IMPLEMENTATION OF THE REVISED TRANSFER

FUNCTION METHOD AND EVALUATION

OF THE CLTD/SCL/CLF METHOD

By

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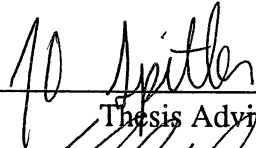
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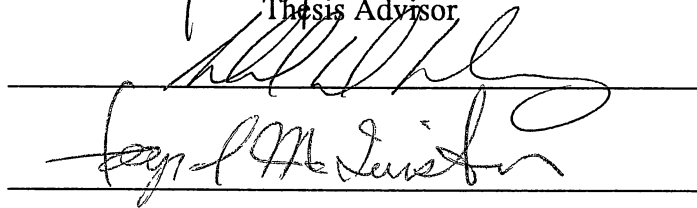the Degree of
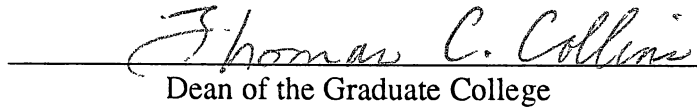MASTER OF SCIENCE
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PREFACE

A professional software program, currently called HVAC, was developed in order to calculate the cooling loads for a building based on the revised Transfer Function Method. This program, written in the C-programming language, executes under Microsoft WINDOWS™ as a user-interactive, menu driven program. In addition to cooling load calculations, the program also performs calculations of the heat extraction rates for desired zones, and the heating load for the building based upon steady state heat transfer.

The results of the CLTD/SCL/CLF Method for three test zones and other test cases of externally shaded glass areas were compared with those of the revised Transfer Function Method. Differences in the implementation and calculation methodology of the methods were pointed out and the results discussed.

I would first like to express my heart-felt gratitude to my parents, Lawrence and Florine Castelino for their undying faith in me and their relentless efforts towards ensuring a bright career for me. I attribute a major portion of my achievements to their continued support and moral encouragement. Special thanks are also due to my sisters Theresa and Claudette and my brother Placid whose prayers, friendship, and good wishes have followed me and constantly reminded me of my goals in life. I love you all.

I wish to express sincere appreciation to my major advisor Dr. Jeffrey D. Spitler for his continued guidance, patience, and inspiration during this demanding endeavor. I am grateful to my other committee member Dr. Ronald D. Delahoussaye for his help during the programming phase of the project, guiding me from obscurity to clarity, and his keen insight in offering useful suggestions and tips. I also extend my gratitude to Dr.

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CHAPTER I

INTRODUCTION

Overview

Air-conditioning has been one of the more recent pursuits of man in his quest for a more comfortable existence. The primary purpose of an air-conditioning system, whether heating or cooling, is to maintain conditions that provide thermal comfort for the building occupants and conditions that are required by the products and processes within the space. Central heating systems were being developed in the Nineteenth Century while the development of comfort cooling systems began in the early Twentieth Century. Since then, progress in this direction has taken rapid strides with significant development in various areas of science and technology.

Earlier load calculation methods paid little attention to the costs of operation of air-conditioning systems often resulting in substantially oversized systems. However, rising energy costs, complex building structures and construction materials, and concerns for the environment and natural resources have necessitated continued refinement of load calculation methods. Present day load calculation methods are directed more towards accurately sized systems which result in economical system performance.

Load calculations of the earlier days were based on the elementary steady state energy equation

$$q = U \, A \, \Delta T \qquad\qquad (1.1)$$

where

q =   cooling load   (Btu/hr)

1

U   =   the heat transfer coefficient   (Btu/hr-ft^2-°F)

A   =   Area   (ft^2)

ΔT =   the difference between the outside

         and inside temperatures   (°F)

By the mid-1940s ASHRAE developed equivalent temperature differentials for exterior surfaces facing different directions for the worst exposure to sunlight (with values 20 to 40 degrees above the actual temperature difference between the outside and inside) and used them to calculate heat gains (Romine, 1992). However, these heat gains were only instantaneous and considered the thermal storage only of these exterior surfaces in delaying the heat passage through them. Subsequent storage of these and other heat gains by the building's interior and its contents were not accounted for. Designers were aware of this fact but were unable to represent it quantitatively. This resulted in over-estimated cooling loads.

In 1967, ASHRAE introduced the Total Equivalent Temperature Difference/Time Averaging (TETD/TA) Method (ASHRAE Handbook of Fundamentals, 1967). This method, in addition to estimating the cooling loads due to convective heat gain from all sources, attempted to evaluate the cooling loads due to radiative heat gains (heat gains absorbed by the building's interior and later convected to the inside air) by a mathematical time-averaging of these radiant heat gains. This procedure, however, was only an approximation of the actual phenomenon of thermal lag. Besides, it required good judgement on the part of the user to estimate the thermal characteristics of the building and decide upon a suitable time-averaging period. In addition, the method required several table look-ups, and the cooling load calculations were tedious and prone to errors considering the kind of calculating tools available to practitioners at that time.

Efforts to explain the phenomenon of thermal lag more accurately and incorporate it into load calculation methodology continued. In 1967, Mitalas and Stephenson developed the thermal response factor method for cooling load calculations.

By this time, digital computers were available and traditional air-conditioning design methods were re-examined in order to take advantage of the capabilities afforded by computers.

The Transfer Function Method, based on an extension of the response factor methodology, successfully interpreted the phenomenon of thermal lag and delayed cooling loads and first appeared in the ASHRAE Handbook (1972). The mid 70's saw the development of the CLTD/CLF method for load calculation. This method, similar in some respects to the TETD/TA method, but with more extensive data calculated using the TFM, was developed as a manual method since computers were not generally available for practicing HVAC engineers.

Advances in the computer industry since the early 80's have led to further changes in load calculation methods. Since computers were now readily available to HVAC designers and engineers, the Transfer Function Method became practical for use by HVAC engineers and this encouraged further development of the method.

As the awareness for more economical air-conditioning systems has taken prime importance, more attention is now focused on the thermal responses of the building components with a view to obtain the most accurate air-conditioning load. The Transfer Function Method is now regarded as the most accurate, yet practical cooling load calculation method*. This Thesis, "Implementation of the Revised Transfer Function Method and Evaluation of the CLTD/SCL/CLF Method", describes the implementation of the revised Transfer Function Method including recent developments (Sowell - 1985 & 1988, McQuiston, et al. 1988). Results of a new manual method, the CLTD/SCL/CLF Method, are compared to those of the revised TF Method.

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* It is generally conceded that the most accurate method for calculation of building loads is the heat-balance method (BLAST User Reference - University of Illinois at Urbana Champaign, 1991). In fact, the heat-balance method was used to determine the room weighting factor coefficients that are used by the TFM. However, it has not been widely used for design load calculations, due to its presumed complexity.

Literature Review

This section surveys previous work carried out on the TFM and CLTD/SCL/CLF Methods. The work carried out is listed in chronological order.

Stephenson and Mitalas (1967)

The Thermal Response Factor Method

Stephenson and Mitalas studied the effects of time-series and response factor techniques in the calculation of transient heat conduction through building components. A time-series is a series of numbers or quantities that represent the values of a particular function at successive intervals of time. Response factors are a set of coefficients that result from a time-series representation of a *linear, invariable system* (Mitalas and Stephenson, 1967) to a unit time-series excitation function.

They developed response factors for walls (room-surface temperature response factors) by modeling the wall response (heat flux) to triangular unit temperature excitation pulses on the outer and inner surfaces of the walls.

Room heat balance equations were derived for the surfaces enclosing a room and the room air. These heat balance equations described the dynamic thermal characteristics of the room. These equations were used to calculate the room thermal response factors. The surface temperature and room thermal response factors were employed to calculate the surface temperatures and subsequently the room temperatures and heat extraction rates, based on the corresponding room excitation components (heat gains). The necessity of a computer to perform calculations was obvious, due to the size of each set of response factors, and the number of sets of response factors.

Stephenson, and Mitalas (1971)

Heat Conduction Transfer Function Calculations

Stephenson and Mitalas further developed their response factor approach by determining and applying the z-transform to problems in transient heat conduction. They obtained the z-transfer functions for various surfaces (roofs and walls) made up of several layers of different materials and subject to arbitrary variations of temperature. The transfer functions replaced the theoretically infinite set of response factors into a finite set of history coefficients which accounted for the past and current values of the variable(s) of interest.

They explained two methods by which z-transfer functions could be calculated. The first consisted of selecting appropriate input functions with known Laplace transforms and z-transforms with an appropriate choice for the sampling interval. The second method involved solving a set of simultaneous linear algebraic equations to obtain the coefficients of a z-transfer function whose frequency response matched that of the s-transfer function at selected frequencies. The resulting z-transfer functions obtained were similar to the thermal response factors, but were more effective and economical in terms of computer memory and run-time speed.

Mitalas (1969, 1972)

Validation of the Weighting Factor Method

The work carried out by Mitalas, Stephenson, and the ASHRAE Task Group on Energy requirements (the thermal response factor and transfer function methods) culminated in the development of the computer-oriented method which is now called the "TRANSFER FUNCTION METHOD" and was incorporated in the 1972 ASHRAE Handbook of Fundamentals. This method was so named because it utilizes the transfer function concept to relate the cooling load to the heat gain, and the heat extraction rate to

the cooling load and the room temperatures. This method is described in detail in chapter II.

An experimental validation check for the method, in particular the room weighting factors that are employed to convert the heat gains into cooling loads was carried out (Mitalas, 1969) and the loads predicted with weighting factors were found to be fairly accurate when compared with the experimental values.

