ESTIMATING SOIL TEMPERATURES FOR USE IN BUILDING DESIGN

by

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ABSTRACT

Air conditioning costs are currently increasing at a faster rate than the initial costs of a building, and still, energy conservation is often considered a low priority objective during the design process. Alternatives in design are needed to reduce the energy requirements of maintaining a building. Using the soil as an isolater from the external environment is an alternative.

This report concerns a graphical representation of soil temperatures at a specific location through the use of the computer, and their use in estimating comfort zone depths. The soil temperatures and comfort zone depths may later be used in determining the feasibility of building underground.

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My research concerns developing computer programs to compute and graphically communicate soil temperatures. This information may then be applied to an alternative method of energy conservation in building design, the use of underground structures.

By estimating soil temperatures at a specific depth below grade for each day of the year, a range of soil temperatures is obtained. This range may then be compared to Olgyay's comfort zone (Appendix I). Temperature conditions falling within the zone indicates a depth at which a person will "feel comfortable". At this depth, only minimal heating and cooling would be needed, an important factor in regards to the energy conserving requirements of today's building design.

The air conditioning costs are inflating at a much faster rate than the initial costs of a building. The increase in air conditioning costs, chiefly caused by the increases in energy costs is a major reason for considering underground buildings.

The poor link between energy conservation and the finished design is in the weighing and ranking of the owners objectives. The owner is usually concerned with initial costs, image, functional circulation and only recently, with building orientation, an important factor when considering energy costs.

Methods of reducing heat gain and heat loss, may include; the reduction of glazing, application of solar screening or isolation of the building from the external environment.

The use of soil as an isolater from climatic condetions is not a new concept.[1] Adobe brick structures and cliff dwellings are known for their thermal ability to retain a constant temperature by having a high heat lag. The same advantages may be attained from bermed earth on the side of a building or to an even greater extent by locating the structure under the earth's surface.

To determine the feasibility of underground architecture: additional structural cost, psychological impact[2], and sociological acceptance. However, it is an alternate method of energy conservation and must be explored in depth to evaluate the possibilities of designing structures for use underground.

I concentrated my research on obtaining data useful in determining the effectiveness of underground architecture as an alternative to air conditioning. Using the Fluker equation, revised in Moreland's article (Appendix III), soil temperatures may be approximated for any location, depth,, and day form the air

1. Labs, Ken, "The Use of Earth Covered Buildings Through History", _Alternatives in Energy Conservation_, 1975, pp. 7-20.

2. Paulus, Paul, "On The Psychology of Earth Covered Buildings", _Alternatives in Energy Conservation_, 1975, pp. 65-70.

temperature. The equation is for flat bare soil; slope, shade, or ground cover were not considered. The computer takes the equation and determines at what depth a range of soil temperatures, estimated over a years period, will comply with Olgyay's comfort zone. Further development of the program located each town on a state map with its corresponding depth.

The program has made one major assumption, that heat generated within underground buildings does not significantly affect the soil temperature. Studying the interaction of soil temperature and heat sources within the building may be considered at a future time.

The purpose of the computer programs is not only to graphically communicate soil temperatures, but also to provide an overview of the uses of the data. By studying the computed map (CZM: Comfort Zone Map), it is possible to identify similar regions where the depth required to attain the "comfort zone" are equal. Therefore, this map gives possible clues into the feasibility of underground architecture in discrete regions.

A graph (SOGRAPH: soil temperature graphs), indicating soil temperatures at a given depth for a particular location, displays the method by which a depth is computed. By using the computer program, the user may visually determine at what depth the desired temperature range is located. By comparing the average annual air temperature to the average annual soil temperature, it may be noted the cooler the air temperatures, the less difference there is between the two temperatures. This is evident in the scattered cases available. In College Station, Texas, the annual average air temperature is 20.9°C and average annual soil temperature is 23.7°C, a difference of 2.8°C[3]. In Normadin, Quebec, Canada the annual average air temperature is 6.0°C and average annual soil temperature is 5.5°C a difference of only .5°C[4].

3. Fluker, B.J., "Soil Temperatures", Soil Science, Vol. 86, No. 1, July 1958, pp. 35 - 45.

4. Edey, S.N., and Joynt, M.J., "Mechanical and Thermal Characteristics of the Soil at Selected Agrometeorological Stations", Agrometeorology Research and Service, Chemistry and Biology Research Institute, Canada Department of Agriculture, Tech. Bull. 84, February 1975.

SOGRAPH

The purpose of SOGRAPH is to graphically communicate the method by which soil depths are computed and selected. The program used the average annual soil temperature in estimating the soil temperature at a given depth and date. Temperatures are calculated and plotted on every sixth day. This was convenient for print size, conserving CPU time, and ample for showing the path of soil temperatures plotted over the year.

SOGRAPH provides an excellent method for viewing the affects of depth on soil temperatures and the temperature lag incurred by the depth of the soil. The versatility of the program allows the user to select any series of depths by inputting the appropriate commands. Temperature ranges and amplitudes may then be determined from the graphs and used in selecting the depth that corresponds to the "comfort zone". Errors caused in inputting a town's air temperature (card 2) or temperature increments (card 3), result in a statement reading, "The temperature of town X exceeds the range of the graph".

General input data and format follows:

Card 1-	given	
Card 2-	columns 1-4	the number of town cards (towns and information to be used) to be used for computing output.
	columns 5-8	starting depth of computations.
	columns 9-12	last depth to be computed.

columns 13-16 increments of depth.

Card 3 the approximate range and increments of temperatures: one space equals one degree and increments are by 5 degrees. Degrees are in Fahrenheit and integer values should be entered into consecutive sets of four columns, ending in the last column of each set.

Card 4-(n-1) are the town cards. Each card designates a town by an index number given in the publication "Climatological Data".[5] Other data needed on this card is the average annual air temperature and location (longitude and latitude). The above mentioned publication also provides this information. The format is as follows:

columns 1-4	index number (integer)
columns 5-8	annual average air temperature. (real)
columns 9-12	longitudinal degrees (real)
columns 13-16	longitudinal minutes (real)
columns 17-20	latitude degrees (real)
columns 21-24	latitude minutes (real)

(For further clarification see figure 1)

Observations-

On each proceeding graph the user may determine if the temperature range complies with the "comfort zone". Also, as the depth increases, the temperature lag becomes obvious

5. "Climatological Data",U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Texas

and the benefits of the lag may be predicted. During late spring and early summer the soil is still under the influence of the cooler winter. The lingering coolness beneath the surface during the summer months is definitely an advantage of underground architecture. The converse to this is true of the winter. The soil, heated by the summer, remains warm at lower depths most of the winter.

