A STUDY TO CATEGORIZE WALLS AND ROOFS ON THE BASIS OF THERMAL RESPONSE

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NOMENCLATURE

A	area, ft^2
a	amplitude ratio, dimensionless
b	conduction transfer function coefficient, $Btu/hr-ft^2-F$
C*	capacity per unit length, coulomb/ft
c	specific heat, Btu/lbm-F
c	conduction transfer function coefficient, $Btu/hr-ft^2-F$
D	time lag, hr
d	conduction transfer function coefficient, dimensionless
G	irradiation, $Btu/hr-ft^2$
h	convective heat transfer coefficient, $Btu/hr-ft^2-F$
k	thermal conductivity, Btu/hr-ft-F
L	total thickness, ft
q	heat transfer, Btu/hr
R	unit thermal resistance, $hr-ft^2-F/Btu$
R*	resistance per unit length, ohm/ft
ΔR	difference between the long wavelength radiation incident on a surface from the sky and the radiation emitted by a black body at the outdoor air temperature, $Btu/hr-ft^2$
r	dimensionless amplitude ratio
t	temperature, F
U	overall heat transfer coefficient, $Btu/hr-ft^2-F$
V	voltage, volts

x thickness, ft

α absorptance, dimensionless

ε emittance, dimensionless

ρ mass density, lbm/ft^3

Θ time, hours

ϕ phase lag, radians

Subscripts

e sol-air

i inside

max maximum

n iteration counter

o outside

ref reference

t total

time increment

CHAPTER I

INTRODUCTION

The determination of heat gain through a building's surface under transient environmental conditions is essential in accurately determining a building's cooling or heating load. Over the years, several effective methods for performing this task have been developed. These include, but are not limited to, the Transfer Function (TF) method (1 & 2)* and the Cooling Load Temperature Difference (CLTD) method (3). The TF method (1 & 2) employs a set of conduction TF coefficients derived from the thermophysical properties of a building surface and combines them with environmental conditions to determine the heat gain through a surface at any time. The method for determining these coefficients for a specific surface, which is composed of multiple layers, requires the use of a complex computer program which is available to very few researchers across the country. Once the conduction TF coefficients have been derived and heat gains determined, a different set of TF coefficients, referred to as weighting factors, are used to convert the heat gains to cooling loads. This new set of co-

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* Numbers in parenthesis refer to bibliography at the end of this thesis.

efficients is dependent on several factors. Included are wall and floor mass, percentage of wall glass, ceiling type, carpeting and drapes, and finally zone size. From this brief description, it is easily seen that determining the cooling load due to a wall, roof, or other building surface is not a simple task.

The CLTD method (3) for determining the cooling loads for a wall or roof is much easier to apply than the TF method (1 & 2) and does not require the use of a complex computer program. This method employs a set of predetermined time dependent temperature differences, CLTDs, for seven different wall types and twenty-six different roof types. These CLTDs were determined from calculations performed using the TF method. To determine which type of wall or roof a particular surface matches, the overall conductance and the product of mass times specific heat is determined for the surface in question. If a surface does not exactly match a wall or roof listed, a complicated set of instructions are followed to pick the best match. Once a surface is chosen, the CLTDs for that surface must be adjusted according to the latitude, room design air temperature, outdoor design air temperature, and the daily range of outdoor air temperature. Finally the corrected CLTDs are multiplied by the overall conductance and surface area to determine the cooling load due to that surface. This method is tedious to apply and its accuracy is questionable under certain conditions.

Since results obtained from the CLTD method (3) are not always reliable, and the computer program used to generate conduction TF coefficients is not generally available, it was decided that an improved procedure should be developed. To do this, a better way of handling the conduction transfer function coefficients for walls and roofs, as well as improved zone weighting factors is required. This thesis deals with the wall and roof transfer function coefficients. The objective was to devise a method for choosing a predetermined set of conduction transfer function coefficients to represent a wall or roof assembly, hereafter referred to as a *surface*. The set of coefficients chosen by the method developed should characterize the transient heat transfer characteristics of the wall or roof with a specified degree of accuracy. The method also had to sat isfy several basic requirements to be directly applicable in the field. One of the requirements was that only simple hand calculations would be necessary in choosing the correct set of conduction transfer function coefficients, and a complicated set of rules, such as those applied in the CLTD method (3), should not be required. Another requirement was that any method developed should be applicable to all reasonably designed walls and roofs and that any error inherent to the method would be conservative; that is to say the heat gains determined with the proposed method would be greater than or equal to the heat gains determined with the accepted TF method (1 & 2). This last requirement is included to help ensure that the use of the method will not result in undersized heating and cooling equipment.

To achieve the goal of developing a simple method for classifying building surfaces, several important steps were taken. These steps, which are discussed in detail further on in this paper, include a literature search, specification of design parameters, development of a new method, and finally the application and verification of the new method.

The literature search, discussed in the next section, investigated methods that fell into two main categories : a) analytical methods; b) correlation methods. The simplified analytical methods investigated predicted approximate time lags (time between peak input and peak output) and amplitude ratios (ratio of peak output to peak input). Also included are electric analogs and curve-fits to analytical solutions for transient heat transfer through one- to three-layer walls and roofs. It was hoped that a simple analytical method could be used to predict transient heat transfer characteristics and that these could be used to choose the conduction transfer function coefficients required to calculate heat gains. Correlation methods categorized different walls and roofs with similar heat transfer characteristics on the basis of their properties. Several parameters were studied, including time constants, mass, specific heat, conductance, and insulation placement. There is nearly an infinite combination of parameters that could be examined. The final method investigated, involved classifying a wall or roof using a grouping method based on a combination of several thermophysical and geometric parameters. This method resulted in the best overall performance as compared to the stated goal and was by far the easiest to apply.

Once the literature search was completed and the grouping method was chosen, data was computed for several thousand walls and roofs so that the accuracy of this method could be tested. The thermophysical and geometric parameters utilized were adjusted until the range of the time lags and amplitude ratios for the walls and roofs in a specific group fell within predetermined limits.

After the grouping method was finalized, an algorithm was developed to implement the methodology into an existing cooling and heating load computer program. This program was then used to generate data from which a comparison between the cooling loads computed using:

(1) Specific transfer function coefficients for a given wall or roof.

(2) Transfer function coefficients for the group in which the wall or roof belonged.

(3) The existing CLTD method.

Data was also examined to ensure that the accuracy of 2 above was within set limits.

The next section deals with the literature search performed for this study. The literature search is followed by a methodology section which describes the procedures and calculations performed to arrive at the final results. The results section details the grouping method developed and describes how well the method performs as compared to accepted methods. Next a conclusions and recommendations section outlines how the method should be applied in the field and what its advantages are over existing procedures. Finally a bibliography is given which lists all references referred to in this study, as well as appendices containing material too detailed for the main body of the thesis. Included in the appendices are computer program listings with sample output and detailed data. A separate report on this study by McQuiston and Harris (4) was submitted to Ayres Sowell Associates in Fullerton, California to fulfill the requirements of the American Society of Heating, Refrigerating and Air Conditioning Engineers, which funded this study.

CHAPTER II

LITERATURE SEARCH

To develop a method for classifying walls and roofs, the literature was screened for alternative procedures which were exhaustively examined before a final method was accepted. As previously stated, these procedures fell into two main categories: a) analytical methods; b) correlation methods.

Analytical Methods

For this study, any method which attempted to solve Fourier's equation for heat conduction through a solid was considered to be an analytical method.

$$k\frac{{}^{2}t}{x^{2}} = \rho c\frac{\partial t}{\partial \Theta} \tag{1}$$

The boundary conditions which are relevant to the particular solution desired for this study are the following.

$$t(x=0) = A\sin(\Pi\Theta/12) \tag{1a}$$

$$t(x=L) = B \tag{1b}$$

These boundary conditions state that the temperature on the outer side of a surface will follow a sinusoidal profile with a twenty-four hour period, while the temperature on the inner side of a surface remains constant. The TF method (1 & 2) was implemented as a reference for determining the feasibility of any method investigated. The TF method (1 & 2) will be discussed in more detail in the next section.

One of the methods investigated was the transmission matrix model. This model simulates the conduction of heat through a single or multi-layer surface by developing a matrix solution for equation (1) in which the matrix elements are composed of conductivity, density, and specific heat terms for each surface layer. Papers discussing this model were written by Carslaw and Jaeger (6), Vodicka (7), Buffington (8), and Rao and Chandra (9). Although this method predicts the transient temperature response of a surface accurately, it involved numerous matrix manipulation techniques which would be difficult at best for field engineers to apply. However, examining this method did provide some insight to the problem by illustrating important thermophysical properties.

The electrical analog method was also considered. When papers by Liebmann (10), Davies (11 & 12), Stephenson (13), Sonderegger (14), and Paschkis (15) were examined, the following equation was found.

$$\frac{\partial V}{\partial \Theta} = \frac{1}{R^{*}C^{*}} \frac{\partial^2 V}{\partial X^2} \qquad (2)$$

This equation is based on the fact that for steady state conditions, the flow of electricity is similar to heat flow. When comparing equation (2) to equation (1), Fourier's equation, one can readily see that voltage is analogous to temperature and that the $1/R^{*}C^{*}$ term in equation (2) is analogous to the $k/\rho c$ term in equation (1). In this manner a surface can be modeled as an electrical circuit. Although this method yields accurate solutions for heat transfer through multi-layer surfaces, difficulties arose when attempting to simplify a solution into a form applicable to industry. The most promising paper out of those listed above presented a new analog method developed by Sonderegger (14). Sonderegger considered a multiple layer surface and combined the layers into an equivalent two or three layer model. Equivalent thermal properties were determined and used to solve the resulting matrix. Although this method had the advantage of being able to handle multiple layers more easily than the other analog methods, matrix manipulation was still required to obtain a solution. A general solution of the matrix was possible, but the results would be difficult to adapt to hand calculation procedures.

Along with electric analog and transmission matrix methods, direct analytical solutions to the Fourier equation were also considered. Among these were solutions by Pratt (16 & 17), Huang and Chang (18), and Mackey and Wright (19 & 20). In each case the analytical solution for a multi-layer surface involved so many calculations that it would be unreasonable to expect anyone to perform the hand calculations required. Of these methods, Mackey and Wright (20) offered an alternative to the strict analytical solution. They presented time lag and amplitude ratio equations which were a function of two equivalent properties, as well as providing graphical solutions to these equations. The following equations illustrate the two equivalent properties.

$$\overline{k\rho c} = 1.1 \frac{\Sigma_1^n (\rho c X)}{\Sigma_1^n (X/k)} - 0.1 \ (k\rho c)_L \tag{3}$$

$$\overline{(X/k)} = \Sigma_1^n (X/k) \tag{4}$$

The $(k\rho c)_L$ term in equation (3) is for the outermost layer of a surface. In preliminary investigations this method appeared to estimate amplitude ratios and time lags quite well, but when a more detailed examination was performed, errors resulted. The thermophysical properties of some common building materials caused the method to fail. Also, the order of the middle layers in the surface assembly had no effect on the values determined for the equivalent properties, which is contrary to reality.

Correlation Methods

A correlation method can be described as any method which attempts to find a correlation between the time lag and amplitude ratio for a surface and its thermophysical properties and geometry. The methods examined included time constants, different combinations of material properties, and finally a grouping technique developed by Sowell (21).

When examining the correlation between time constants and the time lag and amplitude ratio for a surface, it was hoped that all surfaces with the same time constant would exhibit approximately the same transient heat transfer characteristics. The first time constant considered was based on the Fourier and Biot dimensionless numbers as defined by Heisler (22) and Arpaci (23). This time constant assumes the surface has only one layer and is composed of a homogeneous material. Since walls and roofs are normally composed of many layers, an equivalent set of properties, from which an equivalent time constant could be determined, was derived. The equivalent properties for a surface were based on the thickness of each layer and the total surface thickness. Unfortunately, the time constants derived by this method did not correlate well with the the actual transient heat transfer characteristics. Surfaces constructed of different materials, but having nearly identical time lags and amplitude ratios would often have completely different time constants. Several different parameters such as insulation placement, mass, and heat capacitance (mass times specific heat) were examined in conjunction with the time constant, but the results were still unsatisfactory. The Mackey and Wright (20) equivalent properties shown in equations (3) and (4) were multiplied together and divided by the convective heat transfer coefficient, h_o, to form a pseudo time constant. This value did not correlate the time lag and amplitude ratio any better than the time constant obtained using the Fourier and Biot dimensionless numbers.

The effect of many different parameters on the transient heat transfer characteristics of a surface were examined in the hopes that an acceptable correlation would present itself. These parameters included mass, mass times overall conductance, heat capacitance, and overall conductance. After examining the different combinations of mass, conductance, and specific heat, it was decided that the relative placement of mass and insulation should be included, because surfaces with massive layers placed on the outer side of the insulation had similar time lags but up to twice twice the amplitude ratio of the opposite case. When mass placement (mass in, mass out, or integral mass) was combined as a parameter with the aforementioned parameters, the result was a better overall correlation, but there were commonly constructed walls and roofs which did not correlate, regardless of the parameters used.

Grouping Method

After examining the literature discussed above, the decision was made to attempt to group walls and roofs using a method developed by Sowell (21). Sowell grouped building cooling load zone types with similar time lag and amplitude ratios together by examining combinations of zone geometries and properties. Since Sowell was only concerned with the cooling load for a zone, the amplitude ratio was defined as the ratio of the peak cooling load to the peak heat gain. Likewise, the time lag was defined as the time between the peak cooling load and peak heat gain. The geometries and properties he examined included wall glass percentage, zone size, whether or not carpeting or drapes were present, the ASHRAE wall group (5), ceiling type, and finally, the floor type. Sowell investigated the transient cooling load characteristics of the plethora of zone types possible and grouped them into groups having a span of plus or minus one half hour in the time lag and within plus zero and minus twenty percent of the maximum amplitude ratio for that group. Each group could then be represented by a single set of transfer function coefficients for converting heat gain to cooling load. In this manner, thousands of different zone types were represented by fewer than one hundred sets of coefficients.

To apply Sowell's method to heat gain through walls and roofs, a new set of parameters had to be developed. When the appropriate set of parameters were specified, the grouping method achieved the desired results by allowing several different walls or roofs to be described by a single set of conduction transfer function coefficients. The parameters and the methodology behind the application of the grouping method are discussed in detail in the next section.

CHAPTER III

METHODOLOGY

Transient Heat Transfer Characteristics

The basic premise for separating walls and roofs into groups having similar transient heat transfer behavior is that all walls or roofs having the same amplitude ratio and time lag, when excited by a sinusoidal driving function, will respond similarly under actual conditions. To determine the amplitude ratios and time lags for the surfaces considered in this study, the conduction transfer function equation (5), shown below, was used.

$$q_{i,\theta} = A \left[\sum_{n=0} b_n (t_{e,\theta-n\Delta}) - \sum_{n=1} d_n (q_{i,\theta-n\Delta}/A) - t_i \sum_{n=0} c_n \right] \quad (5)$$

In the above equation, the heat gain, $q_{i,\theta}$, is determined from the surface area, A, the sol-air temperature, t_e, the internal room air temperature, t_i, and the conduction transfer function coefficients, b_n, d_n, and c_n. The conduction transfer function coefficients for all surfaces considered in this study were computed using a program developed by Mitalas and Arsenault (24). This program was modified to execute on microcomputers.

To implement equation (5), the sol-air temperature, t_e, is defined by the following equation.

$$t_e = t_o + \frac{\alpha G_t}{h_o} - \frac{\varepsilon \triangle R}{h_o} \qquad (6)$$

In this equation, t_o is the outdoor air temperature which is a function of time, and G_t is the total incident solar radiation on a surface and is also a function of time. The surface absorptance, α, surface emittance, ε, outside convective heat transfer coefficient, h_o, and the difference between the long wavelength radiation incident on the surface from the sky and the radiation emitted by a black body at the outdoor air temperature, R, are all constants.

Following a methodology similar to that applied by Sowell (21), the outdoor air temperature and incident solar radiation terms in equation (6) can be approximated by sinusoids with periods of twenty-four hours. As previously mentioned, the data presented in the ASHRAE Handbook (5) for a design day sol-air temperature profile shows that while several frequencies are present, the 1/24 component is dominant. The last term in equation (6), which represents the energy emitted by a surface, is a small constant. This term can be omitted since it only shifts the value of the sol-air temperature, but does not change the shape of the sinusoid used to approximate it. Applying the information above, the following equation is produced.

$$t_{e,\theta} = t_o + \frac{\alpha G_t}{h_o} = B \sin(\Pi\Theta/12) \qquad (7)$$

In the above equation, B, a constant, can be set equal to the maximum sol-air temperature for a surface, $t_{e,max}$. Thus, the sol-air temperature is defined as a sinusoid with the same period as was assumed for the outdoor air temperature and solar radiation.

Since the amplitude ratio is the ratio of the peak output heat gain to the peak input heat flux, one must define a reference input heat flux to determine this ratio. The sol-air temperature is the only external input in equation (5), so it is logical to define the reference input heat flux with the following equation.

$$(q_{ref}/A)_\theta = h_o t_{e,\theta}$$

$$(q_{ref}/A)_\theta = h_o t_{e,max} \sin(\Pi\Theta/12)$$

$$(q_{ref}/A)_{max} = h_o t_{e,max} \qquad (8)$$

Thus, the reference input heat flux will be a sinusoid with a twenty-four hour period. The sol-air temperature, defined in equation (7), was multiplied by h_o for dimensional agreement and h_o was set equal to 3.0 Btu/hr-ft^2-F to be consistent with normal practice. It should be noted that any value of h_o could be used in equation (8) since it is only a scaling factor. The value of h_o has no effect on the results of this study, as will be shown later.

Finally, the values of $t_{e,\theta}$ from equation (7) are substituted into the conduction transfer equation (5) and t_i, an arbitrary constant, is set equal to zero. The resulting heat gain, determined from equation (5) using an iterative procedure, must also be a sinusoid and the ratio of output heat flux to input heat flux can be determined with the following equation.

$$\frac{q_{i,\theta}}{q_{ref,max}} = a \sin(\Pi\Theta/12 - \phi) = r_\theta \tag{9}$$

In the above equation, a is the dimensionless amplitude ratio, ϕ is the phase lag, and r_θ is the dimensionless heat gain at the hour Θ.

At the times $\Theta = 0$ and $\Theta = 6$, from equation (5)

$$r_0 = a \sin(-\phi) = -a \sin(\phi) \tag{10}$$

and

$$\begin{aligned} r_6 &= a \sin(\Pi 6/12 - \phi) \\ &= a \sin(\Pi/2 - \phi) \\ &= a \cos \phi \;. \end{aligned} \tag{11}$$

Squaring both equations (10) and (11) and adding yields

$$r_0^{\,2} + r_6^{\,2} = a^2 \;(\sin^2\phi + \cos^2\phi) = a^2$$

$$a = (r_0^{\,2} + r_6^{\,2})^{1/2} . \tag{12}$$

To accurately determine the phase lag, ϕ, a computer search was performed to determine where the sinusoidal heat gain curve crossed the phase lag axis with a positive slope. This is of course is valid only if the the input sine wave is symmetric about the zero heat flux axis. The difference between this point and the $\phi = 0$ point for the input curve is the phase lag. The time lag, D, is determined by

$$D = 12\ \phi/\Pi\ . \tag{13}$$

Both the amplitude ratio, a, and the time lag, D, were computed for all of the walls and roofs considered in this study. The program written to perform this task is listed in appendix A along with sample output. A list of the walls and roofs examined is given in appendix E.

The time lags and amplitude ratios for approximately 2600 walls and 500 roofs were determined. This large number of surfaces was required to cover both the range of transient heat transfer characteristics possible, and to ensure that all common wall and roof constructions were included. Because of the large number of surfaces, it was necessary to combine them into a manageable number of groups based on their amplitude ratios and time lags. Criteria were selected, based on the results of Sowell (20), to be plus zero percent and minus twenty percent and plus or minus one hour for the amplitude ratio and time lag respectively. These values were intended to lead to conservative results while keeping the number of groups at a minimum. From the results of the literature search, the grouping method developed by Sowell was used to accomplish the above and is discussed below.

Grouping Method

When first attempting to group all of the walls together, the only parameters considered were wall mass and overall conductance. It was found that the time lags and amplitude ratios for walls with similar mass and overall conductance, but different constructions, did not agree well. The time lag differences were up to four hours and the ratio of the minimum to the maximum amplitude ratio for each group was as low as 0.40. To narrow these values, the location of the massive element(s) in the surface was added as a parameter. For example, if insulation was placed on the inner side of a wall and concrete was placed on the outer side, this was designated the mass out case. If the insulation and concrete placement was reversed, it was termed the mass in case. Finally, if a wall contained two massive components placed on both sides of an insulating layer, the case was designated as integral mass. A mass of 12 lb/ft^2 was chosen as a minimum to represent a massive element. This mass value includes most common masonry building materials such as concrete, concrete block, brick, and clay tile. This appears to be logical when examining the mass of the materials listed in Table VII, and also provided excellent results when correlating the data into groups. The only material with a mass greater than 12 lb/ft^2 which was not considered a massive material was 4 in. wood (B9). This was done because its mass is close to 12 lb/ft^2 and it behaves thermally more like insulation than masonry. Also included in the integral mass case were walls with no insulation and walls with only lightweight components (i.e., < 12 lb/ft^2). By adding mass placement as a parameter, better agreement was achieved, but the lag and amplitude ranges were still too large to be acceptable.

After examining the results of previous grouping attempts, it was decided that a new grouping parameter, the principal wall material, should replace the wall mass parameter. A principal wall material is any material which could be considered the major component of the wall construction. As the term is used in this case, the major component is normally the most massive wall element, although this is not always the case. Twenty-five principal wall materials were chosen after examining all of the walls listed in the ASHRAE Handbook (5). It was also discovered that the principal wall materials were always combined with certain inside or outside layer materials, such as gypsum, stucco, metal siding, finish, or face brick. This inner or outer layer material was also added as a parameter.

A plot of amplitude ratio versus time lag for all of the walls considered in this study is shown in Figure 1. It can be seen that as the time lags become large the amplitude ratios tend to approach zero. After observing this it was decided to normalize the amplitude ratios using their respective overall conductances. The conduction transfer function coefficients for all surfaces with equivalent normalized amplitude ratios and time lags can be derived from a single set of coefficients. This was achieved by multiplying the b_n and c_n coefficients by the ratio of the overall conductance of the surface to the overall conductance of the

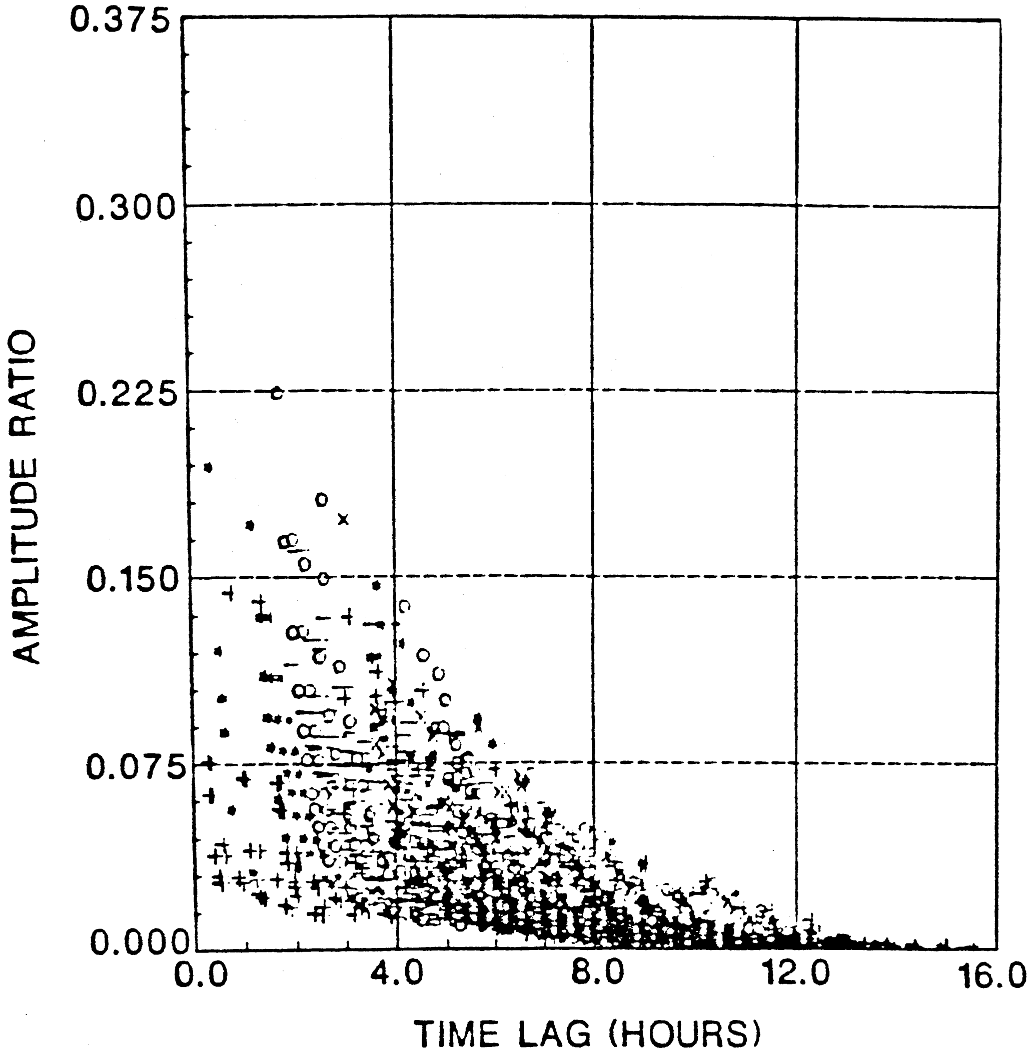

Figure 1. Plot of Amplitude Ratio vs Time Lag for all Walls

surface for which the conduction transfer function coefficients were determined. Details of this method for adjusting conduction transfer function coefficients are listed in the ASHRAE Handbook (5). This scheme resulted in a large reduction in the number of wall groups required. A new plot with normalized amplitude ratios may be seen in Figure 2. The number of wall designations or types was reduced to forty-one. The same procedure was performed for the roofs and resulted in forty-two different roof types. All of the time lags within each wall type were within plus or minus one hour and all normalized amplitude ratios contained in each type were within plus zero and minus twenty percent. The tables presenting the wall groupings are in the next section along with an explanation of how to apply them.

The grouping program used to sort the wall data and generate the tabulated results, shown in the next section, is listed in appendix A. The wall grouping program read a data file containing the time lags, normalized amplitude ratios, mass placements, principal wall materials, overall thermal resistances, and the outer or inner layer materials for each wall considered in this study. This data was sorted and the data for all walls having the same combination of parameters was placed in a new array for further processing. Once all of the data was sorted, the array elements containing more than one wall were analyzed and the minimum, maximum, and mean time lags and normalized amplitude ratios were determined. Finally, this data was examined and wall

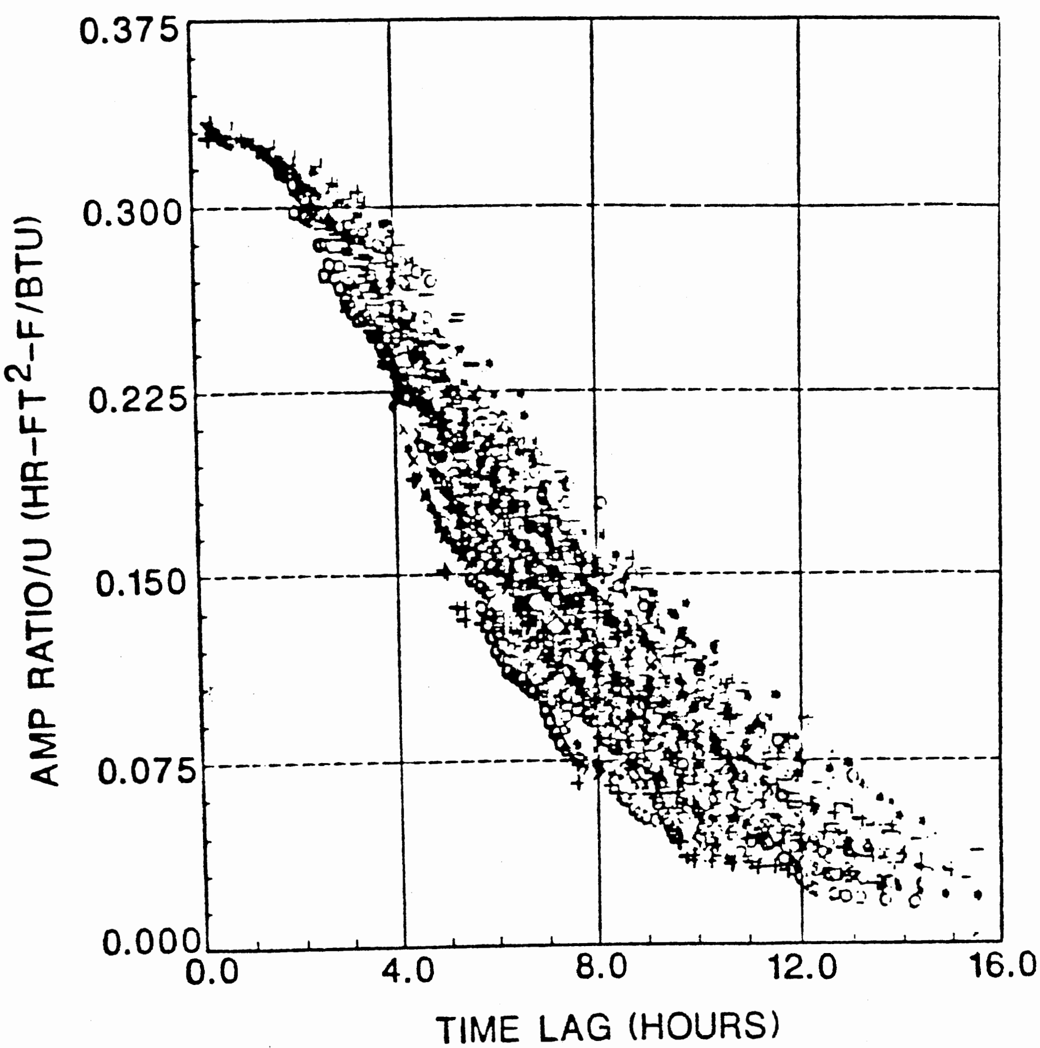

Figure 2. Plot of Normalized Amplitude Ratio vs Time Lag for all Walls

types were formed. All elements with similar time lags and normalized amplitude ratios were then placed into a group specified by a unique wall type number which was represented by a set of conduction transfer function coefficients. Sample output for the wall sorting program is given in appendix A. Data for approximately 2600 walls was analyzed in this phase of the study and the range of time lags and normalized amplitude ratios of the walls represented by each wall type number was within the predescribed error limits.

