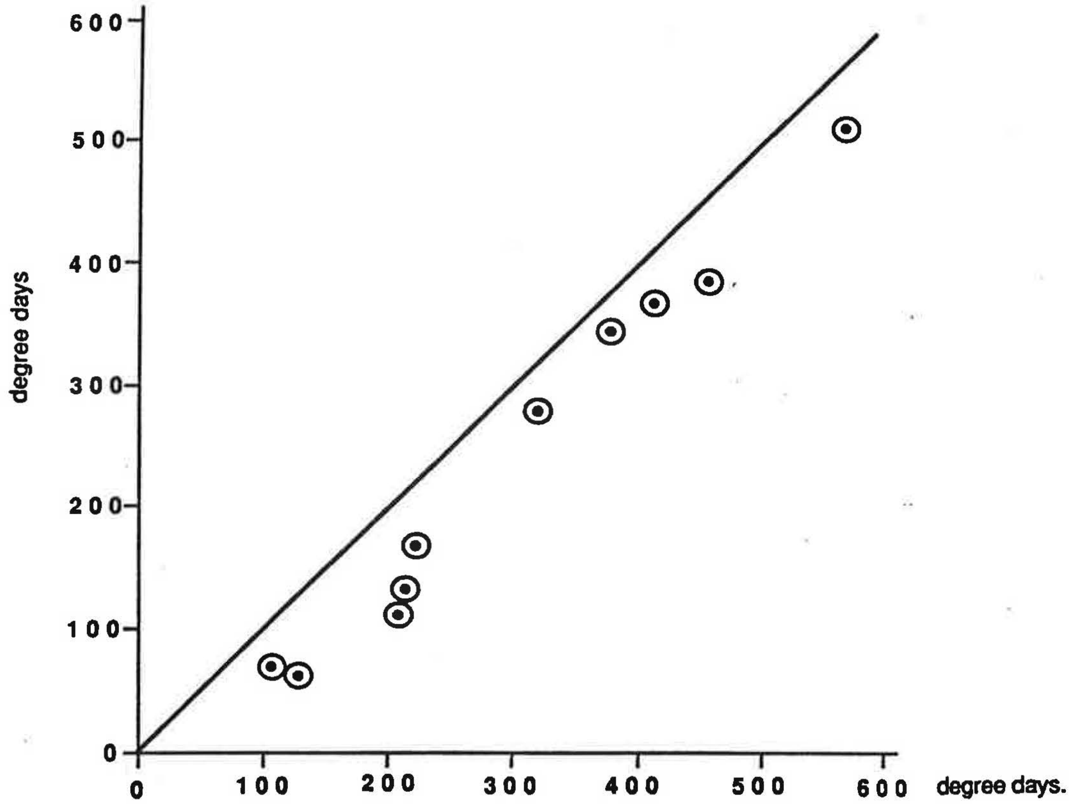

FIGURE 6 Local degree days vs Honington degree days.

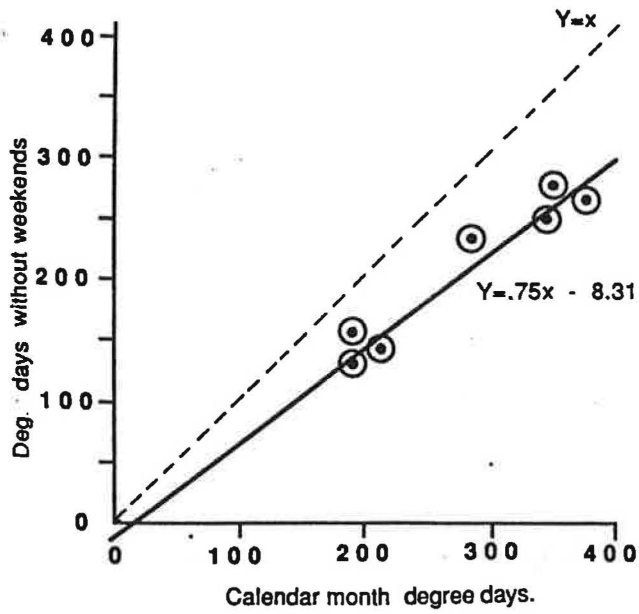

FIGURE 7 Degree days, months without weekends versus degree days for calendar months.