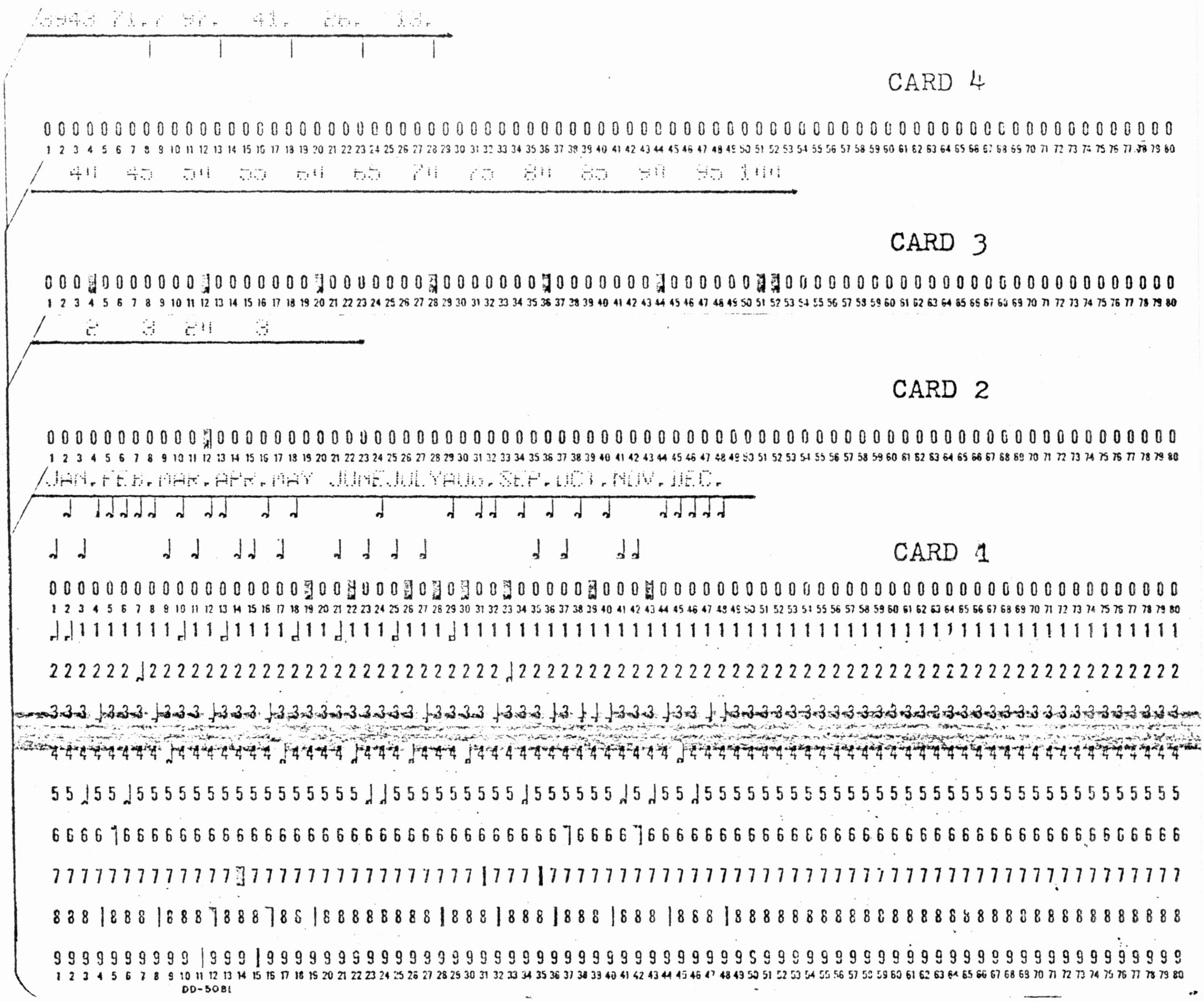


Figure 1 SOGRAPH Cards

```
//$OPTIONS
C
C   COMPUTER PROGRAM SOGRAF
C
C
C   SOGRAF ESTIMATES AND PLOTS SOIL TEMPERATURES
C   AT A GIVEN DEPTH FOR EVERY SIXTH DAY.
C
        DATA IB,IA,IC/' ','.','*'/
        DIMENSION INDEX(50),AIRTEM(50),XLONG(50),
       2XMIN(50),YLAT(50),YMIN(50),AYLAT(50),AXLONG(50),
       3IP(360),KDEPTH(50),TEMP(13),MONTH(12)
        INTEGER TEMP,TEM1,TEM2
C
C   "N" IS THE NUMBER OF THE TOWNS  TO BE GRAPHED.
C
C   "KKKK" IS THE FIRST DEPTH TO BE ESTIMATED AND "KKK" IS
C   THE LAST DEPTH.  KK1 IS THE INCREMENTS.
C
        READ(5,1)(MONTH(I),I=1,12),N,KKKK,KKK,KK1,
       2(TEMP(II),II=1,13)
      1 FORMAT(12A4/4I4/13I4)
C
        DO 80 J=1,N
        READ(5,2)INDEX(J),AIRTEM(J),XLONG(J),XMIN(J),
       2YLAT(J),YMIN(J)
      2 FORMAT(I4,5F5.1)
C
C   TITLE PAGE
C
C
        WRITE(6,90)
     90 FORMAT('1')
        DO 10 NN=1,25
     10 WRITE(6,91)
     91 FORMAT(1X)
        WRITE(6,92)INDEX(J),YLAT(J),YMIN(J),XLONG(J),XMIN(J),
       2AIRTEM(J)
     92 FORMAT(1X,T14,'SOIL TEMPERATURE PROFILE',///,
       2T15,'TOWN INDEX NUMBER=',I4,//,T17,
       3'LATITUDE ',F3.0,1X,F3.0,/,T16,'LONGITUDE ',
       4F4.0,1X,F3.0,//,T16,'ANNUAL AVERAGE AIR',/,T18,
       5'TEMPERATURE IS ',/,T14,F4.1,' DEGREES ',
       6'FAHRENHEIT')
        WRITE(6,90)
C
C   CHANGES FAHRENHEIT TO CENTIGRADE
C
        IF(AIRTEM(J).GT.30.)AIRTEM(J)=(AIRTEM(J)-32.)*
       25./9.
C
C   "AVGSOL" IS THE AVERAGE ANNUAL SOIL TEMPERATURE
C
        AVGSOL=AIRTEM(J)**2*(-.00168)+1.207*AIRTEM(J)-1.
C
C
        DO 70 K=KKKK,KKK,KK1
        KDEPTH(K)=K
C
C   HEADINGS FOR EACH PAGE
```

```
C
      WRITE(6,94)KDEFTH(K),(TEMF(L),L=1,13)
   94 FCRMAT(1X,'TEMPERATURES ARE CALCULATED AT ',I2,' FT',
     2/1X,I2,I5,9I5,I6,I5)
      DC 65 L=6,348,6
C
C  PREPARES GRAPH
C
      DC 20 M=1,85
   20 IP(M)=IB
      IP(L)=L
C
      DC 22 LL=30,330,30
      IF(IP(L).EC.LL) GC TC 31
   22 CCNTINUE
C
      DC 23 LLL=18,348,30
      IF(IP(L).EC.LLL) GC TC 35
   23 CCNTINUE
      GC TC 32
   35 LLLL=(LLL+12)/30
      WRITE(6,95)MCNTH(LLLL)
   95 FCRMAT('+',64X,A4)
      GC TC 32
C
   31 DC 30 KK=2,62
   30 IP(KK)=IA
      GC TC 61
   32 DO 50 KK=2,62,5
   50 IP(KK)=IA
C
   61 TEM1=AVGSOL+12.*(2.71828**(-.134*K))*(SIN
     2(.017*(L-7.828*K-107.)))
C
C  ESTIMATES SCIL TEMPERATURES AT DEPTH "K"
C  CN DAY "L"
C
      TEM1=TEM1*9./5.+32.
C
C  CHANGES CENTIGRADE TO FAHRENHEIT.
C
      N1=(TEM1-TEMP(1))
C
      IF(N1.LT.0)GC TC 79
C
      IP(N1)=IC
C
C  PRINTS CUTPUT
C
      WRITE(6,93)(IP(M),M=1,85)
   93 FCRMAT(1X,85A1)
   65 CCNTINUE
      WRITE(6,90)
   70 CCNTINUE
      GC TC 80
   79 WRITE(6,97)INDEX(J)
   97 FCRMAT(1X,////,10X,'THE TCWN OF ',
     2I4,'HAS TEMPERATURES',//10X,
     2'LESS THAN THCSE DESIGNATED CN THE GRAPH.')
   80 CCNTINUE
      WRITE(6,90)
```

```
      STOP
      END
//$DATA
```

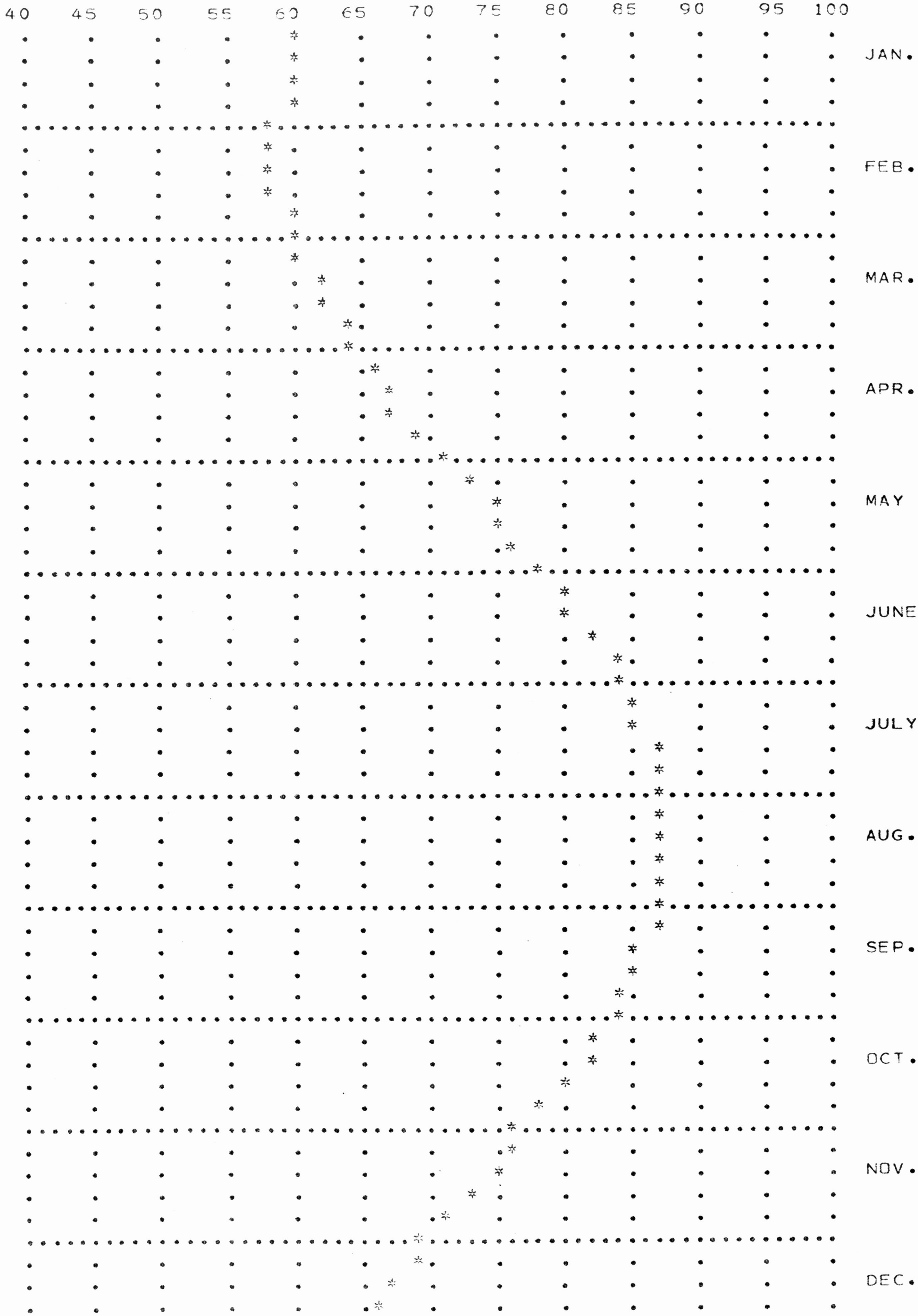
SOIL TEMPERATURE PROFILE

TOWN INDEX NUMBER=3943

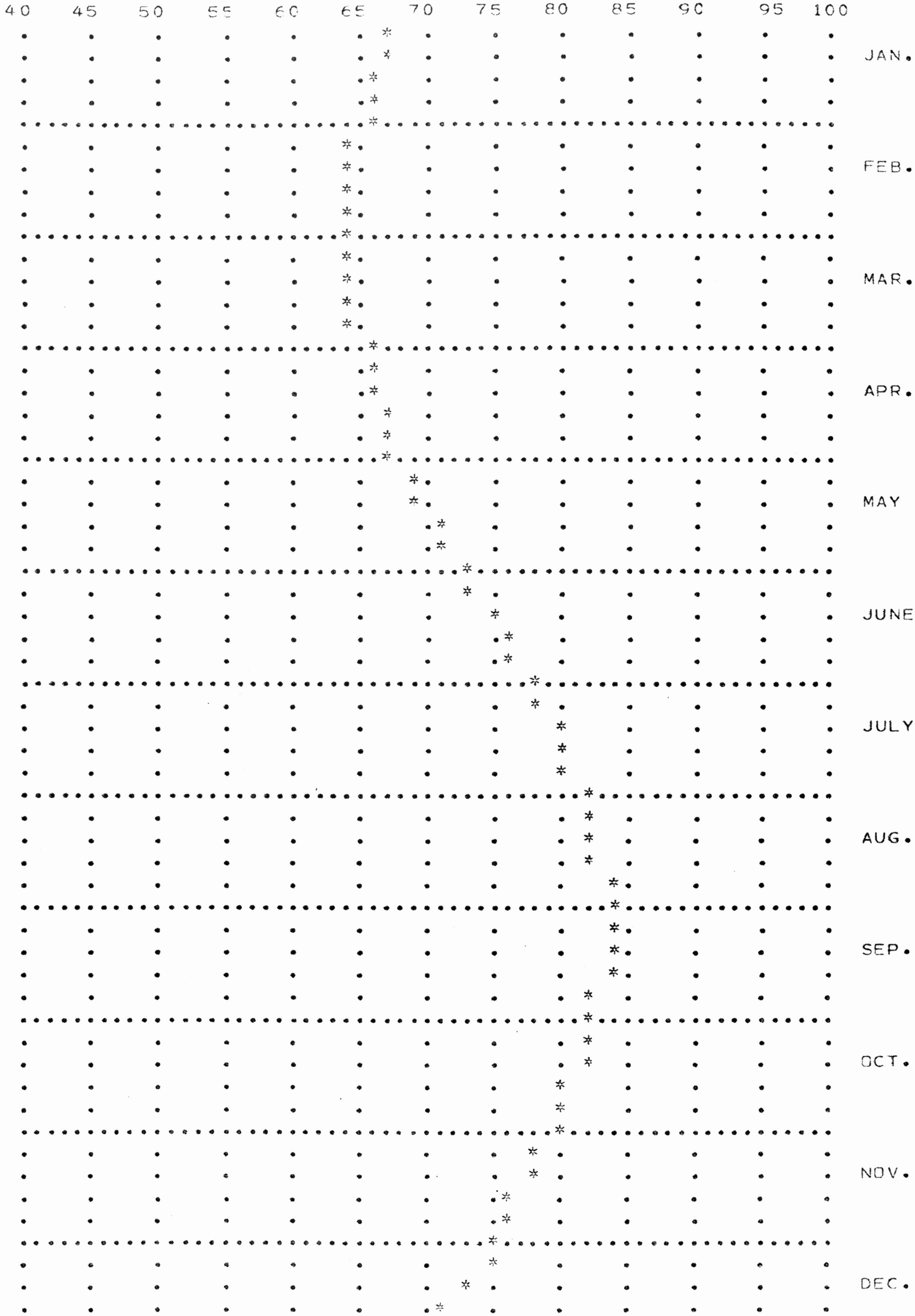
LATITUDE 26. 13.
LONGITUDE 97. 41.