A similar grouping method, which resulted in one table which can be used to classify all roofs, was implemented for the roofs. A set of principal roof materials was selected and included all concrete, wood, and roof terrace systems. Again, the roof conductance and mass placement were used as parameters and the amplitude ratios were normalized with the overall conductance. The final parameter chosen was whether or not the roof assembly was combined with a suspended ceiling. With this set of four parameters, all of the time lags and normalized amplitude ratios for the roofs in each group were within error limits. Data for approximately 500 roofs was generated in this phase of the study. A program similar to that used for the walls was used to sort the data into forty-two unique roof types and generate tabulated results. Again, each roof type number is represented by a unique set of conduction transfer function coefficients. The roof program listing and sample output is listed in appendix A.

To assign a set of conduction transfer function coefficients to each unique wall and roof type, the maximum normalized amplitude ratio and mean time lag for all of the surfaces specified by a particular type number were analyzed. The surface which best matched these transient heat transfer characteristics was chosen to represent each wall or roof type as specified by that surfaces transfer function coefficients. A complete listing of the walls and roofs chosen to represent the various types is given in appendix C. Included are the conduction transfer function coefficients and a description with code letters defining the exact construction of each surface. The 41 walls and 42 roofs, whose conduction transfer function coefficients are listed in appendix C, were selected to represent all possible ranges of transient heat transfer characteristics. The method for selecting the correct wall or roof type from this list for a specific surface is presented in the next chapter.

Earlier in this section an arbitrary value of h_o was selected. Since a value of 3.0 Btu/hr-ft^2-F was used, the maximum possible normalized amplitude ratio is 1/3.0 as evidenced in Figure 2. This value is approached with lightweight frame walls. To show that the value of h_o has no effect on the grouping method discussed above, consider equation (7), which defines the sol-air temperature for this study. The sol-air temperature, as defined for the determination of time lags and amplitude ratios, is not a function of h_o; therefore, the heat gains obtained by equation (5) are independent of the value of h_o for a particular set of conduction transfer function coefficients. The magnitude of the reference input heat flux obtained from equation (8) does however depend on h_o. If, for example, a value of h_o equal to 1.0 Btu/hr-ft^2-F had been used, all normalized amplitude ratios would have a magnitude three times the values shown in Figure 2.

The grouping method used does not depend on the magnitude of the normalized amplitude ratios, but does depend on the ratio of the minimum to the maximum normalized amplitude ratio for surfaces within a particular group. The grouping criterion of plus zero percent to minus twenty percent for normalized amplitude ratios means that the ratio of the minimum to the maximum normalized amplitude ratio for a group will be greater than or equal to 0.8. Assume that the minimum and maximum normalized amplitude ratios for a group with a time lag of plus or minus one hour and h_o of 3.0 Btu/hr-ft^2-F were 0.24 and 0.30 respectively. The ratio of the minimum to the maximum in this case is 0.8. When a value of h_o equal to 1.0 Btu/hr-ft^2-F is used, the minimum and maximum normalized amplitude ratios become 0.72 and 0.90 respectively. Again, the ratio of the minimum to the maximum is 0.8. The value of h_o just acts as a scaling factor. Also, since h_o only affects the magnitude of the reference input heat flux, the time lags determined will be identical for any value of h_o used.

The method of adjusting the b_n and c_n conduction transfer function coefficients for a given surface to represent a new surface with similar transient heat transfer characteristics, but a different overall conductance, is outlined in the ASHRAE Handbook (5). As previously noted, the b_n and c_n coefficients are multiplied by the overall conductance of the surface for which a new set of b_n and c_n coefficients are desired, and divided by the overall conductance of the surface for which the the b_n and c_n coefficients were originally derived. The d_n conduction transfer function coefficients are not modified. This new set of transfer function coefficients could then be used to determine heat gains for the new surface. Since the ASHRAE Handbook (5) presents this method without references or proofs, it was deemed necessary to validate it. This method of adjusting transfer function coefficients is the basis for the application of the classification method developed in this thesis. Whenever the wall or roof type of a surface is determined, the set of conduction transfer function coefficients belonging to that surface type (see appendix C) must be adjusted with the overall conductance of the surface in question, to produce a set of coefficients which would mimic the transient heat transfer characteristics of the surface desired.

To validate this method, the conduction transfer function coefficients for two different wall types were chosen and their corresponding time lags, amplitude ratios, and normalized amplitude ratios were determined. The time lags and amplitude ratios were calculated using the Lag-Amplitude program listed in appendix A. If the transfer function adjustment method is valid, any set of coefficients derived from the original set, by multiplying the b_n and c_n coefficients by the overall conductance ratio, would produce the same time lag and normalized amplitude ratio. Table I summarizes the results of a study undertaken to prove this point.

In Table I, the (a) cases represent the results obtained from the actual conduction transfer function coefficients for wall types 5 and 18. A description of these wall types, along with their corresponding transfer function coefficients, is given in appendix C. Cases (b), (c), and (d) represent the results obtained for three different walls specified by the same wall type. The conduction transfer function coefficients for each of these three cases were derived from the coefficients corresponding to the (a) case by modifying the b_n and c_n coefficients with the corresponding overall conductance ratios. Although the amplitude ratios for cases (b), (c), and (d) are all different, their corresponding time lags and normalized amplitude ratios are equal and identical to those listed for the (a) case. This appears to be valid for any range of R-Values, and shows that the b_n and c_n coefficients control the amplitude ratio while the d_n coefficients control the time lag for a surface. Since the modified conduction transfer function coefficients for cases (b), (c), and (d) produced the same time lags and normalized amplitude ratios as case (a), one can assume that the transfer function modification procedure

TABLE I

VALIDATION OF CONDUCTION TRANSFER FUNCTION MODIFICATION PROCEDURE

Wall Type (case)	R-Value (hr-ft²-F/Btu)	Time Lag (hours)	Amplitude Ratio	Normalized Amplitude Ratio
5 (a)	7.76	5.11	0.02758	0.21397
5 (b)	1.50	5.11	0.15284	0.21397
5 (c)	9.10	5.11	0.03014	0.21397
5 (d)	21.50	5.11	0.00995	0.21397
18 (a)	6.70	8.73	0.01313	0.07970
18 (b)	2.75	8.73	0.02896	0.07970
18 (c)	8.40	8.73	0.00948	0.07970
18 (d)	21.50	8.73	0.00370	0.07970

outlined in the ASHRAE Handbook (5) is valid.

In the classification method developed in this thesis, surfaces are grouped together such that all surfaces, with time lags and normalized amplitude ratios within set limits, are represented by a single set of conduction transfer function coefficients. From this set of coefficients, the time lags and amplitude ratios, and thus the heat gains, may be determined for any surface contained in that particular group or classification.

CHAPTER IV

RESULTS

This chapter provides a detailed discussion of the results obtained with the wall and roof classification method developed in this thesis. Several important items are discussed, including implementation of the procedure for choosing a set of conduction transfer function coefficients to represent a given surface, verification of the new method's accuracy, and a comparison of cooling loads computed by:

(1) Specific conduction transfer function coefficients for a given surface.

(2) Transfer function coefficients for the group in which the surface belongs.

(3) The existing CLTD method.

When comparing the three methods noted above, special care is taken to cover a wide range of possible cases, so that any problems with 2 and 3 above may be identified.

Finally, the effect of different thermal response factors on methods 1 and 2 above are investigated and compared to the CLTD method which can not differentiate between different conduction zone types. The thermal response factors are the transfer function coefficients used to convert heat gains to cooling loads.

Wall Classifications

Tables II, III, and IV show the results for all the walls considered in this study. The numbers in these tables refer to the wall types, where each wall type has a specific set of conduction transfer function coefficients which are shown in appendix C. Table II is for walls with massive layer(s) placed inside compared to insulating layer(s). Table III is for walls with massive layers placed on both sides of any insulating layers, or for walls with no insulation. Table IV is for walls with massive layer(s) placed outside compared to insulating layer(s). These three cases are termed mass in, integral mass, and mass out respectively. The principal wall materials and R-Value ranges used in Tables II, III, and IV are defined in Tables V and VI.

To properly use these tables to classify a wall, one must understand what is meant by the terms massive and insulating layers. For this study, a massive layer was considered to be any layer of building material composed of brick, concrete, concrete block, or clay tile with a thickness of two inches or greater. Table VII, which is a modified version of a similar table in the ASHRAE Handbook (4), lists the thermophysical properties of all building materials considered in this study. Referring to this table, the massive materials are A2, A7, and C1 through C20. All other materials are considered to be non-massive. The insul-

TABLE II

WALL TYPES FOR THE MASS IN CASE.

PRINCIPAL WALL MATERIALS

	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
C	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	*	*	*
O	2	*	5	*	*	*	*	*	*	*	5	*	*	*	*	11	*	2	6	*	*	*	*	*	*	*
M	3	*	5	*	*	*	3	*	2	5	6	*	*	5	*	12	18	2	6	*	*	*	*	*	*	*
B	4	*	5	*	*	*	4	2	2	5	6	*	*	6	12	12	19	2	7	*	*	*	*	*	*	*
I	5	*	5	*	*	*	4	2	3	6	6	10	4	6	17	12	19	2	7	*	*	*	*	5	*	*
N	6	*	6	*	*	*	5	2	4	6	6	11	5	10	17	13	19	2	11	*	*	*	*	10	*	16
E	7	*	6	*	*	*	5	2	4	6	6	11	5	10	18	13	20	2	11	2	*	*	*	10	*	16
D	8	*	6	*	*	*	5	2	5	10	7	12	5	11	18	13	26	2	12	2	*	*	*	10	*	17
	9	*	6	*	*	*	5	4	5	11	7	16	10	11	18	13	20	3	12	4	5	*	*	11	*	18
W/	10	*	6	*	*	*	5	4	5	11	7	17	10	11	18	13	20	3	12	4	9	10	*	11	*	18
	11	*	6	*	*	*	5	4	5	11	7	17	10	11	19	13	27	3	12	4	10	15	4	11	*	18
A1	12	*	6	*	*	*	5	4	5	11	11	17	10	11	19	19	27	3	12	4	10	16	4	11	*	24
	13	*	10	*	*	*	10	4	5	11	11	17	10	11	19	18	27	4	12	5	11	17	9	12	15	25
&/	14	*	10	*	*	*	10	5	5	11	11	18	11	12	25	19	27	4	12	5	11	17	10	16	16	25
OR	15	*	11	*	*	*	10	5	9	11	11	18	15	16	26	19	28	4	12	5	11	17	10	16	22	25
	16	*	11	*	*	*	10	9	9	16	11	18	15	16	26	19	34	4	17	9	16	23	10	16	23	25
E1	17	*	*	*	*	*	*	*	*	*	*	24	16	*	*	*	*	*	*	9	16	24	15	17	24	25
C	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*
O	2	*	3	*	*	*	*	*	2	3	5	*	*	*	*	11	*	2	6	*	*	*	*	*	*	*
M	3	*	5	*	*	*	2	*	2	5	3	*	*	5	*	12	18	2	6	*	*	*	*	*	*	*
B	4	*	5	*	*	*	3	1	2	5	5	*	*	5	11	12	19	2	7	*	*	*	*	*	*	*
I	5	*	5	*	*	*	3	2	2	5	5	6	3	5	12	12	19	2	7	*	*	*	*	5	*	*
N	6	*	6	*	*	*	4	2	2	5	5	10	4	6	12	12	19	2	7	*	*	*	*	5	*	11
E	7	*	6	*	*	*	5	2	2	6	6	11	5	6	17	13	20	2	7	2	*	*	*	6	*	12
D	8	*	6	*	*	*	5	2	3	6	6	11	5	6	18	13	20	2	7	2	*	*	*	6	*	17
	9	*	6	*	*	*	5	2	3	6	6	11	5	6	18	13	20	2	8	2	5	*	*	10	*	17
W/	10	*	6	*	*	*	5	2	3	6	6	12	5	6	18	14	21	2	12	2	5	10	*	11	*	17
	11	*	6	*	*	*	5	2	3	6	6	12	5	6	18	14	21	3	12	4	5	11	4	11	*	18
A3	12	*	6	*	*	*	5	2	3	6	7	12	6	11	19	14	21	3	12	4	10	16	4	11	*	18
	13	*	6	*	*	*	5	2	4	6	7	12	10	11	19	14	27	3	12	5	10	17	5	11	10	18
O	14	*	10	*	*	*	6	4	4	10	7	17	10	11	19	18	27	4	12	5	11	17	9	11	16	18
R	15	*	10	*	*	*	10	4	4	10	11	17	10	11	25	18	28	4	12	5	11	17	10	11	16	18
	16	*	11	*	*	*	10	4	5	11	11	17	10	11	25	18	28	4	12	9	11	18	10	16	17	24
A6	17	*	*	*	*	*	*	*	*	*	*	17	10	*	*	*	*	*	*	9	16	24	11	16	23	25
C	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
O	2	3	*	*	*	*	*	*	*	*	11	*	*	*	*	*	*	6	*	*	*	*	*	*	*	*
M	3	5	11	*	*	*	*	*	6	11	12	*	*	*	*	18	*	6	12	*	*	*	*	*	*	*
B	4	5	12	5	*	*	11	*	11	12	12	*	*	12	*	19	26	7	13	*	*	*	*	*	*	*
I	5	5	12	6	*	*	12	6	12	12	13	*	*	12	24	19	27	7	14	*	*	*	*	*	*	*
N	6	6	13	6	10	*	13	10	12	12	13	17	11	17	25	20	27	7	18	*	*	*	*	16	*	24
E	7	6	13	6	11	*	18	11	12	13	13	18	16	17	26	20	28	7	19	11	*	*	*	17	*	25
D	8	6	13	6	11	*	18	11	12	13	13	24	17	18	26	20	28	12	19	11	*	*	*	17	*	25
	9	6	13	6	11	24	18	11	13	18	13	25	17	18	27	20	29	12	19	11	16	*	*	18	*	26
W/	10	6	13	10	16	25	19	11	13	18	13	25	17	18	27	26	35	12	19	11	17	23	*	18	*	26
	11	6	14	10	16	32	19	11	13	18	14	25	17	18	33	21	35	12	19	16	23	24	16	18	*	33
A2	12	6	14	10	16	32	19	11	13	18	14	26	18	18	34	27	35	12	19	16	24	31	16	19	*	33
	13	6	18	11	16	33	19	12	13	18	18	26	18	18	34	27	36	12	20	17	24	32	17	25	30	33
O	14	10	18	11	17	33	19	12	13	18	18	26	18	18	34	27	36	12	20	17	24	32	23	25	31	34
R	15	10	18	11	17	34	19	16	18	18	18	26	24	25	34	27	36	12	20	17	25	33	24	25	32	34
	16	11	19	15	23	39	26	16	18	24	19	32	24	25	34	27	36	17	26	23	31	33	24	25	32	34
A7	17	*	*	*	23	39	*	16	*	*	*	33	24	*	35	*	*	*	*	23	32	38	24	25	38	39

* - DENOTES A WALL WHICH IS NOT POSSIBLE WITH CHOSEN COMBINATION OF MATERIALS & R-VALUE RANGE.

NOTE: NUMBERS IN TABLE REFER TO TRANSFER FUNCTION COEFFICIENTS LISTED IN APPENDIX C.

TABLE III

WALL TYPES FOR THE INTEGRAL MASS CASE

PRINCIPAL WALL MATERIALS

	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
C	1	1	3	*	*	*	*	*	1	3	3	*	*	*	*	11	*	2	5	*	*	*	*	*	*	*
O	2	1	3	1	*	*	2	*	2	4	4	*	*	5	*	11	17	2	5	*	*	*	*	*	*	*
M	3	1	4	1	*	*	2	2	2	4	4	*	*	5	10	12	17	4	5	*	*	*	*	*	*	*
B	4	1	*	1	*	*	2	2	*	*	*	10	4	5	10	*	17	*	*	*	*	*	*	4	*	*
I	5	1	*	1	2	*	*	4	*	*	*	10	4	*	10	*	*	*	*	*	*	*	*	4	*	10
N	6	1	*	1	2	*	*	*	*	*	*	10	4	*	*	*	*	*	*	2	*	*	*	4	*	10
E	7	1	*	1	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	10
D	8	1	*	2	4	10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*	*	*
	9	1	*	2	4	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*	*	*
W/	10	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	*	*	*	*
	11	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	4	*	*	*
A1	12	1	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*
	13	2	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15	*
&/	14	2	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15	*
OR	15	2	*	2	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	16	2	*	4	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
E1	17	*	*	*	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
C	1	1	3	*	*	*	*	*	1	3	2	*	*	*	*	6	*	1	5	*	*	*	*	*	*	*
O	2	1	3	1	*	*	2	*	1	3	2	*	*	3	*	6	12	1	5	*	*	*	*	*	*	*
M	3	1	4	1	*	*	2	1	2	4	4	*	*	3	10	11	12	2	5	*	*	*	*	*	*	*
B	4	1	*	1	*	*	4	1	*	*	*	5	2	4	10	*	12	*	*	*	*	*	*	4	*	*
I	5	1	*	1	2	*	*	2	*	*	*	5	2	*	10	*	*	*	*	*	*	*	*	4	*	10
N	6	1	*	1	2	*	*	*	*	*	*	10	4	*	*	*	*	*	*	2	*	*	*	4	*	10
E	7	1	*	1	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	10
D	8	1	*	1	2	10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*	*	*
	9	1	*	1	4	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*	*	*
W/	10	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	*	*	*	*
	11	1	*	2	4	16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9	2	*	*	*
A3	12	1	*	2	4	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4	*	*	*
	13	1	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	10	*
O	14	1	*	2	5	17	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15	*
R	15	1	*	2	5	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	16	2	*	4	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
A6	17	*	*	*	9	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
C	1	3	6	*	*	*	*	*	*	*	6	*	*	*	*	*	*	3	11	*	*	*	*	*	*	*
O	2	3	10	*	*	*	*	*	5	10	10	*	*	*	*	17	24	5	11	*	*	*	*	*	*	*
M	3	4	10	5	*	*	5	*	5	10	11	*	*	10	*	17	25	5	16	*	*	*	*	*	*	*
B	4	*	11	5	*	*	10	5	5	11	11	15	10	10	17	18	26	5	17	*	*	*	*	10	*	*
I	5	*	11	5	10	*	10	5	5	11	11	16	10	16	23	18	26	5	17	*	*	*	*	10	*	*
N	6	*	11	*	11	*	10	5	5	16	11	17	10	16	24	18	33	5	17	*	*	*	*	16	*	23
E	7	*	11	*	11	*	10	5	10	16	16	17	10	16	25	25	33	5	17	5	*	*	*	16	*	23
D	8	*	16	*	*	22	10	9	10	16	11	17	11	16	25	25	34	10	18	9	*	*	*	16	*	24
	9	*	16	*	*	23	11	9	10	16	16	24	16	16	26	25	34	10	18	10	15	*	*	17	*	25
W/	10	*	16	*	*	*	15	9	10	16	17	24	15	16	26	26	34	10	18	10	15	22	*	17	*	25
	11	*	16	*	*	*	15	10	10	17	16	24	16	17	33	26	35	10	18	10	16	23	10	23	*	25
A2	12	*	16	*	*	*	16	10	10	17	17	24	16	17	33	26	35	10	18	10	16	23	15	23	*	32
	13	*	16	*	*	*	16	10	10	17	16	25	17	17	33	26	35	10	24	15	23	24	15	24	23	32
O	14	*	17	*	*	*	16	10	15	23	17	31	23	24	33	26	40	10	24	15	23	31	16	23	30	32
R	15	*	17	*	*	*	16	15	15	23	23	31	23	24	38	33	40	10	24	15	24	31	16	23	30	32
	16	*	23	*	*	*	22	15	16	24	24	32	23	24	38	33	41	15	25	15	23	32	22	23	31	32
A7	17	*	*	*	*	*	*	15	*	*	*	32	23	*	39	*	*	*	*	22	30	32	23	24	32	38

* - DENOTES A WALL WHICH IS NOT POSSIBLE WITH CHOSEN COMBINATION OF MATERIALS & R-VALUE RANGE.

NOTE: NUMBERS IN TABLE REFER TO TRANSFER FUNCTION COEFFICIENTS IN APPENDIX C.

TABLE IV

WALL TYPES FOR THE MASS OUT CASE

PRINCIPAL WALL MATERIALS

	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
C	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*
O	2	*	3	*	*	*	*	*	2	3	5	*	*	*	*	6	*	1	5	*	*	*	*	*	*	*
M	3	*	3	*	*	*	2	*	2	4	5	*	*	5	*	11	18	2	5	*	*	*	*	*	*	*
B	4	*	3	*	*	*	2	2	2	5	5	*	*	5	16	11	18	2	5	*	*	*	*	*	*	*
I	5	*	3	*	*	*	2	2	2	5	5	10	4	6	17	11	19	2	6	*	*	*	*	5	*	*
N	6	*	4	*	*	*	4	2	2	5	5	10	4	6	17	11	19	2	6	*	*	*	*	9	*	16
E	7	*	4	*	*	*	4	2	2	5	6	11	5	10	17	12	19	2	6	2	*	*	*	10	*	16
D	8	*	5	*	*	*	4	2	2	5	6	11	5	10	18	11	20	2	6	4	*	*	*	10	*	16
	9	*	5	*	*	*	4	2	2	5	6	11	5	10	18	11	26	2	6	4	9	*	*	10	*	17
W/	10	*	5	*	*	*	5	2	4	5	6	16	10	10	18	12	26	2	6	4	9	15	*	10	*	17
	11	*	5	*	*	*	5	4	4	5	6	16	10	10	18	12	26	2	6	4	10	15	4	11	*	18
A1	12	*	5	*	*	*	5	4	4	10	6	16	10	10	18	12	26	2	10	5	10	16	9	11	*	18
	13	*	5	*	*	*	5	4	4	10	10	17	10	11	18	12	26	2	10	5	11	17	9	11	15	24
&/	14	*	5	*	*	*	5	4	4	10	10	17	10	11	24	18	26	2	10	9	15	23	10	16	16	24
OR	15	*	5	*	*	*	9	4	4	10	10	17	10	15	25	18	26	2	10	9	15	23	10	16	22	24
	16	*	9	*	*	*	9	9	9	15	10	17	10	15	25	18	33	4	11	9	16	24	15	16	23	24
E1	17	*	*	*	*	*	*	*	*	*	*	23	15	*	*	*	*	*	*	9	22	24	15	16	24	25
C	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*
O	2	*	3	*	*	*	*	*	2	3	2	*	*	*	*	6	*	1	5	*	*	*	*	*	*	*
M	3	*	3	*	*	*	2	*	2	3	2	*	*	*	*	10	17	1	5	*	*	*	*	*	*	*
B	4	*	3	*	*	*	2	1	2	4	3	*	*	4	11	11	17	1	5	*	*	*	*	*	*	*
I	5	*	3	*	*	*	2	2	2	4	3	5	2	5	11	11	18	1	6	*	*	*	*	4	*	*
N	6	*	3	*	*	*	2	2	2	4	3	10	3	5	12	11	18	2	6	*	*	*	*	5	*	10
E	7	*	3	*	*	*	2	2	2	5	3	10	4	5	12	11	18	2	6	2	*	*	*	5	*	11
D	8	*	4	*	*	*	2	2	2	5	3	10	4	5	12	11	18	2	6	2	*	*	*	5	*	12
	9	*	4	*	*	*	2	2	2	5	4	11	5	5	17	11	18	2	6	2	5	*	*	6	*	16
W/	10	*	5	*	*	*	2	2	2	5	4	11	5	5	17	11	19	2	6	2	5	10	*	6	*	17
	11	*	5	*	*	*	2	2	2	5	4	11	5	5	17	12	19	2	6	4	5	11	4	10	*	17
A3	12	*	5	*	*	*	4	2	2	5	5	11	5	5	17	12	19	2	6	4	10	15	4	10	*	17
	13	*	5	*	*	*	4	2	2	5	5	11	5	10	18	12	19	2	10	4	10	16	5	10	10	17
O	14	*	5	*	*	*	4	2	4	5	5	16	9	10	18	12	25	2	10	4	10	17	9	10	16	17
R	15	*	5	*	*	*	4	4	4	9	5	16	9	10	18	16	25	2	10	5	11	17	10	10	16	18
	16	*	9	*	*	*	4	4	4	9	9	16	10	10	24	17	25	4	10	5	11	17	10	11	17	18
A6	17	*	*	*	*	*	*	*	*	*	*	16	10	*	*	*	*	*	*	9	16	23	10	15	23	24
C	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
O	2	3	*	*	*	*	*	*	*	*	11	*	*	*	*	*	*	5	*	*	*	*	*	*	*	*
M	3	3	10	*	*	*	*	*	5	10	11	*	*	*	*	17	*	5	12	*	*	*	*	*	*	*
B	4	3	11	5	*	*	10	*	5	11	11	*	*	11	*	18	26	6	12	*	*	*	*	*	*	*
I	5	3	11	5	*	*	10	5	6	11	11	*	*	11	24	18	26	6	13	*	*	*	*	*	*	*
N	6	3	11	5	10	*	10	5	10	11	11	17	10	11	24	18	26	6	13	*	*	*	*	16	*	23
E	7	3	12	5	10	*	10	9	10	11	12	17	11	16	25	19	27	6	17	9	*	*	*	16	*	23
D	8	4	12	5	10	*	10	10	10	12	12	17	15	16	25	19	27	6	17	10	*	*	*	16	*	24
	9	4	12	5	10	23	11	10	10	12	12	23	16	17	26	19	27	10	18	10	15	*	*	16	*	25
W/	10	5	12	5	15	24	11	10	10	16	12	24	16	17	26	19	34	10	18	10	16	22	*	17	*	25
	11	5	12	9	15	30	11	10	10	16	12	24	16	17	26	19	34	10	18	10	16	23	15	17	*	25
A2	12	5	12	10	15	31	11	10	10	17	12	24	16	17	26	25	34	10	18	10	22	24	15	17	*	32
	13	5	17	10	16	32	11	10	11	17	17	24	16	17	26	25	34	11	18	15	23	30	15	23	23	32
O	14	5	17	10	16	32	15	10	11	17	17	25	16	17	33	25	34	11	18	15	23	31	22	23	30	32
R	15	5	17	10	16	32	16	15	15	17	17	25	22	23	33	26	35	11	18	15	23	31	22	23	30	32
	16	9	17	15	16	32	16	15	15	23	17	31	22	23	33	26	40	15	24	15	23	32	23	24	31	32
A7	17	*	*	*	22	38	*	15	*	*	*	31	23	*	33	*	*	*	*	22	30	37	23	24	37	38

* - DENOTES A WALL WHICH IS NOT POSSIBLE WITH CHOSEN COMBINATION OF MATERIALS & R-VALUE RANGE.

NOTE: NUMBERS IN TABLE REFER TO TRANSFER FUNCTION COEFFICIENTS IN APPENDIX C.

