A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR -85-868

CONF-850241--1

LA-UR--85-868

DE85 009545

TITLE DHC: A Diurnal Heat Capacity Program for Microcomputers

AUTHOR(S) J. Douglas Balcomb

SUBMITTED TO First National Conference on Microcomputer Applications for Conservation and Renewable Energy
Tucson, Arizona
February 26-28, 1985

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DHC: A DIURNAL HEAT CAPACITY PROGRAM FOR MICROCOMPUTERS*

J. Douglas Balcomb

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

Diurnal heat capacity is a useful parameter for estimating the temperature swing to be expected in a direct gain passive solar building. This is important to know because a common problem in these buildings is excessively large swings due to an inadequate amount of heat storing thermal mass within the space. The DHC program calculates the diurnal heat capacity for any combination of homogeneous or layered surfaces using closed-form harmonic solutions to the heat diffusion equation. The theory is described, a basic program listing is provided, and an example solution printout is given.

INTRODUCTION

Diurnal heat capacity is a measure of the ability of a building to store heat and return heat on a daily basis. It is important in a direct gain passive solar building, for example, because some of the solar heat entering the building is stored in building mass and contents during the day and released later the next night. It can also be important in night-vent summer cooling in which the building is cooled by natural or forced ventilation at night; the mass of the building then absorbs heat during the next day and the cycle is repeated. The important characteristic of these two examples is the repeating 24-hour nature of heat storage and heat return. This cyclical behavior is called diurnal. Diurnal heat capacity is especially useful in estimating the swing in room temperature in a direct gain building or the cooling load reduction in a night-vent situation.

Not all of the mass in a building will respond equally to a diurnal cycle. Mass that is deep within a wall, for example, is insulated from the give-and-take at the surface by the intervening layers of the wall and will, therefore, not cycle as much in temperature as mass near the surface. Furthermore, there is time delay associated with conduction of heat into the wall and the return of heat to the surface 12 hours later. This time delay means that the cycles of wall surface temperature and wall surface heat flux are up to 6 hours out of phase.

The diurnal heat capacity of a building is always less than the total heat capacity (calculated simply by determining the total mass of each material and the respective heat capacity of that material, and summing up the products). Diurnal heat capacity can be calculated if the nature of the thermal coupling at each surface is known and if the wall surface constructions and material properties are known. A convenient mathematical approach is to use harmonic analysis because of the cyclical nature of the temperature and heat flows. Because the waveform of the response tends to always be the same, it is sufficient to calculate the response for a pure 24-hour sine wave and apply a correction factor to account for higher harmonics. The diurnal heat capacity is simply the heat stored and then returned to the room each 24 hours per unit of room temperature swing--assuming a pure sine-wave input. It has the same units as total heat capacity, Btu/°F or kWh/°C or J/°C.

DHC is a microcomputer program that implements the calculation of diurnal heat capacity. It is intended to be used as an aid during the design process. It is written in BASIC. The calculation is in three stages: (1) determining the diurnal heat capacity (per unit surface area) of each wall, floor, or ceiling type based on input data describing the construction, and a built-in library of material properties (or user-input properties), (2) aggregating the diurnal heat capacities of each surface enclosing a room by vector addition to determine the diurnal heat capacity of each room in the building, and (3) aggregating room diurnal heat capacities to determine whole-building diurnal heat capacity.

The mathematics behind the program are fairly complicated, involving complex numbers and vector algebra; however, the program user is isolated from this complexity. The program is menu driven with built-in prompts that minimize the need for recourse to a manual. The code outputs are room and building diurnal heat capacities. For convenience, wall R-values, total mass, and total heat capacity are also calculated and output. Once known, the diurnal heat capacity can be used in a very simple equation to predict peak-to-peak diurnal room temperature swing.

The purpose of the paper is to make the program listing available and encourage others to incorporate the procedures, either as is or modified, into their

---

*Work performed under the auspices of the US Department of Energy, Office of Solar Heat Technologies.

6 no

own computer work, or into public-domain or proprietary programs. DHC is public domain; the length is 227 lines.

THEORY

The problem facing the designer is to predict temperature swings so as to know when corrective design measures are necessary. The analysis should be simple enough for easy use and yet comprehensive enough to account for the primary effects. The method presented here does not account for inside-temperature swings caused by the swing in outside temperature because this is normally small and out of phase with the direct gain swing. Temperature swings resulting from variations in internal-heat generation could be predicted by a minor extension of the method.