ANNUAL AVERAGE AIR
TEMPERATURE IS
71.7 DEGREES FAHRENHEIT

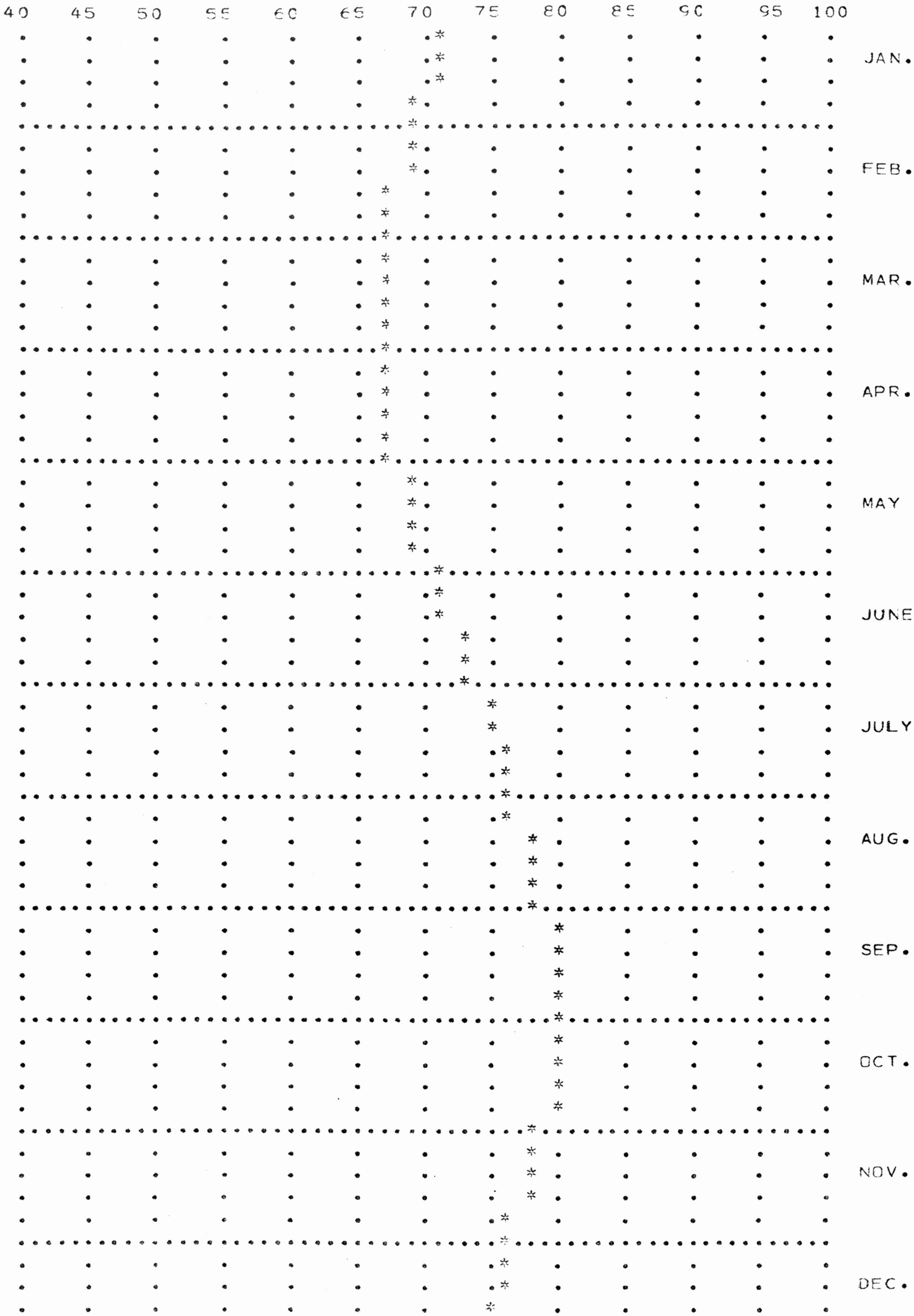
TEMPERATURES ARE CALCULATED AT 3 FT



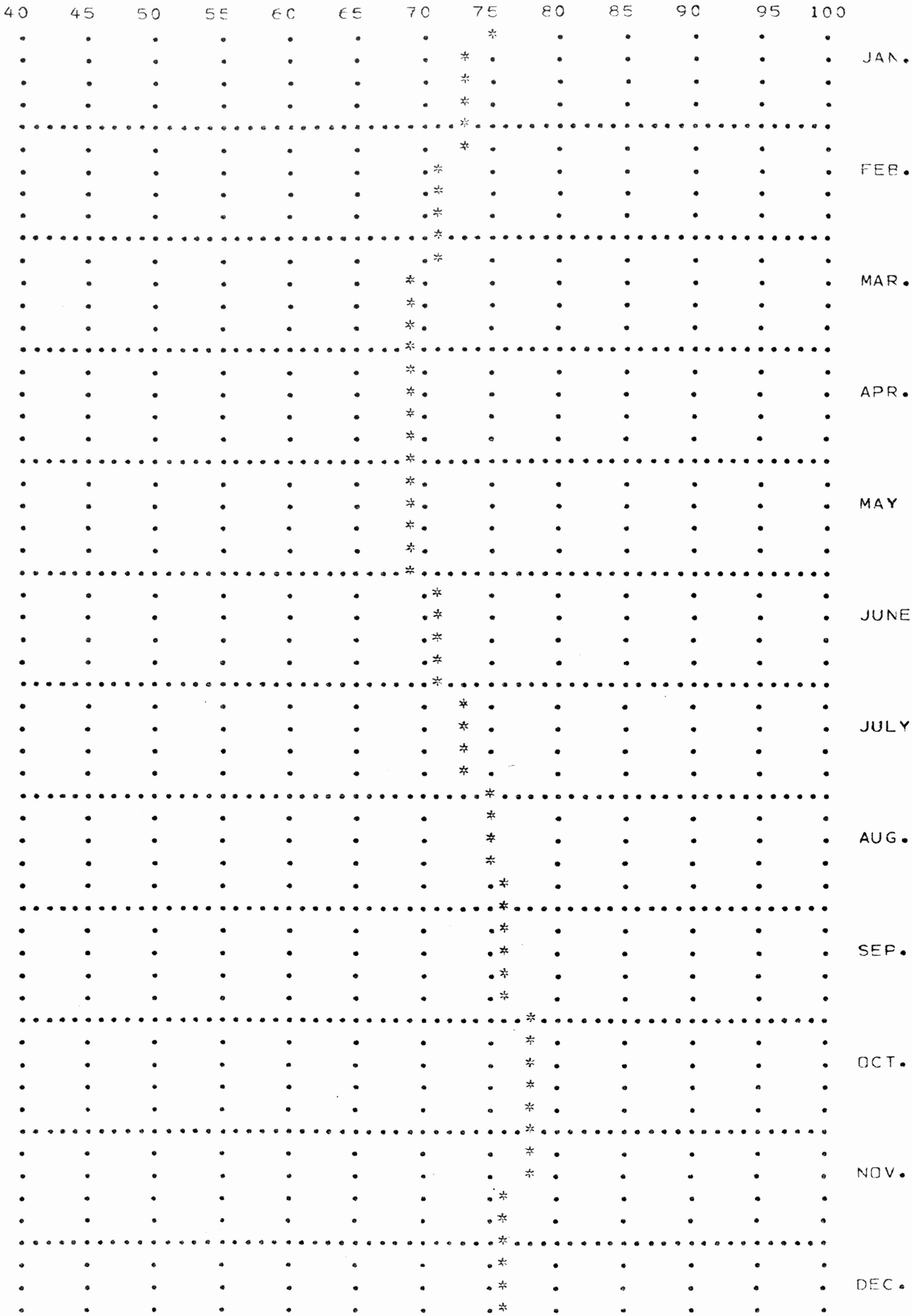
TEMPERATURES ARE CALCULATED AT 6 FT



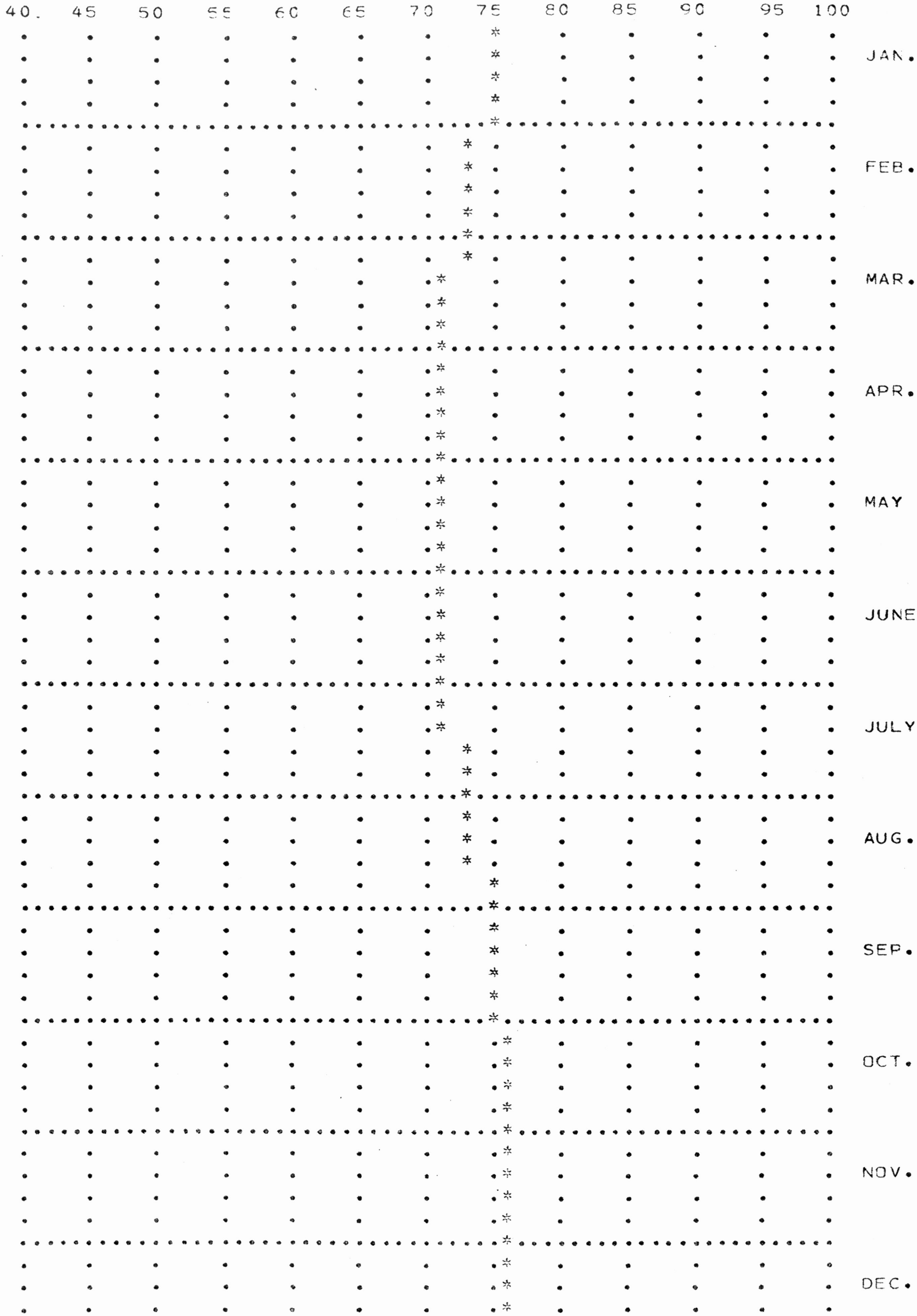
TEMPERATURES ARE CALCULATED AT 9 FT



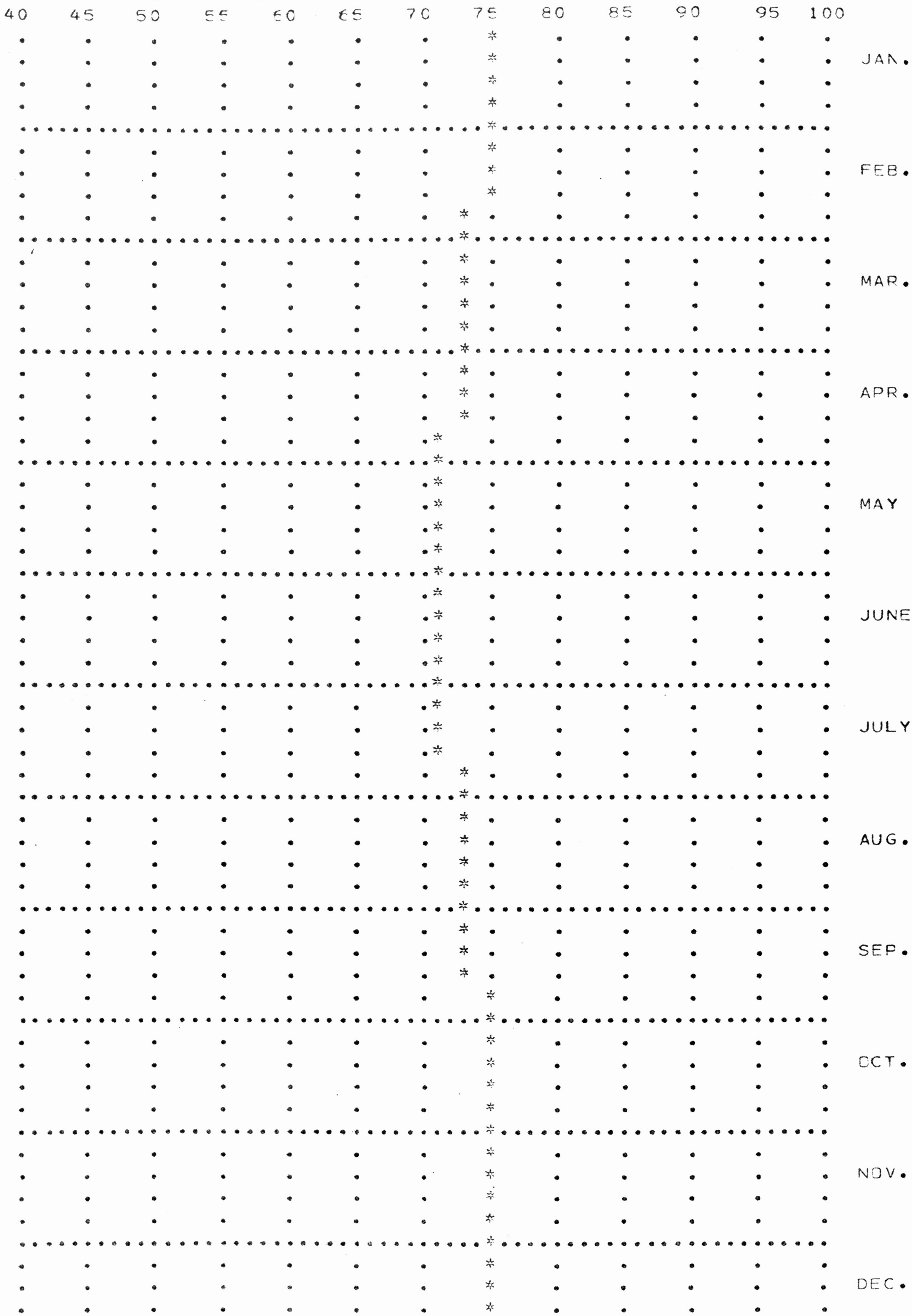
TEMPERATURES ARE CALCULATED AT 12 FT



TEMPERATURES ARE CALCULATED AT 15 FT



TEMPERATURES ARE CALCULATED AT 18 FT



CZM

The CZM (Comfort Zone Map) computer program locates towns on a map of their respective state. A letter corresponding to the minimum depth, required for retaining the "comfort zone", (see Appendix I), is printed at the town's location. The map may then be used to determine regions of similar depths and possible sites for underground habitats.

The map is generated from the northern boundary of the state. Towns are designated by the letter depth calculated from Moreland's equation (Appendix III) and printed line by line for the length of one page. An acetate overlay is used to show the perimeter of the state.

The required input for the CZM program is as follows:

Card 1- given: letter values corresponding to depths.

Card 2- "m" is the number of cards used to plot the state's perimeter. Place the number to the far left of columns 1-5. (integer)

Card 3- "n" is the total number of cards used to plot perimeter points. (integer)

Card 4- consists of the vertical and horizontal ratio, the minimum latitude and the minimum longitude. The map is given a scale by the user relating proportionally to the vertical and horizontal dimension. The varibles should have a ratio of 10 to 9 if the output is printed at eight lines per inch. The vertical figures are punched in columns 1-5 and horizontal figures in columns 6-10. The minimum longitude and the minimum latitude used on the map should be punched in columns 11-15 and 16-20 respectively. (real)

Cards (5-n)- describe the town; location and annual average air temperature available from "Climatalogical Data".

columns 1-4 index number (integer)
5-9 average air temperature (real)
10-14 longitude degrees (real)
15-19 longitude minutes (real)
20-24 latitude degrees (real)
25-29 latitude minutes (real)

(For further clarification see Figure 2)

Observations-

The CZM program prints the computed depths on a map of the given state. Patterns are defined with respect to soil depths and air temperatures. The overlays help interpret the data, as distinct areas of possible use for underground building. These areas do not dictate definite lines or divisions, but only give a rough idea into the most practical sites.

Lines that mark drastic changes in depth may be due to a very obvious change in contour. On the west side of the example program, such a case occurs. Regions of a nominal depth of 8' to 10' are bordered by areas requiring more that 20' of soil. This may be checked by looking at a map of the state showing contours. In this case, the region is mountainous.

The southeastern part of the map is also effected by a geographical condition. The depths along this border appear to be subdued, with little change because of latitude difference. The gulf coast is a definite influence on thesoil depth.