The major advantage of this new load calculation method is that in addition to calculating the cooling loads it can determine the rate at which heat is extracted from the space and also the space temperature when the capacity of the air-conditioning equipment to be used is known. This unique feature helps the designer to check the variations in the inside temperature for various load conditions and thereby select appropriate air-conditioning machinery that will give optimum results working within the comfort zone.

Rudoy and Duran (1975) - The CLTD/CLF
Method and the ASHRAE GRP 158
Load Calculation Manual

The CLTD/CLF method for calculating cooling loads that is described in the Cooling and Heating Load Calculation Manual (ASHRAE GRP 158) is based on research carried out by Rudoy and Duran (1975).

ASHRAE sponsored research in order to compare the TETD/TA and Transfer Function Methods (Rudoy and Duran-1975, ASHRAE H.O.F-1989). As part of their work, Rudoy and Duran developed CLTD and CLF data based on the results of the TFM Method applied to a group of representative applications. Their study involved close scrutiny of each source (variable) that affected the cooling load. The effect of each of these variables was then studied for its sensitivity on the final result. This resulted in the development of CLTDs to be used for the one step calculations of cooling loads from

conduction heat gain through sunlit roofs and walls and conduction through exposed fenestration.

Cooling Load Factors (CLFs) were generated for similar one-step calculation of the solar load through glass areas and the loads from internal sources. Both the CLTDs and CLFs included the effect of the time delay caused by the effect of thermal storage.

This method was basically designed to be a manual method although it was implemented on microcomputers shortly after they became available.

Machler and Iqbal (1985) - Modification of
the ASHRAE Clear Sky Irradiation Model

Machler and Iqbal (1985) highlighted the need to revise the ASHRAE Clear Sky Model and develop new clear sky coefficients. They pointed out the following facts that necessitated the revision of solar constants A, B, and C:

1) The accepted solar constant has been revised by the World Meteorological Organization (1981) from 1322 W/m^2 to 1367 W/m^2.

2) The results of the ASHRAE algorithm do not match the more accurate simulations carried out by Bird and Hulstrom (1981), especially for the winter months.

With the help of the Bird and Hulstrom model, new revised constants A, B, and C were developed, by introducing turbidity in the revised ASHRAE Model. These new values for the constants are used here for the calculation of the solar loads by the revised Transfer Function Method.

Sowell and Chiles (1985) , Sowell (1988 a, b, & c)

Classification of Zones based on Dynamic

Response and Development of Weighting Factors

The CLTD/CLF data presented in ASHRAE GRP158 (1979) and the Handbooks of 1977, 1981, and 1985 were based on the TFM using the weighting factors developed by Mitalas (1967). However, these weighting factors were based on a limited exploration of the now known to be important criteria of zone geometry and construction. Furthermore, it was found that for some zone geometries and constructions, the weighting factors gave inaccurate results and the results of the CLTD/CLF calculations were questionable in other situations.

Another source of erroneous results was the use of the CLFs that were calculated for July 21, 40° N for all northern latitudes during summer months (May through September). It was assumed that the $SHGF_{max}$ (calculated for all directions, months, and northern latitudes from 0°N to 60°N) successfully accounted for the variation in the solar heat gain for other latitudes and dates. Such normalization of the solar heat gain resulted in erroneous values of CLFs for latitude/month combinations other than July 21, 40°N, particularly for locations whose sunrise and sunset times differed significantly from those at July 21, 40°N (Spitler, et al. 1993).

ASHRAE sponsored a research project (RP-359) in order to update the CLTD/CLF tables using more appropriate weighting factors accounting for a wider range of zones. Work on this project resulted in three technical papers by Sowell and Chiles (1985, 1985a, 1985b). Their research confirmed the sensitivity of zone dynamic response to design parameters that had hitherto not been addressed. It also showed that the variables affecting this response had strong interactive effects, and in some situations, unexpected results were obtained.

The main deficiency in their work was that the range of design parameters selected for the parametric variation was limited. The parameters used included floor covering, inside shading, ceilings, exterior wall construction, glass percent, and zone size. Parameters not used and later found to be important included the wall height, zone location, number of exterior walls, partition construction, and furniture. Besides, the DOE-2.1 program that was used for the work was questioned as being "only an energy calculation program" and that its potential to carry out accurate peak cooling load calculations was not established[*].

Project RP-472 was authorized by the ASHRAE Technical Committee 4.1 in order to complete this "unfinished" work. The principal objectives of this project were to validate the results of the calculation of the zone dynamic response to several heat gain components and to classify all zones based on their dynamic thermal response characteristics accounting for a well defined range of design parameters namely: floor plan, zone height, number of exterior walls, glass percent, partition type, interior shading, zone location, slab type, mid-floor construction, wall construction, roof construction, floor covering, ceiling type and interior furnishings.

The findings of Sowell (1988) resulted in three papers that describe the calculation of the cooling load dynamic response of 200,640 zones representing all 14 design parameters. The DOE-2.1c program was modified in order to meet special assumptions for peak load calculations, and the characterization of the zones was based on their dynamic thermal response.

Zones that exhibited similar amplitude and delay were grouped together to form "zone type groups" with a recommended set of weighting factors for each group. Basically 12 classes of zones were formed, representing single, perimeter, and interior zones located on the top, bottom, or mid-floors of multi-story buildings or in single story

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[*] It was shown later (Sowell, 1988b) to have sufficient accuracy.

buildings and the grouping process was carried out for solar, conduction, lighting, and occupant/equipment heat gain components. Tables were generated so that the weighting factors representative of any zone among the 200,640 possible types could be found with ease.

McQuiston and Harris (1988)
Categorization of Roofs and Walls
based on Thermal Response

The CLTD/CLF Method is generally employed as a manual method for the calculation of cooling loads. Wall and roof CLTDs are obtained by selecting a similar wall or roof type from the list (ASHRAE 1977, 1981, 1985, and 1989). If an exact match is not found, complicated adjustments to the CLTDs are required before multiplication to the product of the U-factor and the area. The wall and roof groups delineated in the ASHRAE Handbooks do not cover the entire range of modern construction, and the results obtained by the complicated adjustment to the CLTDs may not yield correct cooling loads. Hence, McQuiston and Harris performed a study to devise a method to group roofs and walls with similar transient heat transfer characteristics.

After investigating existing analytical and correlational methods for their efficiency in predicting transient characteristics of multi-layered walls and roofs and grouping of similar types, they developed a heuristic method wherein a wall or roof assembly was placed into a particular group with transient heat transfer characteristics within a limited range, based on a combination of four thermophysical and geometric parameters. This resulted in an accurate representation of all common wall assemblies in 41 distinct wall groups and all common roof assemblies in 42 roof groups. Each group, besides having a number designation and the code letters defining the exact construction of each surface, has a unique set of conduction heat transfer functions so as to produce

conservative results. These conduction transfer coefficients are used in the Transfer Function Method in order to calculate the conduction heat gain for any representative wall or roof assembly that matches with the particular group.

McQuiston, Spitler, et al. (1992)
Development of the Revised Cooling
and Heating Load Calculation Manual

The results of ASHRAE Research Projects 359 and 472 have necessitated the development of a new load calculation manual incorporating the new data available on zone response and wall/roof groups.

The scope of ASHRAE Research Project 626 was to write a new load calculation manual incorporating the research results discussed above. As part of this project, the CLTD/CLF method was substantially revised and software was developed in order to access the weighting factor data developed by RP-472.

The new cooling and heating load calculation manual (McQuiston and Spitler, 1992) has been recently released by ASHRAE. Papers by Spitler, et al.(1993a, 1993b), and Falconer, et al. (1993), which are currently under publication describe the load calculation manual, the revised "CLTD/SCL/CLF" method, as it is now called, and the software developed to access the weighting factor database. Thesis work by Lindsey (1991) involved the development of the revised CLTD/SCL/CLF method both as a manual and computer-oriented method.

Objectives

This project is part of research funded by the Oklahoma Center for the Advancement of Science And Technology (OCAST) which includes the development of a comprehensive and professional integrated load calculation and duct design program

with marketable graphical user interface (Microsoft WINDOWS^{TM}). The goals of this project are:

1) To develop the software for the technical calculations involved in the load calculation program (cooling load with heat extraction) based on the revised Transfer Function Method and the heating load.

2) To compare the results of the manual and computer-oriented versions of the CLTD/SCL/CLF Method with the Transfer Function Method for different zone configurations and design conditions.

CHAPTER II

THE REVISED TRANSFER FUNCTION METHOD

This chapter describes the methodology of the revised Transfer Function Method for cooling load calculation and heat extraction rate calculations. References are made to the new Load Calculation manual (1992), hereafter known as the LCM, for various tables and other detailed descriptions. As background, brief explanations of the heat transfer rates that affect air-conditioning design are given.

Heat Transfer Flow Rates

Building design load calculations are carried out to ascertain the peak load so as to enable the selection of an appropriately sized HVAC system complete with the associated ducting and water/refrigerant piping.

There are four related heat transfer rates, each of which varies with time:

1) Space heat gain

2) Space cooling or heating load

3) Space heat extraction rate, and

4) Cooling coil load

Space heat gain

The space heat gain (instantaneous rate of heat gain) is defined as the rate at which heat enters into or is generated within a space at a given instant of time. Heat gains usually occur in the following forms:

1) Solar radiation through fenestration.

2) Heat conduction through exterior surfaces like roofs and walls.

3) Heat conduction through interior surfaces like interior partitions, ceilings, and floors with a temperature differential across them.

4) Heat generated within the space by occupants, lighting, and different types of equipment and.