TABLE V

WALL R-VALUE RANGE DEFINITIONS

R-Value Range (R)	R-Values (hr-ft^2-F/Btu)
1	0.00 - 2.00
2	2.00 - 2.50
3	2.50 - 3.00
4	3.00 - 3.50
5	3.50 - 4.00
6	4.00 - 4.75
7	4.75 - 5.50
8	5.50 - 6.50
9	6.50 - 7.75
10	7.75 - 9.00
11	9.00 - 10.75
12	10.75 - 12.75
13	12.75 - 15.00
14	15.00 - 17.50
15	17.50 - 20.00
16	20.00 - 23.00
17	23.00 - 27.00

TABLE VI

PRINCIPAL WALL MATERIALS

MATERIAL NUMBER	LAYER CODE	DESCRIPTION
1	A1, A3, A6, OR E1	1" STUCCO, STEEL SIDING, FINISH, OR GYPSUM
2	A2 OR A7	4" FACE BRICK
3	B7	1" WOOD
4	B10	2" WOOD
5	B9	4" WOOD
6	C1	4" CLAY TILE
7	C2	4" LW CONCRETE BLOCK
8	C3	4" HW CONCRETE BLOCK
9	C4	4" COMMON BRICK
10	C5	4" HW CONC
11	C6	8" CLAY TILE
12	C7	8" LW CONCRETE BLOCK
13	C8	8" HW CONCRETE BLOCK
14	C9	8" COMMON BRICK
15	C10	8" HW CONCRETE
16	C11	12" HW CONCRETE
17	C12	2" HW CONCRETE
18	C13	6" HW CONCRETE
19	C14	4" LW CONCRETE
20	C15	6" LW CONCRETE
21	C16	8" LW CONCRETE
22	C17	8" LW CONCRETE BLOCK(FILLED)
23	C18	8" HW CONCRETE BLOCK(FILLED)
24	C19	12" LW CONCRETE BLOCK(FILLED)
25	C20	12" HW CONCRETE BLOCK(FILLED)

TABLE VII

THERMAL PROPERTIES AND CODE NUMBERS OF LAYERS USED IN WALL AND ROOF DESCRIPTIONS

CODE NUMBER	DESCRIPTION	THICKNESS AND THERMAL PROPERTIES L	K	D	SH	R	MASS
A0	OUTSIDE SURF RESISTANCE	0.0	0.0	0.0	0.0	0.333	0.0
A1	1" STUCCO	0.0833	0.4	116.0	0.20	0.208	9.7
A2	4" FACE BRICK	0.333	0.77	125.0	0.22	0.432	41.7
A3	STEEL SIDING	0.005	26.0	480.0	0.10	0.000	2.4
A4	1/2" SLAG	0.0417	0.11	70.0	0.40	0.379	2.2
A5	OUTSIDE SURF RESISTANCE	0.0	0.0	0.0	0.0	0.333	0.0
A6	FINISH	0.0417	0.24	78.0	0.26	0.174	3.3
A7	4" FACEBRICK	0.333	0.77	125.0	0.22	0.432	41.7
B1	AIR SPACE RESISTANCE	0.0	0.0	0.0	0.0	0.910	0.0
B2	1" INSULATION	0.083	0.025	2.0	0.2	3.333	0.2
B3	2" INSULATION	0.167	0.025	2.0	0.2	6.667	0.3
B4	3" INSULATION	0.25	0.025	2.0	0.2	10.000	0.5
B5	1" INSULATION	0.0833	0.025	5.7	0.2	3.333	0.5
B6	2" INSULATION	0.167	0.025	5.7	0.2	6.667	1.0
B7	1" WOOD	0.0833	0.07	37.0	0.6	10.000	3.1
B8	2.5" WOOD	0.2083	0.07	37.0	0.6	2.976	7.7
B9	4" WOOD	0.333	0.07	37.0	0.6	4.757	12.3
B10	2" WOOD	0.167	0.07	37.0	0.6	2.386	6.2
B11	3" WOOD	0.25	0.07	37.0	0.6	3.571	9.3
B12	3" INSULATION	0.25	0.025	5.7	0.2	10.000	1.4
B13	4" INSULATION	0.333	0.025	5.7	0.2	13.333	1.9
B14	5" INSULATION	0.417	0.025	5.7	0.2	16.667	2.4
B15	6" INSULATION	0.500	0.025	5.7	0.2	20.000	2.9
B16	0.15" INSULATION	0.0126	0.025	5.7	0.2	0.500	0.1
B17	0.3" INSULATION	0.0252	0.025	5.7	0.2	1.000	0.1
B18	0.45" INSULATION	0.0379	0.025	5.7	0.2	1.500	0.2
B19	0.61" INSULATION	0.0505	0.025	5.7	0.2	2.000	0.3
B20	0.76" INSULATION	0.0631	0.025	5.7	0.2	2.500	0.4
B21	1.36" INSULATION	0.1136	0.025	5.7	0.2	4.500	0.6
B22	1.67" INSULATION	0.1388	0.025	5.7	0.2	5.500	0.8
B23	2.42" INSULATION	0.2019	0.025	5.7	0.2	8.000	1.2
B24	2.73" INSULATION	0.2272	0.025	5.7	0.2	9.000	1.3
B25	3.33" INSULATION	0.2777	0.025	5.7	0.2	11.000	1.6
B26	3.64" INSULATION	0.3029	0.025	5.7	0.2	12.000	1.7
B27	4.54" INSULATION	0.3786	0.025	5.7	0.2	15.000	2.2

TABLE VII (Continued)

CODE NUMBER	DESCRIPTION	L	K	D	SH	R	MASS
C1	4" CLAY TILE	0.333	0.33	70.0	0.2	1.009	23.3
C2	4" LW CONCRETE BLOCK	0.333	0.22	38.0	0.2	1.514	12.7
C3	4" HW CONCRETE BLOCK	0.333	0.47	61.0	0.2	0.709	20.3
C4	4" COMMON BRICK	0.333	0.42	120.0	0.2	0.793	40.0
C5	4" HW CONCRETE	0.333	1.0	140.0	0.2	0.333	46.7
C6	8" CLAY TILE	0.667	0.33	70.0	0.2	2.000	46.7
C7	8" LW CONCRETE BLOCK	0.667	0.33	38.0	0.2	2.000	25.3
C8	8" HW CONCRETE BLOCK	0.667	0.6	61.0	0.2	1.111	40.7
C9	8" COMMON BRICK	0.667	0.42	120.0	0.2	1.588	80.0
C10	8" HW CONCRETE	0.667	1.0	140.0	0.2	0.667	93.4
C11	12" HW CONCRETE	1.0	1.0	140.0	0.2	1.000	140.0
C12	2" HW CONCRETE	0.167	1.0	140.0	0.2	0.167	23.3
C13	6" HW CONCRETE	0.5	1.0	140.0	0.2	0.500	70.0
C14	4" LW CONCRETE	0.333	0.1	40.0	0.2	3.333	13.3
C15	6" LW CONCRETE	0.5	0.1	40.0	0.2	5.000	20.0
C16	8" LW CONCRETE	0.667	0.1	40.0	0.2	6.667	26.7
C17	8" LW CONC.BLK(FILLED)	0.667	0.08	18.0	0.2	8.338	12.0
C18	8" HW CONC.BLK(FILLED)	0.667	0.34	53.0	0.2	1.962	35.4
C19	12" LW CONC.BLK(FILLED)	1.000	0.08	19.0	0.2	12.500	19.0
C20	12" HW CONC.BLK(FILLED)	1.000	0.39	56.0	0.2	2.564	56.0
E0	INSIDE SURF RESISTANCE	0.0	0.0	0.0	0.0	0.685	0.0
E1	3/4" PLASTER OR GYPSUM	0.0625	0.42	100.0	0.2	0.149	6.3
E2	1/2" SLAG OR STONE	0.0417	0.83	55.0	0.40	0.050	2.3
E3	3/8" FELT & MEMBRANE	0.0313	0.11	70.0	0.40	0.285	2.2
E4	CEILING AIR SPACE	0.0	0.0	0.0	0.0	1.000	0.0
E5	ACOUSTIC TILE	0.0625	0.035	30.0	0.2	1.786	1.9

(THICKNESS AND THERMAL PROPERTIES: L, K, D, SH, R, MASS)

DEFINITIONS : L - THICKNESS; K - THERMAL CONDUCTIVITY; D - DENSITY;
SH - SPECIFIC HEAT; R - THERMAL RESISTANCE

UNITS : L = ft; K = BTU/hr-ft-F; D = lb/ft^3; SH = BTU/lb-F;
R = $hr\text{-}ft^2\text{-}F/BTU$; MASS = lb/ft^2

ating layers used in this study were B2 through B6 and B12 through B27.

In addition to knowing the mass and insulation placement for a given wall, one also needs to determine the R-value (overall thermal resistance) which includes the inside and outside film resistances, E0 and A0. The R-value for a given wall is calculated by summing all of the individual thermal resistances of the wall components. Also, the principal wall material must be identified, as well as the inner and/or outer layer materials that the principal wall material is combined with. The principal wall materials were considered to be the massive materials previously mentioned, as well as the wood layers B7, B9, and B10. The last material considered was included to allow for lightweight framed walls or partitions. This is listed as material 1 in Tables II, III, and IV, and includes stucco, metal siding, finish, and gypsum which are represented by A1, A3, A6, and E1 respectively. The inner and/or outer layer materials were divided into three groups based on mass. The first group contains stucco and/or gypsum (A1 and/or E1), the second group contains metal siding or finish (A3 or A6), and the final group contains face brick (A2 or A7).

Many of the parameter combinations in these tables are impractical and are designated with an asterisk. The asterisks signify combinations of materials or mass placements which are not possible and R-value ranges which would be considered impractical by normal construction standards. For example, principal wall materials 1, 3, 4, and 5, which include stucco, metal siding, finish, gypsum, and all wood layers, are all non-massive materials. When these materials are combined with face brick, only the mass in or mass out cases are possible, except for a small range of cases when no insulation is present. This accounts for the columns in the tables with only two or three entries. Many wall materials do not have entries in the smaller magnitude R-Value ranges. For instance, principal wall material 24, which is 12 in. lightweight concrete block (filled with insulation), has an R-value of 13.5 hr-ft^2-F/Btu and when combined with film resistances and other layers it could not possibly fit into R-Value ranges 1 through 12.

One final note should be made about the inner and/or outer layer materials. It is common for materials such as stucco or gypsum (A1 or E1) to be present in walls also containing metal siding or finish (A3 or A6). The same can also be said for face brick (A2 or A7). When more than one type of inner and/or outer layer material is present, the most massive inner or outer layer material should be chosen to represent that particular case. Face brick, A2 or A7, is the most massive of these materials, with stucco and gypsum, A1 and E1, being next, and finally, metal siding and finish, A3 and A6, are the most lightweight materials.

Following are some examples of how to apply Tables II, III, and IV. Refer to Table VII for code letter descriptions.

Example 1: Frame Wall

Code Description: A0, A1, B6, A6, E0

R-Value = 8.06 (hr-ft^2-F/Btu)

R-Value Range = 10 (Table V)

Principal Wall Material = 1 (A1, Table VI)

Integral Mass (no massive layers present)

Combined With A6

From Table III: Wall Type 1

Example 2: 12 in. heavyweight concrete wall with 2 in. insulation on the outside

Code Description: A0, A3, B6, C11, E1, E0

R-Value = 8.83 (hr-ft^2-F/Btu)

R-Value Range = 10 (Table V)

Principal Wall Material = 16 (C11, Table VI)

Mass In (insulation on outer side of concrete)

Combined With E1

From Table II: Wall Type 20

Example 3:

Code Description: A0, A7, B1, B12, C19, E1, E0

R-Value = 25.03 (hr-ft^2-F/Btu)

R-Value Range = 17 (Table V)

Principal Wall Material = 24 (C19, Table VI)

Integral Mass (insulation is between massive layers)

Combined With A7

From Table III: Wall Type 32

In each of the above examples, transfer function coefficients from appendix C, corresponding to each wall type are then selected to carry out heat gain calculations.

Roof Classifications

Table VIII shows the results for all roofs considered in this study. As with the walls, principal materials are defined along with R-Value ranges and mass placement. The principal roof materials and R-Value ranges are defined in Tables IX and X. The fourth parameter used to define the roof types was the possibility of a suspended ceiling. A suspended ceiling is defined as an air space and acoustic tile or similar material with or without insulation located below the roof assembly.

The same general rules apply to Table VIII for the roofs as applied to the wall tables. The principal roof materials are defined as follows. Materials 1, 2, 3, and 10 are non-massive wood and metal layers and material 11 is used to define an attic type roof assembly, also considered to be non-massive. Materials 4 through 9 are composed of various thicknesses and types of concrete and are considered to be massive. Finally, materials 12 through 20 are various combinations of roof terrace systems and are also considered to be massive layers. The two concrete layers used to form roof terrace systems, as shown in Table VIII, are listed in the

TABLE VIII

ROOF CLASIFICATIONS

	SC	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
			PRINCIPAL ROOF MATERIAL																			
MASS IN	W/O	1	*	*	*	6	2	7	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		2	*	*	*	7	2	12	4	5	9	*	*	*	*	*	*	*	*	*	*	*
		3	*	*	*	7	4	13	5	10	19	*	*	*	*	*	*	*	*	*	*	*
		4	*	*	*	10	4	13	9	18	20	*	*	*	*	*	*	*	*	*	*	*
		5	*	*	*	10	5	20	9	18	27	*	*	*	*	*	*	*	*	*	*	*
		6	*	*	*	*	*	*	*	18	27	*	*	*	*	*	*	*	*	*	*	*
	WITH	1	*	*	*	8	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		2	*	*	*	15	8	18	4	10	*	*	*	*	*	*	*	*	*	*	*	*
		3	*	*	*	18	13	24	10	18	20	*	*	*	*	*	*	*	*	*	*	*
		4	*	*	*	18	13	25	11	21	28	*	*	*	*	*	*	*	*	*	*	*
		5	*	*	*	23	14	25	18	21	29	*	*	*	*	*	*	*	*	*	*	*
		6	*	*	*	*	*	*	20	28	36	*	*	*	*	*	*	*	*	*	*	*
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
INTEGRAL MASS	W/O	1	1	4	*	3	2	5	2	*	*	1	1	4	6	11	5	10	20	10	18	21
		2	2	5	19	*	*	*	2	4	9	1	2	5	11	20	10	20	27	18	27	29
		3	2	9	21	*	*	*	*	*	*	1	2	9	12	20	10	20	28	20	27	30
		4	4	10	27	*	*	*	*	*	*	2	2	9	18	21	17	26	28	20	28	36
		5	4	18	27	*	*	*	*	*	*	2	4	9	18	27	17	26	35	26	35	36
		6	*	*	28	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	WITH	1	*	*	*	6	3	11	*	*	*	1	*	6	10	13	10	13	21	12	21	*
		2	4	9	20	*	*	11	4	9	*	1	4	13	21	23	20	23	32	28	31	39
		3	5	20	28	*	*	*	*	*	18	2	4	22	23	24	22	32	34	30	39	41
		4	9	21	30	*	*	*	*	*	*	2	5	22	24	33	28	32	40	31	40	41
		5	10	22	37	*	*	*	*	*	*	4	9	22	31	33	29	33	*	37	40	42
		6	10	28	38	*	*	*	*	*	*	*	9	*	*	*	*	*	*	*	*	42
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MASS OUT	W/O	1	*	*	*	6	2	7	*	*	*	*	*	5	7	12	5	10	20	10	20	21
		2	*	*	*	7	3	12	4	5	9	*	*	5	12	13	10	13	22	13	22	29
		3	*	*	*	7	4	13	5	10	18	*	*	7	12	21	11	21	22	20	22	30
		4	*	*	*	10	5	13	9	10	20	*	*	9	12	21	11	21	22	29	28	31
		5	*	*	*	11	5	20	9	18	27	*	*	9	20	21	18	21	28	21	28	36
		6	*	*	*	*	*	*	*	18	27	*	*	*	*	*	*	*	*	*	*	*
	WITH	1	*	*	*	7	3	*	*	*	*	*	*	5	*	*	*	*	*	*	*	*
		2	*	*	*	7	3	12	4	9	*	*	*	5	12	13	10	20	22	13	22	29
		3	*	*	*	7	4	13	5	10	18	*	*	7	12	21	12	21	22	20	22	30
		4	*	*	*	10	5	13	9	18	26	*	*	9	18	21	18	21	28	20	28	31
		5	*	*	*	10	*	20	9	19	27	*	*	9	20	21	18	21	28	21	28	36
		6	*	*	*	*	*	*	17	26	27	*	*	*	*	*	*	*	*	*	*	37

SC - SUSPENDED CEILING.
* - DENOTES A ROOF WHICH IS NOT POSSIBLE WITH CHOSEN COMBINATIONS OF PARAMETERS.
RTS - ROOF TERRACE SYSTEM : FIRST MATERIAL IS OUTER LAYER, SECOND MATERIAL IS INNER LAYER.
NOTE : MASSIVE MATERIALS ARE #'S 4,5,6,7,8,9,12,13,14,15,16,17,18,19, AND 20. NON-MASSIVE MATERIALS ARE #'S 1,2,3,10, AND 11.

TABLE IX

ROOF R-VALUE RANGE DEFINITIONS

R-Value Range (R)	R-Values (hr-ft^2-F/Btu)
1	0.00 - 5.00
2	5.00 - 10.00
3	10.00 - 15.00
4	15.00 - 20.00
5	20.00 - 25.00
6	25.00 - 30.00

TABLE X

PRINCIPAL ROOF MATERIALS

MATERIAL NUMBER	LAYER CODE	DESCRIPTION
1	B7	1" WOOD
2	B8	2.5" WOOD
3	B9	4" WOOD
4	C5	4" HW CONC
5	C12	2" HW CONC
6	C13	6" HW CONC
7	C14	4" LW CONC
8	C15	6" LW CONC
9	C16	8" LW CONC
10	A3	STEEL DECK
11	B7 & E4	ATTIC CEILING COMBINATION
12	C12 - C12	2" HW CONC - 2" HW CONC (RTS)
13	C12 - C5	2" HW CONC - 4" HW CONC (RTS)
14	C12 - C13	2" HW CONC - 6" HW CONC (RTS)
15	C5 - C12	4" HW CONC - 2" HW CONC (RTS)
16	C5 - C5	4" HW CONC - 4" HW CONC (RTS)
17	C5 - C13	4" HW CONC - 6" HW CONC (RTS)
18	C13 - C12	6" HW CONC - 2" HW CONC (RTS)
19	C13 - C5	6" HW CONC - 4" HW CONC (RTS)
20	C13 - C13	6" HW CONC - 6" HW CONC (RTS)

RTS - ROOF TERRACE SYSTEM : FIRST MATERIAL IS OUTER LAYER, SECOND MATERIAL IS INNER LAYER.'

order of outer layer - inner layer. For instance, roof material 17 is listed as C5-C13, so layer C5 is outside of layer C13. As was the case with the walls, Table VII should be referred to for thermophysical properties and descriptions of material codes used.

Again, the asterisk is used to denote parameter combinations that are either improbable or impossible. For example, Table VIII shows no roof terrace system combinations for the mass in case. This is because this combination always has a massive concrete layer as the major outer surface. Thus, a roof terrace system can only have the mass out or integral mass cases. All non-massive roofs are of the integral mass type and roofs with only one massive layer may be the integral mass type only when no insulation is present. If a roof with only one massive layer contains insulation, only the mass in or mass out cases are possible.

The following examples illustrate the proper use of Table VIII. Refer to Table VII for properties applying to the code letter descriptions.

Example 4: Steel sheet with 2 in. insulation

Code Description: A0, E2, E3, B6, A3, A0

R-Value = 8.00 (hr-ft^2-F/Btu)

R-Value Range = 2 (Table IX)

Principal Roof Material = 10 (A3, Table X)

Integral Mass (no massive layers present)

Without Suspended Ceiling

From Table VIII: Roof Type 1

Example 5: 6 in. lightweight concrete with 3 in. insulation

Code Description: A0, E2, E3, C15, A0

R-Value = 16.33 (hr-ft^2-F/Btu)

R-Value Range = 4 (Table IX)

Principal Roof Material = 8 (C15, Table X)

Mass In (massive layer is inside insulation layer)

Without Suspended Ceiling

From Table VIII: Roof Type 10

Example 6: Roof terrace system with suspended ceiling

Code Description: A0, C12, B1, B6, E2, E3, C5, E4, E5, A0

R-Value = 12.19 (hr-ft^2-F/Btu)

R-Value Range = 3 (Table IX)

Principal Roof Material = 13 (C12-C5, Table X)

Integral Mass (insulation is between massive layers)

With Suspended Ceiling

From Table VIII: Roof Type 23

Again, the transfer function coefficients are selected from appendix C for each roof type to make heat gain calculations.

Heat Flux Verification

The heat fluxes determined from the actual conduction transfer function coefficients for two different walls, compared to the heat fluxes determined using the transfer function coefficients for the proper wall types, are shown in Figures 3 and 4. Both walls, A and B, are constructed of 4 in. lightweight concrete with 2 in. of insulation; however, the order of the mass and insulation layers are reversed such that wall A represents the mass in case and wall B represents the mass out case. The heat flux plots, represented by A and B in the figures, were determined using the actual conduction transfer function coefficients for those surfaces.

Wall A is represented by wall type 4, as shown in Table II, and wall B is represented by wall type 5, as shown in Table IV. The conduction transfer function coefficients corresponding to wall types 4 and 5 are listed in appendix C. As previously mentioned, the b_n and c_n coefficients for these wall types were modified using the ratio of the actual overall conductances of walls A and B divided by the overall conductances corresponding to each wall type. For example, the overall conductance of wall A is 0.0879 Btu/hr-ft^2-F and the overall conductance for wall type 4 is 0.0469 Btu/hr-ft^2-F. The ratio of these two values is 1.874, so all b_n and c_n coefficients for wall type 4 were multiplied by 1.874 to develop the correct conduction transfer function coefficients for this case. Once the coefficients were corrected

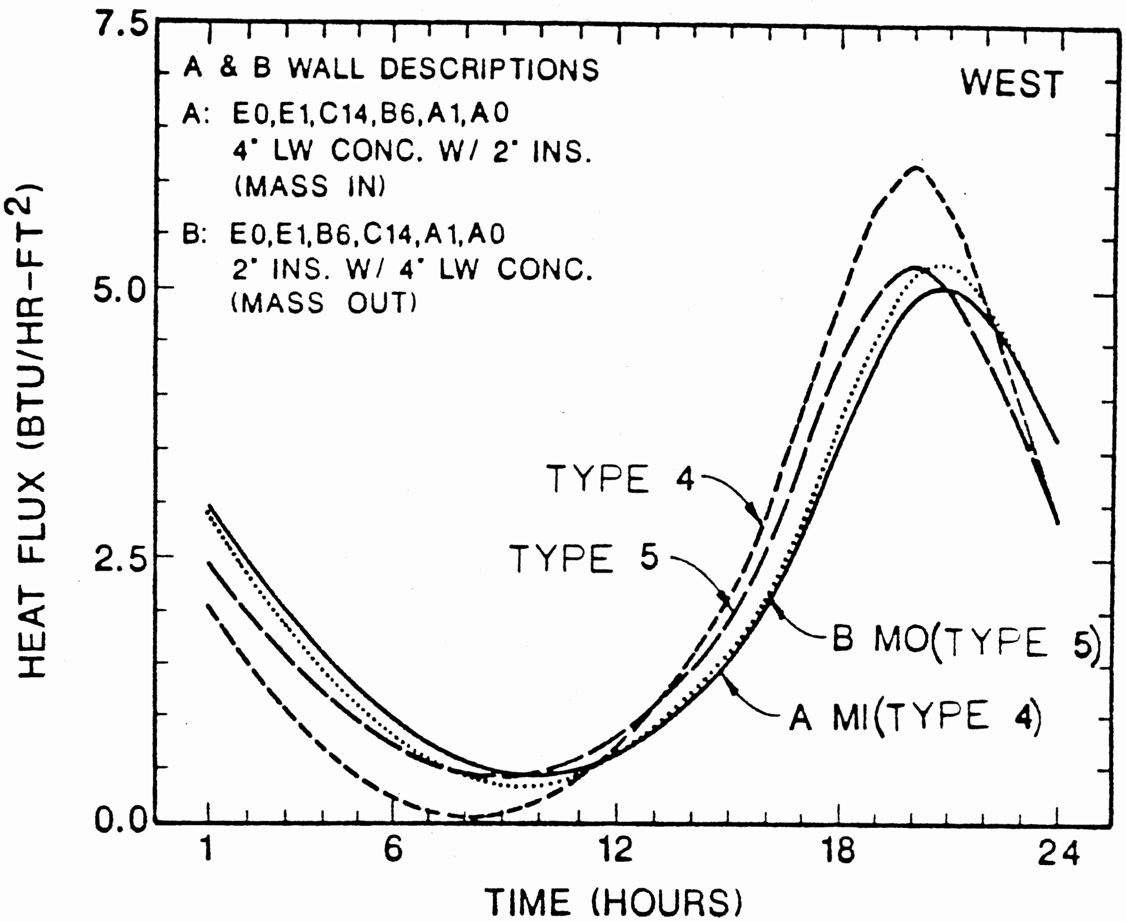

Figure 3. Heat Flux Comparison Between Actual Walls and Walls Chosen From Tables II and IV (West Orientation)

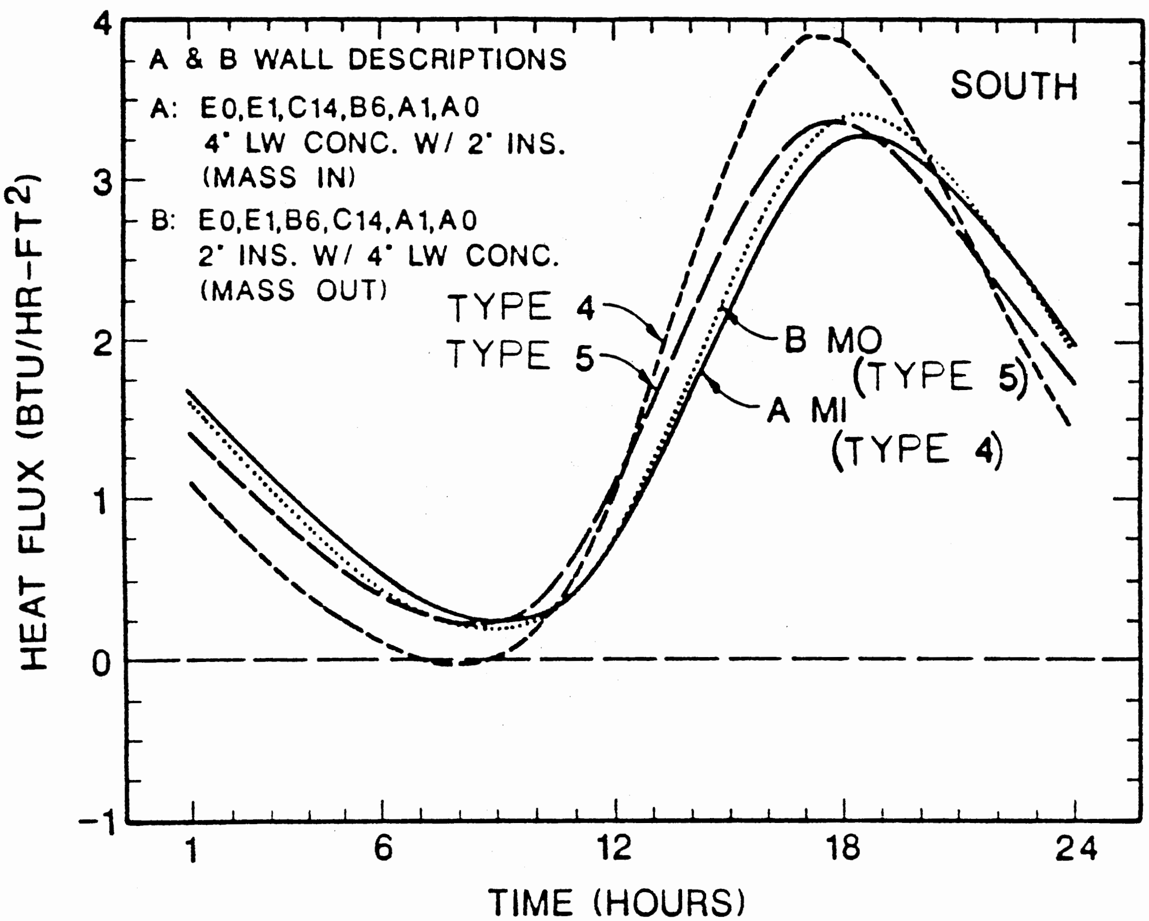

Figure 4. Heat Flux Comparison Between Actual Walls and Walls Chosen From Tables II and IV (South Orientation)

with the overall conductance ratios for each case, the heat flux plots represented by Type 4 and Type 5 in Figures 3 and 4 were made for the surfaces facing west and south respectively. The location used for solar calculations was Stillwater, Oklahoma, with a maximum outdoor air temperature of 96 F and a daily outdoor temperature range of 24 F. The design indoor air temperature was set equal to 75 F. In both figures, the heat fluxes calculated with the transfer function coefficients for the wall types were greater than the heat fluxes obtained with the actual transfer function coefficients. This is true regardless of the wall orientation, west or south. Also, the peak heat fluxes are within the plus twenty percent criterion and the plus or minus one hour time delay used to form the wall types. Although this test is not comprehensive, it is a clear indication that the grouping technique is valid.