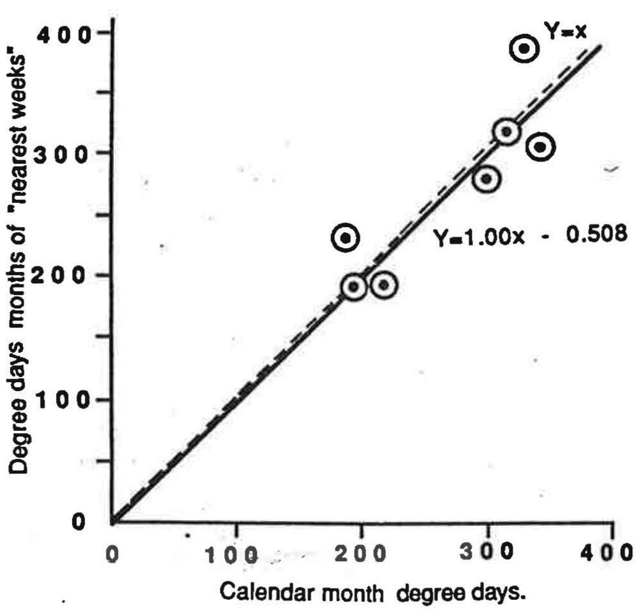

FIGURE 8 Degree days months of "nearest weeks" versus degree days for calendar months.

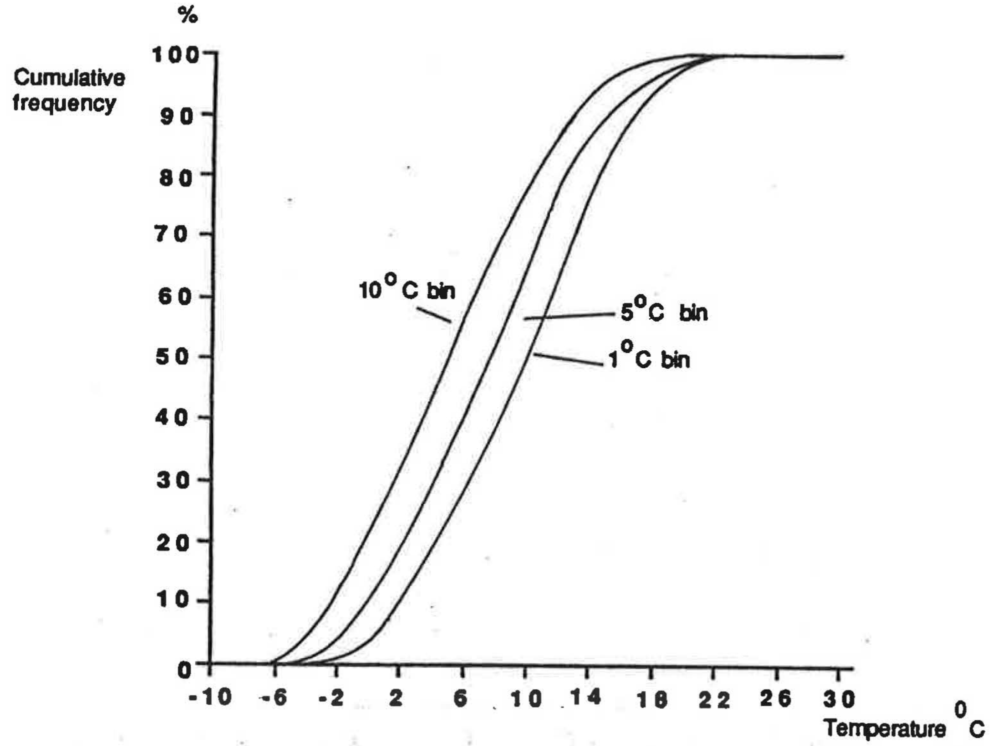

FIGURE 9 Percentage cumulative frequency of hourly temperature for various bin widths vs Average temperature of bin.