5) Energy transfer due to the ventilation and infiltration of outside air into the space.

Heat gain may be sensible and/or latent. Sensible heat gain is directly added to the space by conduction, convection, and radiation. Latent heat gain is associated with the addition of moisture to the conditioned space, including people, infiltration, and other moisture generating processes.

Space Cooling Load

The space cooling load is defined as the rate at which heat must be removed from the space in order to maintain a constant room air temperature. The total space cooling load for a particular hour of the day is seldom the sum of the total instantaneous heat gains for that hour because of the thermal storage effect.

Radiant heat gain is first absorbed by the surfaces enclosing the space - walls, floor, and ceiling or roof and the surfaces within the space such as furniture. As soon as the temperature of these objects exceeds that of the space air, some of their heat is transferred to the surrounding air in the room by way of convection.

Space Heat Extraction Rate

The space heat extraction rate is defined as the rate at which heat is removed from the conditioned space. When the room air temperature is maintained at a constant value throughout the day, the space heat extraction rate equals the space cooling load.

However, the zone temperature does not remain constant throughout the day due to two factors:

1) Intentional variation of the space temperature such as night setback.

2) Proportional control of equipment used to maintain the space temperature resulting in an offset that varies with varying cooling load.

A more realistic estimation of the energy removal of the cooling equipment can be carried out by using a properly modeled control system. This involves including the characteristics of the cooling equipment and its operating schedule for the time period.

Cooling Coil Load

The cooling coil load is defined as the rate at which energy is removed at a cooling coil that serves one or more conditioned spaces. It is obtained by the adding the total sum of the instantaneous cooling loads (considering constant room temperature) or the space heat extraction rates (for varying room temperatures) and the external loads, if any. External loads include the heat gain to the return air and the load imposed by outdoor ventilation air.

The revised Transfer Function Method

The Transfer Function Method, so called because it employs the transfer function concept to relate the cooling loads to heat gains, is considered to be the most accurate, yet practical cooling load calculation method. It is based on two important concepts - Conduction Transfer Functions (CTFs) and Room Transfer Functions (RTFs), commonly referred to as weighting factors. Both conduction transfer functions and room transfer functions are time series that relate a current variable to past values of itself and other variables, at discrete time intervals, usually one hour periods for building load analysis.

Figure 2.1 shows how heat gains and cooling loads are obtained by the revised Transfer Function Method for the different heat gain producing sources in a building.

Transfer Functions

A transfer function is a set of coefficients that relate an output function at some specific time to the value of one or more driving (input excitation) functions at that time and to previous values of both the input and output functions (G.P.Mitalas, 1972). Transfer Functions are commonly derived from response factors (Mitalas and Stephenson, 1967), which are infinite series that relate a current variable to past values of other variables, at discrete time intervals. A transfer function converts the theoretically infinite set of response factors into a finite number of significant terms for calculation purposes (McQuiston and Spitler, 1992). These terms multiply both the past values of the variable under consideration and the past and current values of other variables.

Room Transfer Functions

Room Transfer Functions are also referred to as Weighting Factors. While converting the hourly heat gains to space cooling loads, these weighting factors are applied to the previous and current values of heat gain, and previous values of the cooling load due to that type of heat gain.

The equation for the cooling load in terms of the weighting factors is given as

$$Q_\theta = v_0 q_\theta + v_1 q_{\theta-\delta} + v_2 q_{\theta-2\delta} - w_1 Q_{\theta-\delta} - w_2 Q_{\theta-2\delta} \qquad (2.1)$$

where

δ	=	time interval, 1 hour	(hrs)
θ	=	current hour	
q_θ	=	Heat gain for hour θ	(Btu/hr)
Q_θ	=	Cooling Load for hour θ	(Btu/hr)
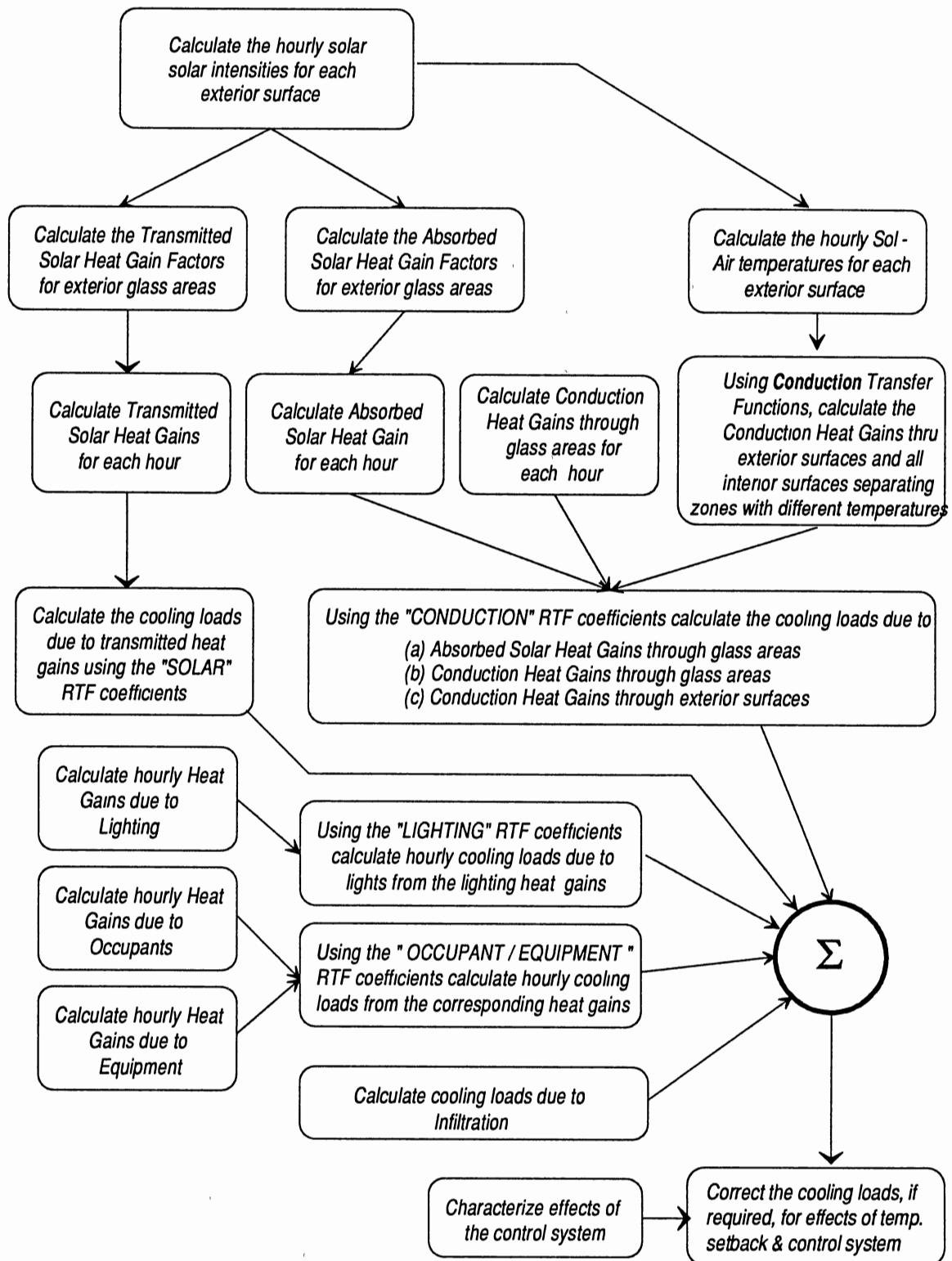
Figure 2.1: The revised Transfer Function Method for calculating heat gains and cooling loads.

The terms v_0, v_1, v_2, w_1, and w_2 are the coefficients of the room transfer function (based on the z-transform) which is given by the relation:

$$K(z) = (v_0 + v_1 z^{-1} + v_2 z^{-2}) / (1 + w_1 z^{-1} + w_2 z^{-2}) \qquad (2.2)$$

There are three criteria governing the selection of the weighting factors:

1) the time interval δ

2) the type of the heat gain in the room and the location of its generation and

3) the thermal characteristics of the room

It was found that the weighting factors developed by Mitalas in 1967, and subsequently used by Rudoy and Duran during the development of the CLTD/CLF method do not apply to all buildings. The basic problem with these weighting factors as pointed out by Sowell (1985,1988) is that these weighting factors do not reflect the effects of a number of design parameters now known to be important. Further research in this direction by Chiles and Sowell in 1985 (ASHRAE RP-339) and Sowell in 1988 (ASHRAE RP-472) resulted in the development of the "v" and "w" weighting factors for 200,640 zone types. These different zone types were based on fourteen parameters, different for each zone. Table I lists the 14 zone parameters required in order to select the appropriate weighting factors and the choices available for their selection. A custom database and software to access the database were also developed.

Software developed as part of this project contains modified routines (Song, 1992) which access the database in order to choose the appropriate sets of weighting factors that closely match the actual zone depending upon the entered parameters.

Sowell, in his paper (1988a) describes the 14 parameters used to classify different zones and subsequently develop the weighting factor database. Their importance and strong interactive effects on the thermal response of zones are also discussed. A brief subjective discussion of these factors is made in the new Load Calculation Manual (McQuiston and Spitler, 1992). In general, different combinations of these parameters result in the increase or decrease of the thermal response of zones.