Wall and Roof Classification Algorithm

After the wall and roof classification was developed, an algorithm was written to implement this procedure in an existing cooling and heating load calculation program. The classification method is simple to apply, but whenever data is abstracted from large tables, there is a possibility for error. Also, the probability of acceptance of new methodologies often depends on how easily they are adapted to computer applications. The computer algorithm consists of three subprograms and four data files. A listing of the subprograms is given in appendix B.

The three subprograms that implement the classification algorithm are named IWALLP, IROOFF, and TRANSF. When called, IWALLP prompts the user to enter the wall or partition overall conductance, principal material, inner or outer layer material, and mass placement. The last three inputs provide a list from which the user can choose the appropriate selection. After entering these inputs, the user is given an opportunity to change any inputs entered incorrectly. Finally, the input values are used to determine the wall type number by reading the data file 'WALLTYPE.DAT'. This is a direct access, binary file containing the data presented in Tables II, III, and IV. If the input data results in a surface which is not possible (* in Tables II, III, and IV), the user is allowed to reenter the data. Also, if the overall conductance is smaller than the minimum value allowed for in the wall classification method, the wall type number for the minimum value is chosen and an appropriate warning is issued. The user is warned that the input value of overall conductance is smaller than allowable for accurate calculation, and that the best approximation will be made.

The subprogram IROOFF, used to determine the roof type number, is similar to IWALLP. The user enters the overall conductance, principal roof material, ceiling description, and mass placement. This input data is used to determine the roof type number by reading the data file 'ROOFTYPE.DAT'. This is a direct access, binary file containing the data in

Table VIII. This subprogram contains all of the features listed above for IWALLP. Sample output data for IWALLP and IROOFF is given in appendix B.

After obtaining the wall or roof type number, the subprogram TRANSF is used to retrieve the conduction transfer coefficients when the user is ready to carry out heat gain calculations. A list of wall and roof descriptions is provided from which the desired wall or roof is selected. The wall type or roof type number of that surface is used to identify the corresponding set of conduction transfer function coefficients which are then retrieved from data file 'WALLTFS.DAT' or 'ROOFTFS.DAT'. These are direct access, binary files containing the conduction transfer function coefficients listed in appendix C.

All three subprograms discussed above, were implemented in an existing cooling and heating load calculation program named LDCAL5. LDCAL5 was developed at Oklahoma State University by Dr. Faye C. McQuiston. It is hoped that this enhanced version of LDCAL5 will provide results for a much larger range of wall and roof data than was previously possible. The previous version of LDCAL5 contained the transfer function coefficients for approximately thirty to forty walls and roofs. These transfer function coefficients had to be generated for each new surface encountered and added to data files before accurate cooling and heating load calculations could be made.

Comparisons Between the Classification Method and Existing Methods

To evaluate the accuracy of the classification method developed in this study, its results for several different surfaces were compared to those obtained with the TF method (1 & 2) using the actual conduction transfer function coefficients, and the CLTD method (3). Cooling loads were determined for several different walls and roofs using each of the three methods. Equivalent cooling load temperature differences, CLTDs, were obtained by dividing the cooling loads by the product of the overall conductance and area for each surface. Comparisons were made for several different surfaces, including:

(1) Surfaces which exactly match those defined in the CLTD method

(2) Surfaces with constructions matching those defined in the CLTD method, but with R-Values which are at least 7 hr-ft^2-F/Btu greater than the maximum values listed

(3) Surfaces which do not match any of those listed in the CLTD method.

The climatic conditions used to determine the cooling loads and CLTDs were the following:

July 21

Latitude = 40 °N

Longitude = 90 °W

Indoor Air Temperature = 78 F

Maximum Outdoor Air Temperature = 95 F

Daily Range of Outdoor Air Temperature = 21 F

These conditions were chosen to duplicate the standard conditions for the CLTD method (3). The set of thermal response factors used to convert the heat gains, obtained with the TF method and the wall and roof classification method, into cooling loads, were chosen to match the set of thermal response factors used in the original development of the CLTD method by Rudoy and Duran (25). This will be discussed in more detail later.

CLTD Comparisons for Walls

Tables XI and XII show a summary of results for walls which match the construction of those given in the CLTD method (3). Table XI is for west facing surfaces and Table XII is for surfaces facing south. A description of walls 1 through 7 is given in Table XIII. Since the TF method is the most widely accepted method for determining heat gains and cooling loads through walls and roofs, it served as a basis for comparison with the classification method developed in this study and the CLTD method. When comparing the wall CLTDs derived using the classification method to the CLTDs obtained with the TF method, as shown in Tables XI and XII, one can see that they are in good agreement. The percent differences between these values range from -5.3 to +12.8,

TABLE XI

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR WALLS
MATCHING THOSE GIVEN IN THE CLTD METHOD
(WEST ORIENTATION)

WALL	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	76.8	18	77.9	19	72.0	17
2	35.6	21	33.7	21	41.0	21
3	39.2	22	44.2	22	41.0	21
4	41.2	21	44.2	22	41.0	21
5	26.3	1	26.8	2	27.0	1
6	32.0	23	34.2	24	27.0	1
7	27.5	1	28.0	1	27.0	1

TABLE XII

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR WALLS
MATCHING THOSE GIVEN IN THE CLTD METHOD
(SOUTH ORIENTATION)

WALL	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	49.9	14	50.9	14	47.0	14
2	26.0	20	24.7	20	30.0	19
3	28.7	21	31.7	20	30.0	19
4	29.5	20	31.7	20	30.0	19
5	20.2	24	20.5	24	21.0	23
6	23.8	22	25.3	22	21.0	23
7	21.0	23	21.3	24	21.0	23

TABLE XIII

DESCRIPTION OF WALLS USED IN TABLES XI AND XII

WALL	LAYER CODE	DESCRIPTION
1	E0,E1,B6,A6,A0	Frame wall with 2 in. insulation (integral mass)
2	E0,A2,C3,B6,A6,A0	Face brick and 4 in. hw concrete block with 2 in. insulation (mass in)
3	E0,E1,C3,B6,A2,A0	Face brick and 4 in. hw concrete block with 2 in. insulation (integral mass)
4	E0,E1,B6,C3,A2,A0	Face brick and 4 in. hw concrete block with 2 in. insulation (mass out)
5	E0,E1,C11,B6,A1,A0	12 in. hw concrete with 2 in. insulation (mass in)
6	E0,E1,C11,A1,A0	12 in. hw concrete with 2 in. insulation (integral mass)
7	E0,E1,B6,C11,A1,A0	12 in. hw concrete with 2 in. insulation (mass out)

and the times of the peak CLTDs are within one hour. For the CLTD method, the percent differences range from -15.6 to +15.4, while the times of the peak CLTDs are off by as much as two hours when compared to the TF method. Although the CLTD method is less conservative, in this case, than the classification method, its results are acceptable. This was expected, since the walls studied in Tables XI and XII were chosen to exactly match those described in the CLTD method.

Tables XIV and XV show a summary of results for walls whose constructions match those listed in the CLTD method, but whose R-Values are at least 7 hr-ft^2-F/Btu greater than the maximum values listed. A description of walls 1 through 6 in Tables XIV and XV is given in Table XVI. These walls are identical to those studied in Tables XI and XII, with the exception of their insulation. These walls have 5 in. of insulation compared to the 2 in. of insulation contained in the walls of Tables XI and XII. The percent differences between the CLTDs derived from the classification method as compared to the TF method range from -5.9 to +11.4, while the times of the peak CLTDs are within one hour. These are similar to the values obtained from Tables XI and XII. For the CLTD method, the percent differences range from -17.5 to -1.1, while the times of the peak CLTDs were off by two hours.

This comparative study shows that the classification method handles the adjustment of R-Values without decreasing its accuracy. On the other hand, the CLTD method shows a

TABLE XIV

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR WALLS MATCHING THE CONSTRUCTION, BUT NOT THE R-VALUES OF THOSE LISTED IN THE CLTD METHOD (WEST ORIENTATION)

WALL	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	72.7	19	71.1	19	60.0	19
2	33.9	23	31.9	24	30.0	24
3	37.0	24	41.2	23	35.0	22
4	39.0	23	41.2	23	35.0	22
5	25.7	2	26.0	2	22.0	--*
6	26.8	2	28.0	2	22.0	--*

* : These cases were represented by one constant CLTD value for all hours of the day.

TABLE XV

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR WALLS MATCHING THE CONSTRUCTION, BUT NOT THE R-VALUES OF THOSE LISTED IN THE CLTD METHOD (SOUTH ORIENTATION)

WALL	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	47.9	16	47.1	16	40.0	16
2	25.0	21	23.7	22	23.0	23
3	27.3	22	29.7	21	27.0	20
4	28.3	21	29.7	21	27.0	20
5	19.8	24	20.0	24	18.0	--*
6	20.5	24	21.4	24	18.0	--*

* : These cases were represented by one constant CLTD value for all hours of the day.

TABLE XVI

DESCRIPTION OF WALLS USED IN TABLES XIV AND XV

WALL	LAYER CODE	DESCRIPTION
1	E0,E1,B14,A6,A0	Frame wall with 5 in. insulation (integral mass)
2	E0,A2,C3,B14,A6,A0	Face brick and 4 in. hw concrete block with 5 in. insulation (mass in)
3	E0,E1,C3,B14,A2,A0	Face brick and 4 in. hw concrete block with 5 in. insulation (integral mass)
4	E0,E1,B14,C3,A2,A0	Face brick and 4 in. hw concrete block with 5 in. insulation (mass out)
5	E0,E1,C11,B14,A1,A0	12 in. hw concrete with 5 in. insulation (mass in)
6	E0,E1,B14,C11,A1,A0	12 in. hw concrete with 5 in. insulation (mass out)

marked decrease in accuracy with an increase in insulation. As previously noted, the CLTD method provides CLTDs for seven wall types. These wall types are designated by the letters A through G. Wall A is defined as being the heaviest wall, thermally, and Wall G is defined as the lightest. If a wall is thermally heavier than wall A, it is assigned a CLTD value which remains constant. This is illustrated by walls 2, 5, and 6 in Tables XIV and XV. When the R-Value of a wall is at least 7 hr-ft^2-F/Btu greater than the equivalent wall listed in the CLTD method, the wall one letter higher is chosen to represent it. This was the case for all of the walls listed in Tables XIV and XV. The results from these tables show that not only is the CLTD method inacurrate, but it is also non-conservative. In each case above, the values predicted by the CLTD method are less than the values predicted by the TF method.

Tables XVII and XVIII summarize results for walls which do not match the construction of those given in the CLTD method. Table XVII is for west facing walls and Table XVIII is for walls facing south. A description of the construction of these walls is given in Table XIX. To determine which of the wall types, A through G in the CLTD method, these surfaces matched best, the sum of mass times specific heat (heat capacitance), the mass, and the overall conductance had to be determined for each wall. The walls in the CLTD method having similar heat capacitance and mass were chosen to represent each wall. The R-Values for all of the walls

TABLE XVII

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR WALLS NOT MATCHING THE CONSTRUCTION OF THOSE GIVEN IN THE CLTD METHOD (WEST ORIENTATION)

WALL	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	35.2	23	36.9	23	30.0	24
2	37.6	23	36.9	23	35.0	22
3	33.3	24	34.2	24	49.0	20
4	24.7	5	25.2	5	22.0	--*
5	23.0	4	24.3	4	22.0	--*

* : These cases were represented by one constant CLTD value for all hours of the day.

TABLE XVIII

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR WALLS NOT MATCHING THE CONSTRUCTION OF THOSE GIVEN IN THE CLTD METHOD (SOUTH ORIENTATION)

WALL	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	25.8	21	27.2	22	23.0	23
2	27.3	21	27.2	22	27.0	20
3	24.7	22	25.2	22	35.0	17
4	19.0	3	19.4	3	18.0	--*
5	17.8	3	18.7	3	18.0	--*

* : These cases were represented by one constant CLTD value for all hours of the day.

TABLE XIX

DESCRIPTION OF WALLS USED IN TABLES XVII AND XVIII

WALL	LAYER CODE	DESCRIPTION
1	E0,E1,C18,B13,A1,A0	8 in. hw concrete block (filled) with 4 in. insualtion (mass in)
2	E0,E1,B13,C18,A1,A0	8 in. hw concrete block (filled) with 4 in. insulation (mass out)
3	E0,E1,B6,B9,A0	4 in. wood with 2 in. insulation (integral mass)
4	E0,E1,C11,B12,A2,A0	12 in. hw concrete and face brick with 2 in. insulation (integral mass)
5	E0,E1,A2,C11,B12,A1,A0	12 in. hw concrete and face brick with 2 in. insulation (mass in)

designated by the CLTD method were at least 7 hr-ft^2-F/Btu smaller than the R-Values determined for the actual walls. This meant that the next higher letter representing the CLTD method wall was chosen for walls 1, 2, and 3 in Tables XVII and XVIII. Since the mass and heat capacitance for walls 4 and 5 were larger than any of those listed in the CLTD method, a specified constant CLTD value was designated. This constant CLTD value is supposed to be representative of any wall which is thermally heavier than the type A wall defined by the CLTD method.

When comparing the CLTDs derived using the TF method to the CLTDs obtained with the classification method, as shown in Tables XVII and XVIII, one can see that they are nearly equal. The percent differences between these CLTDs range from -1.9 to +5.7, and the times of the peak CLTDs are all within one hour. For the CLTD method, the percent differences range from -14.8 to +47.1, while the times of the peak CLTDs are off by as much as five hours. Once again, the CLTD method produced results which were not as accurate as the classification method.

CLTD Comparisons for Roofs

Table XX presents a summary of results for roofs which could be represented by the roof types listed in the CLTD method without corrections due to a large R-Value. Roofs 1, 2, and 3, described in Table XXI, exactly match roof constructions listed in the CLTD method. The heat capacitance

TABLE XX

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR ROOFS LISTED IN THE CLTD METHOD

ROOF	TF METHOD MAX CLTD(F)	TF METHOD TIME	CLASSIFICATION METHOD MAX CLTD(F)	CLASSIFICATION METHOD TIME	CLTD METHOD MAX CLTD(F)	CLTD METHOD TIME
1	81.4	15	84.3	15	75.0	16
2	45.1	22	49.4	21	55.0	20
3	44.3	23	50.9	22	55.0	20
4	44.3	21	46.8	21	29.0	--*
5	42.8	21	47.5	20	29.0	--*

* : These cases were represented by one constant CLTD value for all hours of the day.

TABLE XXI

DESCRIPTION OF ROOFS USED IN TABLE XX

ROOF	LAYER CODE	DESCRIPTION
1	E0,B7,B5,E3,E2,A0	1 in. wood with 1 in. insulation (integral mass)
2	E0,C16,B6,E3,E2,A0	8 in. lw concrete with 2 in. insulation (mass in)
3	E0,E1,B6,C16,E3,E2, A0	8 in. lw concrete with 2 in. insulation (mass out)
4	E0,C13,B6,E3,E2,C12, A0	6 in. hw concrete - 2 in. hw concrete roof terrace system with 2 in. insulation (integral mass)
5	E0,E1,B6,C13,E3,E2, C12,A0	6 in. hw concrete - 2 in. hw concrete roof terrace system with 2 in. insulation (mass out)

and mass of roofs 4 and 5 were calculated and used to determine which roof type best matched them. It was discovered that, with the CLTD method, they were thermally heavier than any roof type listed, so a constant CLTD value was assigned to them.

When comparing the roof CLTDs obtained from the CLTD method to the values derived using the TF method with actual conduction transfer function coefficients, it can be seen that they do not agree well. The percent differences between the values range from -34.5 to 24.2, and the times of the peak CLTDs are off by as much as three hours. For the classification method, the percent differences range from +3.6 to +14.9, while the times of the peak CLTDs are all within one hour. The largest differences between the CLTDs for the CLTD method and the TF method occurred for roofs 4 and 5. This was expected, since there was not a roof exactly matching the constructions of these two surfaces.

Finally, Table XXII summarizes the results for roofs which are similarly constructed to those in Table XX, but with much larger R-Values. The R-Values for these roofs are greater than 7 hr-ft^2-F/Btu larger than the R-Values listed for their equivalent constructions, as determined by the CLTD method. To handle this problem, the CLTD method requires the selection of CLTDs for roofs with similar mass and heat capacitance, but with the times of the peak CLTDs occurring two hours later. This correction is easier stated than accomplished, but the CLTDs best matching these

TABLE XXII

MAXIMUM CLTD VALUES AND TIME OF OCCURRENCE FOR ROOFS WITH R-VALUES GREATER THAN ALLOWABLE FOR CONSTRUCTIONS LISTED IN THE CLTD METHOD

ROOF	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
1	76.1	17	75.9	18	65.0	18
2	41.1	23	42.1	23	38.0	23
3	40.1	24	42.1	23	38.0	23
4	42.6	22	43.6	21	29.0	--*
5	41.3	22	43.5	21	29.0	--*

* : These cases were represented by one constant CLTD value for all hours of the day.

TABLE XXIII

DESCRIPTION OF ROOFS USED IN TABLE XXII

ROOF	LAYER CODE	DESCRIPTION
1	E0,B7,B14,E3,E2,A0	1 in. wood with 5 in. insulation (integral mass)
2	E0,C16,B14,E3,E2,A0	8 in. lw concrete with 5 in. insulation (mass in)
3	E0,E1,B14,C16,E3,E2, A0	8 in. lw concrete with 5 in. insulation (mass out)
4	E0,C13,B14,E3,E2,C12, A0	6 in. hw concrete - 2 in. hw concrete roof terrace system with 5 in. insulation (integral mass)
5	E0,E1,B14,C13,E3,E2, C12,A0	6 in. hw concrete - 2 in. hw concrete roof terrace system with 5 in. insulation (mass out)

specifications were chosen.

When comparing the roof CLTDs in Table XXII from the CLTD method to those obtained with the TF method, the percent differences range from -31.9 to -7.5, while the times of the peak CLTDs are within one hour.Although the times of the peak CLTDs improved, as compared to Table XX, the CLTD values which were conservative in Table XX became non-conservative when the R-Values were increased. This leads one to believe that the CLTD method may overcorrect the CLTDs obtained for roofs with large R-Values. These results are similar to the results obtained for walls with large R-values.

When comparing the roof CLTDs in Table XXII determined with the classification method to the values obtained with the TF method, one can see excellent agreement. The percent differences between the two methods range from 0.0 to +5.3, while the times of the peak CLTDs are, once again, within one hour.

For all of the walls and roofs examined, the maximum difference between the classification method and the TF method was + 14.9 percent. This is well within the plus twenty percent error criterion used to develop the method. The only cases which produced non-conservative results were within -5.9 percent. Although this is below the minus zero percent criterion used to classify surfaces, it is close enough to be tolerable.

The Effects of Thermal Response Factors

All of the cooling load and CLTD values determined up to this point, have been calculated with one specific set of thermal response factors. It should be remembered that thermal response factors are used to convert heat gains to cooling loads. Different sets of thermal response factors exist for different types of heat gains. These include the following:

(1) Conduction through opaque surfaces

(2) Radiation through glass

(3) Lighting

(4) Occupants and equipment.

Since this thesis deals with conduction through walls and roofs, the primary concern is with 1 above.

In the paper by Sowell (21), discussed earlier, five different sets of thermal response factors were identified for conduction through walls and roofs. These factors depend on room geometry, the presence of carpets or drapes, type of wall and floor, the percentage of wall glass, and finally, whether or not a suspended ceiling is present.

In the development of the CLTD method, Rudoy and Duran (25), who originally derived the method, used only one set of thermal response factors to convert heat gains to cooling loads. The conditions noted above from Sowell (21) were not known to be important at that time. When Rudoy and Duran

(25) developed the CLTD method, thermal response factors for conduction existed only for rooms with low, medium, and high mass. They concluded that the differences between the CLTDs obtained from these three sets of factors were small when applied to the same surface. Thus, all of the CLTDs were determined for the medium mass case.

To provide the best comparison between the classification method developed in this study and the CLTD and TF methods, all of the CLTDs shown in the tables up to this point were determined with the set of thermal response factors best matching the medium mass case discussed by Rudoy and Duran (25). In Sowell's method (21), the five sets of thermal response factors were identified by the conduction zone classifications A, B, C, D, and E. The A conduction zone classification best matches the characteristics of the medium mass case used by Rudoy and Duran (25), and is the most common conduction zone classification presented by Sowell (21). Table XXIV summarizes the results obtained when the five possible conduction zone classifications were examined. The wall used for comparison in Table XXIV is shown as wall 4 in Table XIII. This wall was chosen since it provided excellent agreement between the classification, CLTD, and TF methods, when CLTDs were determined. The climatic conditions used to determine the CLTDs in Table XXIV are identical to those used for the previous CLTD tables.

When comparing the results of the classification method to the TF method, one observes excellent agreement. The per-

TABLE XXIV

MAXIMUM WALL CLTDS AND TIME OF OCCURRENCE FOR DIFFERENT CONDUCTION ZONE CLASSIFICATIONS (WEST ORIENTATION)

CONDUCTION ZONE CLASSIFICATION	TF METHOD		CLASSIFICATION METHOD		CLTD METHOD	
	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME	MAX CLTD(F)	TIME
A	41.2	21	44.2	21	41.0	21
B	37.6	22	40.1	22	41.0	21
C	35.8	22	37.0	22	41.0	21
D	33.8	22	35.6	22	41.0	21
E	43.1	22	46.2	22	41.0	21

NOTE : See Table XIII, wall 4, for a description of the wall used in this table.

cent differences range from +5.3 for conduction zone classification D to +7.3 for conduction zone classification A. The times of the peak CLTDs are all within one hour. For the CLTD method, the percent differences range from -4.9 to +21.3, while the times of the peak CLTDs are within one hour. The CLTDs from the CLTD method remain constant since they do not account for differences in the conduction zone type. On the other hand, the classification method can make use of different conduction thermal response factors to account for different conduction zone classifications. This point is especially important when considering cases where the CLTD method produces a large error for the medium mass case of Rudoy and Duran (25) and the conduction zone classification is C or D.

The next section discusses some conclusions drawn about the classification method developed in this thesis and makes some recommendations for future applications and improvements.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

After investigating numerous methods for determining the transient heat transfer characteristics of walls and roofs, the classification method developed in this study was shown to be superior. It is a significant improvement over the CLTD method (3). When implemented, the classification method can be used to predict heat gains, and thus cooling loads, within twenty percent of the results obtainable with the most sophisticated computer programs. This is less than half the error attributable to the CLTD method.

Also, the classification method is easy to apply. It requires only that one understand how walls and roofs are constructed and how to determine their overall conductance. The CLTD method requires the above, plus one has to determine several other thermophysical properties to calculate a surface's mass and heat capacitance. If the construction for a wall or roof doesn't match the limited variety supplied in the CLTD method, nebulous adjustments are required. Fortunately, the classification method has no special cases to account for. It can handle any reasonable wall or roof construction.

The wall and roof classification method allows for any possible conduction zone classification to convert heat gains to cooling loads. The CLTD method was only developed for room zones of medium mass. Since the CLTDs obtained from the CLTD method are used to directly estimate the cooling load, different conduction zone classifications cannot be accounted for.

Finally, the method developed in this thesis is the first of its kind in allowing one to accurately choose the best set of conduction transfer function coefficients to model a wall or roof. This means that access to the complex computer programs required to generate these coefficients is no longer required. This makes the TF method (1 & 2) much more accessible to engineers in the field.

Recommendations

One can provide several recommendations for implementation of the wall and roof classification method. These include developing a more sophisticated computer algorithm for interpreting the construction of a wall or roof, combining the results of this study with research just completed by Sowell (26) for converting heat gains to cooling loads, and finally, applying the classification method to building envelope surfaces other than walls and roofs.

A computer algorithm to interpret the construction of a wall or roof would reduce the chance for errors due to incorrect user inputs. Such an algorithm could be developed many different ways. One possibility is for the user to simply input a surfaces code layer description (see appendix E). This description can then be interpreted by the algorithm and the various parameters, required by the classification, determined and used to select the correct wall or roof type number.

In the research just completed by Sowell (26), expanded wall and roof zone classifications were determined. Sowell used a grouping method like the one implemented in this study to determine all parameters which affected the conversion of all heat gains to cooling loads. The results of this study can be implemented in existing computer programs once the huge amount of tabulated data presented by Sowell is reduced to a practical size and an algorithm is developed to apply it.

The final recommendation concerns applying the classification method to surfaces other than just walls and roofs. The construction of floors over unconditioned spaces is similar to the construction of many roofs. A study should be made to determine whether or not the classification method for roofs is valid when applied to floors.