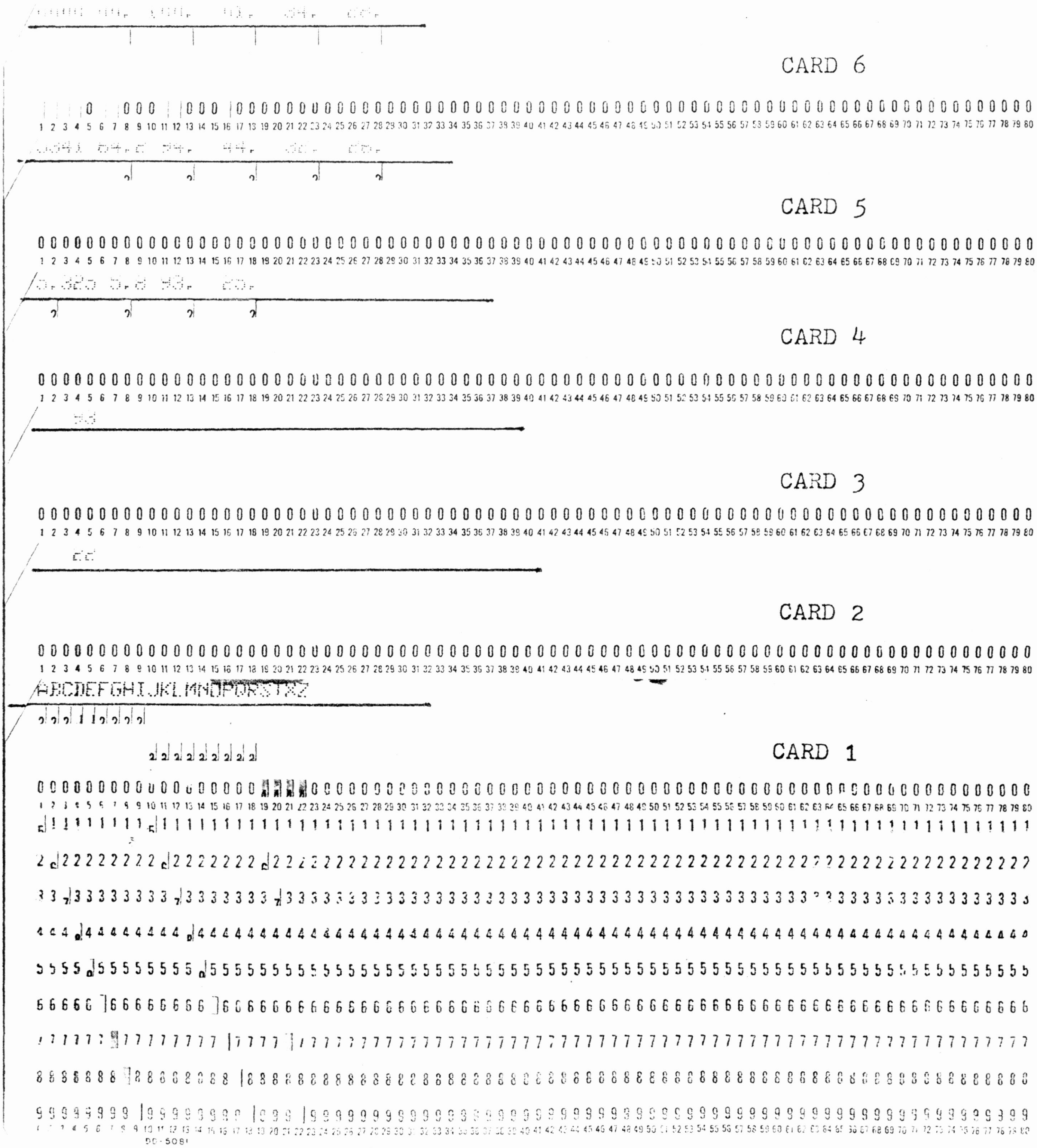


Figure 2 CZM Cards

```
//$OPTIONS
C
C   COMPUTER PROGRAM CZM
C
C
C   CZM DETERMINES THE DEPTH AT WHICH SOIL TEMPERATURES
C   REMAIN IN THE COMFORT ZONE YEAR AROUND
C
          DATA IB,IA,IC/' ','*','+'/
          REAL LON,LAT,LONG
          DIMENSION INDEX(150),AIRTEM(150),XLONG(150),
         2XMIN(150),YLAT(150),YMIN(150),AYLAT(150),AXLONG(150),
         3IP(132),KDEPTH(150)
          READ(5,11)(KDEPTH(J),J=1,22),M,N,AA,BB,LON,LAT
       11 FORMAT(22A1/I5/I5/4F5.3)
          READ(5,1)(INDEX(I),AIRTEM(I),XLONG(I),XMIN(I),
         2YLAT(I),YMIN(I),I=1,N)
        1 FORMAT(I4,5F5.1)
          WRITE(6,20)
       20 FORMAT('1')
          I=61
          LONG=LON-8.
C
C   TITLE PAGE
C
          WRITE(6,26)
       26 FORMAT(1X,//////////////////////////,
         2T13,'SOIL DEPTHS FOR ATTAINING
         2',//T13,'THE COMFORT ZONE IN TEXAS')
          WRITE(6,20)
          L=M+1
C
C   PRINTS AND RANKS TOWNS IN NUMERICAL ORDER
C
          CALL BSORT(INDEX,AIRTEM,XLONG,XMIN ,YLAT,
         2YMIN,N,L)
          WRITE(6,301)
      301 FORMAT('0',T6,'TOWN',T15,'LONGITUDE',
         2T30,'LATITUDE',T45,'AVG. ANN. AIR TEMP.')
          DO 302 J=M,N
      302 WRITE(6,300)INDEX(J),XLONG(J),XMIN(J),
         2YLAT(J),YMIN(J),AIRTEM(J)
      300 FORMAT(T6,I4,T15,F4.0,2X,F4.0,T30,F4.0,
         22X,F4.0,T45,F6.2,//)
          WRITE(6,20)
          GO TO 5
        8 I=I-1
          IF(I.LT.1)GO TO 203
        5 DO 2 K=1,105
        2 IP(K)=IB
          KK=0
          DO 3 J=1,N
C
C   DETERMINES LOCATIONS OF TOWNS FOR PLOTTING.
C
          AYLAT(J)=YLAT(J)+YMIN(J)/60.
          IY=(AYLAT(J)-LAT)*AA
          IF(IY.NE.I)GO TO 3
          AXLONG(J)=XLONG(J)+XMIN(J)/60.
          IX=(AXLONG(J)-LON)*(-1.*BB)+LONG
```

```
          IP(IX)=IC
C
C   PLOTS MAP
C
          IF(AIRTEM(J).EQ.0..AND.KK.EQ.0)GO TO 12
          IF(AIRTEM(J).EQ.0..AND.KK.NE.0)GO TO 30
C
C   CHANGES FAHRENHEIT TO CENTIGRADE
C
          IF(AIRTEM(J).GT.30.)AIRTEM(J)=(AIRTEM(J)-32.)
        2*5./9.
          AVGSOL=AIRTEM(J)**2*(-.00168)+1.207*AIRTEM(J)-1.
C
C   "K" IS THE DEPTH AT WHICH SOIL TEMPERATURES
C   ARE BEING ESTIMATED AT.
C
          DO 36 K=1,60
C
C   "L" IS THE DAY    AT WHICH SOIL TEMPERATURES
C   ARE BEING ESTIMATED AT.
C
          DO 70 L=1,366,6
          TEMP=AVGSOL+12.*(2.71828**(-.134*K))*(SIN(.017*
        2(L-7.828*K-107.)))
C
C   CHECKING IF ESTIMATE IS IN COMFORT ZONE
C
          IF(TEMP.LT.18..OR.TEMP.GT.27.)GOTO36
       70 CONTINUE
C
C   DETERMINES WHAT LETTER
C   DEPTH TO CORRESPOND TO FEET.
C
          IF(K.GT.20.AND.K.LT.101)GO TO 34
          IP(IX)=KDEPTH(K)
          GO TO 35
       34 IP(IX)=KDEPTH(21)
       35 IF(KK)149,149,147
       36 CONTINUE
          IP(IX)=KDEPTH(22)
          IF(KK)149,149,147
C
C   PRINTS OUTPUT
C
       12 WRITE(6,13)(IP( M),M=1, 85)
       13 FORMAT(1X, 85A1)
          GO TO 9
       30 WRITE(6,31)(IP(M),M=1, 85)
       31 FORMAT('+', 85A1)