TABLE I

ZONE PARAMETERS

No.	Parameter	Meaning	Choices
1	ZG	Zone Geometry	100 ft x 20 ft., 15 ft x 15 ft., 100 ft x 100 ft.
2	ZH	Zone Height	8 ft., 10 ft., 20 ft.
3	NW	# of Ext. Walls	1, 2, 3, 4, 0
4	ZL	Zone Location	Single-Story, Top Floor, Bottom Floor, Mid Floor
5	IS	Interior Shade	100, 50, 0 percent
6	FN	Furniture	With, Without
7	EC	Ext. Wall Constrn.	1, 2, 3, 4 (*Table 2-3, LCM*)
8	PT	Partition Type	5/8 in. Gyp-Air-5/8 in. Gyp, 8 in. Concrete Block
9	MF	Mid Flr. Type	8 in. Conc., 2.5 in. Conc., 1 in. Wood
10	ST	Slab Type	Mid Flr. Type, 4 in. Slab on 12 in. Soil
11	CT	Ceiling Type	3/4 in. Acoustic Tile & Air Space, Without Ceiling
12	RT	Roof Type	1, 2, 3, 4 (*Table 2-4, LCM*)
13	FC	Floor Covering	Carpet with Rubber Pad, Vinyl Tile
14	GL	Glass Percent	10, 50, 90

Calculation of heat gains

Before any calculations for the cooling loads and the heat extraction rates can be carried out, it is necessary to determine the heat gains through the various components that comprise the space under consideration.

The following sections describe the methodology of calculating the heat gains due to

(a) solar radiation through fenestration

(b) transient heat conduction through exterior surfaces

(c) heat conduction through interior surfaces

(d) internal heat generating sources, and

(e) infiltration and ventilation of air.

Solar Radiation

Generally, cooling load calculations are carried out on an hourly basis. In order to have a suitable representation of the solar radiation for a whole hour, calculations of the solar radiation intensity are carried out at half past the hour. For example, for the 2:00 p.m. - 3:00 p.m. hour, the solar radiation intensity is calculated for 2:30 p.m., which is an adequate representation for the hour.

Time

The earth is divided into 360 degrees of a circular arc by the lines of longitude running across its circumference and passing through the poles. Every 15 degrees of longitude correspond to 1/24th of a day or 1 hour of time. The *Universal Time* or Greenwich Civil Time (GCT) is the time along the zero longitude line that passes through Greenwich, England. Local Civil Time (LCT) for a particular place depends upon its longitude. Usually, a time zone covers roughly 15 degrees of longitude, even though the zone may be irregular in shape. *Standard Time* is defined as the Local Civil Time for a selected meridian near the center of the zone. In the continental United States, the four standard time zones with their standard meridians are:

Eastern Standard Time	:	75 degrees
Central Standard Time	:	90 degrees
Mountain Standard Time	:	105 degrees
Pacific Standard Time	:	120 degrees

In most of the United States, clocks are set one hour ahead during the Spring leading to the time known as *Daylights Savings Time.*

The *Local Solar Time* (LST) is calculated from the Local Civil Time by using a quantity known as the *equation of time.* This is done as follows:

$$LST = LCT + \text{equation of time} \tag{2.3}$$

The equation of time for the 21st day of each month is tabulated in Table II. The above equation can be written in terms of the Standard Time as follows:

$$LST = \text{Standard Time} + 4 \text{ min./deg.} * (L_{st} - L_{loc}) + \text{eqn. of time} \tag{2.4}$$

where

L_{st} = The standard meridian for the local time zone (degrees) and

L_{loc} = The longitude of the location under consideration (degrees)

Solar Angles

The three fundamental quantities that are necessary to determine the solar radiation incident on a specific location on the earth's surface are:

1) The location of the point on the earth's surface

2) The time of the day and

3) The day of the year

The above quantities can be used to determine the latitude, the hour angle, and the sun's declination. Refer to figure 2.2. Consider a point P on the earth's surface which represents a location in the northern hemisphere. The latitude l is the angular distance of this point north(or south) of the equator. It is measured as the angle between the radius line OP and the projection of this line on the equatorial plane (OP'), where O is the center of the earth. The hour angle h is the angle between OP' the line joining the sun's and the earth's centers on that plane. It is calculated as follows:

$$h = 0.25 \text{ deg./min.} * (\text{minutes of time from local solar noon}) \tag{2.5}$$

Fifteen degrees of the hour angle correspond to one hour of time. The hour angle is maximum at sunrise or sunset and zero during local solar noon.
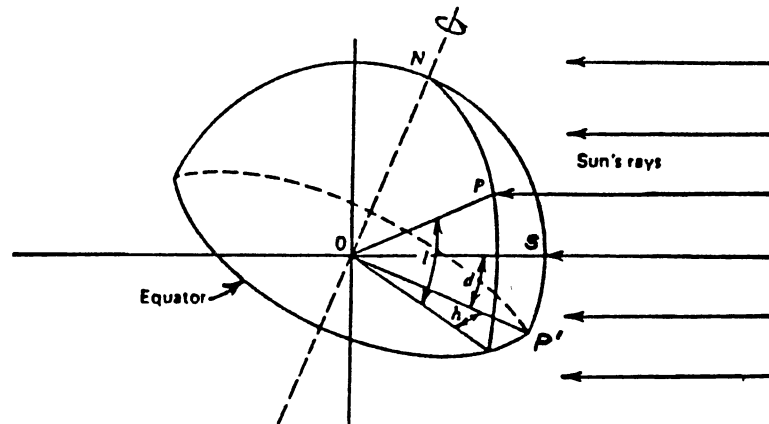
Figure 2.2: Latitude (*l*), hour angle (*h*), and declination (δ)
(Reproduced from McQuiston and Parker-1988)

Solar noon can be described as the time when the sun is at its highest point in the sky. The hour angles at sunrise and sunset on a given day are thus symmetric with respect to the solar noon. The sign convention followed for the software is that hour angles are considered negative for hours before solar noon and positive for the hours after solar noon.

The sun's declination (δ) is the angular distance of the sun's rays north (or south) of the equator. It is represented as the angle between the line connecting the center of the earth and the sun (OS) and the projection of that line on the equatorial plane (OP'). Table II shows the declination of the sun for the 21st day of each month of the year. Although

declination differs slightly from year to year, for calculation purposes it is taken to be the same.

The solar altitude angle (β), is the angular distance of the sun above the horizon (see Fig 2.3). It is calculated by the following equation:

$$\sin \beta = \cos l \cos h \cos\delta + \sin l \sin\delta \tag{2.6}$$

The solar azimuth angle (ϕ) is the angle measured in the horizontal plane between the south and the projection of the sun's rays on that plane. It is calculated as follows:

$$\cos \phi = (\sin\beta \sin l - \sin\delta) / (\cos\beta \cos l) \tag{2.7}$$

ϕ's are negative for negative hour angles (before solar noon), and positive for positive hour angles (after solar noon).

The surface solar azimuth (γ), calculated for non-horizontal surfaces is the angle between the projection of the sun's rays on a horizontal plane and the projection of the normal to the surface in the horizontal plane. If ψ is the surface azimuth angle then we have the following relation:

$$\gamma = |\phi - \psi| \tag{2.8}$$

where

ψ is taken to be negative for surfaces facing east of south and positive for surfaces facing west of south.

The angle of incidence (θ) is the angle between the sun's rays and the normal to the surface. The angle of tilt (α) is the angle between the normal to surface and the horizontal. The angle of incidence can be calculated as:

$$\cos \theta = \cos \beta \cos \gamma \sin \alpha + \sin \beta \cos \alpha \tag{2.9}$$

Thus, for a vertical surface

$$\cos \theta = \cos \beta \cos \gamma \tag{2.10}$$

and for a horizontal surface

$$\cos \theta = \sin \beta \tag{2.11}$$
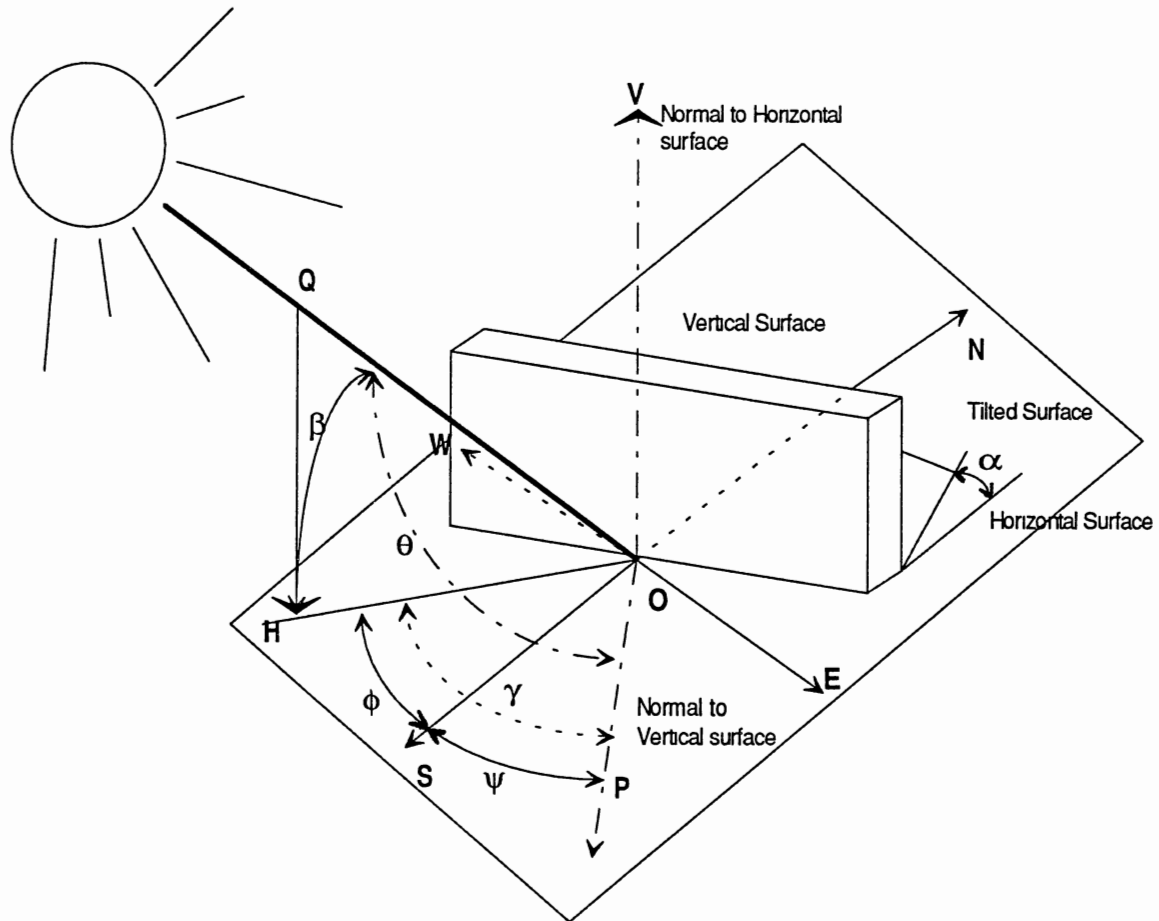
Figure 2.3: The solar altitude angle (β), solar azimuth angle (φ), surface azimuth (ψ), solar azimuth angle (γ), the angle of incidence (θ), and the tilt angle(α) for an arbitrarily tilted surface.