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APPENDICES

APPENDIX A

LISTINGS OF WALL AND ROOF GROUPING PROGRAMS WITH SAMPLE OUTPUT

LISTING OF WALL GROUPING PROGRAM

```
C
C     THIS PROGRAM WAS USED TO READ THE FILE WALL.GPU AND
C     GROUP THE WALL DATA.
C
      COMMON/BLOCK1/IITYPE(3825,4)
      COMMON/BLOCK2/TLAG(2500),AMPRAT(2500),ITYPE
      DIMENSION INS(2500),IWITH(2500),RVALUE(2500),IWALL(2500)
      CHARACTER*20 FNAME
      CHARACTER*1 A,B,C,AA(25),BB(25),CC(25)
10    FORMAT(A20)
15    FORMAT(I4)
20    FORMAT(F9.6,2X,F9.7,2(1X,I1),1X,F4.1,1X,I2)
30    FORMAT(19X,'AMPLITUDE',6X,'DELAY',7X,'CENTROID',4X,'AMP-RATIO',
     +1X,'DEL-DIF')
40    FORMAT(13X,'N',4X,'MAX',4X,'MIN',4X,'MAX',3X,'MIN',4X,'AMP',4X,
     +'DEL',4X,'MIN/MAX',2X,'MAX-MIN',2X,'GROUP',/)
50    FORMAT(1X,2(I1,'-'),I2,'-',I2,2X,I2,2X,F6.4,1X,F6.4,1X,
     +F5.2,1X,F5.2,1X,F6.4,2X,F5.2,4X,F4.2,4X,F5.2,6X,3A1)
60    FORMAT(/,' INS-WITH-RTYPE-IWTYPE')
      WRITE(*,*)' ENTER NAME OF FILE CONTAINING SORT DATA'
      READ(*,10)FNAME
      OPEN(5,FILE=FNAME,STATUS='OLD')
      READ(5,15)NUMBER
      DO 100 I=1,NUMBER
100   READ(5,20)TLAG(I),AMPRAT(I),INS(I),IWITH(I),RVALUE(I),IWALL(I)
      CLOSE(5)
      WRITE(6,30)
      WRITE(6,40)
      ITYPE=0
C
C     SET GROUPING PARAMETERS
C
      DO 200 IINS=1,3
      DO 300 IWTYPE=1,3
      DO 400 IR=1,17
      IF(IR.EQ.1) THEN
      RMIN=0.0
      RMAX=2.0
      ELSEIF(IR.EQ.2) THEN
      RMIN=2.0
      RMAX=2.5
      ELSEIF(IR.EQ.3) THEN
      RMIN=2.5
      RMAX=3.0
      ELSEIF(IR.EQ.4) THEN
      RMIN=3.0
      RMAX=3.5
      ELSEIF(IR.EQ.5) THEN
      RMIN=3.5
```

```
      RMAX=4.0
      ELSEIF(IR.EQ.6) THEN
      RMIN=4.0
      RMAX=4.75
      ELSEIF(IR.EQ.7) THEN
      RMIN=4.75
      RMAX=5.5
      ELSEIF(IR.EQ.8) THEN
      RMIN=5.5
      RMAX=6.5
      ELSEIF(IR.EQ.9) THEN
      RMIN=6.5
      RMAX=7.75
      ELSEIF(IR.EQ.10) THEN
      RMIN=7.75
      RMAX=9.0
      ELSEIF(IR.EQ.11) THEN
      RMIN=9.0
      RMAX=10.75
      ELSEIF(IR.EQ.12) THEN
      RMIN=10.75
      RMAX=12.75
      ELSEIF(IR.EQ.13) THEN
      RMIN=12.75
      RMAX=15.0
      ELSEIF(IR.EQ.14) THEN
      RMIN=15.0
      RMAX=17.5
      ELSEIF(IR.EQ.15) THEN
      RMIN=17.5
      RMAX=20.0
      ELSEIF(IR.EQ.16) THEN
      RMIN=20.0
      RMAX=23.0
      ELSEIF(IR.EQ.17) THEN
      RMIN=23.0
      RMAX=27.0
      ENDIF
      DO 500 IWALLT=1,25
      N=0
      ITYPE=ITYPE+1
C
C     BEGIN SORTING DATA
C
      DO 600 I=1,NUMBER
      IFLAG1=0
      IFLAG2=0
      IF((INS(I).EQ.IINS).AND.(IWITH(I).EQ.IWTYPE))IFLAG1=1
      IF(IFLAG1.EQ.0)GO TO 600
      IF(((RVALUE(I).LE.RMAX).AND.(RVALUE(I).GT.RMIN)).AND.
     + (IWALL(I).EQ.IWALLT))IFLAG2=1
      IF(IFLAG2.EQ.0)GO TO 600
      N=N+1
```

```
      IITYPE(ITYPE,N)=I
600   CONTINUE
      IF(N.NE.0)THEN
                CALL WRCALC(N,A1,A2,D1,D2,AC,DC,AR,DELD)
                CALL GROUP(A1,A2,D1,D2,AC,DC,A,B,C)
                AA(IWALLT)=A
                BB(IWALLT)=B
                CC(IWALLT)=C
                ENDIF
      IF(N.EQ.0)THEN
                AA(IWALLT)=' '
                BB(IWALLT)='*'
                CC(IWALLT)=' '
                A1=0.0
                A2=0.0
                D1=0.0
                D2=0.0
                AC=0.0
                DC=0.0
                AR=0.0
                DELD=0.0
                ENDIF
C
C     WRITE OUT RESULTS
C
      IF(N.NE.0)WRITE(6,50)IINS,IWTYPE,IR,IWALLT,N,A1,A2,D1,D2,AC,DC,AR,
     +DELD,A,B,C
500   CONTINUE
      WRITE(4,1000)(AA(JJ),BB(JJ),CC(JJ),JJ=1,25)
1000  FORMAT(15X,25(3A1))
400   CONTINUE
      WRITE(4,2000)
2000  FORMAT(2(/))
300   CONTINUE
      WRITE(4,3000)
3000  FORMAT(10(/))
200   CONTINUE
      WRITE(6,60)
      STOP
      END
C
C     ******************************************************************
C
      SUBROUTINE WRCALC(N,A1,A2,D1,D2,AC,DC,AR,DELD)
      COMMON/BLOCK1/IITYPE(3825,4)
      COMMON/BLOCK2/TLAG(2500),AMPRAT(2500),ITYPE
      DIMENSION AMP(50),DEL(50)
C
C     VARIABLES:
C               A1   : MAX AMPLITUDE
C               A2   : MIN AMPLITUDE
C               D1   : MAX TIME LAG
C               D2   : MIN TIME LAG
```

```
C               AC   : CENTROID OF AMPLITUDE
C               DC   : CENTROID OF TIME LAG
C               AR   : RATIO OF MIN TO MAX AMPLITUDE (A2/A1)
C               DELD : MAX TIME LAG - MIN TIME LAG (D1-D2)
C
                A1=0.0
                A2=1.0
                D1=0.0
                D2=100.0
                SUMA=0.0
                SUMD=0.0
                DO 10 I=1,N
                AMP(I)=AMPRAT(IITYPE(ITYPE,I))
                DEL(I)=TLAG(IITYPE(ITYPE,I))
                IF(AMP(I).GT.A1)A1=AMP(I)
                IF(AMP(I).LT.A2)A2=AMP(I)
                IF(DEL(I).GT.D1)D1=DEL(I)
                IF(DEL(I).LT.D2)D2=DEL(I)
C
C               SUM AMPLITUDES AND TIME LAGS FOR CENTROID CALCULATIONS
C
                SUMA=SUMA+AMP(I)
                SUMD=SUMD+DEL(I)
10              CONTINUE
                AC=SUMA/FLOAT(N)
                DC=SUMD/FLOAT(N)
                AR=A2/A1
                DELD=D1-D2
                RETURN
                END
C
C     *******************************************************************
C
      SUBROUTINE GROUP(A1,A2,D1,D2,AC,DC,A,B,C)
C
C     VARIABLES:
C               A : TIME LAG DEPENDENT
C               B : AMPLITUDE RATIO DEPENDENT
C               C : CONFORMITY
C
      DIMENSION AMAX(8),NG(8)
      CHARACTER*1 A,B,C,D(8),NUM(8)
      DATA AMAX/0.3348,0.3168,0.2784,0.2243,0.1584,0.1215,0.0813,0.0504/
      DATA NUM/'1','2','3','4','5','6','7','8'/
      DATA NG/1,2,5,6,7,8,7,5/
      DATA D/'A','B','C','D','E','F','G','H'/
      C=' '
      DO 10 I=1,8
      HMIN=2.0*FLOAT(I-1)+0.25
      HMAX=2.0*FLOAT(I)+0.25
      IF((DC.GE.HMIN).AND.(DC.LT.HMAX))THEN
         A=D(I)
         IF((D1.GT.HMAX).OR.(D2.LT.HMIN))C='*'
```

```
         B='0'
         DO 20 J=1,NG(I)
         ARMAX=AMAX(I)*REDUCE(J-1)
         ARMIN=AMAX(I)*REDUCE(J)
      IF((AC.LE.ARMAX).AND.(AC.GT.ARMIN)) B=NUM(J)
      IF((B.EQ.NUM(J)).AND.((A1.GT.ARMAX).OR.(A2.LT.ARMIN))) C='*'
20    CONTINUE
      ENDIF
10    CONTINUE
      RETURN
      END
C
C     ******************************************************************
C
      FUNCTION REDUCE(K)
      IF(K.EQ.0) REDUCE=1.0
      IF(K.NE.0) REDUCE=0.8**K
      RETURN
      END
```

SAMPLE OUTPUT FOR WALL GROUPING COMPUTER PROGRAM

		AMPLITUDE		DELAY		CENTROID		AMP-RATIO	DEL-DIF	
	N	MAX	MIN	MAX	MIN	AMP	DEL	MIN/MAX	MAX-MIN	GROUP
1-1- 5- 6	2	.2266	.2266	4.68	4.68	.2266	4.68	1.00	.00	C1
1-1- 7- 6	1	.2124	.2124	4.99	4.99	.2124	4.99	1.00	.00	C2
1-1- 7- 7	1	.2608	.2608	4.04	4.04	.2608	4.04	1.00	.00	B1
1-1- 7- 8	2	.2263	.2249	4.55	4.48	.2256	4.52	.99	.06	C1
1-1- 7- 9	2	.1506	.1497	6.16	6.11	.1502	6.14	.99	.05	C3
1-1- 7-10	2	.1444	.1437	5.70	5.65	.1440	5.68	.99	.05	C3
1-1- 7-11	1	.1275	.1275	7.80	7.80	.1275	7.80	1.00	.00	D3
1-1- 7-12	1	.2003	.2003	5.80	5.80	.2003	5.80	1.00	.00	C2
1-1- 7-13	1	.1471	.1471	6.52	6.52	.1471	6.52	1.00	.00	D2
1-1- 7-14	1	.0803	.0803	8.89	8.89	.0803	8.89	1.00	.00	E4
1-1- 7-15	2	.0740	.0736	7.99	7.94	.0738	7.97	1.00	.05	D5
1-1- 7-16	1	.0439	.0439	10.20	10.20	.0439	10.20	1.00	.00	E6
1-1- 7-17	1	.2553	.2553	3.49	3.49	.2553	3.49	1.00	.00	B1
1-1- 7-18	1	.1197	.1197	6.42	6.42	.1197	6.42	1.00	.00	D3
1-1- 7-19	1	.2867	.2867	3.46	3.46	.2867	3.46	1.00	.00	B1
1-1- 7-23	1	.1514	.1514	6.96	6.96	.1514	6.96	1.00	.00	D2
1-1- 7-25	1	.1092	.1092	8.92	8.92	.1092	8.92	1.00	.00	E2
1-1- 8- 2	1	.1645	.1645	5.46	5.46	.1645	5.46	1.00	.00	C3
1-1- 8- 6	3	.2060	.2048	5.16	5.09	.2052	5.14	.99	.06	C2
1-1- 8- 7	2	.2562	.2546	4.21	4.14	.2554	4.17	.99	.07	B1
1-1- 8- 9	1	.1451	.1451	6.27	6.27	.1451	6.27	1.00	.00	D2
1-1- 8-10	1	.1399	.1399	5.85	5.85	.1399	5.85	1.00	.00	C4
1-1- 8-11	1	.1132	.1132	8.11	8.11	.1132	8.11	1.00	.00	D4
1-1- 8-12	1	.1841	.1841	6.14	6.14	.1841	6.14	1.00	.00	C2
1-1- 8-13	2	.1404	.1396	6.67	6.62	.1400	6.64	.99	.06	D3
1-1- 8-14	2	.0664	.0661	9.59	9.54	.0663	9.56	.99	.05	E4
1-1- 8-15	1	.0811	.0811	7.69	7.69	.0811	7.69	1.00	.00	D5
1-1- 8-16	3	.0413	.0411	10.31	10.26	.0412	10.30	1.00	.05	F5
3-3-13- 3	1	.1750	.1750	6.92	6.92	.1750	6.92	1.00	.00	D2
3-3-13- 4	1	.1233	.1233	9.07	9.07	.1233	9.07	1.00	.00	E2
3-3-13- 5	1	.0520	.0520	13.05	13.05	.0520	13.05	1.00	.00	G3
3-3-13- 6	1	.1298	.1298	8.20	8.20	.1298	8.20	1.00	.00	D3
3-3-13- 7	2	.1639	.1609	7.50	7.07	.1624	7.28	.98	.42	D2
3-3-13- 8	1	.1429	.1429	7.68	7.68	.1429	7.68	1.00	.00	D3
3-3-13- 9	1	.0981	.0981	9.04	9.04	.0981	9.04	1.00	.00	E3
3-3-13-10	1	.0996	.0996	8.26	8.26	.0996	8.26	1.00	.00	E3
3-3-13-11	4	.0667	.0656	11.26	10.87	.0662	11.06	.98	.39	F3
3-3-13-12	1	.1053	.1053	9.66	9.66	.1053	9.66	1.00	.00	E2
3-3-13-13	1	.0912	.0912	9.55	9.55	.0912	9.55	1.00	.00	E3
3-3-13-15	1	.0516	.0516	10.60	10.60	.0516	10.60	1.00	.00	F4
3-3-13-16	1	.0285	.0285	12.86	12.86	.0285	12.86	1.00	.00	G5
3-3-13-20	1	.0965	.0965	10.66	10.66	.0965	10.66	1.00	.00	F2

MASS-WITH-RTYPE-IWTYPE

LISTING OF ROOF GROUPING PROGRAM

```
C
C     THIS PROGRAM READS THE DATA FILE ROOF.GPU AND SORT THE
C     DATA INTO GROUPS
C
      COMMON/BLOCK1/IITYPE(3825,4)
      COMMON/BLOCK2/TLAG(2500),AMPRAT(2500),ITYPE
      DIMENSION INS(2500),IWITH(2500),RVALUE(2500),IWALL(2500)
      CHARACTER*20 FNAME
      CHARACTER*1 A,B,C,AA(25),BB(25),CC(25)
10    FORMAT(A20)
15    FORMAT(I4)
20    FORMAT(F9.6,2X,F9.7,2(1X,I1),1X,F4.1,1X,I2)
30    FORMAT(19X,'AMPLITUDE',6X,'DELAY',7X,'CENTROID',4X,'AMP-RATIO',
     +1X,'DEL-DIF')
40    FORMAT(13X,'N',4X,'MAX',4X,'MIN',4X,'MAX',3X,'MIN',4X,'AMP',4X,
     +'DEL',4X,'MIN/MAX',2X,'MAX-MIN',2X,'GROUP',/)
50    FORMAT(1X,2(I1,'-'),I2,'-',I2,2X,I2,2X,F6.4,1X,F6.4,1X,
     +F5.2,1X,F5.2,1X,F6.4,2X,F5.2,4X,F4.2,4X,F5.2,6X,3A1)
60    FORMAT(/,' INS-WITH-RTYPE-IWTYPE')
      WRITE(*,*)' ENTER NAME OF FILE CONTAINING SORT DATA'
      READ(*,10)FNAME
      OPEN(5,FILE=FNAME,STATUS='OLD')
      READ(5,15)NUMBER
      DO 100 I=1,NUMBER
100   READ(5,20)TLAG(I),AMPRAT(I),INS(I),IWITH(I),RVALUE(I),IWALL(I)
      CLOSE(5)
      WRITE(6,30)
      WRITE(6,40)
      ITYPE=0
C
C     SET GROUPING PARAMETERS
C
      DO 200 IINS=1,3
      DO 300 IWTYPE=1,2
      DO 400 IR=1,6
      IF(IR.EQ.1) THEN
      RMIN=0.0
      RMAX=5.0
      ELSEIF(IR.EQ.2) THEN
      RMIN=5.0
      RMAX=10.0
      ELSEIF(IR.EQ.3) THEN
      RMIN=10.0
      RMAX=15.0
      ELSEIF(IR.EQ.4) THEN
      RMIN=15.0
      RMAX=20.0
      ELSEIF(IR.EQ.5) THEN
      RMIN=20.0
```

```
      RMAX=25.0
      ELSEIF(IR.EQ.6) THEN
      RMIN=25.0
      RMAX=30.0
      ENDIF
      DO 500 IWALLT=1,20
      N=0
      ITYPE=ITYPE+1
C
C     BEGIN SORTING DATA
C
      DO 600 I=1,NUMBER
      IFLAG1=0
      IFLAG2=0
      IF((INS(I).EQ.IINS).AND.(IWITH(I).EQ.IWTYPE))IFLAG1=1
      IF(IFLAG1.EQ.0)GO TO 600
      IF(((RVALUE(I).LE.RMAX).AND.(RVALUE(I).GT.RMIN)).AND.
     + (IWALL(I).EQ.IWALLT))IFLAG2=1
      IF(IFLAG2.EQ.0)GO TO 600
      N=N+1
      IITYPE(ITYPE,N)=I
600   CONTINUE
      IF(N.NE.0)THEN
                CALL WRCALC(N,A1,A2,D1,D2,AC,DC,AR,DELD)
                CALL GROUP(A1,A2,D1,D2,AC,DC,A,B,C)
                AA(IWALLT)=A
                BB(IWALLT)=B
                CC(IWALLT)=C
                ENDIF
      IF(N.EQ.0)THEN
                AA(IWALLT)=' '
                BB(IWALLT)='*'
                CC(IWALLT)=' '
                A1=0.0
                A2=0.0
                D1=0.0
                D2=0.0
                AC=0.0
                DC=0.0
                AR=0.0
                DELD=0.0
                ENDIF
C
C     WRITE OUTPUT DATA
C
      IF(N.NE.0)WRITE(6,50)IINS,IWTYPE,IR,IWALLT,N,A1,A2,D1,D2,AC,DC,AR,
     +DELD,A,B,C
500   CONTINUE
      WRITE(4,1000)(AA(JJ),BB(JJ),CC(JJ),JJ=1,20)
1000  FORMAT(15X,20(3A1))
400   CONTINUE
300   CONTINUE
      WRITE(4,2000)
```

```
2000  FORMAT(2(/))
200   CONTINUE
      WRITE(6,60)
      STOP
      END
C
C     ******************************************************************
C
      SUBROUTINE WRCALC(N,A1,A2,D1,D2,AC,DC,AR,DELD)
      COMMON/BLOCK1/IITYPE(3825,4)
      COMMON/BLOCK2/TLAG(2500),AMPRAT(2500),ITYPE
      DIMENSION AMP(50),DEL(50)
C
C     VARIABLES:
C               A1   : MAX AMPLITUDE
C               A2   : MIN AMPLITUDE
C               D1   : MAX TIME LAG
C               D2   : MIN TIME LAG
C               AC   : CENTROID OF AMPLITUDE
C               DC   : CENTROID OF TIME LAG
C               AR   : RATIO OF MIN TO MAX AMPLITUDE (A2/A1)
C               DELD : MAX TIME LAG - MIN TIME LAG (D1-D2)
C
                A1=0.0
                A2=1.0
                D1=0.0
                D2=100.0
                SUMA=0.0
                SUMD=0.0
                DO 10 I=1,N
                AMP(I)=AMPRAT(IITYPE(ITYPE,I))
                DEL(I)=TLAG(IITYPE(ITYPE,I))
                IF(AMP(I).GT.A1)A1=AMP(I)
                IF(AMP(I).LT.A2)A2=AMP(I)
                IF(DEL(I).GT.D1)D1=DEL(I)
                IF(DEL(I).LT.D2)D2=DEL(I)
C
C               SUM AMPLITUDES AND TIME LAGS FOR CENTROID CALCULATIONS
C
                SUMA=SUMA+AMP(I)
                SUMD=SUMD+DEL(I)
10              CONTINUE
                AC=SUMA/FLOAT(N)
                DC=SUMD/FLOAT(N)
                AR=A2/A1
                DELD=D1-D2
                RETURN
                END
C
C     ******************************************************************
C
      SUBROUTINE GROUP(A1,A2,D1,D2,AC,DC,A,B,C)
C
```

```
C     VARIABLES:
C               A : TIME LAG DEPENDENT
C               B : AMPLITUDE RATIO DEPENDENT
C               C : CONFORMITY
C
      DIMENSION AMAX(8),NG(8)
      CHARACTER*1 A,B,C,D(8),NUM(8)
      DATA AMAX/0.3329,0.3147,0.2845,0.2024,0.1677,0.1006,0.0594,0.0116/
      DATA NUM/'1','2','3','4','5','6','7','8'/
      DATA NG/1,2,4,7,9,8,7,1/
      DATA D/'S','T','U','V','W','X','Y','Z'/
      C=' '
      DO 10 I=1,8
      HMIN=2.0*FLOAT(I-1)
      HMAX=2.0*FLOAT(I)
      IF((DC.GE.HMIN).AND.(DC.LT.HMAX))THEN
         A=D(I)
         IF((D1.GT.HMAX).OR.(D2.LT.HMIN))C='*'
         B='0'
         DO 20 J=1,NG(I)
         ARMAX=AMAX(I)*REDUCE(J-1)
         ARMIN=AMAX(I)*REDUCE(J)
      IF((AC.LE.ARMAX).AND.(AC.GT.ARMIN)) B=NUM(J)
      IF((B.EQ.NUM(J)).AND.((A1.GT.ARMAX).OR.(A2.LT.ARMIN))) C='*'
20    CONTINUE
      ENDIF
10    CONTINUE
      RETURN
      END
C
C     ******************************************************************
C
      FUNCTION REDUCE(K)
      IF(K.EQ.0) REDUCE=1.0
      IF(K.NE.0) REDUCE=0.8**K
      RETURN
      END
```

SAMPLE OUTPUT FOR ROOF GROUPING PROGRAM

		AMPLITUDE		DELAY		CENTROID		AMP-RATIO	DEL-DIF	
	N	MAX	MIN	MAX	MIN	AMP	DEL	MIN/MAX	MAX-MIN	GROUP
1-1- 1- 5	2	.2733	.2617	3.39	2.88	.2675	3.14	.96	.51	T1
1-1- 1- 6	1	.1606	.1606	5.59	5.59	.1606	5.59	1.00	.00	U3
1-1- 2- 4	2	.1628	.1616	5.49	5.38	.1622	5.44	.99	.12	U3
1-1- 2- 6	3	.1189	.1083	6.73	6.38	.1127	6.58	.91	.35	V3
1-1- 2- 7	1	.2559	.2559	4.26	4.26	.2559	4.26	1.00	.00	U1
1-1- 2- 8	1	.2141	.2141	5.83	5.83	.2141	5.83	1.00	.00	U2
1-1- 2- 9	1	.1636	.1636	7.63	7.63	.1636	7.63	1.00	.00	V1
1-1- 3- 4	1	.1544	.1544	5.99	5.99	.1544	5.99	1.00	.00	U3
1-1- 3- 5	1	.2432	.2432	4.27	4.27	.2432	4.27	1.00	.00	U1
1-1- 3- 6	1	.1036	.1036	7.21	7.21	.1036	7.21	1.00	.00	V4
1-1- 3- 7	1	.2210	.2210	5.31	5.31	.2210	5.31	1.00	.00	U2
1-1- 3- 8	1	.1491	.1491	7.31	7.31	.1491	7.31	1.00	.00	V2
1-1- 3- 9	1	.1090	.1090	9.01	9.01	.1090	9.01	1.00	.00	W2
1-1- 4- 4	1	.1475	.1475	6.80	6.80	.1475	6.80	1.00	.00	V2
1-1- 4- 5	1	.2345	.2345	5.09	5.09	.2345	5.09	1.00	.00	U1
1-1- 4- 6	1	.0996	.0996	7.77	7.77	.0996	7.77	1.00	.00	V4
1-1- 4- 7	1	.2023	.2023	6.14	6.14	.2023	6.14	1.00	.00	V1
1-1- 4- 8	1	.1320	.1320	8.00	8.00	.1320	8.00	1.00	.00	W2
1-1- 4- 9	1	.0880	.0880	9.75	9.75	.0880	9.75	1.00	.00	W3
1-1- 5- 4	1	.1420	.1420	7.39	7.39	.1420	7.39	1.00	.00	V2
1-1- 5- 5	1	.2263	.2263	5.68	5.68	.2263	5.68	1.00	.00	U2
1-1- 5- 6	1	.0947	.0947	8.60	8.60	.0947	8.60	1.00	.00	W3
1-1- 5- 7	1	.1924	.1924	6.73	6.73	.1924	6.73	1.00	.00	V1
1-1- 5- 8	1	.1170	.1170	8.95	8.95	.1170	8.95	1.00	.00	W2
1-1- 5- 9	1	.0747	.0747	10.73	10.73	.0747	10.73	1.00	.00	X2
1-1- 6- 8	1	.1095	.1095	9.59	9.59	.1095	9.59	1.00	.00	W2
1-1- 6- 9	1	.0664	.0664	11.63	11.63	.0664	11.63	1.00	.00	X2
1-2- 1- 4	1	.1296	.1296	5.74	5.74	.1296	5.74	1.00	.00	U4
1-2- 1- 5	1	.2114	.2114	4.22	4.22	.2114	4.22	1.00	.00	U2
1-2- 2- 4	2	.0680	.0680	6.77	6.77	.0680	6.77	1.00	.00	V5
1-2- 2- 5	2	.1265	.1265	5.66	5.66	.1265	5.66	1.00	.00	U4
1-2- 2- 6	2	.0505	.0453	7.66	7.54	.0479	7.60	.90	.11	V7
1-2- 2- 7	1	.2317	.2317	5.00	5.00	.2317	5.00	1.00	.00	U1
1-2- 2- 8	1	.1618	.1618	7.14	7.14	.1618	7.14	1.00	.00	V2

MASS-WITH-RTYPE-IRTYPE

LISTING OF LAG AMPLITUDE PROGRAM

```
C
C      SOURCE CODE FOR LAG-AMPLITUDE PROGRAM
C
       CHARACTER*80 FNAME1,FNAME2,FNAME3
       CHARACTER*64 WRTYPE
       DIMENSION WRTYPE(300)
       DOUBLE PRECISION B(7,300),D(7,300),UWRTWR(300)
       DOUBLE PRECISION BT(7),DT(7),QEWR(48),TSWR(48),CNS,DUM,ERR,TROOM
       DOUBLE PRECISION TCNS,ERROR,EPSILN,PI,HO,QOMIN,QOMAX,TLAG(300)
       DOUBLE PRECISION AREA,TMAX,AMPRAT(300),QEMAX,HPOS,QPOS
       FNAME1='TRSF.TXT'
       FNAME2='DATA.TXT'
       FNAME3='PLOT.TXT'
       CALL INPUT(FNAME1,'T','INPUT NAME OF TRANSFER FUNCTION FILE$')
       CALL INPUT(FNAME2,'T','INPUT NAME OF DATA FILE$')
       CALL INPUT(FNAME3,'T','INPUT NAME OF PLOTING DATA FILE$')
       OPEN(3,FILE=FNAME1,STATUS='OLD')
       OPEN(4,FILE=FNAME2,STATUS='NEW')
       OPEN(5,FILE=FNAME3,STATUS='NEW')
       READ(3,101)I
101    FORMAT(I3)
       DO 10 N=1,I
       WRITE(*,*)' SURFACE # ',N
       READ(3,200) WRTYPE(N),(B(J,N),J=1,7),(D(L,N),L=1,7),UWRTWR(N)
200    FORMAT(A64,/,5E13.6,/,5E13.6,/,4E13.6,F9.6)
10     CONTINUE
       CLOSE(3)
       DO 201 JKK=1,I
       WRITE(*,*)' JKK = ',JKK
       ERROR=1.0E-8
       HO=3.0
       TROOM=0.0
       AREA=1.0
       QOMIN=-100.0
       QOMAX=100.0
       PI=3.1415926536
       DO 100 J=1,48
       TSWR(J)=0.0
100    CONTINUE
       DO 110 JJ=1,48
       TSWR(JJ)=(1.0/(AREA*HO))*((QOMAX)*DSIN(PI*JJ/12.0))
110    CONTINUE
       DO 305 II=1,7
       BT(II)=B(II,JKK)
       DT(II)=D(II,JKK)
305    CONTINUE
       NCOUNT=0
       CNS=0.0
       DO 310 II=1,7
```

```
      CNS=CNS+BT(II)
310   CONTINUE
      TCNS=TROOM*CNS
      DO 320 II=1,24
      QEWR(II)=0.0
      IP24=II+24
      QEWR(IP24)=0.0
      TSWR(IP24)= TSWR(II)
320   CONTINUE
360   DO 330 K=25,48
      DO 340 J=1,7
      JJ=K+1-J
      QEWR(K) = QEWR(K)+BT(J)*TSWR(JJ)-DT(J)*QEWR(JJ)
340   CONTINUE
      QEWR(K) = QEWR(K)-TCNS
330   CONTINUE
      NCOUNT=NCOUNT+1
      DO 350 II=1,24
      DUM= QEWR(II+24)
      IF(DABS(DUM).LT.1.0E-04)  GO TO 350
      ERR = DABS((QEWR(II)-DUM)/DUM)
      IF(ERR.GT.ERROR)  GO TO 352
350   CONTINUE
      IF(NCOUNT.LT.5)    GO TO 352
      GO TO 365
352   DO 355 II=1,24
      QEWR(II)=QEWR(II+24)
355   CONTINUE
      GO TO 360
365   CONTINUE
400   CONTINUE
      TLAG(JKK)=0.0
      AMPRAT(JKK)=((QEWR(24)**2+QEWR(6)**2)**0.5)/QOMAX
      QEMAX=AMPRAT(JKK)*QOMAX
      I1=1
      I2=1
      DO 3000 IK=2,24
      IF((QEWR(IK).GT.0.00).AND.(QEWR(I1).LT.0.00)) I2=IK
      I1=IK
3000  CONTINUE
      QPOS=QEWR(I2)/QEMAX
      HPOS=DASIN(QPOS)*12.0/PI
      TLAG(JKK)=FLOAT(I2)-HPOS
      WRITE(4,500) WRTYPE(JKK),TLAG(JKK),AMPRAT(JKK)
500   FORMAT(A64,/,' TLAG = ',F9.6,' HRS',4X,'AMPL RATIO = ',F9.7)
      WRITE(5,510) TLAG(JKK),AMPRAT(JKK)
510   FORMAT(F9.6,2X,F9.7)
201   CONTINUE
      CLOSE(4)
      CLOSE(5)
      END
```