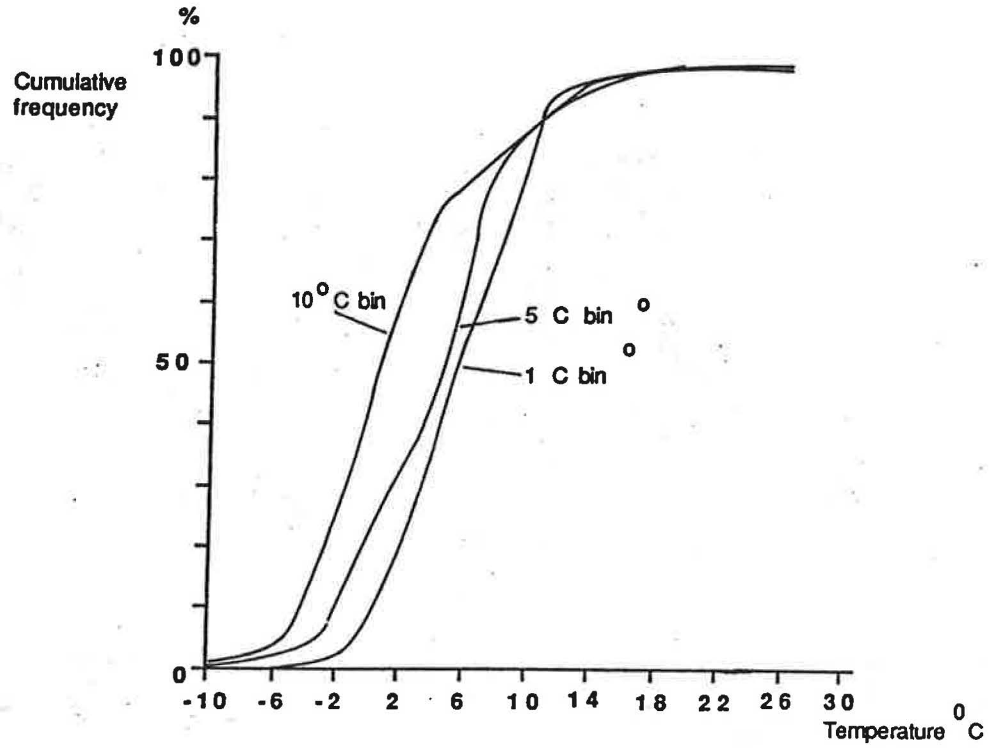

FIGURE 10 Percentage cumulative frequency of hourly temperature for various bin widths for the heating season vs Average temperature of bin