(Adapted from ASHRAE Handbook of Fundamentals, 1989)

Solar Irradiation

The mean solar constant is the rate at which irradiation from the sun occurs on a surface normal to its rays beyond the earth's atmosphere and at the mean earth-sun

distance. From recent studies, the value of the mean solar constant is found to be 433.4 Btu/hr-ft^2 or 1367 W/m^2.

The sun's radiation which enters the earth's atmosphere that contributes to the cooling load is made up of the direct, diffuse, and reflected radiation components. Diffuse radiation is that portion of the radiation scattered by the atmospheric constituents. The remainder reaches the earth's surface as direct radiation. Besides, radiation may also be reflected to a surface from other surfaces in its vicinity. The total irradiation on a surface normal to the sun's rays is thus the sum of the normal direct irradiation, diffuse irradiation, and the reflected irradiation.

Solar intensity and the ASHRAE Clear Sky Model

The value of the mean solar constant mentioned earlier is for a surface outside the earth's atmosphere and does not account for the absorption and scattering of the earth's atmosphere, which can be significant even for clear days.

The direct normal intensity of the solar radiation at the earth's surface for a clear day is given by the ASHRAE Clear Sky Model (ASHRAE, 1977):

$$I_{DN} = A \exp^{(-B / \sin \beta)} \tag{2.12}$$

where

A and B are the modified solar coefficients (Machler and Iqbal, 1985) given in table II.

The direct (beam) radiation I_D, on the surface is determined as

$$I_D = I_{DN} \cos \theta \tag{2.13}$$

where $\cos\theta > 0$

The beam radiation is zero if the incident angle is less than zero.

TABLE II

SOLAR DETAILS FOR THE 21st DAY OF EACH MONTH

Month	Eqn of Time (min)	Declination (degrees)	A Btu /hr-ft².	B (Dimensionless)	C
January	-11.2	-20.00	381.2	0.141	0.103
February	-13.9	-10.80	376.4	0.142	0.104
March	-7.5	0.00	369.1	0.149	0.109
April	1.1	11.60	358.3	0.164	0.120
May	3.3	20.00	350.7	0.177	0.130
June	-1.4	23.45	346.3	0.185	0.137
July	-6.2	20.60	346.6	0.186	0.138
August	-2.4	12.30	351.0	0.182	0.134
September	7.5	0.00	360.2	0.165	0.121
October	15.4	-10.50	369.7	0.152	0.111
November	13.8	-19.80	377.3	0.142	0.106
December	1.6	-23.45	381.8	0.141	0.103

NOTE: A, B, and C are modified coefficients (Machler and Iqbal,1985)

For vertical surfaces, the ratio between the diffuse radiation striking the surface and the diffuse radiation incident on a horizontal surface, Y, is calculated as

$$Y = 0.55 + 0.437 \cos\theta + 0.313 \cos^2\theta \qquad (2.14)$$

where $\cos\theta > -0.2$

else,

$$Y = 0.45 \qquad (2.15)$$

Equation 2.14 is based upon research carried out by Threlkeld (1963) on solar radiation of surfaces for clear days, and is essentially a curve fit equation for the plot of Y against $\cos\theta$.

The total diffuse intensity of radiation (I_d) is the sum of the diffuse radiation from the sky incident on the surface (I_{ds}) and the diffuse radiation incident on the surface reflected from the ground (I_{dg}). Thus,

$$I_d = I_{ds} + I_{dg} \qquad (2.16)$$

For vertical surfaces we have

$$I_{ds} = C \, Y \, I_{DN} \qquad (2.17)$$

where C = The modified solar model coefficient (table II)

and

$$I_{dg} = 0.5 * I_{DN} \, (\, C + \sin \beta \,) \, \rho_g \qquad (2.18)$$

where

ρ_g = The reflectance of the ground (generally $\rho_g = 0.2$)

For non-vertical surfaces

$$I_{ds} = C \, I_{DN} \, (\, 1 + \cos \alpha \,) \, / \, 2 \text{ and} \qquad (2.19)$$

$$I_{dg} = I_{DN} \, (\, C + \sin \beta \,) \, \rho_g \, (\, 1 - \cos \alpha \,) \, / \, 2 \qquad (2.20)$$

The total intensity of solar radiation is then given by

$$I_t = I_D + I_d \qquad (2.21)$$

External Shading

Since the heat transmitted through exposed fenestration contributes much to the cooling load, the most effective way of reducing the solar load is to minimize the extent of direct radiation by some means before it reaches the glass area. Effective shading techniques can result in reductions of the solar radiation up to a maximum of about 80%. Fenestration can be shaded by roof overhangs, vertical and horizontal architectural projections, awnings, and other shading devices.

Several methods have been developed in order to calculate the solar heat gain through glass areas with external shading by determining the shaded and unshaded areas

of the glass (ASHRAE 1975, Walton 1979, McCluney 1990). Walton and McCluney developed shading calculation routines for complex geometries. However, the calculation of the solar loads through shaded fenestration for this project is based on the "X-Y shading" concept delineated by Threlkeld (1971) and McQuiston and Parker (1988). From figure 2.4 we see that the dimensions x and y can be found as

$$x = b \tan \gamma \quad \text{and}$$
$$y = b \tan \delta \tag{2.22}$$

where

$$\tan \delta = \tan \beta / \cos \gamma \tag{2.23}$$

and

β =   the sun's altitude angle

γ =   the surface solar azimuth angle and

ϕ =   the solar azimuth angle

ψ =   the surface azimuth angle measured east or west from the south

The above equations are used on the assumption that the overhang is wide enough so that the shadow extends completely across the window. The sign convention used for the shading calculations is as follows:

If hour angle h is negative , then the solar azimuth angle ϕ is taken to be negative.

If hour angle h is positive , then the solar azimuth angle ϕ is taken to be positive. This successfully takes care of the angle γ for surfaces facing east or west of south both in the morning and afternoon hours.

If γ is greater than 90 degrees, the surface is entirely in the shade. By calculating the x and y lengths for the fenestration, the shaded and unshaded areas are determined. While the unshaded portion of the window receives both direct and diffuse radiation, the shaded portion is assumed to receive only diffuse radiation.
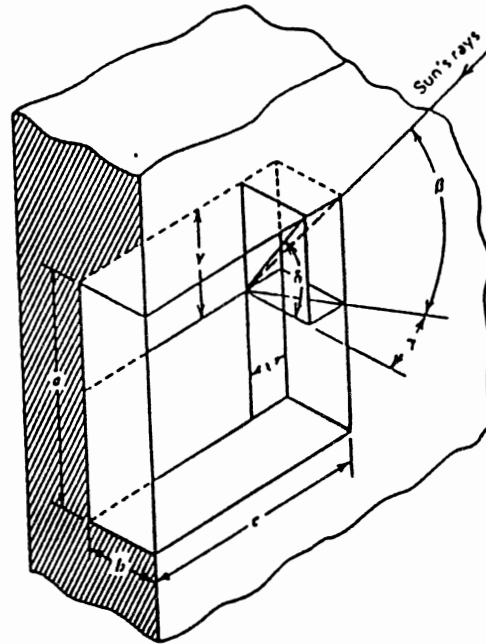
Figure 2.4: X-Y Shading for a Window with reveal
(Reproduced from McQuiston & Parker-1988)