In the initial analysis, a 24-hour sine wave will be considered; this is the diurnal portion of the building response. At a later stage a modification will be made to account for higher harmonics. The final result is an estimate of the temperature swing resulting from direct gain during a sequence of clear midwinter days.

The one-dimensional heat diffusion equation can be solved in closed form for a single frequency.[1] Consider a slab of material of thickness (X) with sinusoidal temperatures (T) and heat fluxes (q) at faces 1 and 2. The result is

$$q_1 = q_2 \cosh \gamma X + T_2 k \sinh \gamma X \quad , \qquad (1)$$

$$T_1 = T_2 \cosh \gamma X + (q_2/k\gamma) \sinh \gamma X \quad , \qquad (2)$$

where $\gamma = (1 + i)\sqrt{\pi\rho c/Pk}$, $i = \sqrt{-1}$, P = period of the oscillation (1 day).

We are interested in the heat transferred through face 1 during one-half cycle compared with the peak-to-peak temperature swing at face 1. This is the diurnal heat capacity, referred to here as dhc. This is closely related to the thermal admittance, y_1, used by Davies:[1]

$$y_1 = \hat{q}_1/\hat{T}_1; \quad \text{dhc} = (P/2\pi)y_1 \quad ,$$

where $\hat{q}_1$ and $\hat{T}_1$ refer to the peak departure of q_1 and T_1 from their average values.

If the wall is infinite in thickness, $\text{dhc}_\infty = \sqrt{P\rho ck/2\pi}$.

If the wall is finite and $q_2 = 0$, $\text{dhc} = \text{dhc}_\infty Zg$, where $Z = \tanh \gamma X$ and $g = e^{i\pi/4}$.

The magnitude and phase of Zg can be expressed in terms of real variables as follows:

$$\text{mag}(Zg) = \sqrt{(\cosh 2\tau - \cos 2\tau)/(\cosh 2\tau + \cos 2\tau)} ,$$

and

$$\text{phase}(Zg) = \arctan(\sin 2\tau/\sinh 2\tau) + \pi/4 \quad ,$$

where $\tau = X\sqrt{\pi\rho c/Pk}$.

The magnitude of dhc is shown in Fig. 1 for several common building materials. The phase varies from 90° for thin materials to 45° for thick materials.

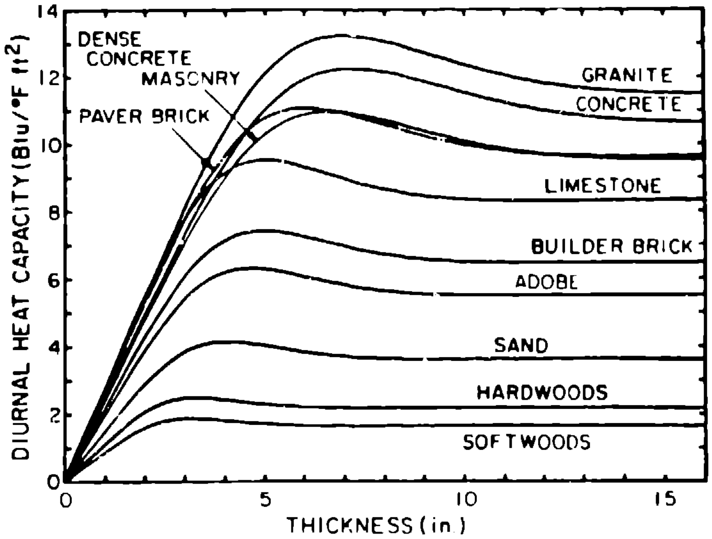

Fig. 1. Diurnal heat capacities of various materials as a function of thickness. For interior partition walls, use 1/2 the total wall thickness to determine the diurnal heat capacity for each of the two surfaces. These curves apply to radiation-coupled mass.

If the wall consists of several layers of different materials, the dhc of the composite wall can be determined from y_1 using Eqs. (1) and (2) as follows:

$$y_1/a = (y_2/a + Zg)/(1 + Zy_2/ag) \quad , \qquad (3)$$

where $a = \sqrt{2\pi k\rho c/P}$.