          GO TO 9
      147 WRITE(6,148)(IP(M),M=1, 85)
      148 FORMAT('+', 85A1)
          GO TO 9
      149 WRITE(6,150)(IP( M),M=1, 85)
      150 FORMAT(1X, 85A1)
        9 KK=KK+1
        3 CONTINUE
          IF(KK)7,7,8
        7 WRITE(6,21)
       21 FORMAT(1X)
          GO TO 8
```

```
  203 CONTINUE
C
C  KEY
C
      WRITE(6,22)
   22 FORMAT(1X,///,5X,'KEY',/5X,
     2'_________________________________')
      K=1
   23 L=K+1
      J=L+1
      WRITE(6,24)KDEPTH(K),K,KDEPTH(L),L,KDEPTH(J),J
   24 FORMAT(1X,//5X,A1,' = ',I2,' FT.',8X,A1,' = ',
     2I2,' FT.',8X,A1,' = ',I2,' FT.')
      K=K+3
      IF(K.LT.20) GO TO 23
      WRITE(6,25)
   25 FORMAT(1X,/,5X,'X IS BETWEEN 21 FT. AND ',
     2'100 FT.',//,5X,'Z NEVER REMAINS WITHIN THE  ',
     3'BIOCLIMATIC ZONE',/5X,'ALL YEAR UNLESS AIRCONDI-',
     4'TIONING IS USED OR ALTERNATIVE',/5X,
     5'SURFACE CONDITIONS ARE PRESENT')
      WRITE(6,20)
      STOP
      END
C
C
C  BUBBLE SORT RANKS INDEX NUMBERS IN
C  NUMERICAL ORDER.
C

      SUBROUTINE BSORT(M,A,B,C,D,E,N,L)
      DIMENSION M(150),A(150),B(150),C(150),D(150),
     2E(150)
      DO  1 I=L,N
      MM=M(I)
      AA=A(I)
      BB=B(I)
      CC=C(I)
      DD=D(I)
      EE=E(I)
      M(I)=M(I-1)
      A(I)=A(I-1)
      B(I)=B(I-1)
      C(I)=C(I-1)
      D(I)=D(I-1)
      E(I)=E(I-1)
      J=I-2
    2 IF(J.LT.1) GO TO 4
      IF(MM.LT.M(J)) GO TO 3
    4 M(J+1)=MM
      A(J+1)=AA
      B(J+1)=BB
      C(J+1)=CC
      D(J+1)=DD
      E(J+1)=EE
      GO TO 1
    3 M(J+1)=M(J)
      A(J+1)=A(J)
      B(J+1)=B(J)
      C(J+1)=C(J)
      D(J+1)=D(J)
```

```
      E(J+1)=E(J)
      J=J-1
      GO TO 2
    1 CONTINUE
      RETURN
      END
```

```
//$DATA
```

SOIL DEPTHS FOR ATTAINING

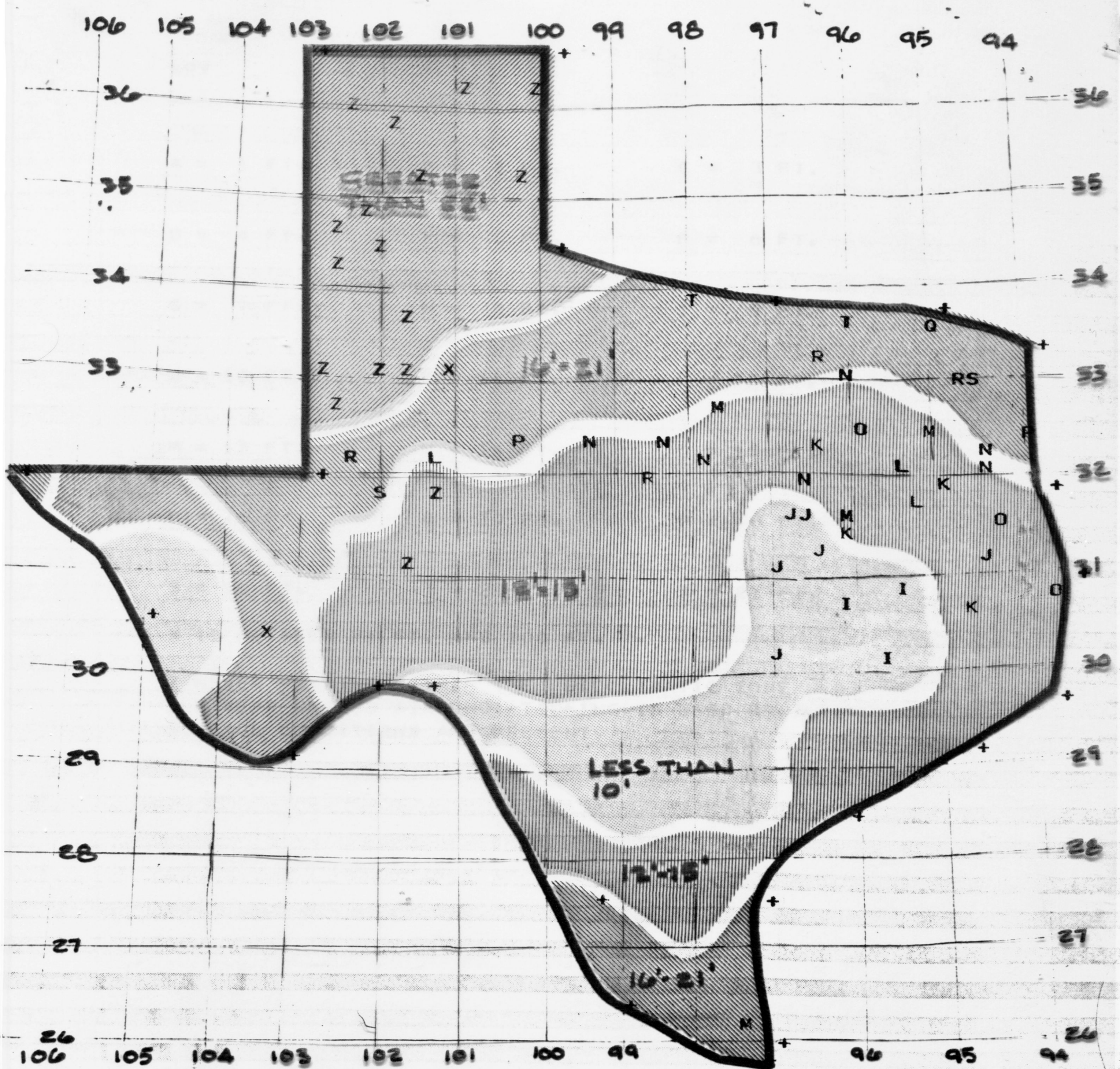
THE COMFORT ZONE IN TEXAS

TOWN	LONGITUDE		LATITUDE		AVG. ANN. AIR TEMP.
16	99.	41.	32.	26.	64.00
174	103.	40.	30.	21.	61.00
211	101.	42.	35.	14.	57.70
248	102.	32.	32.	19.	62.70
404	95.	50.	32.	10.	65.20
786	101.	27.	32.	15.	64.90
1128	102.	16.	33.	11.	58.80
2240	102.	33.	36.	1.	54.80
2463	102.	13.	34.	33.	55.80
2617	101.	58.	35.	52.	55.90
3368	102.	43.	34.	38.	56.10
3445	101.	28.	31.	52.	60.70
3618	97.	24.	28.	40.	69.70
3622	97.	27.	29.	30.	67.70
3770	96.	32.	31.	31.	65.40
3943	97.	41.	26.	13.	71.70
4081	94.	45.	32.	11.	63.90
4084	96.	5.	30.	6.	66.70
4098	102.	28.	34.	48.	55.20
4182	97.	7.	32.	1.	64.10

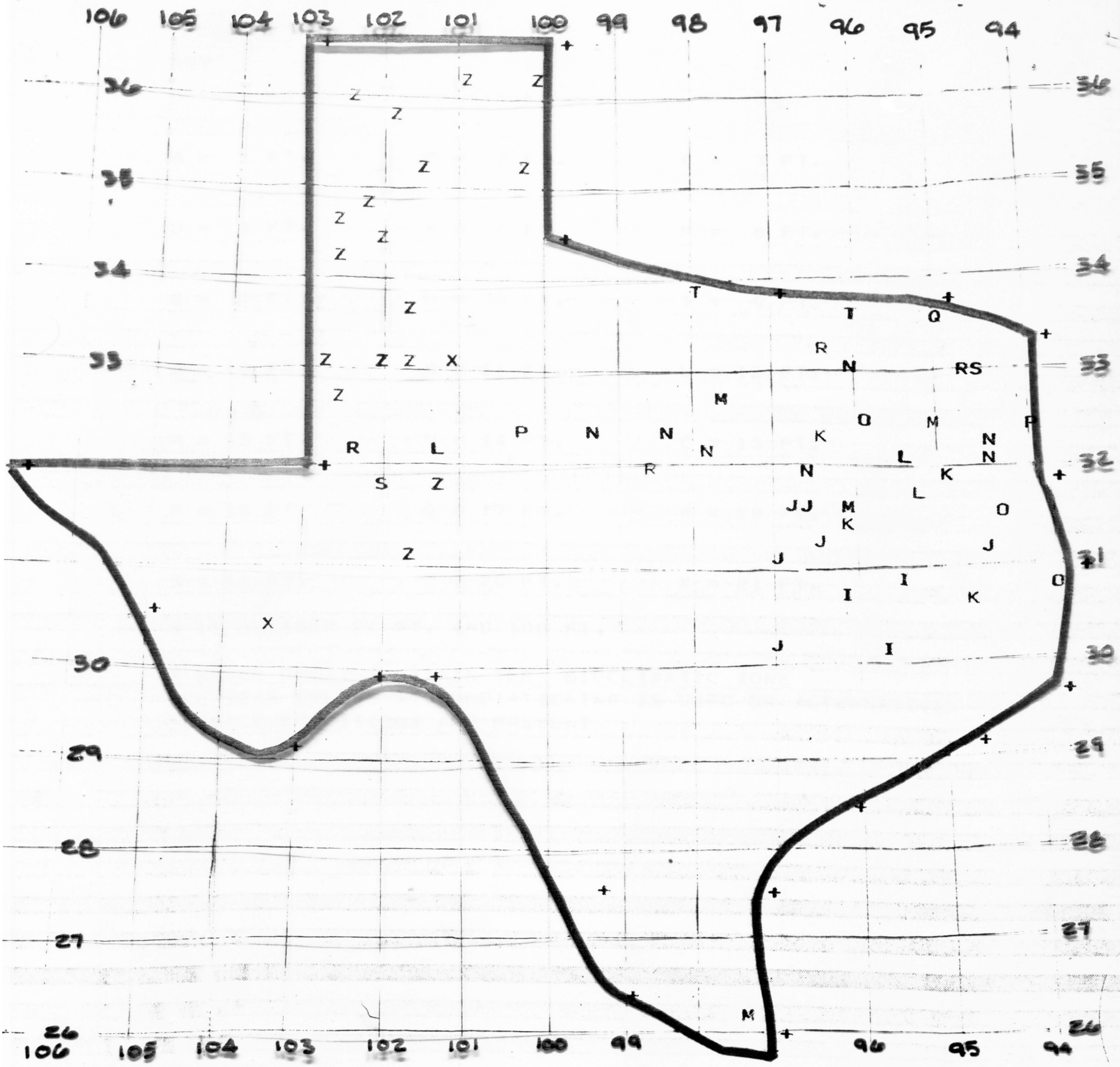
4254	99.	8.	29.	21.	67.40
4382	96.	33.	30.	43.	66.70
4525	95.	17.	31.	58.	65.90
4563	94.	2.	30.	54.	63.60
4605	98.	24.	30.	17.	64.80
4670	99.	47.	30.	30.	65.10
4705	96.	19.	32.	35.	63.80
4903	96.	52.	29.	54.	68.00
5013	101.	56.	31.	3.	60.70
5018	93.	11.	31.	3.	62.90
5048	101.	34.	29.	48.	66.60
5060	99.	28.	27.	31.	72.00
5113	99.	46.	29.	44.	65.10
5247	100.	16.	36.	14.	56.00
5271	94.	56.	30.	44.	65.40
5341	94.	44.	32.	26.	64.20
5410	101.	49.	33.	42.	59.50
5424	94.	45.	31.	14.	66.00
5477	95.	55.	30.	57.	67.40
5611	96.	51.	31.	20.	66.30