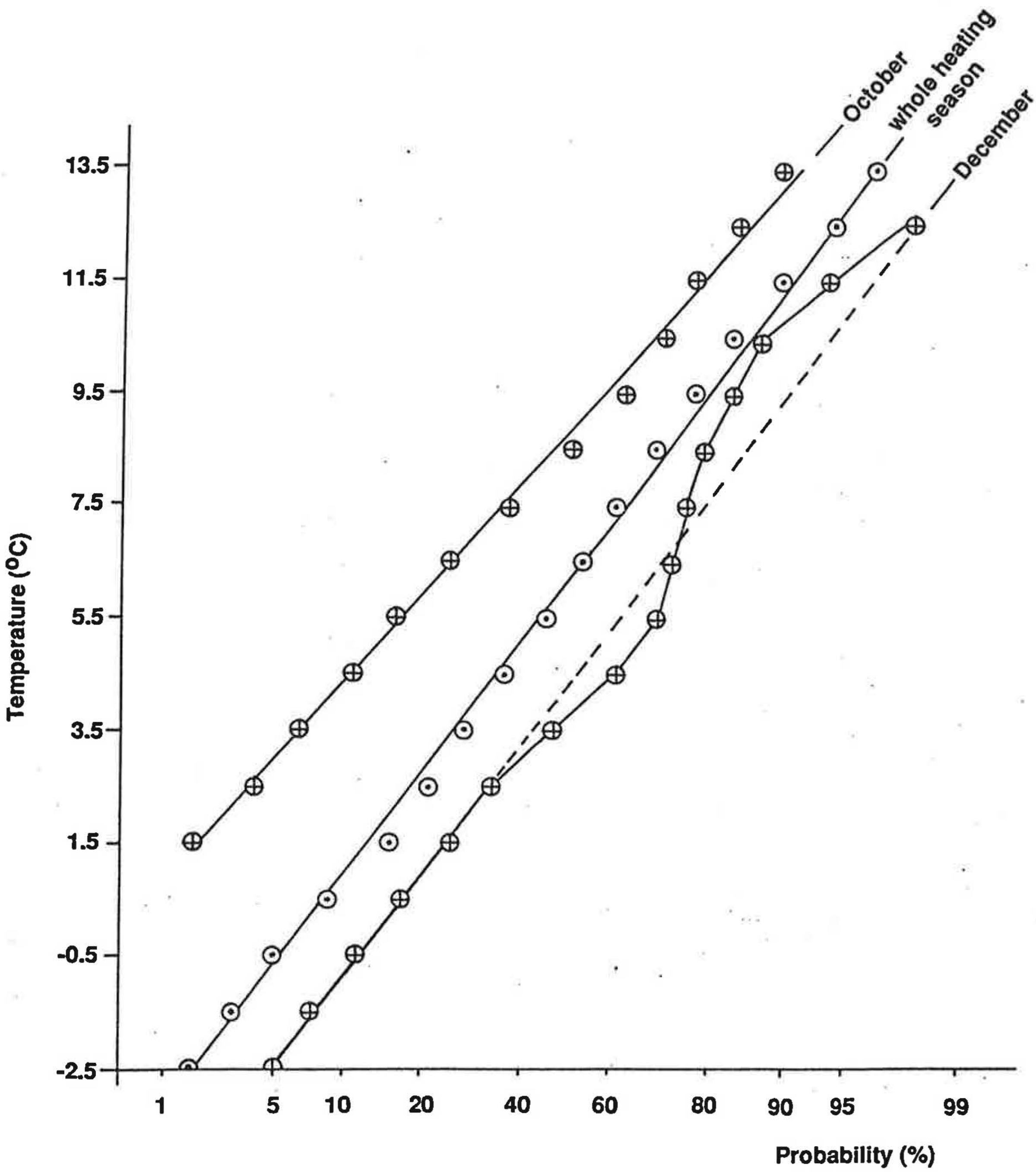

FIGURE II **Cumulative frequency distributions on a probability graph.**

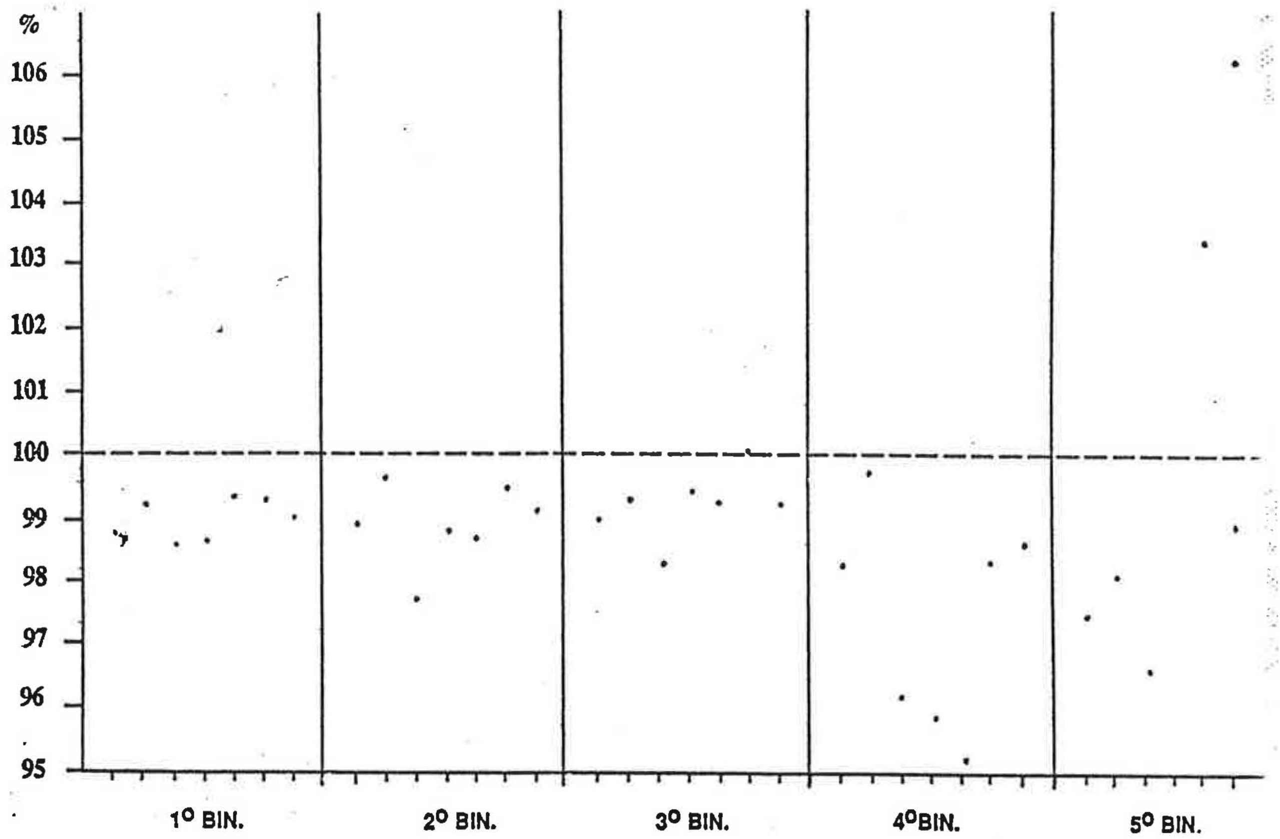

FIGURE 12 $\frac{\text{Bin temperature