This equation is used repetitively, working from the outside layer inward, layer by layer, by setting y_2 for each subsequent layer equal to y_1 for the previous layer at the interface. The procedure and derivations are outlined in more detail by Davies[1] and Balcomb.[2]

RELATIONSHIP BETWEEN dhc AND ROOM-TEMPERATURE SWING

Thus far, diurnal heat storage has been related to surface-temperature swing. To use this result, we must somehow establish a relationship between room-temperature swing and surface-temperature swing. The total heat stored will be a sum of heat stored in the various surfaces that enclose the room in question. At this point the procedure becomes approximate because a precise solution is overly complex.

We distinguish two primary categories of situation: those in which the incoming energy is radiatively coupled to the surface (either by shortwave solar radiation or by longwave infrared radiation from other surfaces), and those convectively coupled to the room air. In the first case the air temperature follows the wall-surface temperatures; in the second case the wall temperature follows the air temperature. Furthermore, thermal comfort is related to a composite of air temperature and mean radiant temperature. We simplify by equating room temperature and wall-surface temperature in radiatively coupled situations and by accounting for an air-film impedance in the case of convectively coupled situations. To compute dhc for the convectively coupled case, the air-film impedance, 1/U, is added vectorially to the wall impedance, $1/y_1$, to obtain a modified total impedance that is then used to calculate dhc (U is the air-film conductance, normally 1.5 Btu/h °F ft²).

PROCEDURE

Diurnal Heat Capacity of a Whole Room

The diurnal heat capacity of a whole room or a whole building can be determined by aggregating the individual diurnal heat capacities of all surfaces acting in parallel.[3] This will be called DHC. Technically, it is the vector sum of all the DHC values for all the various surfaces that enclose the room.

$$DHC = \sum_i A_i \cdot dhc_i \quad , \qquad (4)$$

where A_i is the area of the i^{th} surface, ft^2, and
dhc_i is the dhc of the i^{th} surface, Btu/°F ft^2,

so that DHC has units of Btu/°F.

The first step is to categorize the exposed mass surfaces inside the building. Two categories are distinguished:

Radiation-coupled mass. Solar energy is transferred to the storage mass by either solar or thermal radiation. The mass must be either within the space that the sunshine enters or form an enclosing surface of the space. It is not necessary for the mass to be in the direct sun, but there must be a direct line of sight between the mass surface and absorbing or reflecting surfaces that are in direct sun. For these surfaces the dhc is calculated in terms of surface temperature.

Convection-coupled mass. Solar energy is transferred to the storage mass by natural convection of warm air. Doorway or other convection openings must be provided with a total open area of at least 4% of the storage-mass surface, or 2% of the storage-mass surface if the openings are spaced more than 6 vertical feet apart.

Massive floors require special consideration. Floors in direct gain rooms that receive no direct sun are considered convection coupled because of the lack of line-of-sight radiative coupling. Floors not in direct gain rooms should be ignored because of very poor convective coupling.

Next look up values of dhc from appropriate tables for each material type for the appropriate thickness and form the appropriate (dhc) · (A) products. Tables of both radiation-coupled and convection-coupled dhc have been compiled by Balcomb[2] for common building materials. Next, calculate the DHC of the furniture and room air. This can be estimated as 2 Btu/°F for each ft^2 of floor area for typical furnishings.

Estimation of Room-Temperature Swing

The amount of heat stored in the building during clear winter days can be estimated knowing the direct gain glazing area, the solar penetration per square foot of glazing area, and the heat-loss characteristics of the building. A heat balance is calculated over the 12-hour period from 0600 to 1800, accounting for solar gains plus internal heat minus heat losses. The heat losses are calculated based on the total heat-loss coefficient of the building (TLC) and the difference between average inside temperature and average outside temperature.

The energy balance described above can be put in equation form as follows:

$$DHC \cdot \Delta T(swing) = Q_s \cdot A - (T_r - T_a)TLC/2 + Q_i/2 \quad ,$$

where $\Delta T(swing)$ = peak-to-peak room-temperature swing,
T_r = daily average room temperature,
T_a = daily average ambient temperature,
Q_s = clear-day solar gains per unit area of direct gain glazing,
Q_i = daily internal heat (assumed uniform), and
A = direct gain glazing area.