The routines developed for shading calculation purposes for this project also accommodate overhangs with projections on the exterior as well as window reveal. Refer to figure 2.5. The figure depicts a glass window with external shading by means of an awning of length 'a'. It is assumed that the awning extends over the entire width of the window. The distance from the top of the window to the awning is 'b'. The awning has a protrusion of length 'c'. Further, the window is within a reveal of length 'd'. Depending upon the type of construction different cases of external shading exist. Based upon the different values entered for a, b, c, and d the x and y lengths of the glass area for each hour are calculated and the shaded and unshaded areas determined. Table III shows the calculations involved for the different cases of shading.
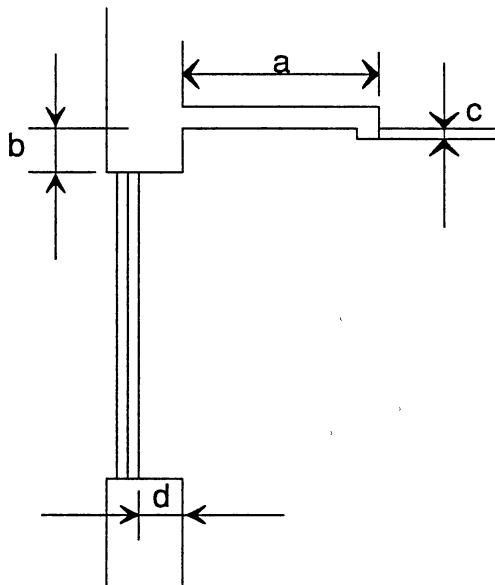
Figure 2.5:Externally shaded glass area
with reveal

TABLE III

X AND Y SHADING CALCULATIONS FOR EXTERNALLY SHADED GLASS AREAS

CASE	X	Y
1 (b = 0, c = 0)	$= (d) * \tan(\gamma)$	$= [(a+d) * \tan(\beta)] / \cos(\gamma)$
2 (b > 0, c = 0)	$= (d) * \tan(\gamma)$	$= [((a+d) * \tan(\beta)) / \cos(\gamma)] - b$
3 (b = 0, c > 0)	$= (d) * \tan(\gamma)$	$= [((a+d) * \tan(\beta)) / \cos(\gamma)] + c$
4 (b > 0, c > 0)		
(i) b < c	$= (d) * \tan(\gamma)$	$= [((a+d) * \tan(\beta)) / \cos(\gamma)] + (c-b)$
(ii) b > c	$= (d) * \tan(\gamma)$	$= [((a+d) * \tan(\beta)) / \cos(\gamma)] - (b-c)$
(iii) b = c	SAME AS CASE 1	

NOTE: a = Overhang length,   b = Window top to Overhang,
        c = Overhang protrusion, d = Reveal depth

Determination of heat gains

through Windows

The heat gain through fenestration is dependent upon a number of factors of which the following are important:

1) The solar radiation intensity and the angle of incidence

2) The difference between the outdoor and indoor temperatures

3) The velocity and direction of air flow across the exterior and interior surfaces

4) The low temperature radiation exchange between the glass surfaces and the surroundings.

5) The exterior or interior shading

Typically about 8% of the radiant energy from the solar radiation incident on an unshaded window is reflected back outdoors. 5 to 50% of it is absorbed by the glass depending upon its thickness and composition and the rest is transmitted directly inside to contribute to the cooling load. The sum of the inward flowing absorbed heat gain and the transmitted portions of the radiant energy represents the solar heat gain. In addition, there is conduction through the glass due to the temperature difference across the window. Thus the total heat gain across the window is as given below:

Total heat gain = Transmitted radiation + Inward flowing absorbed radiation +

Conduction heat gain

i.e.

Total heat gain = Solar heat gain + Conduction heat gain

The calculation of solar heat gain is dependent upon the solar irradiation which is discussed earlier in this chapter. The heat gains are expressed in terms of the solar heat gain factors and shading coefficients. The solar heat gain factor is the hourly solar heat gain through 1 ft^2 of double strength sheet glass (DSA), the reference glass used by ASHRAE, for a given orientation and time. The earlier version of the Transfer Function

Method had SGHFs which combined both the transmitted and absorbed solar heat gains. However, refinements to the method have caused the two to be treated separately for calculation purposes (Sowell, 1988). The transmitted solar heat gain that occurs through one square foot of DSA glass is defined as the Transmitted Solar Heat Gain Factor (TSHGF) and that absorbed by one square foot of the glass is called the Absorbed Solar Heat Gain Factor (ASHGF).

Given that the direct and diffuse radiation intensities have been calculated earlier, the procedure for calculating the Solar Heat Gain Factors is as follows:

The Transmitted Solar Heat Gain Factor (TSHGF) is calculated as

$$TSHGF = I_D \sum_{j=0}^{5} t_j \, [\cos \theta]^j + I_d * 2 \sum_{j=0}^{5} t_j / (j+2) \qquad (2.24)$$

where

t_j =   Transmission Coefficients for the glass (Table IV)

τ_D =   Transmittance of the DSA glass to direct (beam) radiation incident

         upon the glass surface at an angle θ

τ_d =   Transmittance of the DSA glass to diffuse radiation incident upon the

         glass surface

The Absorbed Solar Heat Gain Factor (ASHGF) is given by:

$$ASHGF = I_D \sum_{j=0}^{5} a_j \, [\cos \theta]^j + I_d * 2 \sum_{j=0}^{5} a_j / (j+2) \qquad (2.25)$$

where

a_j =   Absorption Coefficients for the glass (Table IV)

α_D =   Absorptance of the DSA glass to direct (beam) radiation incident upon

         the glass surface at an angle θ.

α_d =   Absorptance of the DSA glass to diffuse radiation

After the TSHGFs and ASHGFs have been calculated, the transmitted and absorbed solar heat gains can be determined. The transmitted solar heat gain (TSHG) is given by

$$TSHG = TSHGF * SC * Area \qquad (2.26)$$

where

SC $\quad$ = $\quad$ Shading coefficient

The shading coefficient, as determined by the ASHRAE procedure for estimating solar heat gains is the ratio between the solar heat gain through any given type of fenestration system and the DSA glass. Thus the use of this shading coefficient here is an approximation as the shading coefficients due to the individual transmitted and absorbed components are not available.

The absorbed solar heat gain (ASHG) is given by:

$$ASHG = ASHGF * SC * N_i * Area \qquad (2.27)$$

where

N_i $\quad$ = $\quad$ The inward flowing fraction of the absorbed solar heat gain

The inward flowing fraction depends upon the inside and outside heat transfer coefficients, h_i and h_o respectively and is approximated as:

$$N_i = h_i / (h_i + h_o) \qquad (2.28)$$

The shading coefficients are calculated based upon natural convection conditions at the inner surface of the fenestration, and the wind speed at the outer surface. The values of h_o for wind speeds of 7.5mph and 5 mph are 4.0 Btu/hr-ft^2-°F 3.0 Btu/hr-ft^2-°F respectively. For natural convection conditions on the inside, h_i = 1.46 Btu/hr-ft^2-°F which gives a values of 0.267 (with wind speed = 7.5 mph) and 0.3274 (with wind speed = 5 mph) for N_i. Depending upon the prevalent indoor and outdoor conditions, the appropriate value of the flowing fraction can be determined for calculation purposes.

TABLE IV

COEFFICIENTS OF TRANSMISSION AND
ABSORPTION FOR DSA GLASS

j	a_j	t_j
0	0.01154	-0.00885
1	0.77674	2.71235
2	-3.94657	-0.62062
3	8.57881	-7.07329
4	-8.38135	9.75995
5	3.01188	-3.89922

Transient Heat Conduction through

Walls and Roofs

The Transfer Function Method uses conduction transfer functions to express the heat gain through walls and roofs as a function of the previous values of the heat gain and the previous values of the inside and outside temperatures. Since the TFM uses fixed convection and radiation coefficients both on the inside and outside surfaces, the conduction transfer functions are based upon the sol-air temperatures on the outside and the room temperature, which is assumed to remain constant on the inside. The sol-air temperature is defined as that temperature of the outdoor air, which, in the absence of all radiation exchanges, gives the same rate of heat flux into the surface as would exist with the actual combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air. From an energy balance on an exposed surface, the instantaneous rate of heat transfer, q_o, from the environment to the outside sunlit surface is given by:

$$q_o = h_o \, (t_o - t_{wo}) + \alpha \, I - \varepsilon \delta R \tag{2.29}$$

where

h_o =   coefficient of heat transfer at the outside surface (Btu/hr-ft^2-°F)

t_o =   temperature of the outdoor air   (°F)

t_{wo} =   temperature of the outside surface   (°F)

α =   absorptivity of the outside surface to solar radiation

I =   the combined incident solar radiation (direct, diffuse, and reflected) on

              the outside surface   (Btu/hr-ft^2)

ε =   the hemispherical emittance of the surface

δR =   the difference between the long wave radiation incident on the surface

              from the sky and surroundings, and the radiation emitted by a black

              body at outdoor air temperature   (Btu/hr-ft^2)

In terms of the sol-air temperature t_e , the rate of heat transfer can be expressed as:

$$q_o = h_o \, (t_e - t_{wo}) \tag{2.30}$$

Thus,

$$t_e = t_o + \alpha \, I/h_o - \varepsilon \delta R/h_o \tag{2.31}$$

For horizontal surfaces that receive long wave radiation only from the sky, δR is about 20 Btu/hr-ft^2 and if $\varepsilon = 1$ and $h_o = 3.0$ Btu/hr-ft^2-°F, the long wave correction term is about -7.5 °F . Vertical surfaces receive long wave radiation from the ground and the surrounding buildings as well as from the sky. Hence it is difficult to estimate an accurate value for δR. During times of high solar radiation intensities, exterior surfaces are at higher temperatures than the outside air and so the long wave radiation from these surfaces compensates to some extent for the low emittance of the sky. Hence, for vertical surfaces δR is taken to be zero.