hours}}{\text{True temperature hours}}$ % for 1° to 5° bins.

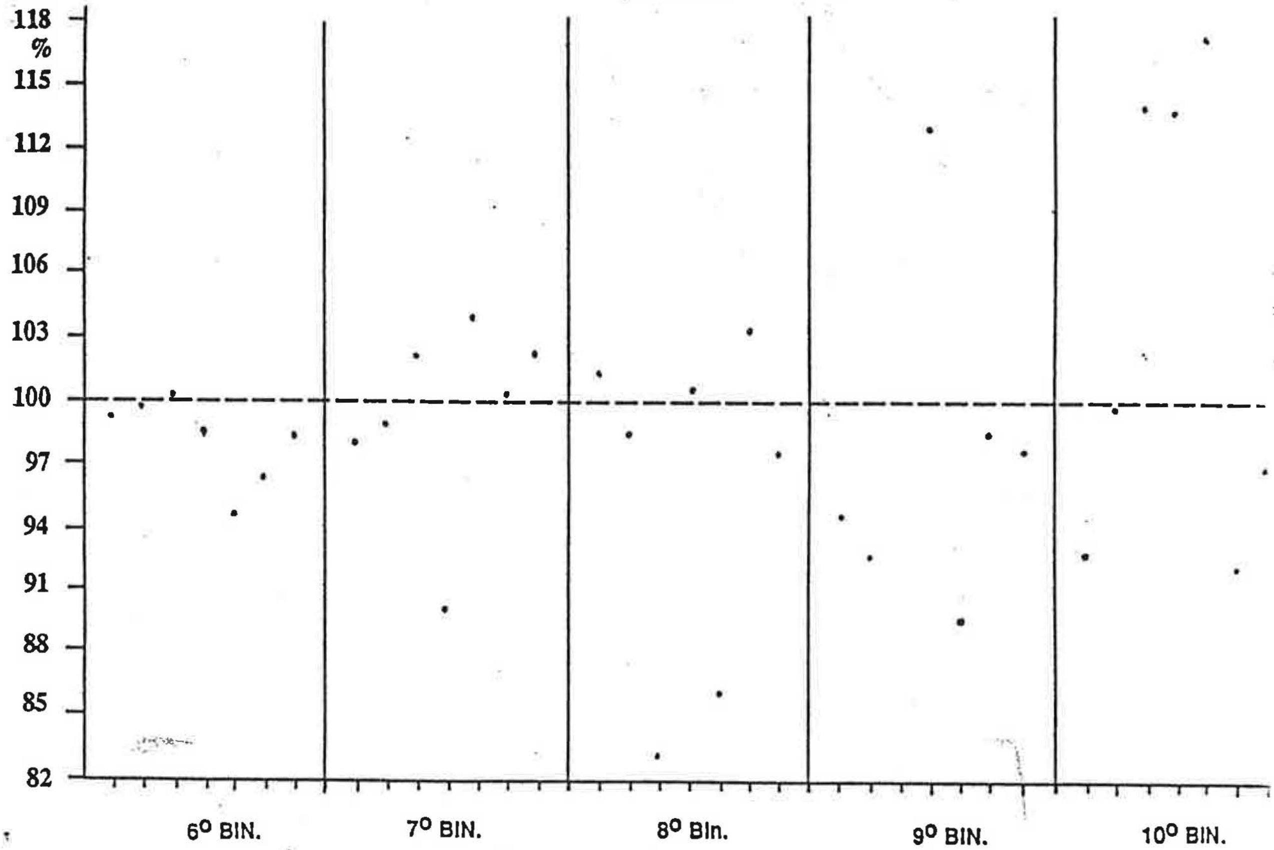

FIGURE 13 $\frac{\text{Bin temperature hours}}{\text{True temperature hours}}$ % for 6° to 10° bins.