If the building uses no auxiliary heat (the normal case in a passive building on a clear winter day), a daily heat balance gives

$$Q_s \cdot A = (T_r - T_a)\ TLC - Q_i \quad .$$

Therefore,

$$\Delta T(swing) = 0.50\ Q_s \cdot A/DHC \quad .$$

A factor can be used to account for higher harmonics. From study of typical profiles we find:

$$\Delta T(swing,\ actual) = 1.22 \cdot \Delta T\ (swing,\ 24\text{-h harmonic}) \quad .$$

Thus, $\Delta T(swing) = 0.61\ Q_s \cdot A/DHC$. (5)

Spot checks have been made to assess the accuracy of the procedures outlined. Comparisons made between the $\Delta T(swing)$ calculated using involved thermal-network computer simulations and the simplified procedures proposed here show correspondence within 5 to 8%.

COMPUTER PROGRAM

The DHC computer program implements the calculation of DHC as given by Eq. (4). When the program is run, a list of 5 menu options are presented as follows:

1. List of materials,
2. Input surfaces,
3. Calculate room,
4. Total of all rooms,
5. Zero room totals.

Menu 1 (line 350) simply prints a list of material choices built into the program library for the user's convenience. Menu 2 (line 450) is used to specify as many layered wall constructions as desired. Each surface is given an identification number. The program prompts for the number of layers and then for the type number and thickness of each layer. Airgaps are permitted. The user may select either a library material, a "formula" material (for which the specific heat and thermal conductivity are specified functions of density) or he may specify all the material properties. After the last layer is specified, the program prompts for the film conductance between the inner surface and the room air. Both radiation-coupled and convection-coupled values of dhc are calculated according to Eq. (3) and are saved in arrays R1, P1, and R2, P2, respectively (R refers to magnitude and P refers to phase). Mistakes made while running Menu 2 can be rectified by repeating the menu with the same surface type numbers.

Menu 3 (line 1350) implements the vector summation of (area) x (dhc) products as specified in Eq. (4). The user specifies whether the thermal connection is radiative (1) or convective (0).

Menu 4 (line 1770) implements the vector summation of several rooms. Menu 5 (line 250) re-zeros the room totals so that additional calculations can be made without having to re-specify rooms or surface types.

EXAMPLE CALCULATION

Suppose a 200 ft^2 workshop is enclosed by four walls (180 ft^2), a ceiling (200 ft^2) and a floor (200 ft^2), of which 1/2 is covered by furniture or carpet. The wall is 6-in. concrete and the ceiling is 2-in. wood, each with insulation outside. The floor is 1-in. hardwood laid on a 4-in. concrete slab laid on earth. The room has 30 ft^2 of direct gain windows facing south. Calculate the clear-day winter temperature swing.

Run the DHC program in order to determine DHC as needed to calculate Eq. (5) for $\Delta T(swing)$. The computer printout is shown below. The first step is to select Menu 2 three times in succession in order to calculate the dhc of each surface type. The layers are described working from the outside inward. The dhc values shown on each line refer to the dhc determined at the inner surface of each successive layer so that the final answer on the last line is the cumulative dhc. The last line (airgap) refers to the inside film coefficient ($h = 1.5$ Btu/°F ft^2 h) and is therefore the convective dhc. The line above this gives the radiative dhc. Lag refers to the phase, which is given in hours. For example, the radiative dhc for the floor (surface type 3) is 3.6 Btu/°F ft^2 with a phase lag of 1.5 hours (22.5°). Note that the earth was represented by adobe properties. The choice of a 24-in. thickness was chosen to represent an essentially infinite thickness for diurnal effects. The total heat capacity (HC) and total mass are also listed.

The next step is to select Menu 3. The wall is surface type 1, the ceiling is surface type 2, and the floor is surface type 3. The final DHC is 2751 Btu/°F, indicating that the room surfaces will store and return 2751 Btu for each 1°F of sinusoidal room temperature swing.

To complete the calculation of $\Delta T(swing)$, we need to know Q_S, the daily transmitted solar radiation per ft^2 of direct gain glazing. At 40° latitude, this is about 1440 Btu/ft^2 per day. A is 30 ft^2. Therefore, using Eq. (5):

$$\Delta T(swing) = (0.61)(1440)(30)/(2751) \quad ,$$

$$\Delta T(swing) = 9.6^{\circ}F \quad .$$

This is the peak-to-peak temperature swing to be expected on a clear winter day.

REFERENCES

1. M. G. Davies, "The Thermal Admittance of Layered Walls," Building Science, 8, 207-220 (1973).

2. J. D. Balcomb, "Heat Storage and Distribution Inside Passive Solar Buildings," Los Alamos National Laboratory Report LA-9694-MS (1983).