For the HVAC software, in the case of inclined surfaces, a cosine fit is applied to calculate δR depending upon the tilt of the surface from the horizontal. Thus

$$\delta R(\text{inclined}) = 20.0 * \cos(\alpha) \tag{2.32}$$

where

α   =   the tilt angle from the horizontal

The equation for calculating the heat gain through exterior walls and roofs, considering the previous room temperatures to be constant is:

$$q_{e,\theta} = A \left[\sum_{n=0} b_n \, (t_{e,\theta - n\delta}) - \sum_{n=1} d_n \, \{(q_{e,\theta - n\delta}) / A\} - t_{rc} \sum_{n=0} c_n \right] \qquad (2.33)$$

where

$q_{e,\theta}$	=	the heat gain through the surface	(Btu / hr.)
A	=	the indoor surface area	(ft^2)
q	=	time	(hours)
δ	=	the time interval	(hours)
n	=	the summation index (each summation has as many terms as there are non-zero values of the coefficients)	
$t_{e,\theta-n\delta}$	=	the sol - air temperature at time θ - nδ	(°F)
t_{rc}	=	the constant indoor room temperature	(°F)
$b_n \, c_n \, d_n$	=	the Conduction Transfer Function Coefficients	

Since the heat flux history terms on the right hand side are not known before hand, the above equation needs to be solved iteratively for the 24 hour time period until convergence is reached. Initially, all 24 heat flux terms are assumed to be zero.

Software has been developed in order to access the appropriate conduction transfer function (CTF) coefficients from the database for the representative roof and wall assemblies. This software is based on the routines originally written by Sowell (1988). The conduction transfer function coefficients for walls and roofs are determined using the CTF routines written. These CTF coefficients are selected from 41 wall and 42 roof types grouped by McQuiston and Harris (1988) based on their thermal response

characteristics. The b_n and c_n coefficients obtained from the database are required to be "unnormalized" in case the actual calculated value of the U-factor is different from that of the representative roof/wall. This is done by multiplying by the ratio of the U-factor for the actual wall or roof assembly to the U-factor of the matching representative wall or roof.

Following are the parameters that are specified to the *wget* routine that accesses the CTF coefficients for a wall:

1) R-value Range: There are 17 different range values for the resistance depending upon the construction of the wall. Table 2.5 in the LCM shows a list of construction materials normally used for walls/roofs from which the resistances of the wall materials are chosen. In case a wall material from this table is not found then an approximate substitute from the table must be chosen. After the total R-value has been obtained, the R-value range can be determined from table 2-6(a) of the LCM.

2) Primary Wall Material: This parameter represents the material with the most thermal mass in the wall assembly and is chosen from the list in table 2-6(b) of the LCM.

3) Mass Location: There are three categories for the location of the thermal mass in the wall with respect to the insulation viz. inside, outside, or integral. Table 2-6(c) of the LCM shows the numerical values corresponding to the three choices.

4) Secondary Wall Material: This parameter represents the material with the most thermal mass after the primary wall material. It is chosen from the 6 categories of materials in table 2-6(d) of the LCM.

For a roof, the following parameters are to be specified to the *rget* routine in order to access the CTF coefficients:

1) R-value Range: There are 6 different range values for the resistance depending upon the construction of the roof. Table 2.5 of the LCM is used to choose the resistances for the materials used for the roof. After the total R-value has been obtained, the R-value range can be determined from table 2-7(a) of the LCM.

2) Roof Material: This represents the material that is the most thermally massive and is chosen from table 2-7(b) of the LCM which lists 20 different material categories.

3) Mass Location: Again, there are three categories for the location of the thermal mass in the roof with respect to the insulation viz. inside, outside, or integral. The choice is made from table 2-6(c) of the LCM.

4) Suspended Ceiling: There may or may not be a suspended ceiling for the roof under consideration. Depending upon this a value of either 1 (with) or 2 (without) is chosen.

The "HVAC" software program automatically calculates the R-value and chooses the corresponding R-value range for roofs and walls once the construction materials have been selected.

Calculation of the CTF coefficients is based on the exterior and interior heat transfer coefficients, h_o and h_i respectively. Values of 3.0 Btu/hr-sq.ft-°F for h_o and 1.46 Btu/hr-sq.ft-°F for h_i are used for these calculations. These same values are employed for the calculation of the sol-air temperatures.

Heat Gains through ceilings,
inter-zone partitions, and floors

If the conditioned space is adjacent to other areas where the temperatures, other than being different, constantly change with time, the equation 2.32 is used to calculate the heat gains by substituting the temperature of the adjacent space for the sol-air temperature* . However, if the temperature of the adjacent space is constant throughout the day or the variations in the adjacent air temperature are very small as compared to the difference between the two temperatures, then the steady state heat transfer equation is used for the calculation of the heat gains, namely:

---

* This can only be done if the temperature in the other zone is known before calculation. Otherwise, the heat balance method may be used.

$$q_{ip\theta} = U A (t_b - t_{rc}) \tag{2.34}$$

where

U	=	Overall heat transfer coeff. of the inter-zone surface (Btu/hr-ft^2-°F)
t_b	=	the air temperature of the adjacent space (°F)
t_{rc}	=	design air temperature of the space under consideration (°F)

The HVAC program performs cooling load calculations for inter-zone partitions based on the assumption that the temperature in the adjacent zone is constant throughout the zone and hence equation 2.34 is used.

Internal Heat Gains

The internal sources of heat gain in a building include occupancy, lighting, and equipment. It is very important to closely examine the internal load diversity within a building since the internal heat gain sources have particular schedules of operation depending upon the type of activity in the building. This way an accurate estimation of the internal heat gain can be made.

Occupancy

Heat gain from people is made up of two components, sensible heat gain and latent heat gain. The amounts of these heat gains depend upon the level of activity of the occupants and their metabolic rate. In general, the greater the level of activity, the greater the relative amount of latent heat gain. Table 3 in chapter 26 of the ASHRAE Handbook of Fundamentals gives rates of heat gains from occupants of conditioned spaces. This table is often used for cooling load calculations. The sensible and latent heat gains from occupants are calculated as

$$q_s = N * F_u * q'_s \tag{2.35}$$

and
$$q_l = N * F_u * q'_l \tag{2.36}$$

where

N = The maximum occupancy for the space

F_u = use factor, equals 1 for a room

q' = The heat gain per person (Table 3 - ASHRAE H.O.F, 1989)

The sensible and latent heat gain components are calculated separately for cooling load purposes. Whereas the latent heat gain instantaneously becomes cooling load, there is a delay in the conversion of the sensible heat gain into cooling load, depending upon certain parameters of the conditioned space. For conversion of the heat gains due to occupancy to the corresponding cooling loads, the sensible heat gain is assumed to be split up as 30% convective - 70% radiant. If the split is other than this, the weighting factors are normalized as follows (Load Calculation Manual, 1992):

$$v'_0 = (r / r_1) v_0 + (1 - r / r_1)$$

$$v'_1 = (r / r_1) v_1 + (1 - r/r1) w_1 \text{ and}$$

$$v'_2 = (r / r_1) v_2 + (1 - r / r_1) w_2$$

where

$v_0, v_1,$ and v_2 = the original weighting factors

$v'_0, v'_1,$ and v'_2 = the modified weighting factors

r_1 = 0.7 (the radiative fraction based on which the original weighting factors are calculated)

r = the actual radiative fraction ($0 \leq r \leq 1$)

The weighting factors w_1 and w_2 remain unchanged.

Lighting

The main heat producing sources in lighting are the light emitting elements (e.g tungsten) or lamps, with additional heat being added by the other associated components

in the lighting fixtures that house these lamps. The instantaneous heat gain from electric lighting is calculated as

$$q = 3.412 * W * F_u * F_s \qquad (2.37)$$

where

W $\quad =$ The total installed lighting wattage

$F_u \quad =$ Use Factor, the ratio of the wattage in use to the total installed wattage, generally equals 1 for commercial applications

$F_s \quad =$ Special Allowance Factor or Ballast Factor in the case of fluorescent and ventilated lighting fixtures .

The LCM gives a brief description of the special allowance factors for various kinds of lighting. Normally, a value of 1.2 for this factor is used for general fluorescent lighting. The conversion of the heat gains due to lighting to the corresponding cooling loads is based on a convective-radiant split of 41 percent convective and 59 percent radiant heat gain. If different, the weighting factors are normalized as explained earlier (in this case $r_1 = 0.59$).

Miscellaneous Equipment

Calculations of the heat gains from equipment includes estimation of the heat gains from all types of appliances - steam, gas, and electrical. The enormous variety of such appliances and their operating schedules make the heat gain estimations very subjective. However, careful analysis of the available data, namely the schedule of operation and the load factor for each piece of equipment results in reliable input information for the heat gain calculations. The ASHRAE Handbook (1989) gives an exhaustive list of appliances used in most conditioned areas with their recommended rates of heat gain, heat gain factors, and operating efficiencies. Also given are the equations to be used to calculate the heat gains for equipment for different locations of

the driver and driven machinery, and for different types of appliances (equations 21 through 27 of Chapter 26).

Generally, for all unhooded appliances, the sensible heat gain is split into 30 percent convective and 70 percent radiant for cooling load calculations (Sowell, 1988). In the case of hooded appliances, the convective heat gains are instantaneously converted into cooling load and thus all heat gain in the space is assumed to be radiant, which is about 32% of the total heat gain.

For most commercial office buildings, the equipment heat gains are contributed to by computing equipment, typewriters and copiers, mail processing machinery and other miscellaneous equipment such as coffee makers and microwave ovens. Table 9 (Chapter 26) of the ASHRAE Handbook of Fundamentals, 1989 delineates the recommended heat gains for various office equipment. The heat gain from office equipment, similar to that in the case of unhooded appliances, is divided as 30 percent convective and 70 percent radiant for conversions of the heat gains into cooling loads.