5618	94.	21.	32.	32.	63.40
5766	96.	37.	33.	12.	64.00
5770	100.	33.	35.	14.	58.10
5869	96.	29.	31.	41.	64.70
5890	102.	12.	31.	56.	62.50
5954	95.	33.	32.	35.	64.30
5958	98.	4.	32.	47.	64.60
6108	95.	0.	33.	10.	62.50
6119	95.	14.	33.	11.	62.90
6135	102.	43.	34.	14.	56.10
6176	94.	39.	31.	36.	63.60
6330	102.	50.	31.	16.	62.70
6757	95.	39.	31.	47.	64.90
6794	95.	34.	33.	40.	63.10
7028	96.	57.	33.	24.	62.70
7074	102.	50.	33.	11.	58.30
7206	101.	24.	33.	12.	61.60
7426	98.	42.	32.	28.	64.20
7633	98.	58.	32.	6.	62.90
7743	100.	32.	32.	27.	63.30

7744	97.	1.	31.	43.	66.00
8201	102.	40.	32.	43.	59.70
8274	96.	37.	33.	39.	62.40
8523	101.	11.	36.	11.	57.70
8624	98.	12.	32.	17.	64.00
8818	101.	49.	33.	10.	59.40
8851	97.	24.	30.	5.	66.00
8910	97.	21.	31.	6.	66.10
9419	97.	13.	31.	37.	66.30
9522	96.	51.	32.	24.	65.80
9729	98.	29.	33.	58.	62.30
0	99.	28.	27.	31.	0.00



106 105 104 103 102 101 100 99 98 97 96 95 94
36
35
34
33
32
31
30
29
28
27
26
GREATER THAN 22'
16'-21'
12'-15'
LESS THAN 10'
12'-15'
16'-21'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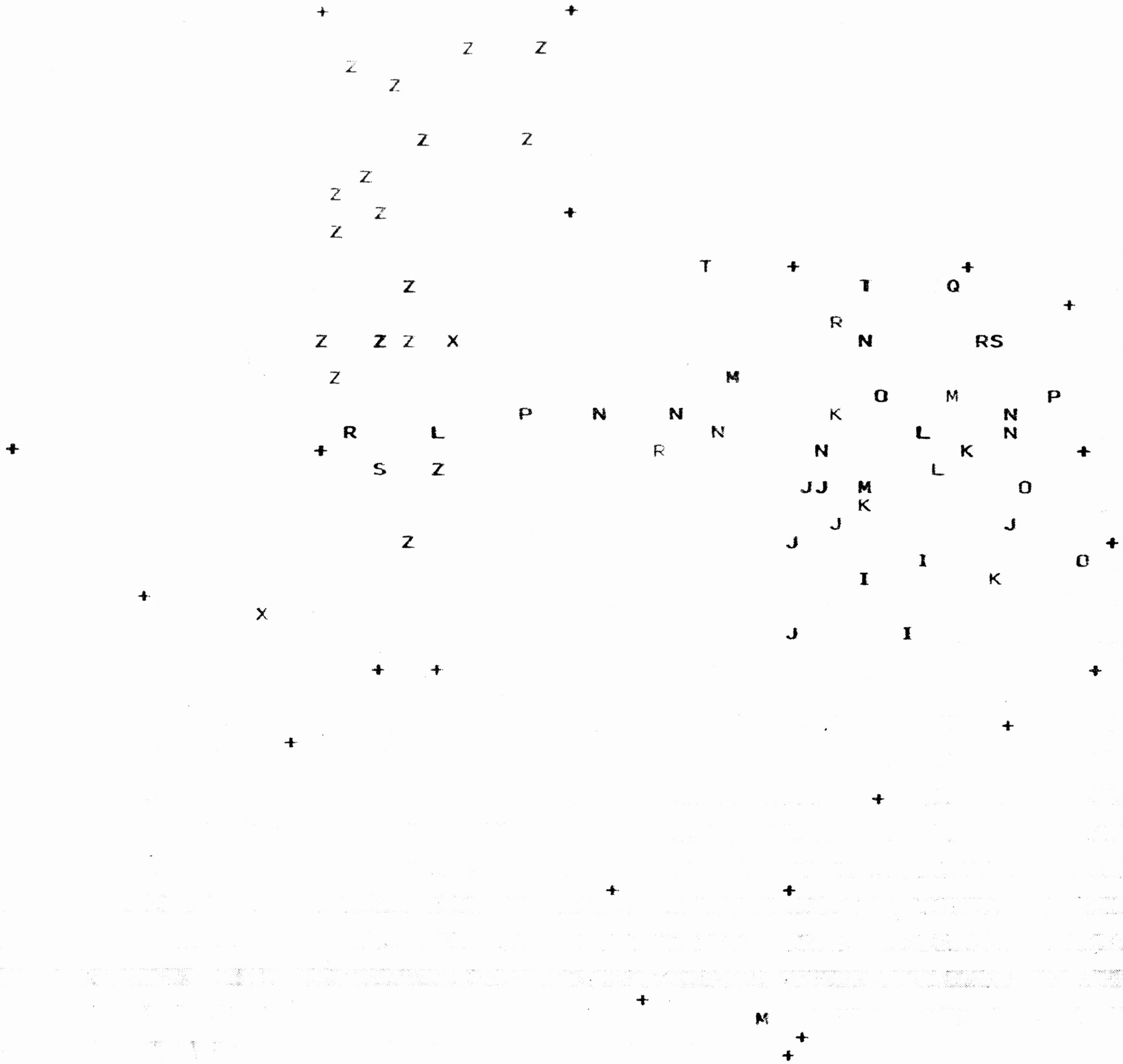
36
35
34
33
32
31
30
29
28
27
26
106 105 104 103 102 101 100 99 96 95 94
Z Z Z Z Z Z Z Z Z Z Z Z Z Z Z Z Z Z
X X
T T Q
R N RS
M O M P
P N N N K N N
R L R N L K
S Z L
JJ M K O
J J
J I O
I K
J I
M



KEY

A = 1 FT.	B = 2 FT.	C = 3 FT.
D = 4 FT.	E = 5 FT.	F = 6 FT.
G = 7 FT.	H = 8 FT.	I = 9 FT.
J = 10 FT.	K = 11 FT.	L = 12 FT.
M = 13 FT.	N = 14 FT.	O = 15 FT.
P = 16 FT.	Q = 17 FT.	R = 18 FT.
S = 19 FT.	T = 20 FT.	X = 21 FT.

X IS BETWEEN 21 FT. AND 100 FT.

Z NEVER REMAINS WITHIN THE BIOCLIMATIC ZONE
ALL YEAR UNLESS AIRCONDI-TIONING IS USED OR ALTERNATIVE
SURFACE CONDITIONS ARE PRESENT

SOLTEM

The SOLTEM (Soil Temperature) program is the basic computer program of the three. The computed information is used in selecting the depth where the range of temperatures complies with the comfort zone. The printout includes the maximum and minimum temperatures for a given depth and location, and the days they occurred.

The required input for the SOLTEM program is as follows:

Cards 1-(n-1) are the town cards, identical to the previous cards describing a town's location and annual average air temperature, available from "Climatological Data".

Card n given. (For further clarification see Fig. 3)

Observations-

The output data displays the relation between air temperature and the estimated soil depth. By using dummy values with increments of one-halfdegree, the optimum average air temperature is computed to be between 67.5°F. and 68.5°F. corresponding to a depth of 8 feet. The temperature range at this depth was from 65°F. to 80°F., the complete range of the comf ort zone.

As the temperature increased from 68°F. (or decreased), the temperature amplitude decreased. In the case of cooler temperatures the problem encountered was trying to remain within the cool end of the comfort zone. Increasing the depth solved the problem, however at the expense of a greater soil depth. A similar situation occurs with the warmer temperatures, amplitude decreases as the depth increases. Here the problem is at the warm end of the zone. The depth must continue to drop in order to accomodate the increasing air temperature. At less than 10^{o}, plus or minus from the optimum air temperature of 68^{o}F., the amplitude has decreased to one degree and the depth has increased to over 30 feet. For underground habitats this is structurally unfeasible, particularly due to cost. Another varible must be introduced to reduce the estimated depth.