3. J. D. Balcomb, "Prediction of Internal Temperature Swings in Direct Gain Passive Solar Buildings," Proc. Solar World Congress, Perth, Australia, August 14-19, 1983. (Los Alamos National Laboratory internal report LA-UR-83-2246.)

ROOM TOTALS ZEROED

SURFACE TYPE 1

MATERIAL	Thick	Dens.	Cp	k	R	Mass	HC	dhc	Lag
CONCRETE, 143	6.0	143	.210	1.000	.5	72	15.0	11.9	4.0
AIRGAP	0.0	0	0.000	0.000	.7	0	0.0	4.4	1.2
TOTAL	6.0				1.2	72	15.0		

SURFACE TYPE 2

MATERIAL	Thick	Dens.	Cp	k	R	Mass	HC	dhc	Lag
SOFTWOOD	2.0	32	.330	.067	2.5	5	1.8	1.6	4.7
AIRGAP	0.0	0	0.000	0.000	.7	0	0.0	1.4	3.8
TOTAL	2.0				3.2	5	1.8		

SURFACE TYPE 3

MATERIAL	Thick	Dens.	Cp	k	R	Mass	HC	dhc	Lag
ADOBE	24.0	120	.200	.332	6.0	240	48.0	5.5	3.0
CONCRETE, 143	4.0	143	.210	1.000	.3	48	10.0	10.3	3.6
HARDWOOD	1.0	45	.300	.092	.9	4	1.1	3.6	1.5
AIRGAP	0.0	0	0.000	0.000	.7	0	0.0	2.2	.9
TOTAL	29.0				7.9	291	59.1		

ROOM IS SHOP

Surface	Area	Connection	Mass	HC	DHC	Lag
1	180	1.00	12870	2703	2149	4.0
2	200	1.00	1067	352	321	4.7
3	100	1.00	29142	5914	355	1.5
TOTAL	480		43078	8968	2751	3.7