SAMPLE OUTPUT FOR LAG AMPLITUDE PROGRAM

```
E0 ,A6 ,B16,A2 ,A0 ,
 TLAG =  3.539687 HRS    AMPL RATIO =  .1182241
E0 ,A6 ,B17,A2 ,A0 ,
 TLAG =  3.762470 HRS    AMPL RATIO =  .0927485
E0 ,A6 ,B18,A2 ,A0 ,
 TLAG =  3.912888 HRS    AMPL RATIO =  .0760554
E0 ,A6 ,B19,A2 ,A0 ,
 TLAG =  4.022780 HRS    AMPL RATIO =  .0644710
E0 ,A6 ,B20,A2 ,A0 ,
 TLAG =  4.109846 HRS    AMPL RATIO =  .0559176
E0 ,A6 ,B5 ,A2 ,A0 ,
 TLAG =  4.222397 HRS    AMPL RATIO =  .0460771
E0 ,A6 ,B21,A2 ,A0 ,
 TLAG =  4.360729 HRS    AMPL RATIO =  .0364161
E0 ,A6 ,B22,A2 ,A0 ,
 TLAG =  4.464893 HRS    AMPL RATIO =  .0309855
E0 ,A6 ,B6 ,A2 ,A0 ,
 TLAG =  4.579446 HRS    AMPL RATIO =  .0265347
E0 ,A6 ,B23,A2 ,A0 ,
 TLAG =  4.725596 HRS    AMPL RATIO =  .0225051
E0 ,A6 ,B12,A2 ,A0 ,
 TLAG =  4.942984 HRS    AMPL RATIO =  .0185688
E0 ,A6 ,B26,A2 ,A0 ,
 TLAG =  5.210587 HRS    AMPL RATIO =  .0155182
E0 ,A6 ,B27,A2 ,A0 ,
 TLAG =  5.650608 HRS    AMPL RATIO =  .0124602
E0 ,A6 ,B14,A2 ,A0 ,
 TLAG =  5.899818 HRS    AMPL RATIO =  .0112716
E0 ,A6 ,B15,A2 ,A0 ,
 TLAG =  6.495277 HRS    AMPL RATIO =  .0092144
E0 ,A2 ,A1 ,A0 ,
 TLAG =  3.648266 HRS    AMPL RATIO =  .1469585
E0 ,A6 ,B16,A3 ,A0 ,
 TLAG =   .422385 HRS    AMPL RATIO =  .1945518
E0 ,A6 ,B18,A3 ,A0 ,
 TLAG =   .558623 HRS    AMPL RATIO =  .1214505
E0 ,A6 ,B19,A3 ,A0 ,
 TLAG =   .602905 HRS    AMPL RATIO =  .1022817
E0 ,A6 ,B20,A3 ,A0 ,
 TLAG =   .641387 HRS    AMPL RATIO =  .0883298
E0 ,A6 ,B21,A3 ,A0 ,
 TLAG =   .780977 HRS    AMPL RATIO =  .0570713
E0 ,A6 ,B24,A3 ,A0 ,
 TLAG =  1.164569 HRS    AMPL RATIO =  .0316677
E0 ,E1 ,B16,A1 ,A0 ,
 TLAG =  1.201930 HRS    AMPL RATIO =  .1717175
E0 ,E1 ,B18,A1 ,A0 ,
 TLAG =  1.425647 HRS    AMPL RATIO =  .1109600
E0 ,E1 ,B19,A1 ,A0 ,
 TLAG =  1.495473 HRS    AMPL RATIO =  .0942745
```

APPENDIX B

LISTINGS OF SURFACE CLASSIFICATION ALGORITHM WITH SAMPLE OUTPUT

LISTING OF WALL CLASSIFICATION SUBROUTINE

```
      SUBROUTINE IWALLP(IWP,TEXTIS,IS,U)
C
C     SUBROUTINE TO GET INPUTS FOR WALLS OR PARTITIONS AND TO USE THESE
C     INPUTS TO CHOOSE WALL TYPE FROM DATA FILE 'WALLTYPE.DAT'.
C
      CHARACTER*80 TEXTIS
      INTEGER*2 IWP
      DIMENSION R(17)
      DATA R/2.,2.5,3.,3.5,4.,4.75,5.5,6.5,7.75,9.,10.75,12.75,15.,17.5,
     +20.,23.,27./
      IR=1
      U=0.1
      TEXTIS='WALL1'
      IWM=10
      IC=2
      MP=2
      WRITE(*,10)IS
10    FORMAT(//,' THE FOLLOWING ARE INPUTS FOR SURFACE TYPE # ',I2,
     +', A WALL OR PATITION',/)
20    CALL INPUT(TEXTIS,'T','ENTER SURFACE DESCRIPTION$')
50    CALL INPUT(U,'R','ENTER WALL OR PARTITION U-VALUE(BTU/HR-FT**2-F)$
     +')
      ICHK=0
      RR=1.0/U
      DO 100 I=1,17
      IF(RR.LT.R(I))GO TO 101
100   CONTINUE
      IR=17
      GO TO 104
101   IR=I
104   IF(RR.GT.30.0)GO TO 102
      GO TO 103
102   WRITE(*,*)' WARNING : U-VALUE ENTERED IS SMALLER THAN ALLOWABLE'
      WRITE(*,*)' FOR ACCURATE CALCULATIONS. BEST APPROXIMATION WILL BE'
      WRITE(*,*)' MADE . (MINIMUM U-VALUE = 0.033 BTU/HR-FT**2-F)'
103   CONTINUE
      WRITE(*,*)' '
      WRITE(*,*)' CHOOSE NUMBER OF PRINCIPAL WALL OR PARTITION MATERIAL
     +FROM LIST BELOW'
      WRITE(*,*)' (1)  - 1" STUCCO, STEEL SIDING, FINISH, OR GYPSUM'
      WRITE(*,*)' (2)  - 4" FACE BRICK *     (14) - 8" COMMON BRICK'
      WRITE(*,*)' (3)  - 1" WOOD             (15) - 8" HW CONC'
      WRITE(*,*)' (4)  - 2" WOOD             (16) - 12" HW CONC'
      WRITE(*,*)' (5)  - 4" WOOD             (17) - 2" HW CONC'
      WRITE(*,*)' (6)  - 4" CLAY TILE        (18) - 6" HW CONC'
      WRITE(*,*)' (7)  - 4" LW CONC BLK      (19) - 4" LW CONC'
      WRITE(*,*)' (8)  - 4" HW CONC BLK      (20) - 6" LW CONC'
      WRITE(*,*)' (9)  - 4" COMMON BRICK     (21) - 8" LW CONC'
      WRITE(*,*)' (10) - 4" HW CONC          (22) - 8" LW CONC BLK(FILLE
```

```
     +D)'
      WRITE(*,*)' (11) - 8" CLAY TILE        (23) - 8" HW CONC BLK(FILLE
     +D)'
      WRITE(*,*)' (12) - 8" LW CONC BLK      (24) - 12" LW CONC BLK(FILL
     +ED)'
      WRITE(*,*)' (13) - 8" HW CONC BLK      (25) - 12" HW CONC BLK(FILL
     +ED)'
      WRITE(*,*)' * - NOTE : DO NOT USE FACE BRICK (2) AS THE PRINCIPAL'
      WRITE(*,*)'            MATERIAL IF ANY OF THE MATERIALS (3) THRU'
      WRITE(*,*)'            (25) ARE USED IN COMBINATION WITH IT !!!!'
      CALL INPUT(IWM,'I','ENTER NUMBER OF PRINCIPAL WALL OR PARTITION M
     +ATERIAL$')
      WRITE(*,*)' '
      WRITE(*,*)' '
      WRITE(*,*)' CHOOSE OUTSIDE OR INSIDE LAYER MATERIAL USED WITH PRIN
     +CIPAL MATERIAL'
      WRITE(*,*)' (1) - 1" STUCCO AND/OR GYPSUM'
      WRITE(*,*)' (2) - STEEL SIDING OR FINISH'
      WRITE(*,*)' (3) - 4" FACE BRICK'
      WRITE(*,*)' '
      CALL INPUT(IC,'I','ENTER NUMBER FROM LIST ABOVE$')
      WRITE(*,*)' '
      WRITE(*,*)' '
      WRITE(*,*)' CHOOSE MASS PLACEMENT'
      WRITE(*,*)' (1) - MASS IN   (2) - INTEGRAL MASS   (3) - MASS OUT'
      WRITE(*,*)' '
      CALL INPUT(MP,'I','ENTER NUMBER FROM LIST ABOVE$')
      WRITE(*,*)' '
      WRITE(*,*)' '
      WRITE(*,*)' INPUT DATA :'
      WRITE(*,*)
      WRITE(*,15)TEXTIS,U,IWM,IC,MP
15    FORMAT(/,10X,'DESCRIPTION : ',A18,', U = ',F6.4,' BTU/H-FT**2-F',
     +/,10X,'PRINCIPAL MAT = ',I4,', OUTER OR INNER LAYER MATERIAL = ',
     +I4,/,10X,'MASS PLACEMENT = ',I4)
      WRITE(*,*)' IF THIS INPUT DATA IS CORRECT ENTER (0) '
      CALL INPUT(ICHK,'I','IF INCORRECT ENTER (1) TO REENTER INPUT DATA$
     +')
      IF(ICHK.EQ.1)GO TO 20
C
C     CALCULATE RECORD NUMBER FROM INPUT DATA FOR WALLTYPE.DAT
C
      IRECW=IRECWP(MP,IC,IR,IWM)
      OPEN(9,FILE='WALLTYPE.DAT',STATUS='OLD',ACCESS='DIRECT',
     $FORM='BINARY',RECL=2)
      READ(9,REC=IRECW)IWP
C
C     CHECK TO SEE IF R-VALUE IS OUT OF RANGE IF IWP=0
C
      IF((IWP.EQ.0).AND.(IR.EQ.17))THEN
      IRECW=IRECWP(MP,IC,IR-1,IWM)
      READ(9,REC=IRECW)IWP
          IF(IWP.EQ.0)GO TO 123
```

```
          IF(IWP.NE.0)WRITE(*,*)' U-VALUE ENTERED IS OUT THE RANGE OF TA
     +BULATED DATA. BEST APPROXIMATION CHOSEN.'
          GO TO 200
      ENDIF
123   IF(IWP.EQ.0)WRITE(*,*)' NO SURFACE EXISTS FOR THESE INPUTS, CHECK
     +INPUT DATA AND REENTER'
      IF(IWP.NE.0)GO TO 200
      GO TO 50
200   CONTINUE
      WRITE(6,15)TEXTIS,U,IWM,IC,MP
      WRITE(6,16)IWP
16    FORMAT(10X,'ASHRAE WALL NUMBER ',I2,' CHOSEN',/)
      CLOSE(9)
      RETURN
      END
C
C
C
      FUNCTION IRECWP(MP,IC,IR,IWM)
C
C     FUNCTION TO FIND WALL OR PATITION POSITION IN FILE 'WALLTYPE.DAT'
C
      IRECWP=(MP-1)*1275+(IC-1)*425+(IR-1)*25+IWM
      RETURN
      END
```

SAMPLE OUTPUT FOR WALL CLASSIFICATION SUBROUTINE

```
INPUTS FOR SURFACE TYPE  1

DESCRIPTION : WALL1                , U =  .1249 BTU/H-FT**2-F
PRINCIPAL MAT =    1, OUTER OR INNER LAYER MATERIAL =    1
MASS PLACEMENT =    2
ASHRAE WALL NUMBER  1 CHOSEN

INPUTS FOR SURFACE TYPE  2

DESCRIPTION : WALL2                , U =  .1111 BTU/H-FT**2-F
PRINCIPAL MAT =    8, OUTER OR INNER LAYER MATERIAL =    3
MASS PLACEMENT =    1
ASHRAE WALL NUMBER 13 CHOSEN

INPUTS FOR SURFACE TYPE  3

DESCRIPTION : WALL3                , U =  .1114 BTU/H-FT**2-F
PRINCIPAL MAT =    8, OUTER OR INNER LAYER MATERIAL =    3
MASS PLACEMENT =    2
ASHRAE WALL NUMBER 10 CHOSEN

INPUTS FOR SURFACE TYPE  4

DESCRIPTION : WALL4                , U =  .1114 BTU/H-FT**2-F
PRINCIPAL MAT =    8, OUTER OR INNER LAYER MATERIAL =    3
MASS PLACEMENT =    3
ASHRAE WALL NUMBER 10 CHOSEN

INPUTS FOR SURFACE TYPE  5

DESCRIPTION : WALL5                , U =  .1106 BTU/H-FT**2-F
PRINCIPAL MAT =   16, OUTER OR INNER LAYER MATERIAL =    1
MASS PLACEMENT =    1
ASHRAE WALL NUMBER 27 CHOSEN

INPUTS FOR SURFACE TYPE  6

DESCRIPTION : WALL6                , U =  .4210 BTU/H-FT**2-F
PRINCIPAL MAT =   16, OUTER OR INNER LAYER MATERIAL =    1
MASS PLACEMENT =    2
ASHRAE WALL NUMBER 17 CHOSEN

INPUTS FOR SURFACE TYPE  7

DESCRIPTION : WALL7                , U =  .1106 BTU/H-FT**2-F
PRINCIPAL MAT =   16, OUTER OR INNER LAYER MATERIAL =    1
MASS PLACEMENT =    3
ASHRAE WALL NUMBER 26 CHOSEN
```

LISTING OF ROOF CLASSIFICATION SUBROUTINE

```
      SUBROUTINE IROOFF(IRF,TEXTIS,IS,U)
C
C     SUBROUTINE TO GET INPUTS FOR ROOFS OR FLOORS AND TO USE THESE
C     INPUTS TO CHOOSE WALL TYPE FROM DATA FILE 'ROOFTYPE.DAT'.
C
      CHARACTER*80 TEXTIS
      INTEGER*2 IRF
      DIMENSION R(6)
      DATA R/5.,10.,15.,20.,25.,30./
      IR=1
      U=0.1
      TEXTIS='ROOF1'
      IRM=10
      ISC=2
      MP=2
      WRITE(*,10)IS
10    FORMAT(//,' THE FOLLOWING ARE INPUTS FOR SURFACE TYPE # ',I2,
     +', A ROOF OR FLOOR',/)
20    CALL INPUT(TEXTIS,'T','ENTER SURFACE DESCRIPTION$')
50    CALL INPUT(U,'R','ENTER ROOF OR FLOOR U-VALUE(BTU/HR-FT**2-F)$')
      ICHK=0
      RR=1.0/U
      DO 100 I=1,17
      IF(RR.LT.R(I))GO TO 101
100   CONTINUE
      IR=6
      GO TO 104
101   IR=I
104   IF(RR.GT.33.0)GO TO 102
      GO TO 103
102   WRITE(*,*)' WARNING : U-VALUE ENTERED IS SMALLER THAN ALLOWABLE'
      WRITE(*,*)' FOR ACCURATE CALCULATIONS. BEST APPROXIMATION WILL BE'
      WRITE(*,*)' MADE . (MINIMUM U-VALUE = 0.033 BTU/HR-FT**2-F)'
103   CONTINUE
      WRITE(*,*)' '
      WRITE(*,*)' CHOOSE NUMBER OF PRINCIPAL ROOF OR FLOOR MATERIAL FROM
     + LIST BELOW'
      WRITE(*,*)' (1)  - 1" WOOD         (11) - ATTIC CEILING COMBINATION
     +'
      WRITE(*,*)' (2)  - 2.5" WOOD       (12) - 2" HW CONC - 2" HW CONC (
     +RTS) *'
      WRITE(*,*)' (3)  - 4" WOOD         (13) - 2" HW CONC - 4" HW CONC (
     +RTS)'
      WRITE(*,*)' (4)  - 4" HW CONC      (14) - 2" HW CONC - 6" HW CONC (
     +RTS)'
      WRITE(*,*)' (5)  - 2" HW CONC      (15) - 4" HW CONC - 2" HW CONC (
     +RTS)'
      WRITE(*,*)' (6)  - 6" HW CONC      (16) - 4" HW CONC - 4" HW CONC (
     +RTS)'
```

```
      WRITE(*,*)' (7)  - 4" LW CONC     (17) - 4" HW CONC - 6" HW CONC (
     +RTS)'
      WRITE(*,*)' (8)  - 6" LW CONC     (18) - 6" HW CONC - 2" HW CONC (
     +RTS)'
      WRITE(*,*)' (9)  - 8" LW CONC     (19) - 6" HW CONC - 4" HW CONC (
     +RTS)'
      WRITE(*,*)' (10) - STEEL DECK     (20) - 6" HW CONC - 6" HW CONC (
     +RTS)'
      WRITE(*,*)' *  RTS - ROOF TERRACE SYSTEM : FIRST MATERIAL IS OUTER
     +'
      WRITE(*,*)'          LAYER, SECOND MATERIAL IS INNER LAYER.'
      CALL INPUT(IRM,'I','ENTER NUMBER OF PRINCIPAL ROOF OR FLOOR MATERI
     +AL$')
      WRITE(*,*)' '
      WRITE(*,*)' '
      WRITE(*,*)' CEILING DESCRIPTION :'
      WRITE(*,*)'    (1) - WITHOUT SUSPENDED CEILING'
      WRITE(*,*)'    (2) - WITH SUSPENDED CEILING'
      CALL INPUT(ISC,'I','ENTER NUMBER FROM LIST ABOVE$')
      WRITE(*,*)' '
      WRITE(*,*)' '
      WRITE(*,*)' CHOOSE MASS PLACEMENT'
      WRITE(*,*)' (1) - MASS IN   (2) - INTEGRAL MASS   (3) - MASS OUT'
      WRITE(*,*)' '
      CALL INPUT(MP,'I','ENTER NUMBER FROM LIST ABOVE$')
      WRITE(*,*)' '
      WRITE(*,*)' '
      WRITE(*,*)' INPUT DATA :'
      WRITE(*,*)
      WRITE(*,15)TEXTIS,U,IRM,ISC,MP
15    FORMAT(/,10X,'DESCRIPTION : ',A18,', U = ',F6.4,' BTU/H-FT**2-F',
     +/,10X,'PRINCIPAL MAT = ',I4,' , CEILING DESCRIPTION = ',I2,
     +/,10X,'MASS PLACEMENT = ',I4)
      WRITE(*,*)' IF THIS INPUT DATA IS CORRECT ENTER (0) '
      CALL INPUT(ICHK,'I','IF INCORRECT ENTER (1) TO REENTER INPUT DATA$
     +')
      IF(ICHK.EQ.1)GO TO 20

C
C     CALCULATE RECORD NUMBER FROM INPUT DATA FOR ROOFTYPE.DAT
C
      OPEN(9,FILE='ROOFTYPE.DAT',STATUS='OLD',ACCESS='DIRECT',
     $FORM='BINARY',RECL=2)
      IRECR=IRECRF(MP,ISC,IR,IRM)
      READ(9,REC=IRECR)IRF
C
C     CHECK TO SEE IF R-VALUE IS OUT OF RANGE IF IRF=0
C
      IF((IRF.EQ.0).AND.(IR.EQ.6))THEN
      IRECR=IRECRF(MP,ISC,IR-1,IRM)
      READ(9,REC=IRECR)IRF
          IF(IRF.EQ.0)GO TO 123
          IF(IRF.NE.0)WRITE(*,*)' U-VALUE ENTERED IS OUT THE RANGE OF TA
```

```
     +BULATED DATA. BEST APPROXIMATION CHOSEN.'
         GO TO 200
      ENDIF
123   IF(IRF.EQ.0)WRITE(*,*)' NO SURFACE EXISTS FOR THESE INPUTS, CHECK
     +INPUT DATA AND REENTER'
      IF(IRF.NE.0)GO TO 200
      GO TO 50
200   CONTINUE
      WRITE(6,15)TEXTIS,U,IRM,ISC,MP
      WRITE(6,16)IRF
16    FORMAT(10X,'ASHRAE ROOF NUMBER ',I2,' CHOSEN',/)
      CLOSE(9)
      RETURN
      END
C
C
      FUNCTION IRECRF(MP,ISC,IR,IRM)
C
C     FUNCTION TO FIND ROOF OR FLOOR POSITION IN FILE 'ROOFTYPE.DAT'
C
      IRECRF=(MP-1)*240+(ISC-1)*120+(IR-1)*20+IRM
      RETURN
      END
```

SAMPLE OUTPUT FOR ROOF CLASSIFICATION SUBROUTINE

```
INPUTS FOR SURFACE TYPE  1

DESCRIPTION : ROOF1                , U =  .0500 BTU/H-FT**2-F
PRINCIPAL MAT =   16 , CEILING DESCRIPTION =  2
MASS PLACEMENT =    2
ASHRAE ROOF NUMBER 33 CHOSEN

INPUTS FOR SURFACE TYPE  2

DESCRIPTION : ROOF2                , U =  .0650 BTU/H-FT**2-F
PRINCIPAL MAT =    8 , CEILING DESCRIPTION =  1
MASS PLACEMENT =    3
ASHRAE ROOF NUMBER 10 CHOSEN

INPUTS FOR SURFACE TYPE  3

DESCRIPTION : ROOF3                , U =  .0900 BTU/H-FT**2-F
PRINCIPAL MAT =   11 , CEILING DESCRIPTION =  1
MASS PLACEMENT =    2
ASHRAE ROOF NUMBER  2 CHOSEN

INPUTS FOR SURFACE TYPE  4

DESCRIPTION : ROOF4                , U =  .1000 BTU/H-FT**2-F
PRINCIPAL MAT =   10 , CEILING DESCRIPTION =  1
MASS PLACEMENT =    2
ASHRAE ROOF NUMBER  1 CHOSEN

INPUTS FOR SURFACE TYPE  5

DESCRIPTION : ROOF5                , U =  .1200 BTU/H-FT**2-F
PRINCIPAL MAT =    3 , CEILING DESCRIPTION =  2
MASS PLACEMENT =    2
ASHRAE ROOF NUMBER 20 CHOSEN

INPUTS FOR SURFACE TYPE  6

DESCRIPTION : ROOF6                , U =  .0400 BTU/H-FT**2-F
PRINCIPAL MAT =   20 , CEILING DESCRIPTION =  2
MASS PLACEMENT =    2
ASHRAE ROOF NUMBER 42 CHOSEN

INPUTS FOR SURFACE TYPE  7

DESCRIPTION : ROOF7                , U =  .0410 BTU/H-FT**2-F
PRINCIPAL MAT =    5 , CEILING DESCRIPTION =  2
MASS PLACEMENT =    1
ASHRAE ROOF NUMBER 14 CHOSEN
```

LISTING OF TRANSFER FUNCTION COEFFICIENT RETRIEVAL SUBROUTINE

```
      SUBROUTINE TRANSF(BT,DT,UWRT,EPSILN,MC,IB,NSTYPE,KSTYPE,TEXTIS,IS,
     +JSTYPE)
C
C     THIS SUBROUTINE SELECTS THE CHOSEN CONDUCTION TRANSFER FUNCTION
C     COEFFICIENTS FROM FILE WALLTFS.DAT OR ROOFTFS.DAT ACCORDING TO
C     USER INPUTS
C
      CHARACTER*80 TEXTIS(15)
      CHARACTER*64 WRTYPE
      DIMENSION KSTYPE(15),IS(15),BT(7),DT(7)
      DIMENSION BR(7,4),DR(7,4),UWRTR(4)
      DATA BR/.78785E-02,.22323E-01,.3095E-02,.11659E-04,.4686E-10,
     +.15321E-16,0.,.155969E-01,.625E-01,.57019E-02,.113507E-04,
     +.221129E-13,0.,0.,.77579E-04,.26427E-02,.44282E-02,.90555E-03,
     +.21036E-04,.31931E-07,.15873E-11,.35383E-05,.6607E-03,.34298E-02,
     +.24933E-02,.31818E-03,.6204E-05,.10343E-07/
      DATA DR/1.0,-.29813,.5651E-02,-.12572E-04,.10942E-19,0.,0.,1.0,
     +-.41266,.624691E-01,-.38269E-10,.82367E-21,0.,0.,1.0,-1.02645,
     +.20712,-.98212E-02,.49224E-04,-.38092E-08,.54842E-13,1.0,
     +-1.67313,.82703,-.1083,.44096E-02,-.47704E-04,.26864E-08/
      DATA UWRTR/0.047,0.076,0.047,0.138/
      CALL DEBUG('TRANSF',1)
      IF(IB.NE.3)GO TO 3000
C
C     CHOOSE SURFACE TYPE
C
      WRITE(*,*)' '
      WRITE(*,*)' SURFACE TYPES ENTERED - CHOOSE NUMBER REPRESENTING'
      WRITE(*,*)' THIS ROOM AND SURFACE'
      WRITE(*,*)' '
      DO 700 I=1,NSTYPE
700   WRITE(*,710)I,TEXTIS(I)
710   FORMAT(4X,'(',I2,') - ',A65)
C
C     OPEN CORRECT DATA FILE AND RETRIEVE TRANSFER FUNCTION
C     COEFFICIENTS TO SEND BACK TO MAIN PROGRAM
C
      JSTYPE=1
      CALL INPUT(JSTYPE,'I','ENTER NUMBER FROM LIST ABOVE$')
      IF(IS(JSTYPE).EQ.1)OPEN(9,FILE='WALLTFS.DAT',STATUS='OLD',
     +ACCESS='DIRECT',FORM='BINARY',RECL=124)
      IF(IS(JSTYPE).EQ.2)OPEN(9,FILE='ROOFTFS.DAT',STATUS='OLD',
     +ACCESS='DIRECT',FORM='BINARY',RECL=124)
      READ(9,REC=KSTYPE(JSTYPE))WRTYPE,(BT(I),I=1,7),(DT(J),J=1,7),UWRT
      CLOSE(9)
      GO TO 7800
3000  IF((IB.NE.3).AND.(EPSILN.LE.45.))IRES=1
      IF((IB.EQ.1).AND.(EPSILN.GT.45.))IRES=2
      IF((IB.EQ.2).AND.(EPSILN.GT.45.).AND.(MC.EQ.1))IRES=2
```

```
      IF((IB.EQ.2).AND.(EPSILN.GT.45.).AND.(MC.EQ.2))IRES=3
      IF((IB.EQ.2).AND.(EPSILN.GT.45.).AND.(MC.EQ.3))IRES=4
      DO 3200 KK=1,7
      BT(KK)=BR(KK,IRES)
      DT(KK)=DR(KK,IRES)
3200  CONTINUE
      UWRT=UWRTR(IRES)
      CALL DEBUG('TRANSF',2)
7800  RETURN
      END
```

APPENDIX C

CONDUCTION TRANSFER FUNCTION COEFFICIENTS FOR ALL WALL AND ROOF TYPES

b,c, AND d TRANSFER FUNCTION COEFFICIENTS FOR WALLS

WALL TYPE 1 : E0,A3,B1,B13,A3,A0
STEEL SIDING W/ 4" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.76794E-02	.34978E-01	.71911E-02	.55759E-04	.94018E-08	.13353E-13	.15183E-15	Cn = .049904
dn	.10000E+01	-.24072E+00	.16764E-02	-.51488E-06	.25837E-11	-.39151E-19	.65086E-32	U = .065581

WALL TYPE 2 : E0 ,E1 ,B14,A1 ,A0 ,
FRAME WALL W/ 5" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.15618E-03	.54544E-02	.96078E-02	.21547E-02	.51664E-04	.47736E-07	.25103E-12	Cn = .017425
dn	.10000E+01	-.93389E+00	.27396E+00	-.25609E-01	.14239E-03	-.19319E-08	.60005E-17	U = .055386

WALL TYPE 3 : E0 ,C3 ,B5 ,A6 ,A0 ,
4" H.W. CONC. BLK. W/ 1" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.41066E-02	.32305E-01	.14744E-01	.46550E-03	.28937E-06	.62274E-13	-.43623E-15	Cn = .051621
dn	.10000E+01	-.76963E+00	.40143E-01	-.41970E-03	.27284E-09	-.12997E-21	.20665E-36	U = .191122

WALL TYPE 4 : E0 ,E1 ,B6 ,C12,A0 ,
2" INS. W/ 2" H.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.10663E-04	.10790E-02	.38405E-02	.18711E-02	.13427E-03	.87708E-06	.19822E-09	Cn = .006936
dn	.10000E+01	-.13758E+01	.61544E+00	-.93889E-01	.22104E-02	-.89008E-06	.21209E-11	U = .046874

WALL TYPE 5 : E0 ,A6 ,B21,C7 ,A0 ,
1.36" INS. W/ 8" L.W. CONC. BLK.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.80326E-04	.44353E-02	.10182E-01	.29601E-02	.10453E-03	.23140E-06	.97085E-11	Cn = .017762
dn	.10000E+01	-.11604E+01	.32547E+00	-.27463E-01	.20980E-03	-.15254E-07	.40784E-14	U = .128916

WALL TYPE 6 : E0 ,E1 ,B2 ,C5 ,A1 ,A0 ,
1" INS. W/ 4" H.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.50539E-03	.93807E-02	.10572E-01	.12730E-02	.88344E-05	.60571E-09	.43398E-16	Cn = .021740
dn	.10000E+01	-.11758E+01	.30071E+00	-.15606E-01	.58619E-05	-.12039E-11	.56442E-24	U = .198884

WALL TYPE 7 : E0 ,A6 ,C5 ,B3 ,A3 ,A0 ,
4" H.W. CONC. W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.98849E-03	.83611E-02	.36141E-02	.69313E-04	.10034E-07	.18942E-13	-.33976E-16	Cn = .013033
dn	.10000E+01	-.93970E+00	.46636E-01	-.21210E-05	.17233E-10	-.43539E-19	.87073E-30	U = .121878

WALL TYPE 8 : E0 ,A2 ,C12,B5 ,A6 ,A0 ,
FACE BRICK & 2" H.W. CONC. W/ 1" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.14401E-03	.45986E-02	.73304E-02	.13529E-02	.24650E-04	.18978E-07	.97973E-13	Cn = .013451
dn	.10000E+01	-.12001E+01	.27937E+00	-.10391E-01	.53403E-04	-.86842E-09	.47859E-17	U = .195190

UNITS : U, bn, Cn = BTU/hr-ft**2-°F
SEE APPENDIX B FOR THE TIME LAGS AND AMPLITUDE RATIOS CORRESPONDING TO THESE COEFFICIENTS.