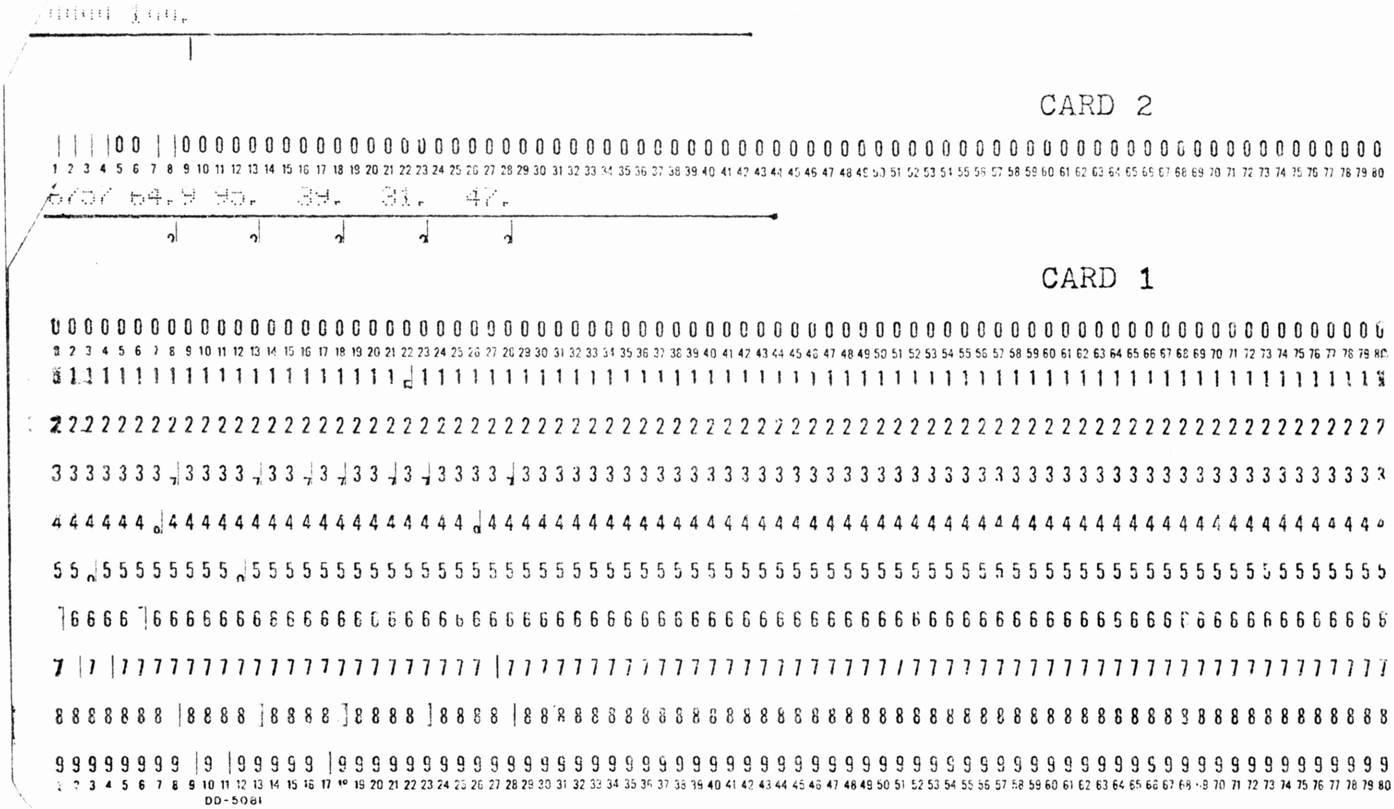


Figure 3 SOLTEM Cards

```
//$OPTIONS
C
C  COMPUTER PROGRAM SOLTEM
C
C
C  APPROXIMATE SOIL TEMPERATURES ARE CALCULATED FOR
C  EVERY SIXTH DAY TO CONSERVE CPU TIME. THE OUTPUT
C  INCLUDES THE SOIL TEMPERATURE MAXIMUM AND MINIMUM
C  AND THE DAYS THAT THEY  OCCURRED AND AT THE DEPTH
C  THEY OCCURRED FOR EACH TOWN INDEX NUMBER.
C
C
        II=0
        WRITE(6,95)
     95 FORMAT('1')
        WRITE(6,26)
     26 FORMAT(1X,///////////////////////////,
       2T13,'SOIL DEPTHS FOR ATTAINING
       2',//T13,'THE COMFORT ZONE IN TEXAS')
        WRITE(6,95)
        DO201I=1,500
C
C  THE TOWN AND ANNUAL AVERAGE TEMPERATURE ARE READ.
C
      6 READ(5,100) INDEX,AIRTEM
    100 FORMAT(I4,F5.1)
        II=II+8
        IF(II.GT.56)WRITE(6,95)
        IF(II.GT.56) II=0
C
C  TRAILER CARD .
C
        IF(AIRTEM.EQ.100.)GOTO203
C
C  IF THE TEMPERATURE IS IN FAHRENHEIT,
C  IT IS CHANGED TO CENTIGRADE.
C
        IF(AIRTEM.GT.30.)AIRTEM=(AIRTEM-32.)*5./9.
        AVGSOL=AIRTEM**2*(-.00168)+1.207*AIRTEM-1.
     30 K=0
        MINDAY=0
        MAXDAY=0
C
C  SOIL TEMPERATURES ARE APPROXIMATED FOR THE
C  DEPTH "K".
C
        DO 36 K=1,60
     31 J=0
        SOLMIN=30.
        SOLMAX=(-20.)
        DO 70 J=1,366,6
C
C  "TEMP" IS THE SOIL TEMPERATURE AT A DEPTH OF
C  "K" FEET ON DAY "J".
C
        TEMP=AVGSOL+12.*(2.71828**(-.134*K))*(SIN(.017*
       2(J-7.828*K-107.)))
C
C  IF TEMPERATURE EXCEEDS COMFORT ZONE,
C  DEPTH IS INCREMENTED.
```

```
C
      IF(TEMP.LT.18..OR.TEMP.GT.27.)GOTO36
      IF(TEMP.LT.SOLMIN)GOTO50
      IF(TEMP.GT.SOLMAX)GOTO60
      GOTO70
C
C  DETERMINE INFORMATION
C
   50 SOLMIN=TEMP
      MINDAY=J
      GOTO70
   60 SOLMAX=TEMP
      MAXDAY=J
   70 CONTINUE
   71 KDEPTH=K
      GOTO149
   36 CONTINUE
      GOTO200
C
C  CHANGE CENTIGRADE TO FAHRENHEIT.
C
  149 AIRTEM=AIRTEM*9./5.+32.
      SOLMIN=SOLMIN*9./5.+32.
      SOLMAX=SOLMAX*9./5.+32.
C
C  PRINT OUT
C
  150 WRITE(6,151)INDEX,AIRTEM,SOLMIN,MINDAY,SOLMAX,
     2MAXDAY,KDEPTH
  151 FORMAT(1X,//,3X,'THE TOWN OF ',I4,' WITH A MEAN ',
     2'AIR',/,3X,'TEMPERATURE OF',F6.2,' MAY BE CONSID',
     3'ERED FOR ',/,3X,'UNDERGROUND CONSTRUCTION. THE ',
     4'SOIL TEMPERATURES ',/,3X,'MINIMUM WAS ',F6.1,
     5' ON THE ',I3,' DAY OF THE YEAR AND ',/,3X,'THE SOIL',
     6'TEMPERATURE MAXIMUM OF ',F6.2,' OCCURRED ON ',/,
     73X,'THE ',I3,' DAY AT A DEPTH OF ',I2,' FT.')
      GOTO201
  200 WRITE(6,202)INDEX
  202 FORMAT(1X,//,3X,'THE TOWN OF',I5,' IS DETERMINED',
     2' TO',/,3X,'BE UNECONOMICAL FOR AN UNDERGROUND ',
     3'RESIDENCE ',/,3X,'UNLESS ALTERNATIVE MEASURES ARE ',
     4'TAKEN TO ALTER',/,3X,'SOIL TEMPERATURES.')
  201 CONTINUE
  203 CONTINUE
      WRITE(6,95)
      STOP
      END

//$DATA
```

SOIL DEPTHS FOR ATTAINING THE COMFORT ZONE IN TEXAS

THE TOWN OF 4563 WITH A MEAN AIR
TEMPERATURE OF 63.60 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.5 ON THE 133 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 70.30 OCCURRED ON
THE 319 DAY AT A DEPTH OF 15 FT.

THE TOWN OF 5271 WITH A MEAN AIR
TEMPERATURE OF 65.40 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.5 ON THE 103 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 74.41 OCCURRED ON
THE 283 DAY AT A DEPTH OF 11 FT.

THE TOWN OF 5341 WITH A MEAN AIR
TEMPERATURE OF 64.20 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.8 ON THE 127 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 71.40 OCCURRED ON
THE 307 DAY AT A DEPTH OF 14 FT.

THE TOWN OF 5424 WITH A MEAN AIR
TEMPERATURE OF 66.00 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.5 ON THE 91 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 75.81 OCCURRED ON
THE 277 DAY AT A DEPTH OF 10 FT.

THE TOWN OF 5477 WITH A MEAN AIR
TEMPERATURE OF 67.40 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 65.3 ON THE 85 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 78.22 OCCURRED ON
THE 271 DAY AT A DEPTH OF 9 FT.

THE TOWN OF 5618 WITH A MEAN AIR
TEMPERATURE OF 63.40 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.6 ON THE 139 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 69.71 OCCURRED ON
THE 325 DAY AT A DEPTH OF 16 FT.

THE TOWN OF 5954 WITH A MEAN AIR
TEMPERATURE OF 64.30 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.4 ON THE 115 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 72.00 OCCURRED ON
THE 301 DAY AT A DEPTH OF 13 FT.

THE TOWN OF 6108 WITH A MEAN AIR
TEMPERATURE OF 62.50 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.5 ON THE 163 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 67.84 OCCURRED ON
THE 349 DAY AT A DEPTH OF 19 FT.

THE TOWN OF 6119 WITH A MEAN AIR
TEMPERATURE OF 62.90 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.7 ON THE 157 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 68.54 OCCURRED ON
THE 343 DAY AT A DEPTH OF 18 FT.

THE TOWN OF 6176 WITH A MEAN AIR
TEMPERATURE OF 63.60 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.5 ON THE 133 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 70.30 OCCURRED ON
THE 319 DAY AT A DEPTH OF 15 FT.

THE TOWN OF 6757 WITH A MEAN AIR
TEMPERATURE OF 64.90 MAY BE CONSIDERED FOR
UNDERGROUND CONSTRUCTION. THE SOIL TEMPERATURES
MINIMUM WAS 64.6 ON THE 109 DAY OF THE YEAR AND
THE SOILTEMPERATURE MAXIMUM OF 73.22 OCCURRED ON
THE 295 DAY AT A DEPTH OF 12 FT.

CONCLUSION

In this study of soil temperatures, the situation involved searching for the depth at which the ideal temperature gange occurs. Rather than using corrective measures to alter the climatic conditions, soil was used as an isolater from the external environment.

Numerous assumptions have been made and many varibles disregarded in computing the soil depths. A combination of corrective measures and soil is a more practical solution. Olgyay's bioclimatic chart offers possible alternatives that should be considered in attaining the comfort zone for a particular location.