APPENDIX

Program Listing

Standard Hewlett-Packard BASIC. The program requires about 26K of memory.

```
20 Feb 1934          17:00:41

 10 '  DHC                DIUPNAL HEAT CAPACITY
 20 '  LAYEPED WALLS     MULTIPLE PATHS      MULTIPLE POOMS
 30 '  AUTHOP: BALCOMB,LOS ALAMOS. 11 6 84
 40  OPTION BASE 1
 50  DIM D(11),C(11),K(11),M$(11)[14]
 60  DIM P1(20),P1(20),P2(20),P2(20),P3(20),P3(20),M4(20),H4(20)
 70  DEG
 80  N1=11
 90  DATA 143,.21,1,"CONCPETE, 143#"
100  DATA 140,.209,.822,"BLOCK, 140#"
110  DATA 135,.24,.758,"PAVEP BPICK"
120  DATA 120,.2,.417,"BUILDEP BPICK"
130  DATA 120,.2 .332,"ADOBE"
140  DATA 95,.19,.19,"SAND"
150  DATA 167,.2,1.05,"GRANITE"
160  DATA 153,.22,.54,"LIMESTONE"
170  DATA 50,.26,.093,"GYPBOAPD"
180  DATA 45,.3,.092,"HAPDWOOD"
190  DATA 32,.33,.067,"SOFTWOOD"
200  FOP I=1 TO N1
210    PEAD D(I),C(I),K(I),M$(I)
220  NEXT I
230  A6=M6=H6=X6=Y6=0
240  PPINT
250  PPINT "ROOM TOTALS ZEROED"
260  DISP
270  DISP "1-LIST OF MATEPIALS"
280  DISP "2-INPUT SURFACES"
290  DISP "3-CALCULATE ROOM"
300  DISP "4-TOTAL OF ALL ROOMS"
310  DISP "5-ZERO POOM TOTALS"
320  INPUT "MENU NUMBER",N2
330  IF N2 =0 OP N2>5 THEN 320
340  ON N2 GOTO 350,450,1350,1770,230
350  PRINT
360  PPINT "  #    MATERIAL     DENSITY   Cp      K"
370  PRINT USING 430;0,"AIPGAP"
380  FOP I=1 TO N1
390    PPINT USING 430;I,M$(I),D(I),C(I),K(I)
400  NEXT I
410  PPINT USING 430;N1+1,"FOPMULA"
420  PPINT USING 430;N1+2,"USEP SPECIFIED"
430  IMAGE 3D,2X,14A,6D,2(3D.3D)
440  GOTO 260
450  INPUT "SUPFACE TYPE",S
460  INPUT "NUMBEP OF LAYERS",N
470  PPINT
480  PPINT "SURFACE TYPE ",S
490  PPINT "MATEPIAL        Thick  Dens.   Cp      K       P      Mass       HC
dhc     Lag"
500  G4=H4=M4=L4=0
510  FOP I=1 TO N
520    INPUT "TYPE, THICKNESS",T,L
530    IF L =0 THEN L=1E-50
540    IF T<>0 THEN 640
550    ! AIPGAP
560    INPUT "U-VALUE",U
570    IF U<=0 THEN U=1E-50
580    A=U                               ! ADMITANCE
590    Z=0                               ! DIMENSIONLESS THICKNESS
600    D=C=K=M=H=0
610    N$="AIPGAP"
620    G=1/U                             ! PESISTANCE
630    GOTO 840
```

```
640    IF T>N1 THEN 710
650    ! LIBRARY MATERIAL
660    D=D(T)                          ! DENSITY
670    C=C(T)                          ! SPECIFIC HEAT
680    K=K(T)                          ! CONDUCTIVITY
690    N$=M$(T)
700    GOTO 790
710    IF T>N1+1 THEN 780
720    ! FORMULA MATERIAL
730    INPUT "DENSITY",D
740    C=1/(3.934+.006*D)              ! FORMULA FOR C
750    K=.05*EXP(.02*D)                ! FORMULA FOR K
760    N$="FORMULA"
770    GOTO 790
780    INPUT "NAME,DENSITY,SPECIFIC HEAT, CONDUCTIVITY",N$,D,C,K
790    A=SQR(PI*D*C*K/12)               ! ADMITTANCE (INF. THICK)
800    Z=L/12*SQR(PI*D*C/24/K)          ! DIMENSIONLESS THICKNESS
810    G=L/12/K                         ! RESISTANCE
820    M=L/12*D                         ! MASS
830    H=M*C                            ! HEAT CAPACITY
840    L4=L4+L
850    G4=G4+G
860    M4=M4+M
870    H4=H4+H
880    IF I=1 AND T=0 THEN 970
890    IF I>1 THEN 1000
900    GOSUB 2160                       ! OUTER MASS LAYER
910    X=A1
920    Y=B1
930    GOSUB 1880                       ! RECT TO POLAR
940    P=P+45
950    R=R*A
960    GOTO 1160
970    R=A                              ! OUTER AIR FILM
980    P=0
990    GOTO 1160
1000   IF T=0 THEN 1090
1010   R=R/A                            ! INNER MASS LAYER
1020   GOSUB 1930                       ! POLAR TO RECT
1030   C1=X
1040   D1=Y
1050   GOSUB 1970                       ! TRANSFER MATRIX