WALL TYPE 9 : E0 ,A6 ,B15,B10,A0 ,
6" INS. W/ 2" WOOD

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.35081E-07	.63821E-04	.85866E-03	.14648E-02	.50642E-03	.37673E-04	.52063E-06	Cn = .002932
dn	.10000E+01	-.16335E+01	.86971E+00	-.18121E+00	.14453E-01	-.30536E-03	.99873E-06	U = .042413

WALL TYPE 10 : E0,E1,C2,B5,A2,A0
4" L.W. CONC. BLK. W/ 1" INS. & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.72162E-05	.10184E-02	.44117E-02	.25989E-02	.23871E-03	.24701E-05	.13649E-08	Cn = .008277
dn	.10000E+01	-.16636E+01	.82440E+00	-.11098E+00	.35088E-02	-.43699E-05	.10989E-09	U = .155161

WALL TYPE 11 : E0,E1,C8,B6,A1,A0,
8" H.W. CONC. BLK. W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.34085E-05	.61426E-03	.28902E-02	.18273E-02	.18442E-03	.22725E-05	.20763E-08	Cn = .005522
dn	.10000E+01	-.15248E+01	.67146E+00	-.98438E-01	.23897E-02	-.23571E-05	.39632E-09	U = .109090

WALL TYPE 12 : E0 ,E1 ,B1 ,C10,A1 ,A0 ,
8" H.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.15708E-04	.19814E-02	.81619E-02	.46745E-02	.43793E-03	.51955E-05	.41275E-08	Cn = .015277
dn	.10000E+01	-.15166E+01	.64261E+00	-.83816E-01	.28873E-02	-.72458E-05	.49361E-09	U = .338747

WALL TYPE 13 : E0 ,A2 ,C5 ,B19,A6 ,A0 ,
FACE BRICK & 4" H.W. CONC. W/ 0.61" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.26083E-04	.20290E-02	.60073E-02	.23346E-02	.12949E-03	.75936E-06	.20618E-09	Cn = .010527
dn	.10000E+01	-.14135E+01	.48697E+00	-.32176E-01	.56718E-03	-.80080E-06	.81209E-11	U = .251432

WALL TYPE 14 : E0 ,A2 ,A2 ,B6 ,A6 ,A0 ,
FACE BRICK & FACE BRICK W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.11169E-05	.29943E-03	.16719E-02	.12341E-02	.15533E-03	.29997E-05	.63766E-08	Cn = .003365
dn	.10000E+01	-.15299E+01	.62059E+00	-.63288E-01	.19603E-02	-.63858E-05	.18049E-08	U = .114460

WALL TYPE 15 : E0 ,A6 ,C17,B1 ,A7 ,A0 ,
8" L.W. CONC, BLK.(FILLED) & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.85864E-08	.30915E-04	.60237E-03	.14516E-02	.73636E-03	.87564E-04	.22493E-05	Cn = .002911
dn	.10000E+01	-.20000E+01	.13680E+01	-.37388E+00	.38846E-01	-.14032E-02	.14291E-04	U = .091982

WALL TYPE 16 : E0 ,A6 ,C18,B1 ,A7 ,A0 ,
8" H.W. CONC. BLK.(FILLED) & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.12864E-06	.14018E-03	.16884E-02	.27022E-02	.86402E-03	.56177E-04	.61038E-06	Cn = .005452
dn	.10000E+01	-.20026E+01	.13289E+01	-.32486E+00	.23607E-01	-.52205E-03	.14500E-05	U = .222421

WALL TYPE 17 : E0 ,A2 ,C2 ,B15,A0 ,
FACE BRICK & 4" L.W. CONC. BLK. W/ 6" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.36855E-09	.45258E-05	.13363E-03	.43665E-03	.30010E-03	.51204E-04	.21448E-05	Cn = .000928
dn	.10000E+01	-.20087E+01	.13712E+01	-.37897E+00	.39616E-01	-.16467E-02	.22889E-04	U = .043219

WALL TYPE 18 : E0 ,A6 ,B25,C9 ,A0 ,
3.33" INS. W/ 8" COMMON BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.20365E-08	.11756E-04	.26457E-03	.70621E-03	.39828E-03	.54197E-04	.16799E-05	Cn = .001437
dn	.10000E+01	-.19291E+01	.12441E+01	-.33029E+00	.36628E-01	-.14670E-02	.18237E-04	U = .072005

WALL TYPE 19 : E0 ,C9 ,B6 ,A6 ,A0 ,
8" COMMON BRICK W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.36640E-07	.52302E-04	.63836E-03	.98752E-03	.29960E-03	.18685E-04	.20852E-06	Cn = .001997
dn	.10000E+01	-.17816E+01	.96017E+00	-.16904E+00	.95754E-02	-.16149E-03	.31284E-06	U = .105710

WALL TYPE 20 : E0 ,C11,B19,A6 ,A0 ,
12 " H.W. CONC. W/ 0.61" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.17688E-06	.12414E-03	.11930E-02	.15370E-02	.38443E-03	.18806E-04	.14937E-06	Cn = .003258
dn	.10000E+01	-.18603E+01	.10593E+01	-.19508E+00	.10016E-01	-.16302E-03	.43092E-06	U = .237431

WALL TYPE 21 : E0 ,C11,B6 ,A1 ,A0 ,
12" H.W. CONC. W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.26360E-08	.97325E-05	.18808E-03	.44635E-03	.21849E-03	.23898E-04	.51297E-06	Cn = .000887
dn	.10000E+01	-.21281E+01	.15397E+01	-.45512E+00	.52984E-01	-.15838E-02	.55520E-05	U = .112281

WALL TYPE 22 : E0 ,C14,B15,A2 ,A0 ,
4" L.W. CONC. W/ 6" INS. & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.30443E-10	.12492E-05	.57527E-04	.26335E-03	.25174E-03	.61381E-04	.38573E-05	Cn = .000639
dn	.10000E+01	-.22871E+01	.18546E+01	-.63564E+00	.88586E-01	-.46319E-02	.85032E-04	U = .040354

WALL TYPE 23 : E0 ,E1 ,B15,C7 ,A2 ,A0 ,
6" INS. W/ 8" L.W. CONC. BLK.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.81452E-12	.17047E-06	.15262E-04	.11677E-03	.18835E-03	.83698E-04	.10926E-04	Cn = .000415
dn	.10000E+01	-.25423E+01	.24377E+01	-.11074E+01	.24599E+00	-.25098E-01	.10146E-02	U = .042336

WALL TYPE 24 : E0 ,A6 ,C20,B1 ,A7 ,A0 ,
12" H.W. CONC. BLK.(FILLED) & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.17539E-09	.37281E-05	.15108E-03	.66035E-03	.61821E-03	.14868E-03	.91417E-05	Cn = .001591
dn	.10000E+01	-.24800E+01	.22260E+01	-.87231E+00	.14275E+00	-.85023E-02	.17944E-03	U = .196143

WALL TYPE 25 : E0 ,A2 ,C15,B12,A6 ,A0 ,
FACE BRICK & 6" L.W. CONC. W/ 3" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.93315E-11	.64030E-06	.36129E-04	.19239E-03	.21497E-03	.63683E-04	.52562E-05	Cn = .000513
dn	.10000E+01	-.22857E+01	.18076E+01	-.58999E+00	.81554E-01	-.49980E-02	.12829E-03	U = .060153

WALL TYPE 26 : E0 ,A2 ,C6 ,B6 ,A6 ,A0 ,
FACE BRICK & 8" CLAY TILE W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.18559E-09	.30131E-05	.99742E-04	.35627E-03	.26597E-03	.49298E-04	.22546E-05	Cn = .000777
dn	.10000E+01	-.21878E+01	.16093E+01	-.46185E+00	.50512E-01	-.21757E-02	.31054E-04	U = .096848

WALL TYPE 27 : E0 ,E1 ,B14,C11,A1 ,A0 ,
5" INS. W/ 12 " H.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.23644E-12	.77776E-07	.77703E-05	.63509E-04	.10831E-03	.50848E-04	.70411E-05	Cn = .000238
dn	.10000E+01	-.25594E+01	.24594E+01	-.11255E+01	.25621E+00	-.27212E-01	.10705E-02	U = .052480

WALL TYPE 28 : E0,E1,C11,B13,A1,A0
12" H.W. CONC. W/ 4" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.38452E-11	.30303E-06	.18247E-04	.10360E-03	.12434E-03	.39646E-04	.34531E-05	Cn = .000290
dn	.10000E+01	-.23767E+01	.20431E+01	-.79860E+00	.14868E+00	-.12308E-01	.36692E-03	U = .063714

WALL TYPE 29 : E0 ,A2 ,C11,B5 ,A6 ,A0 ,
FACE BRICK & 12" H.W. CONC. W/ 1" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.24396E-10	.90818E-06	.42934E-04	.20609E-03	.20987E-03	.55717E-04	.39455E-05	Cn = .000519
dn	.10000E+01	-.24290E+01	.20818E+01	-.75768E+00	.11461E+00	-.67366E-02	.15303E-03	U = .167892

WALL TYPE 30 : E0 ,E1 ,B19,C19,A2 ,A0 ,
0.61" INS. W/ 12" L.W. CONC. BLK.(FILLED) & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.52097E-13	.32167E-07	.52742E-05	.61556E-04	.14758E-03	.10030E-03	.21442E-04	Cn = .000336
dn	.10000E+01	-.28363E+01	.31038E+01	-.16573E+01	.45360E+00	-.62121E-01	.39277E-02	U = .062038

WALL TYPE 31 : E0 ,E1 ,B15,C15,A2 ,A0 ,
6" INS. W/ 6" L.W. CONC. & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.93675E-15	.54544E-08	.14444E-05	.22459E-04	.68740E-04	.59658E-04	.16696E-04	Cn = .000169
dn	.10000E+01	-.29029E+01	.32897E+01	-.18545E+01	.55033E+00	-.83839E-01	.59914E-02	U = .037595

WALL TYPE 32 : E0 ,E1 ,B23,B9 ,A2 ,A0 ,
2.42" INS. W/ FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.23315E-13	.25737E-07	.41994E-05	.48011E-04	.11163E-03	.72710E-04	.14679E-04	Cn = .000251
dn	.10000E+01	-.28227E+01	.30454E+01	-.15841E+01	.41423E+00	-.51859E-01	.27293E-02	U = .069288

WALL TYPE 33 : E0 ,A2 ,C6 ,B15,A6 ,A0 ,
FACE BRICK & 8" CLAY TILE W/ 6" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.11102E-14	.90751E-08	.19045E-05	.24724E-04	.63287E-04	.45294E-04	.10244E-04	Cn = .000145
dn	.10000E+01	-.26895E+01	.27128E+01	-.12887E+01	.30051E+00	-.33375E-01	.17522E-02	U = .042291

WALL TYPE 34 : E0 ,C11,B21,A2 ,A0 ,
12" H.W. CONC. W/ 1.36" INS. & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.28541E-10	.75376E-06	.32186E-04	.14521E-03	.13829E-03	.33100E-04	.19511E-05	Cn = .000351
dn	.10000E+01	-.26708E+01	.25809E+01	-.10797E+01	.18237E+00	-.10574E-01	.20788E-03	U = .142970

WALL TYPE 35 : E0 ,E1 ,B14,C11,A2 ,A0 ,
5" INS. W/ 12" H.W. CONC. & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.49266E-14	.16403E-08	.54871E-06	.98554E-05	.34184E-04	.33667E-04	.10821E-04	Cn = .000089
dn	.10000E+01	-.29685E+01	.34561E+01	-.20288E+01	.64302E+00	-.10884E+00	.90555E-02	U = .051869

WALL TYPE 36 : E0 ,A2 ,C11,B25,A6 ,A0 ,
FACE BRICK & 12' H.W. CONC. W/ 3.33" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.42202E-13	.30072E-07	.38953E-05	.36955E-04	.71277E-04	.38026E-04	.61936E-05	Cn = .000156
dn	.10000E+01	-.25513E+01	.23660E+01	-.99023E+00	.19505E+00	-.18141E-01	.75485E-03	U = .072821

WALL TYPE 37 : E0 ,E1 ,B25,C19,A2 ,A0 ,
3.33" INS. W/ 12" L.W. CONC. BLK.(FILLED) & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.55511E-16	.33875E-09	.21000E-06	.54540E-05	.25802E-04	.34516E-04	.15463E-04	Cn = .000081
dn	.10000E+01	-.31776E+01	.40046E+01	-.25633E+01	.89048E+00	-.16764E+00	.16379E-01	U = .039671

WALL TYPE 38 : E0 ,E1 ,B15,C20,A2 ,A0 ,
6" INS. W/ 12" H.W. CONC. BLK.(FILLED) & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	-.42882E-14	.34806E-09	.20925E-06	.53384E-05	.24899E-04	.32864E-04	.14505E-04	Cn = .000078
dn	.10000E+01	-.31499E+01	.39512E+01	-.25379E+01	.89438E+00	-.17209E+00	.17057E-01	U = .041385

WALL TYPE 39 : E0 ,A2 ,C16,B14,A6 ,A0 ,
FACE BRICK & 8" L.W. CONC. W/ 5" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.87430E-15	.43899E-09	.24575E-06	.58111E-05	.24919E-04	.29927E-04	.11902E-04	Cn = .000073
dn	.10000E+01	-.29939E+01	.34588E+01	-.19583E+01	.57704E+00	-.88443E-01	.68742E-02	U = .040041

WALL TYPE 40 : E0 ,A2 ,C20,B15,A6 ,A0 ,
FACE BRICK & 12" H.W. CONC. BLK.(FILLED) W/ 6" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	-.36221E-14	.45744E-09	.24489E-06	.56404E-05	.23664E-04	.27815E-04	.10807E-04	Cn = .000068
dn	.10000E+01	-.29758E+01	.34224E+01	-.19332E+01	.56765E+00	-.85683E-01	.65209E-02	U = .041342

WALL TYPE 41 : E0,E1,C11,B14,A2,A0
12" H.W. CONC. W/ 5" INS. & FACE BRICK

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	-.43993E-14	.11957E-08	.37563E-06	.63723E-05	.20707E-04	.18765E-04	.54091E-05	Cn = .000052
dn	.10000E+01	-.30830E+01	.36662E+01	-.21199E+01	.62142E+00	-.89165E-01	.56059E-02	U = .051869

b,c, AND d TRANSFER FUNCTION COEFFICIENTS FOR ROOFS

ROOF TYPE 1 : E0 ,A3 ,B25,E3 ,E2 ,A0 ,
STEEL SHEET W/ 3.33" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.48703E-02	.34736E-01	.13652E-01	.35823E-03	.23339E-06	.77659E-12	-.19875E-15	Cn = .053616
dn	.10000E+01	-.35451E+00	.22670E-01	-.46908E-04	.30920E-09	-.13754E-16	.32374E-28	U = .080251

ROOF TYPE 2 : E0 ,A3 ,B14,E3 ,E2 ,A0 ,
STEEL SHEET W/ 5" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.55584E-03	.12022E-01	.12817E-01	.14330E-02	.12926E-04	.45185E-08	.20582E-13	Cn = .026841
dn	.10000E+01	-.60064E+00	.86016E-01	-.13527E-02	.12858E-05	-.10446E-10	.84718E-18	U = .055454

ROOF TYPE 3 : E0 ,E5 ,E4 ,C12,E3 ,E2 ,A0 ,
2" H.W. CONC. W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.61344E-02	.39829E-01	.13754E-01	.24851E-03	.90887E-07	.25257E-13	-.39498E-15	Cn = .059966
dn	.10000E+01	-.75615E+00	.14387E-01	-.60003E-04	.71457E-10	-.73722E-21	.00000E+00	U = .232261

ROOF TYPE 4 : E0 ,E1 ,B15,E4 ,B7 ,A0 ,
ATTIC ROOF W/ 6" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.29438E-05	.65306E-03	.33867E-02	.23970E-02	.28879E-03	.48569E-05	.74294E-08	Cn = .006733
dn	.10000E+01	-.13466E+01	.59384E+00	-.92953E-01	.29637E-02	-.57855E-05	.18771E-08	U = .042814

ROOF TYPE 5 : E0 ,B14,C12,E3 ,E2 ,A0 ,
5" INS. W/ 2" H.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.55526E-04	.25555E-02	.47745E-02	.10009E-02	.21154E-04	.28998E-07	.94604E-12	Cn = .008408
dn	.10000E+01	-.11040E+01	.26169E+00	-.47482E-02	.21450E-04	-.77618E-09	.10491E-14	U = .054946

ROOF TYPE 6 : E0 ,C5 ,B17,E3 ,E2 ,A0 ,
4" H.W. CONC. W/ 0.3" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.29012E-02	.31434E-01	.21138E-01	.12012E-02	.17968E-05	.30135E-11	.36508E-15	Cn = .056676
dn	.10000E+01	-.97905E+00	.13444E+00	-.27189E-02	.54600E-08	-.10116E-15	.23403E-28	U = .371225

ROOF TYPE 7 : E0 ,B22,C12,E3 ,E2 ,C12,A0 ,
1.67" INS. W/ 2" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.59119E-03	.86740E-02	.68771E-02	.37485E-03	.38508E-06	.96297E-11	-.34560E-15	Cn = .016518
dn	.10000E+01	-.11177E+01	.23731E+00	-.81562E-04	.55144E-08	-.78474E-14	.92552E-26	U = .138145

ROOF TYPE 8 : E0 ,B16,C13,E3 ,E2 ,A0 ,
0.15" INS. W/ 6" H.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.98388E-03	.19384E-01	.20827E-01	.21888E-02	.14924E-04	.24665E-08	.72781E-15	Cn = .043398
dn	.10000E+01	-.11023E+01	.20750E+00	-.28654E-02	.24761E-05	-.51142E-11	.12905E-20	U = .424307

UNITS : U, bn, Cn = BTU/hr-ft**2-°F
RTS : ROOF TERRACE SYSTEM
SEE APPENDIX B FOR THE TIME LAGS AND AMPLITUDE RATIOS CORRESPONDING TO THESE COEFFICIENTS.

ROOF TYPE 9 : E0 ,E5 ,E4 ,B12,C14,E3 ,E2 ,A0 ,
3" INS. W/ 4" L.W. CONC. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.31296E-06	.24455E-03	.21733E-02	.25081E-02	.55406E-03	.23441E-04	.15058E-06	Cn =	.005504
dn	.10000E+01	-.14060E+01	.58814E+00	-.90336E-01	.44423E-02	-.57037E-04	.67593E-07	U =	.057246

ROOF TYPE 10 : E0 ,E5 ,E4 ,C15,B16,E3 ,E2 ,A0 ,
6" L.W. CONC. W/ 0.15" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.29155E-06	.24937E-03	.24091E-02	.30337E-02	.73964E-03	.35543E-04	.28164E-06	Cn =	.006468
dn	.10000E+01	-.15570E+01	.73120E+00	-.11774E+00	.59992E-02	-.75519E-04	.17266E-06	U =	.103708

ROOF TYPE 11 : E0 ,C5 ,B15,E3 ,E2 ,A0 ,
4" H.W. CONC. W/ 6" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.25044E-06	.12506E-03	.97422E-03	.10173E-02	.19801E-03	.68017E-05	.29359E-07	Cn =	.002322
dn	.10000E+01	-.16147E+01	.79142E+00	-.13242E+00	.61096E-02	-.81333E-04	.36169E-07	U =	.046113

ROOF TYPE 12 : E0 ,C13,B16,E3 ,E2 ,C12,A0 ,
6" H.W. CONC.-0.15" INS.-2" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.47450E-04	.35559E-02	.10578E-01	.40431E-02	.18888E-03	.64267E-06	.92034E-10	Cn =	.018414
dn	.10000E+01	-.15927E+01	.72160E+00	-.82751E-01	.29414E-03	-.16165E-06	.37449E-12	U =	.396230

ROOF TYPE 13 : E0 ,C13,B6 ,E3 ,E2 ,A0 ,
6" H.W. CONC. W/ 2" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.18820E-04	.13616E-02	.37252E-02	.12912E-02	.55471E-04	.17856E-06	.24310E-10	Cn =	.006453
dn	.10000E+01	-.13445E+01	.44285E+00	-.43441E-01	.15834E-03	-.68216E-07	.16836E-12	U =	.117195

ROOF TYPE 14 : E0 ,E5 ,E4 ,C12,B13,E3 ,E2 ,A0 ,
2" H.W. CONC. W/ 4" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.48865E-05	.46075E-03	.14326E-02	.56641E-03	.30458E-04	.15234E-06	.35244E-10	Cn =	.002495
dn	.10000E+01	-.13374E+01	.41454E+00	-.33463E-01	.30859E-03	-.14791E-06	.43718E-12	U =	.056736

ROOF TYPE 15 : E0 ,E5 ,E4 ,C5 ,B6 ,E3 ,E2 ,A0 ,
4" H.W. CONC. W/2" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.98911E-05	.66225E-03	.16275E-02	.48742E-03	.18491E-04	.63809E-07	.95544E-11	Cn =	.002806
dn	.10000E+01	-.12435E+01	.28741E+00	-.12738E-01	.90481E-04	-.46519E-07	.11675E-12	U =	.089674

ROOF TYPE 16 : E0 ,E5 ,E4 ,C13,B20,E3 ,E2 ,A0 ,
6" H.W. CONC. W/ 0.76" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6		
bn	.61572E-05	.59629E-03	.19718E-02	.86082E-03	.54900E-04	.37610E-06	.12787E-09	Cn =	.003490
dn	.10000E+01	-.13918E+01	.46336E+00	-.47139E-01	.58021E-03	-.12080E-05	.35322E-11	U =	.139616

ROOF TYPE 17 : E0 ,E5 ,E4 ,B15,C14,E3 ,E2 ,A0 ,
6" INS. W/ 4" L.W. CONC. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.37155E-09	.66041E-05	.21354E-03	.73558E-03	.53125E-03	.95992E-04	.42982E-05	Cn = .001587
dn	.10000E+01	-.18732E+01	.12095E+01	-.32904E+00	.37986E-01	-.16883E-02	.23765E-04	U = .036405

ROOF TYPE 18 : E0 ,C12,B15,E3 ,E2 ,C5 ,A0 ,
2" H.W. CONC.-6" INS.-4" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.85314E-08	.17870E-04	.27047E-03	.51579E-03	.19492E-03	.15018E-04	.19464E-06	Cn = .001014
dn	.10000E+01	-.21093E+01	.15084E+01	-.40880E+00	.32491E-01	-.68278E-03	.86690E-06	U = .045761

ROOF TYPE 19 : E0 ,C5 ,B27,E3 ,E2 ,C12,A0 ,
4" H.W. CONC.-4.54" INS.-2" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.17161E-06	.91235E-04	.73477E-03	.77770E-03	.14723E-03	.46366E-05	.18962E-07	Cn = .001756
dn	.10000E+01	-.18285E+01	.10286E+01	-.17574E+00	.55571E-02	-.33031E-04	.32245E-07	U = .058835

ROOF TYPE 20 : E0 ,B21,C16,E3 ,E2 ,A0 ,
1.36" INS. W/ 8" L.W. CONC.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.39415E-08	.21481E-04	.43536E-03	.10256E-02	.48671E-03	.51181E-04	.10739E-05	Cn = .002021
dn	.10000E+01	-.19200E+01	.12197E+01	-.30000E+00	.26304E-01	-.61152E-03	.22851E-05	U = .079575

ROOF TYPE 21 : E0 ,C13,B12,E3 ,E2 ,C12,A0 ,
6" H.W. CONC.-3" INS.-2" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.16272E-06	.88617E-04	.72176E-03	.77161E-03	.14798E-03	.47480E-05	.19920E-07	Cn = .001735
dn	.10000E+01	-.18458E+01	.10324E+01	-.17182E+00	.61655E-02	-.29771E-04	.37892E-07	U = .083196

ROOF TYPE 22 : E0 ,B22,C5 ,E3 ,E2 ,C13,A0 ,
1.67" INS.-4" H.W. CONC.-6" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.28456E-06	.13665E-03	.99846E-03	.93655E-03	.14892E-03	.35550E-05	.91867E-08	Cn = .002224
dn	.10000E+01	-.17998E+01	.94786E+00	-.13443E+00	.36023E-02	-.11347E-04	.17639E-08	U = .129236

ROOF TYPE 23 : E0 ,E5 ,E4 ,C12,B14,E3 ,E2 ,C12,A0 ,
2" H.W. CONC.-5" INS.-2" H.W. CONC RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.23233E-07	.21026E-04	.22183E-03	.30760E-03	.82203E-04	.42230E-05	.34289E-07	Cn = .000637
dn	.10000E+01	-.18990E+01	.11358E+01	-.23586E+00	.12758E-01	-.15343E-03	.50529E-06	U = .047276

ROOF TYPE 24 : E0 ,E5 ,E4 ,C5 ,E3 ,E2 ,B6 ,B1 ,C12,A0 ,
4" H.W. CONC.-2" INS.-2" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.25226E-06	.76174E-04	.47351E-03	.39283E-03	.56164E-04	.12674E-05	.35881E-08	Cn = .001000
dn	.10000E+01	-.17308E+01	.85681E+00	-.11614E+00	.23938E-02	-.13118E-04	.15366E-07	U = .081776

ROOF TYPE 25 : E0 ,E5 ,E4 ,C13,B13,E3 ,E2 ,A0 ,
6" H.W. CONC. W/ 4" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.13261E-07	.17914E-04	.20917E-03	.31059E-03	.90897E-04	.54540E-05	.57513E-07	Cn = .000634
dn	.10000E+01	-.16345E+01	.78078E+00	-.14422E+00	.94007E-02	-.11347E-03	.28667E-06	U = .055684

ROOF TYPE 26 : E0 ,E5 ,E4 ,B15,C15,E3 ,E2 ,A0 ,
6" INS. W/ 6" L.W. CONC. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.31746E-12	.15802E-06	.17231E-04	.14257E-03	.24072E-03	.11132E-03	.15346E-04	Cn = .000527
dn	.10000E+01	-.22946E+01	.19369E+01	-.75741E+00	.14252E+00	-.12514E-01	.45509E-03	U = .034319

ROOF TYPE 27 : E0 ,C13,B15,E3 ,E2 ,C12,A0 ,
6" H.W. CONC.-6" INS.-2" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.23896E-09	.25570E-05	.73656E-04	.23870E-03	.16043E-03	.25513E-04	.90624E-06	Cn = .000502
dn	.10000E+01	-.22781E+01	.18216E+01	-.60696E+00	.76958E-01	-.24582E-02	.14246E-04	U = .045414

ROOF TYPE 28 : E0 ,B9 ,B14,E3 ,E2 ,A0 ,
4" WOOD W/ 5" INS.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.16596E-12	.92888E-07	.10882E-04	.95971E-04	.17308E-03	.85875E-04	.12734E-04	Cn = .000379
dn	.10000E+01	-.24192E+01	.21793E+01	-.93062E+00	.19840E+00	-.20119E-01	.81087E-03	U = .043879

ROOF TYPE 29 : E0 ,E5 ,E4 ,C12,B13,E3 ,E2 ,C5 ,A0 ,
2" H.W. CONC.-4" INS.-4" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.11412E-07	.14999E-04	.17706E-03	.26259E-03	.73408E-04	.39108E-05	.33464E-07	Cn = .000532
dn	.10000E+01	-.19941E+01	.12022E+01	-.20898E+00	.10579E-01	-.98637E-04	.12921E-06	U = .055684

ROOF TYPE 30 : E0 ,E5 ,E4 ,B9 ,B6 ,E3 ,E2 ,A0 ,
4" WOOD W/ 2" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.49355E-11	.45361E-06	.27781E-04	.15535E-03	.18038E-03	.54893E-04	.45501E-05	Cn = .000423
dn	.10000E+01	-.22966E+01	.18639E+01	-.65737E+00	.10295E+00	-.63080E-02	.11710E-03	U = .064203

ROOF TYPE 31 : E0 ,B27,C13,E3 ,E2 ,C13,A0 ,
4.54" INS.-6" H.W. CONC.-6" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.11430E-10	.60165E-06	.29365E-04	.13913E-03	.13684E-03	.34191E-04	.21775E-05	Cn = .000342
dn	.10000E+01	-.22988E+01	.18573E+01	-.64691E+00	.10024E+00	-.59279E-02	.62355E-04	U = .057153

ROOF TYPE 32 : E0 ,E5 ,E4 ,C5 ,B20,E3 ,E2 ,C13,A0 ,
4" H.W. CONC.-0.76" INS.-6" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.14691E-07	.19105E-04	.23549E-03	.37109E-03	.11300E-03	.68740E-05	.73647E-07	Cn = .000746
dn	.10000E+01	-.20934E+01	.13512E+01	-.26478E+00	.12806E-01	-.17539E-03	.72972E-06	U = .133413