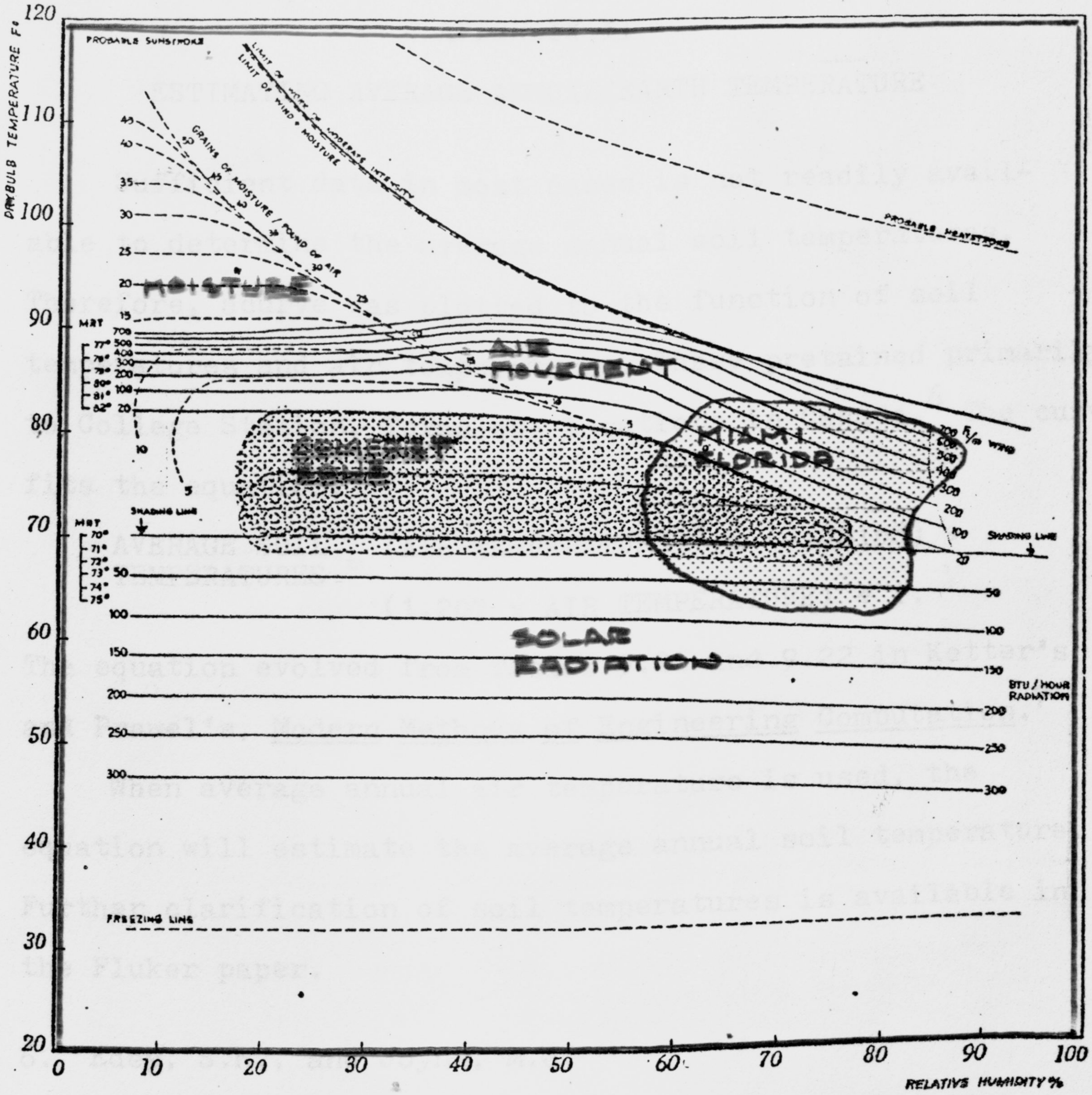
Further development into the feasibility of underground architecture should be the next steps taken. In this particular study the varibles; groundcover, soil moisture, contours, and generated heat, should be incorporated into the programs, offering the user alternatives to greater soil depths or energy consuming devices. Other assumptions or varibles divert a qualitative answer to the practical applicability of building underground. However, reducing air conditioning costs through going underground, needs to be considered as a possible solution.

APPENDIX I

OLGYAY'S BIOCLIMATIC CHART

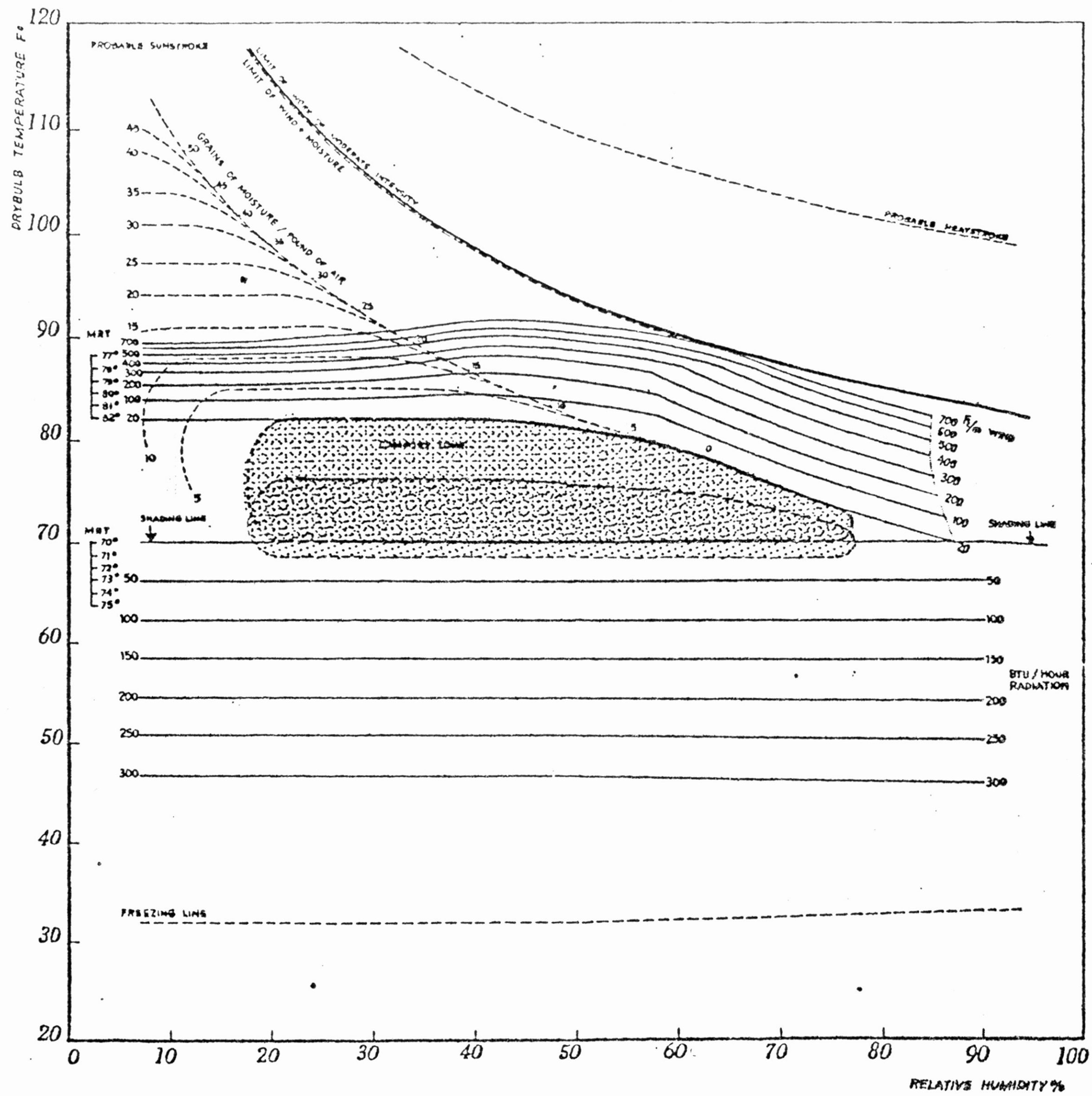
Olgyay's "bioclimatic zone" displays methods for altering uncomfortable climate conditions to a "comfort zone". The "comfort zone" indicates thermal conditions in which a person will feel comfortable. When plotted values of temperatures and relative humidity fall outside the comfort zone, corrective measures; air movement, sunshine, or moisture, can produce comfortable conditions. These may be achieved by landscaping, structure openings, and orientation where as others may require mechanical air conditioning.

Use of the comfort zone may be illustrated by an example. The overlay indicates a temperature and humidity relationship for a typical year in Miami Florida. this hot humid location generally has high relative humidity conditions with moderate temperature variations. The chart indicates shading and air movement are needed most of the year to achieve a comfortable environment.



Bioclimatic Chart, for U.S. moderate zone inhabitants.

Figure 4 Olgyay's Bioclimatic Chart



Bioclimatic Chart, for U.S. moderate zone inhabitants.

Figure 4 Olgyay's Bioclimatic Chart

APPENDIX II

ESTIMATING AVERAGE ANNUAL EARTH TEMPERATURE

Sufficient data in most cases is not readily available to determine the average annual soil temperatures. Therefore, acurve was plotted to the function of soil temperatures and air temperatures. These pretained primarily to College Station, Texas and locations in Canada.[6] The curve fits the equation;

$$\text{AVERAGE SOIL TEMPERATURES} = (\text{AIR TEMPERATURE})^2 \times (-.00168) + (1.207 \times \text{AIR TEMPERATURE}) + 1.$$

The equation evolved from Tables 9.21 and 9.22 in Ketter's and Prawel's, Modern Methods of Engineering Computation.[7]

When average annual air temperature is used, the equation will estimate the average annual soil temperature. Further clarification of soil temperatures is available in the Fluker paper.

6. Edey, S.N., and Joynt, M.J.
7. Ketter, Robert L.,and Prawel, Sherwood P., Modern Methods of Engineering Computation, New York: McGraw-Hill, Inc., 1969, pp. 212-213.

APPENDIX III

SOIL TEMPERATURE ESTIMATION

The source for the equation to estimate soil temperatures is Moreland's revision of Fluker's equation.[8] Moreland gave credit to Mr. Peter Sharr of the University of Texas Medical Research Center for much of the development.

The equation for soil temperature given in Moreland's article is:

$$\theta(x,t) = A_o + A_1 e^{-kx} \sin w(t - Dx - Q)$$

where:

A_o = average annual earth temperature

A_1 = temperature amplitude @ 2" depth

$k = \sqrt{\frac{w}{2c}} = \frac{1}{\text{relaxation distance}}$

c = diffusivity; a soil property combining thermal conductivity, specific heat, and density.

$w = \frac{2\pi}{364}$ radians per day; a factor relating time in days from Dec. 31 to angular measurement.

$\phi = \frac{2Q\pi}{364}$; where Q = the number of days from Dec. 31 to the time when the bare ground equals its annual average.

x = depth in feet

t = time in days

$D = \frac{1}{\sqrt{2cw}}$; the delay term, in days per foot.

Fluker's data was collected at College Station, Texas. The soil profile in the test area ranged from a sandy clay at the surface to a high dry strength clay at 10 feet. For this soil, without groundcover, or shade, he determined the following:

$$A_o = 23.7^oC.$$

$$A_1 = 12^oC.$$

$$k = .134 \text{ ft.}^{-1}$$

$$c = .48 \text{ ft.}^2/\text{day}$$

$$Q = 107 \text{ days}$$

Without knowledge of soil specifications from a location, only the average annual soil temperatures, of the above figures is manipulated. A_1 is a constant 12^o provided "k", "c", or "Q" are not changed, because the sine curve retains the same function at 2" depths regardless of soil temperatures.

Of the other varibles "k", "c", and "Q", "k" is directly related to"c" and"c" may be used as an estimate for diffusitivity across the state. "Q" is the number of days from December 31 to the first day the soil temperature reaches the annual average. This figure also may be used satisfactorily, as the day seldom varies by more than five days for any location.

8. Moreland, Frank, "Appendix IV", Alternatives in Energy Conservation, 1975, pp. 203 - 204.

LITERARY REVIEW

Alternatives in Energy Conservation; The Use of Earth Covered Buildings. Proceedings and Notes of a Conference Held in Fort Worth, Texas, July 9-12, 1975. These proceedings describe the conference held at the University of Texas in Arlington on the use of earth covered buildings to provide energy efficient buildings as well as a better physical environment. The potential for energy conservation by underground construction is great because of the need for fuel conservation due to depleting resources, and an increase in fuel consumption. Topics include: Historical Perspectives; Economics; Environmental Psychology; Energy and Materials; Examples of Earth Covered Buildings; City Patterns; Political and Legal Considerations; Technical Considerations. In addition, an extensive Bibliography on earth covered buildings is presented.

Edey, S. N. and Joynt, M. J., "Mechanical and Thermal Characteristics of the Soil at Selected Agrometeorological Stations"
This report presents the results of an analysis of soil samples taken at seven agrometeorological stations. Mechanical and thermal characteristics of the soil surrounding the temperature sensors at the particular installations was the major concern of the study.

Fluker, B. J., "Soil Temperatures"
The purpose of this paper is to describe the measurement of natural soil temperatures at a specific site and to present and discuss the soil temperature data obtained in the 5-year period 1951-1955, inclusive. This paper was an excellent source for developing the computer programs. Any questions as to the soil temperature equation, may be answered in the article. The charts and graphs also provide visual material in patterns of soil temperature data.

Geiger, R., The Climate Near the Ground,
This book concerns the climate and the factors influencing the climate near the ground. Subjects include the influence of soil tillage, soil moisture, rain, snow, type and condition of the soil, and temperature affects in different kinds of soil. The book will be of particular help in continuing the research.

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Olgyay, . ., Design with Climate,

Paulus, Paul, On the Psychology of Earth Covered Buildings", Alternatives in Energy Conservation, July 1975, pp. 65 - 70.