1060   GOSUB 1880                       ! RECT TO POLAR
1070   R=R*A
1080   GOTO 1160
1090   R=R/A                            ! INNER AIRGAP
1100   GOSUB 1930                       ! POLAR TO RECT
1110   C1=X
1120   D1=Y
1130   GOSUB 2110                       ! PURE CONDUCTANCE
1140   GOSUB 1880                       ! RECT TO POLAR
1150   R=R*A
1160   R=R*12/PI                        ! CONVERT TO DHC
1170   PRINT USING 1180;N$,L,D,C,K,G,M,H,R,P/15
1180   IMAGE 13A,4D.D,7D,2(3D.3D),5D.D,8D,3(6D.D)
1190   R=R*PI/12                        ! CONVERT TO ADMITTANCE
1200   IF I=N+1 THEN 1280
1210   R1(S)=R*12/PI                    ! DHC
1220   P1(S)=P                          ! PHASE
1230  NEXT I
1240  INPUT "FILM CONDUCTANCE",U
1250  T=0
1260  L=0
1270  GOTO 570
1280  PRINT USING 1290;"TOTAL",L4,G4,M4,H4
1290  IMAGE 13A,4D.D,26D.D,8D,6D.D
1300  R2(S)=R*12/PI                     ! DHC WITH AIR FILM
1310  P2(S)=P                           ! PHASE WITH AIR FILM
1320  M4(S)=M4
1330  H4(S)=H4
1340  GOTO 260
1350  !  ROOM CALCULATION
1360  A5=M5=H5=X5=Y5=0
1370  INPUT "ROOM NAME",N$
1380  PRINT
1390  PRINT "ROOM IS ";N$
1400  PRINT "Surface    Area   Connection    Mass          HC          DHC
 Lag"
1410  INPUT "NUMBER OF SURFACES",N
1420  FOR I=1 TO N
1430    INPUT "SURFACE TYPE,AREA,THERMAL CONNECTION (0 IS CONVECTIVE, 1 IS RAD
IATIVE)",S,A,C
```

```
1440     IF C<0 THEN C=0
1450     IF C>1 THEN C=1
1460     X1=Y1=0
1470     R=A*R1(S)*C
1480     P=P1(S)
1490     GOSUB 1930                        ! POLAR TO RECT
1500     X1=X1+X
1510     Y1=Y1+Y
1520     R=A*R2(S)*(1-C)
1530     P=P2(S)
1540     GOSUB 1930                        ! POLAR TO RECT
1550     X=X1+X
1560     Y=Y1+Y
1570     GOSUB 1880                        ! RECT TO POLAR
1580     X5=X5+X
1590     Y5=Y5+Y
1600     M5=M5+M4(S)*A
1610     H5=H5+H4(S)*A
1620     A5=A5+A
1630     PRINT USING 1640;S,A,C,M4(S)*A,H4(S)*A,R,P/15
1640     IMAGE 4D,11D,7D.2D,12D,12D,12D,8D.D
1650  NEXT I
1660  X=X5
1670  Y=Y5
1680  GOSUB 1880                           ! RECT TO POLAR
1690  PRINT USING 1700;"TOTAL",A5,M5,H5,R,P/15
1700  IMAGE 6A,9D,22D,12D,12D,8D.D
1710  A6=A6+A5
1720  M6=M6+M5
1730  H6=H6+H5
1740  X6=X6+X
1750  Y6=Y6+Y
1760  GOTO 260
1770  ! TOTALS OF ALL ROOMS
1780  X=X6
1790  Y=Y6
.800  GOSUB 1880                           ! RECT TO POLAR
1810  PRINT
1820  PRINT "SUBTOTAL OF ALL  ROOMS"
1830  PRINT USING 1840;"AREA=",A6,"  MASS=",M6,"  HC=",H6,"  DHC=",R,"  Lag=",
P 15
1840  IMAGE 5A,6D,7A,7D,5A,7D,6A,7D,6A,4D.D
1850  GOTO 260
1860  END
1870 !                         SUBROUTINES
1880 ! RECT TO POLAR
1890  R=SQR(X^2+Y^2)
1900  P=ATN(Y/X)
1910  IF X<0 THEN P=P+180
1920  RETURN
1930 ! POLAR TO RECT
1940  X=R*COS(P)
1950  Y=R*SIN(P)
1960  RETURN
1970 ! TRANSFEP MATRIX
1980  GOSUB 2160                           ! Tanh
1990  X=A1-B1+C1*SQR(2)
2000  Y=A1+B1+D1*SQR(2)
2010  GOSUB 1880                           ! RECT TO POLAR
2020  R1=R
2030  P1=P
2040  X=A1*C1-B1*D1+B1*C1+A1*D1+SQP(2)
2050  Y=B1*D1+B1*C1+A1*D1-A1*C1
2060  GOSUB 1880                           ! PECT TO POLAR
2070  R=P1/P
2080  P=P1-P
2090  GOSUB 1930
2100  PETURN
2110 ! PURE CONDUCTANCE
2120  D3=C1^2+2*C1+1+D1^2
2130  X=(C1^2+C1+D1^2)/D3
2140  Y=D1/D3
2150  RETURN
2160 ! Tanh[(1+i)*Z]
2170  PAD
2180  S2=(EXP(Z)-EXP(-Z))/2
2190  C2=(EXP(Z)+EXP(-Z))/2
2200  S3=SIN(Z)
2210  C3=COS(Z)
2220  D3=(C2*C3)^2+(S2*S3)^2
2230  A1=S2*C2/D3
2240  B1=S3*C3/D3
2250  DEG
2260  RETUPN
2270 !                           END SUBROUTINES
```