ROOF TYPE 33 : E0 ,E5 ,E4 ,C5 ,B13,E3 ,E2 ,C5 ,A0 ,
4" H.W. CONC.-4" INS.-4" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.36034E-09	.22915E-05	.50969E-04	.12986E-03	.67090E-04	.80146E-05	.21341E-06	Cn = .000258
dn	.10000E+01	-.20786E+01	.13396E+01	-.27670E+00	.20886E-01	-.57717E-03	.40113E-05	U = .055174

ROOF TYPE 34 : E0 ,E5 ,E4 ,C13,B23,E3 ,E2 ,C5 ,A0 ,
6" H.W. CONC.-2.42" INS.-4" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.36276E-09	.23013E-05	.51258E-04	.13052E-03	.66784E-04	.77614E-05	.19892E-06	Cn = .000259
dn	.10000E+01	-.21324E+01	.14345E+01	-.32023E+00	.21879E-01	-.38350E-03	.23222E-05	U = .076643

ROOF TYPE 35 : E0 ,C5 ,B15,E3 ,E2 ,C13,A0 ,
4" H.W. CONC.-6" INS.-6" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.50329E-11	.31496E-06	.17843E-04	.96509E-04	.10906E-03	.32000E-04	.25050E-05	Cn = .000258
dn	.10000E+01	-.25123E+01	.22582E+01	-.87306E+00	.14066E+00	-.78546E-02	.16442E-03	U = .045074

ROOF TYPE 36 : E0 ,C13,B27,E3 ,E2 ,C13,A0 ,
6" H.W. CONC.-4.54" INS.-6" H.W. CONC. RTS

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.36058E-11	.26869E-06	.16013E-04	.89962E-04	.10577E-03	.32462E-04	.26596E-05	Cn = .000247
dn	.10000E+01	-.25027E+01	.22394E+01	-.88012E+00	.15928E+00	-.11763E-01	.18428E-03	U = .057153

ROOF TYPE 37 : E0 ,E5 ,E4 ,B15,C13,E3 ,E2 ,C13,A0 ,
6" INS.-6" H.W. CONC.-6" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.98532E-15	.61292E-08	.13920E-05	.18937E-04	.50440E-04	.37439E-04	.87277E-05	Cn = .000117
dn	.10000E+01	-.27554E+01	.28819E+01	-.14462E+01	.36631E+00	-.46359E-01	.26915E-02	U = .039780

ROOF TYPE 38 : E0 ,E5 ,E4 ,B9 ,B15,E3 ,E2 ,A0 ,
4" WOOD W/ 6" INS. & SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	-.63421E-14	.90628E-09	.39525E-06	.79352E-05	.29442E-04	.30539E-04	.10339E-04	Cn = .000079
dn	.10000E+01	-.28143E+01	.30506E+01	-.16277E+01	.45499E+00	-.65693E-01	.45520E-02	U = .034607

ROOF TYPE 39 : E0 ,E5 ,E4 ,C13,B20,E3 ,E2 ,C13,A0 ,
6" H.W. CONC.-0.76" INS.-6" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.46150E-09	.29035E-05	.69122E-04	.19262E-03	.11040E-03	.14596E-04	.41991E-06	Cn = .000390
dn	.10000E+01	-.23071E+01	.17759E+01	-.52057E+00	.55968E-01	-.11804E-02	.82771E-05	U = .130506

ROOF TYPE 40 : E0 ,E5 ,E4 ,C5 ,B26,E3 ,E2 ,C13,A0 ,
4" H.W. CONC.-3.64" INS.-6" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.19457E-10	.48120E-06	.18111E-04	.70173E-04	.56071E-04	.11139E-04	.55783E-06	Cn = .000157
dn	.10000E+01	-.22698E+01	.16834E+01	-.45628E+00	.47116E-01	-.17958E-02	.23386E-04	U = .058522

ROOF TYPE 41 : E0 ,E5 ,E4 ,C13,B6 ,E3 ,E2 ,C13,A0 ,
6" H.W. CONC.-2" INS.-6" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	.22623E-10	.52261E-06	.19310E-04	.73942E-04	.57916E-04	.10988E-04	.50227E-06	Cn = .000163
dn	.10000E+01	-.23584E+01	.18663E+01	-.56900E+00	.64659E-01	-.15746E-02	.13278E-04	U = .084613

ROOF TYPE 42 : E0 ,E5 ,E4 ,C13,B14,E3 ,E2 ,C13,A0 ,
6" H.W. CONC.-5" INS.-6" H.W. CONC. RTS W/ SUSP. CEIL.

	n=0	n=1	n=2	n=3	n=4	n=5	n=6	
bn	-.20609E-14	.70092E-08	.10271E-05	.10448E-04	.21202E-04	.11720E-04	.19406E-05	Cn = .000046
dn	.10000E+01	-.26863E+01	.26309E+01	-.11685E+01	.24692E+00	-.22693E-01	.62453E-03	U = .045833

APPENDIX D

TIME LAGS AND AMPLITUDE RATIOS FOR WALLS IN APPENDIX C

TIME LAGS AND AMPLITUDE RATIOS FOR THE 41 WALL TYPES

WALL TYPE	TIME LAG (HOURS)	AMPLITUDE RATIO
1	1.297059	.0213425
2	3.208371	.0168219
3	3.333828	.0497227
4	4.757103	.0127118
5	5.113376	.0275841
6	5.277028	.0356658
7	5.137740	.0167249
8	6.212045	.0228326
9	7.020450	.0081724
10	7.052668	.0275132
11	7.109008	.0136341
12	7.246206	.0378108
13	7.168101	.0232445
14	7.900837	.0084973
15	8.644959	.0143649
16	8.910645	.0279845
17	9.362870	.0043517
18	9.226263	.0058248
19	8.969641	.0070534
20	9.271847	.0129515
21	10.203030	.0047419
22	10.360460	.0048573
23	11.165227	.0039346
24	11.294651	.0153348
25	11.443573	.0037991
26	10.991605	.0049443
27	11.818500	.0021335
28	11.395920	.0020670
29	12.059530	.0043740
30	12.653506	.0050486
31	12.969825	.0026462
32	13.053068	.0035833
33	12.957620	.0016949
34	12.854283	.0044867
35	13.688992	.0013828
36	12.822816	.0014936
37	14.702269	.0019120
38	14.393254	.0016366
39	14.641625	.0013177
40	14.382719	.0011638
41	14.870791	.0010760

TIME LAGS AND AMPLITUDE RATIOS FOR THE 42 ROOF TYPES

ROOF TYPE	TIME LAG (HOURS)	AMPLITUDE RATIO
1	1.628491	.0259039
2	2.427546	.0174351
3	3.386045	.0582559
4	4.848394	.0117090
5	4.821886	.0123946
6	4.570005	.0737886
7	4.998372	.0256418
8	5.452969	.0662212
9	6.319966	.0114098
10	7.142617	.0168556
11	7.388400	.0065447
12	7.081713	.0533545
13	6.731912	.0127384
14	7.058720	.0048714
15	7.161502	.0048207
16	7.542935	.0070162
17	8.225434	.0060944
18	9.210828	.0062001
19	8.417201	.0073185
20	8.927517	.0085651
21	8.929730	.0072724
22	8.990119	.0086159
23	9.260696	.0025939
24	8.842534	.0032684
25	8.770795	.0016374
26	10.435242	.0034549
27	10.475146	.0035591
28	11.182021	.0028337
29	10.573895	.0028807
30	11.218857	.0028629
31	11.266128	.0023516
32	11.312823	.0045363
33	11.471482	.0014851
34	11.625296	.0015699
35	12.286617	.0026749
36	12.667027	.0024031
37	13.020689	.0014581
38	13.334339	.0010054
39	12.232056	.0029551
40	12.677077	.0011344
41	12.845526	.0013011
42	14.172897	.0005310

APPENDIX E

WALL AND ROOF CODE LAYER DESCRIPTIONS

WALL CODE LAYER DESCRIPTIONS (SEE TABLE VII)

```
E0 ,E1 ,B16,C9 ,A2 ,A0
E0 ,E1 ,B21,C9 ,A2 ,A0
E0 ,E1 ,B24,C9 ,A2 ,A0
E0 ,A6 ,B16,C9 ,A0
E0 ,A6 ,B18,C9 ,A0
E0 ,A5 ,B5 ,C9 ,A0
E0 ,A6 ,B22,C9 ,A0
E0 ,A6 ,B24,C9 ,A0
E0 ,A6 ,B13,C9 ,A0
E0 ,A6 ,B15,C9 ,A0
E0 ,E1 ,B18,C9 ,A1 ,A0
E0 ,E1 ,B21,C9 ,A1 ,A0
E0 ,E1 ,B24,C9 ,A1 ,A0
E0 ,C9 ,B19,A2 ,A0
E0 ,C9 ,B22,A2 ,A0
E0 ,C9 ,B5 ,B27,A2 ,A0
E0 ,E1 ,C9 ,A0
E0 ,A2 ,C9 ,B17,A6 ,A0
E0 ,A2 ,C9 ,B20,A6 ,A0
E0 ,A2 ,C9 ,B22,A6 ,A0
E0 ,A2 ,C9 ,B25,A6 ,A0
E0 ,A2 ,C9 ,B27,A6 ,A0
E0 ,A2 ,C9 ,B15,A6 ,A0
E0 ,C9 ,B17,A6 ,A0
E0 ,C9 ,B20,A6 ,A0
E0 ,C9 ,B21,A6 ,A0
E0 ,C9 ,B6 ,A6 ,A0
E0 ,C9 ,B24,A6 ,A0
E0 ,C9 ,B14,A6 ,A0
E0 ,C9 ,B16,A1 ,A0
E0 ,C9 ,B20,A1 ,A0
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E0 ,A2 ,A2 ,B6 ,A6 ,A0
E0 ,A2 ,A2 ,B12,A6 ,A0
E0 ,A2 ,A2 ,B27,A6 ,A0
E0 ,A2 ,A2 ,B15,A6 ,A0
E0 ,A2 ,B17,A6 ,A0
E0 ,A2 ,B19,A6 ,A0
E0 ,A2 ,B5 ,A6 ,A0
E0 ,A2 ,B22,A6 ,A0
E0 ,A2 ,B23,A6 ,A0
E0 ,A2 ,B26,A6 ,A0
E0 ,A2 ,B14,A6 ,A0
E0 ,A2 ,B16,A1 ,A0
E0 ,A2 ,B18,A1 ,A0
E0 ,A2 ,B20,A1 ,A0
E0 ,A2 ,B21,A1 ,A0
E0 ,A2 ,B6 ,A1 ,A0
E0 ,A2 ,B12,A1 ,A0
E0 ,A2 ,B27,A1 ,A0
E0 ,A2 ,B15,A1 ,A0
E0 ,E1 ,B17,B7 ,A2 ,A0
E0 ,E1 ,B20,B7 ,A2 ,A0
E0 ,E1 ,B21,B7 ,A2 ,A0
E0 ,E1 ,B6 ,B7 ,A2 ,A0
E0 ,E1 ,B25,B7 ,A2 ,A0
E0 ,E1 ,B14,B7 ,A2 ,A0
E0 ,A6 ,B7 ,A2 ,A0
E0 ,A6 ,B16,B7 ,A0
E0 ,A6 ,B18,B7 ,A0
E0 ,A6 ,B20,B7 ,A0
E0 ,A6 ,B21,B7 ,A0
E0 ,A6 ,B23,B7 ,A0
E0 ,A6 ,B26,B7 ,A0
E0 ,A6 ,B14,B7 ,A0
E0 ,E1 ,B7 ,A0
E0 ,E1 ,B17,B7 ,A0
E0 ,E1 ,B19,B7 ,A0
E0 ,E1 ,B5 ,B7 ,A0
E0 ,E1 ,B22,B7 ,A0
E0 ,E1 ,B24,B7 ,A0
E0 ,E1 ,B13,B7 ,A0
E0 ,E1 ,B6 ,A2 ,A0
E0 ,E1 ,B12,A2 ,A0
E0 ,E1 ,B27,A2 ,A0
E0 ,E1 ,B15,A2 ,A0
E0 ,A2 ,B16,A2 ,A0
E0 ,A2 ,B19,A2 ,A0
E0 ,A2 ,B21,A2 ,A0
E0 ,A2 ,B23,A2 ,A0
E0 ,A6 ,A2 ,A6 ,A0
E0 ,A2 ,A2 ,B16,A6 ,A0
E0 ,A2 ,A2 ,B18,A6 ,A0
E0 ,A2 ,A2 ,B5 ,A6 ,A0
E0 ,A2 ,A2 ,B22,A6 ,A0
E0 ,A2 ,A2 ,B23,A6 ,A0
E0 ,A2 ,A2 ,B26,A6 ,A0
E0 ,A2 ,A2 ,B14,A6 ,A0
E0 ,A2 ,B16,A6 ,A0
E0 ,A2 ,B18,A6 ,A0
E0 ,A2 ,B20,A6 ,A0
E0 ,A2 ,B21,A6 ,A0
E0 ,A2 ,B6 ,A6 ,A0
E0 ,A2 ,B12,A6 ,A0
E0 ,A2 ,B27,A6 ,A0
E0 ,A2 ,B15,A6 ,A0
E0 ,A2 ,B17,A1 ,A0
E0 ,A2 ,B19,A1 ,A0
E0 ,A2 ,B5 ,A1 ,A0
E0 ,A2 ,B22,A1 ,A0
E0 ,A2 ,B23,A1 ,A0
E0 ,A2 ,B26,A1 ,A0
E0 ,A2 ,B14,A1 ,A0
E0 ,E1 ,B16,B7 ,A2 ,A0
E0 ,E1 ,B18,B7 ,A2 ,A0
E0 ,E1 ,B5 ,B7 ,A2 ,A0
E0 ,E1 ,B22,B7 ,A2 ,A0
E0 ,E1 ,B24,B7 ,A2 ,A0
E0 ,E1 ,B13,B7 ,A2 ,A0
E0 ,E1 ,B15,B7 ,A2 ,A0
E0 ,A6 ,B7 ,A0
E0 ,A6 ,B17,B7 ,A0
E0 ,A6 ,B19,B7 ,A0
E0 ,A6 ,B5 ,B7 ,A0
E0 ,A6 ,B22,B7 ,A0
E0 ,A6 ,B24,B7 ,A0
E0 ,A6 ,B13,B7 ,A0
E0 ,A6 ,B15,B7 ,A0
E0 ,E1 ,B16,B7 ,A0
E0 ,E1 ,B18,B7 ,A0
E0 ,E1 ,B20,B7 ,A0
E0 ,E1 ,B21,B7 ,A0
E0 ,E1 ,B23,B7 ,A0
E0 ,E1 ,B26,B7 ,A0
E0 ,E1 ,B14,B7 ,A0
```

```
E0 ,E1 ,B15,B7 ,A0
E0 ,A2 ,B17,B7 ,A0
E0 ,A2 ,B20,B7 ,A0
E0 ,A2 ,B21,B7 ,A0
E0 ,A2 ,B23,B7 ,A0
E0 ,A2 ,B25,B7 ,A0
E0 ,A2 ,B14,B7 ,A0
E0 ,E1 ,B17,B9 ,A2 ,A0
E0 ,E1 ,B5 ,B9 ,A2 ,A0
E0 ,E1 ,B23,B9 ,A2 ,A0
E0 ,E1 ,B26,B9 ,A2 ,A0
E0 ,E1 ,B15,B9 ,A2 ,A0
E0 ,A6 ,B9 ,A2 ,A1 ,A0
E0 ,A6 ,B17,B9 ,A0
E0 ,A6 ,B21,B9 ,A0
E0 ,A6 ,B23,B9 ,A0
E0 ,A6 ,B13,B9 ,A0
E0 ,A6 ,B15,B9 ,A0
E0 ,E1 ,B17,B9 ,A0
E0 ,E1 ,B21,B9 ,A0
E0 ,E1 ,B23,B9 ,A0
E0 ,E1 ,B13,B9 ,A0
E0 ,E1 ,B15,B9 ,A0
E0 ,A2 ,B9 ,B19,A6 ,A0
E0 ,A2 ,B9 ,B22,A6 ,A0
E0 ,A2 ,B9 ,B12,A6 ,A0
E0 ,A2 ,B16,B7 ,A0
E0 ,A2 ,B18,B7 ,A0
E0 ,A2 ,B5 ,B7 ,A0
E0 ,A2 ,B22,B7 ,A0
E0 ,A2 ,B24,B7 ,A0
E0 ,A2 ,B13,B7 ,A0
E0 ,A2 ,B15,B7 ,A0
E0 ,E1 ,B19,B9 ,A2 ,A0
E0 ,E1 ,B22,B9 ,A2 ,A0
E0 ,E1 ,B12,B9 ,A2 ,A0
E0 ,E1 ,B27,B9 ,A2 ,A0
E0 ,E1 ,B9 ,A2 ,A0
E0 ,A6 ,B9 ,A0
E0 ,A6 ,B20,B9 ,A0
E0 ,A6 ,B22,B9 ,A0
E0 ,A6 ,B12,B9 ,A0
E0 ,A6 ,B27,B9 ,A0
E0 ,E1 ,B9 ,A0
E0 ,E1 ,B20,B9 ,A0
E0 ,E1 ,B22,B9 ,A0
E0 ,E1 ,B12,B9 ,A0
E0 ,E1 ,B27,B9 ,A0
E0 ,A2 ,B9 ,B17,A6 ,A0
E0 ,A2 ,B9 ,B5 ,A6 ,A0
E0 ,A2 ,B9 ,B23,A6 ,A0
E0 ,A2 ,B9 ,B26,A6 ,A0
```

ROOF CODE LAYER DESCRIPTIONS (SEE TABLE VII)

```
E0 ,E2 ,E3 ,B8 ,A0
E0 ,E2 ,E3 ,B23,B8 ,A0
E0 ,E2 ,E3 ,B14,B8 ,A0
E0 ,E2 ,E3 ,B22,B8 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B27,B8 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B17,A3 ,A0
E0 ,E2 ,E3 ,B25,A3 ,A0
E0 ,E2 ,E3 ,B15,A3 ,A0
E0 ,E2 ,E3 ,B5 ,A3 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B13,A3 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B16,B7 ,A0
E0 ,E2 ,E3 ,B12,B7 ,A0
E0 ,E2 ,E3 ,B15,B7 ,A0
E0 ,E2 ,E3 ,B26,B7 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B14,B7 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B18,B9 ,A0
E0 ,E2 ,E3 ,B25,B9 ,A0
E0 ,E2 ,E3 ,B15,B9 ,A0
E0 ,E2 ,E3 ,B5 ,B9 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B13,B9 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C12,B17,A0
E0 ,E2 ,E3 ,C12,B25,A0
E0 ,E2 ,E3 ,C12,B15,A0
E0 ,E2 ,E3 ,B17,C12,A0
E0 ,E2 ,E3 ,B25,C12,A0
E0 ,E2 ,E3 ,B15,C12,A0
E0 ,E2 ,E3 ,C12,B5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C12,B13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B5 ,C12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B13,C12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C5 ,B17,A0
E0 ,E2 ,E3 ,C5 ,B25,A0
E0 ,E2 ,E3 ,C5 ,B15,A0
E0 ,E2 ,E3 ,B17,C5 ,A0
E0 ,E2 ,E3 ,B25,C5 ,A0
E0 ,E2 ,E3 ,B15,C5 ,A0
E0 ,E2 ,E3 ,C5 ,B5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C5 ,B13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B5 ,C5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B13,C5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C13,B16,A0
E0 ,E2 ,E3 ,C13,B25,A0
E0 ,E2 ,E3 ,C13,B15,A0
E0 ,E2 ,E3 ,B16,C13,A0
E0 ,E2 ,E3 ,B25,C13,A0
E0 ,E2 ,E3 ,B15,C13,A0
E0 ,E2 ,E3 ,C13,B23,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B5 ,B8 ,A0
E0 ,E2 ,E3 ,B13,B8 ,A0
E0 ,E2 ,E3 ,B16,B8 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B12,B8 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B15,B8 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B6 ,A3 ,A0
E0 ,E2 ,E3 ,B14,A3 ,A0
E0 ,E2 ,E3 ,A3 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B23,A3 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B15,A3 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B21,B7 ,A0
E0 ,E2 ,E3 ,B27,B7 ,A0
E0 ,E2 ,E3 ,B19,B7 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B6 ,B7 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B15,B7 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B6 ,B9 ,A0
E0 ,E2 ,E3 ,B14,B9 ,A0
E0 ,E2 ,E3 ,B9 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B24,B9 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B15,B9 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C12,B22,A0
E0 ,E2 ,E3 ,C12,B14,A0
E0 ,E2 ,E3 ,C12,A0
E0 ,E2 ,E3 ,B22,C12,A0
E0 ,E2 ,E3 ,B14,C12,A0
E0 ,E2 ,E3 ,C12,B16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C12,B23,E4 ,E5 ,A0
E0 ,EE2,E3 ,C12,B14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B16,C12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B23,C12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B14,C12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C5 ,B22,A0
E0 ,E2 ,E3 ,C5 ,B14,A0
E0 ,E2 ,E3 ,C5 ,A0
E0 ,E2 ,E3 ,B22,C5 ,A0
E0 ,E2 ,E3 ,B14,C5 ,A0
E0 ,E2 ,E3 ,C5 ,B16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C5 ,B23,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C5 ,B14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B16,C5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B23,C5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B14,C5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C13,B22,A0
E0 ,E2 ,E3 ,C13,B27,A0
E0 ,E2 ,E3 ,C13,A0
E0 ,E2 ,E3 ,B22,C13,A0
E0 ,E2 ,E3 ,B27,C13,A0
E0 ,E2 ,E3 ,C13,B20,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C13,B13,E4 ,E5 ,A0
```

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E0 ,E2 ,E3 ,C13,B14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B20,C13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B13,C13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C14,B20,A0
E0 ,E2 ,E3 ,C14,B13,A0
E0 ,E2 ,E3 ,C14,A0
E0 ,E2 ,E3 ,B23,C14,A0
E0 ,E2 ,E3 ,B14,C14,A0
E0 ,E2 ,E3 ,C14,B22,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C14,B27,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B22,C14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B27,C14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C15,B17,A0
E0 ,E2 ,E3 ,C15,B25,A0
E0 ,E2 ,E3 ,C15,B15,A0
E0 ,E2 ,E3 ,B17,C15,A0
E0 ,E2 ,E3 ,B25,C15,A0
E0 ,E2 ,E3 ,B15,C15,A0
E0 ,E2 ,E3 ,C15,B5 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C15,B13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B5 ,C15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B13,C15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C16,B16,A0
E0 ,E2 ,E3 ,C16,B24,A0
E0 ,E2 ,E3 ,C16,B15,A0
E0 ,E2 ,E3 ,B16,C16,A0
E0 ,E2 ,E3 ,B24,C16,A0
E0 ,E2 ,E3 ,B15,C16,A0
E0 ,E2 ,E3 ,C16,B6 ,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C16,B14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B18,C16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B26,C16,E4 ,E5 ,A0
E0 ,C12,B17,E2 ,E3 ,C12,A0
E0 ,C12,B25,E2 ,E3 ,C12,A0
E0 ,C12,B15,E2 ,E3 ,C12,A0
E0 ,C12,E2 ,E3 ,C12,B22,A0
E0 ,C12,E2 ,E3 ,C12,B27,A0
E0 ,C12,E2 ,E3 ,C12,E3 ,E4 ,A0
E0 ,C12,B23,E2 ,E3 ,C12,E4 ,E5 ,A0
E0 ,C12,B14,E2 ,E3 ,C12,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C12,B5 ,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C12,B13,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,B16,C5 ,A0
E0 ,C12,E2 ,E3 ,B25,C5 ,A0
E0 ,C12,E2 ,E3 ,B15,C5 ,A0
E0 ,C12,E2 ,E3 ,C5 ,B22,A0
E0 ,C12,E2 ,E3 ,C5 ,B27,A0
E0 ,C12,E2 ,E3 ,C5 ,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,B23,C5 ,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,B14,C5 ,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C5 ,B23,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B23,C13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B14,C13,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C14,B23,A0
E0 ,E2 ,E3 ,C14,B14,A0
E0 ,E2 ,E3 ,B20,C14,A0
E0 ,E2 ,E3 ,B13,C14,A0
E0 ,E2 ,E3 ,C14,B16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C14,B12,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C14,B15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B16,C14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B12,C14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B15,C14,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C15,B6 ,A0
E0 ,E2 ,E3 ,C15,B14,A0
E0 ,E2 ,E3 ,C15,A0
E0 ,E2 ,E3 ,B6 ,C15,A0
E0 ,E2 ,E3 ,B14,C15,A0
E0 ,E2 ,E3 ,C15,B16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C15,B23,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C15,B15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B16,C15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B23,C15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B15,C15,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C16,B21,A0
E0 ,E2 ,E3 ,C16,B27,A0
E0 ,E2 ,E3 ,C16,A0
E0 ,E2 ,E3 ,B21,C16,A0
E0 ,E2 ,E3 ,B27,C16,A0
E0 ,E2 ,E3 ,C16,B18,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C16,B26,E4 ,E5 ,A0
E0 ,E2 ,E3 ,C16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B6 ,C16,E4 ,E5 ,A0
E0 ,E2 ,E3 ,B14,C16,E4 ,E5 ,A0
E0 ,C12,B22,E2 ,E3 ,C12,A0
E0 ,C12,B27,E2 ,E3 ,C12,A0
E0 ,C12,E2 ,E3 ,C12,B17,A0
E0 ,C12,E2 ,E3 ,C12,B25,A0
E0 ,C12,E2 ,E3 ,C12,B15,A0
E0 ,C12,B5 ,E2 ,E3 ,C12,E4 ,E5 ,A0
E0 ,C12,B13,E2 ,E3 ,C12,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C12,B16,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C12,B23,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C12,B14,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,B22,C5 ,A0
E0 ,C12,E2 ,E3 ,B27,C5 ,A0
E0 ,C12,E2 ,E3 ,C5 ,B16,A0
E0 ,C12,E2 ,E3 ,C5 ,B25,A0
E0 ,C12,E2 ,E3 ,C5 ,B15,A0
E0 ,C12,E2 ,E3 ,B19,C5 ,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,B13,C5 ,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C5 ,B19,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C5 ,B13,E4 ,E5 ,A0
```

```
E0 ,C12,E2 ,E3 ,C5 ,B14,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,B22,C13,A0
E0 ,C12,E2 ,E3 ,B27,C13,A0
E0 ,C12,E2 ,E3 ,C13,B16,A0
E0 ,C12,E2 ,E3 ,C13,B12,A0
E0 ,C12,E2 ,E3 ,C13,B15,A0
E0 ,C12,E2 ,E3 ,B20,C13,E4 ,E5 A0
E0 ,C12,E2 ,E3 ,B13,C13,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C13,B20,E4 ,E5 ,A0
E0 ,C12,E2 ,E3 ,C13,B13,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B16,C12,A0
E0 ,C5 ,E2 ,E3 ,B25,C12,A0
E0 ,C5 ,E2 ,E3 ,B15,C12,A0
E0 ,C5 ,E2 ,E3 ,C12,B22,A0
E0 ,C5 ,E2 ,E3 ,C12,B27,A0
E0 ,C5 ,E2 ,E3 ,C12,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B23,C12,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B14,C12,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,C12,B23,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,C12,B14,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B22,C5 ,A0
E0 ,C5 ,E2 ,E3 ,B12,C5 ,A0
E0 ,C5 ,E2 ,E3 ,C5 ,B16,A0
E0 ,C5 ,E2 ,E3 ,C5 ,B12,A0
E0 ,C5 ,E2 ,E3 ,C5 ,B15,A0
E0 ,C5 ,E2 ,E3 ,B20,C5 ,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B13,C5 ,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,C5 ,B20,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,C5 ,B13,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B16,C13,A0
E0 ,C5 ,E2 ,E3 ,B12,C13,A0
E0 ,C5 ,E2 ,E3 ,B15,C13,A0
E0 ,C5 ,E2 ,E3 ,C13,B22,A0
E0 ,C5 ,E2 ,E3 ,C13,B27,A0
E0 ,C5 ,E2 ,E3 ,C13,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,B23,C13,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,BB1,C13,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,C13,B23,E4 ,E5 ,A0
E0 ,C5 ,E2 ,E3 ,C13,B14,E4 ,E5 ,A0
E0 ,C13,E2 ,E3 ,B22,C12,A0
E0 ,C13,E2 ,E3 ,B27,C12,A0
E0 ,C13,E2 ,E3 ,C12,B16,A0
E0 ,C13,E2 ,E3 ,C12,B12,A0
E0 ,C13,E2 ,E3 ,C12,B15,A0
E0 ,C13,E2 ,E3 ,B20,C12,E4 ,E5 ,A0
E0 ,C13,E2 ,E3 ,B13,C12,E4 ,E5 ,A0
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E0 ,C5 ,E2 ,E3 ,C12,B25,A0
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E0 ,B7 ,B14,E3 ,E2 ,A0
E0 ,B7 ,B15,E3 ,E2 ,A0
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VITA

Steven M. Harris

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Doctor of Philosophy

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