Heat Gain through below
grade surfaces

For cooling load calculations, the heat gain or loss through below-grade surfaces and floors on grade is considered to be negligible. However, the thermal mass of these surfaces is taken into account by the weighting factors during the conversion of the heat gains into cooling loads.

Heat Gains due to Infiltration
and Ventilation of Air

Infiltration of air is caused by a greater pressure on the outside of the building than on the inside, and the amount of air infiltrated depends upon this pressure

difference. A number of methods that calculate the rate of infiltration for building structures exist. The most commonly used are the *crack* method and the *air change* method.

The crack method involves calculating the effective leakage area of cracks in windows, doors, lighting fixtures, adjoining walls and roofs, and the building material and using this in conjunction with the pressure difference due to various factors to calculate the rate of infiltration.

Most experienced engineers and designers often estimate the infiltration rate by the air change method wherein an assumption is made of the number of air changes per hour (ACH) for the space under consideration based on the building structure and use. The rate of infiltration is then given as

$$CFM = ACH * VOL/60 \tag{2.38}$$

where

CFM = The rate of infiltration   (ft^3/min)

VOL = The volume of the space   (ft^3)

Sometimes outdoor air is supplied directly to the space for ventilation purposes. In modern air-conditioning systems, however, the outdoor air is mixed with recirculated air from the space and conditioned before being resupplied back to the space. While infiltrated air is a load on the space, ventilated air introduced through the heating or cooling system is a load on the heating or cooling coil.

In the summer, infiltrated air has to be cooled to the inside design temperature. Assuming standard air conditions, this cooling load is calculated as

$$Q_s = 1.10 * (T_{out} - T_{in}) * CFM \tag{2.39}$$

where

Q_s = The sensible cooling load due to infiltration   (ft^3/min)

T_{out} = Temperature of the outdoor air   (°F)

T_{in} = Inside design temperature   (°F)

CFM   =   The rate of infiltration   (ft^3/min.)

Infiltrated air also causes a latent load on the conditioned space since some of the water vapor condenses during the cooling of the outdoor air. This latent load due to infiltration is calculated as

$$Q_l = 4840 * (W_{out} - W_{in}) * CFM \qquad\qquad (2.40)$$

where

Q_l	=	The latent cooling load due to infiltration	(Btu/hr)
W_{out}	=	The specific humidity of outdoor air	(lbmv/lbma)
W_{in}	=	The specific humidity of inside air	(lbmv/lbma)

Equations 2.39 and 2.40, with the terms inside the brackets interchanged, can be used with reasonable accuracy to calculate the heating load due to infiltration of air.

Conversion of the heat gains into cooling loads

After the heat gain q_θ from the various components has been estimated, the corresponding cooling load Q_θ for the hour is calculated using equation 2.1:

$$Q_\theta = v_0 q_\theta + v_1 q_{\theta - \delta} + v_2 q_{\theta - 2\delta} - w_1 Q_{\theta - \delta} - w_2 Q_{\theta - 2\delta}$$

As discussed earlier, the weighting coefficients are chosen from the database using the Weighting Factor routines. In order to convert the heat gains to corresponding cooling loads, the procedure followed is the same for all components. Depending upon the type of component, the WF routines return the appropriate weighting factors. There are basically four types:

1) SOLAR - these are applied to the solar heat gains through fenestration

2) CONDUCTION - these are applied to the conduction heat gains from exterior surfaces like walls and roofs, and interior partitions, as well as the absorbed heat gains through fenestration systems.

3) LIGHTING - these are applied to the heat gains due to lighting and

4) OCCUPANT or EQUIPMENT - these are applied to the occupant and equipment heat gains.

After the appropriate weighting factors have been selected, equation 2.1 is solved iteratively for the 24 hour time period until convergence is reached. The initial values of the cooling loads are taken to be zero. The cooling loads due to the infiltration of air are calculated and added to the sum of the cooling loads for each zone for each hour to arrive at the total cooling load for the building space.

Heat Extraction Rate and

the Space Air Temperature

The procedures for calculating the cooling load by the revised TFM described in the preceding sections are based on a constant inside design temperature throughout the day. However, the inside room temperature actually does not remain constant. It may vary due to the following reasons:

1) Temperature setback which may be employed during the night time and weekends, resulting in the space temperature to float during times when the space is unoccupied.

2) The cooling system cannot maintain exact control over the room temperature, and the temperature may vary as the load varies throughout the day.

Heat extraction calculations along with the estimation of the space air temperatures are possible with the TFM provided certain specifications of the cooling system and the operating conditions are known. These include the maximum cooling capacity and the cooling characteristics (heat extraction rate v/s the room air temperature) of the system. The cooling loads calculated by the TFM are used as input data in order to determine the heat extraction rate and the space air temperature. In addition, a space air transfer function that relates the room air temperature to the heat extraction rate is used.

Heat Extraction Rate

The heat extraction characteristics of a cooling unit can be generally approximated by the following linear equation:

$$ER_\theta = W_\theta + (S * t_{r\theta}) \tag{2.41}$$

where

ER_θ = The rate of heat removal from the space at time θ

$t_{r\theta}$ = The air temperature of the space at time θ

W, S = parameters that characterize the performance of the cooling equipment

The above equation is assumed to be applicable in the throttling range of the control system. When the space air temperature lies outside the throttling range, the parameter S is calculated as the slope of the line describing the extraction rate as a function of the space air temperature. It is determined as follows:

$$S = (ER_{max} - ER_{min})/ \Delta t_{tr} \tag{2.42}$$

where

ER_{max} = the maximum extraction rate over the throttling range

ER_{min} = the minimum extraction rate over the throttling range

Δt_{tr} = the throttling range of the control system

The intercept of this line, W_θ is calculated as

$$W_\theta = (ER_{max} + ER_{min}) / 2 - (S\ t^*_{r\theta}) \tag{2.43}$$

where

$t^*_{r\theta}$ = the thermostat set point temperature at time θ, equals the midpoint of the throttling range

The Space Air Transfer Function

The space air transfer function relates the rate of heat extraction to the space air temperature. It is represented as

$$\sum_{i=0}^{1} p_i(ER_{\theta-i\delta} - Q_{\theta-i\delta}) = \sum_{i=0}^{2} g_i(t_{rc} - t_{\theta-i\delta}) \qquad (2.44)$$

where

g_i, p_i = the coefficients of the space air transfer function

Q = the calculated cooling load for the room at time θ, based on an assumed constant room temperature t_{rc}

Table V gives the normalized values of the g and p coefficients for light, medium, and heavy constructions.

TABLE V

THE NORMALIZED SPACE AIR TRANSFER
FUNCTION COEFFICIENTS

Room Envelope Construction	g_0^*	g_1^*	g_2^*	p_0	p_1
	Btu /hr-ft^2°F			(Dimensionless)	
Light	+1.68	-1.73	+0.05	1.0	-0.82
Medium	+1.81	-1.89	+0.08	1.0	-0.87
Heavy	+1.85	-1.95	+0.10	1.0	-0.93

NOTE : For descriptions of light, medium, and heavy constructions, please refer Table 24 on page 26.27 of the ASHRAE Handbook of Fundamentals, 1989.

The values of the g coefficients are unnormalized using the following equations:

$$g_{0,\theta} = g^*_0 * A + p_0 [\, UA + 1.1 \, (V_\theta + VI_\theta) \,] \qquad (2.45a)$$

$$g_{1,\theta} = g^*_1 * A + p_1 [\, UA + 1.1 \, (V_{\theta-\delta} \; VI_{\theta-\delta}] \qquad (2.45b)$$

$$g_{2,\theta} = g^*_2 * A \qquad (2.45c)$$

where

UA	=	the overall UA value for the zone	(Btu/hr-ft^2-°F)
V	=	the flow rate of ventilation air introduced directly into	
		the space	(CFM)
VI	=	the flow rate of infiltration air	(CFM)

Heat Extraction Rate and Space

Air Temperature Calculations

By simultaneous solving equations 2.41 and 2.44, the following equation for the rate of heat extraction is obtained:

$$ER_\theta = (\, W_\theta g_0 + I_\theta S \,) / (\, S + g_0 \,) \qquad (2.46)$$

where

$$I_\theta = t_{rc} \sum_{i=0}^{2} g_{i,\theta} - \sum_{i=0}^{2} g_{i,\theta} \, t_{r\theta-i\delta} + \sum_{i=0}^{1} p_i \, Q_{r\theta-i\delta} - \sum_{i=1}^{1} p_i \, ER_{\theta-i\delta} \qquad (2.47)$$

In case the calculated value of ER_θ from the above equation is greater than the maximum extraction rate of the cooling unit ER_{max}, ER_θ is set to be equal to ER_{max}. If the calculated value of ER_θ is less than ER_{min}, ER_θ is set to be equal to ER_{min}. The space air temperature $t_{r\theta}$ is then calculated as

$$t_{r\theta} = (\, I_\theta - ER_\theta \,) / g_{0,\theta} \qquad (2.48)$$

Since the prior values of ER_θ and $t_{r\theta}$ are not known initially, the initial values of ER_θ are set at 0 Btu/hr for all 24 hours while those for $t_{r\theta}$ are set at 80°F. Equation 2.54 is solved iteratively for the 24 hour time period until convergence for both the heat extraction and space air temperatures is reached.

CHAPTER III

THE CLTD/SCL/CLF METHOD

The CLTD/SCL/CLF method, as it is now referred to, is basically a manual method that was developed to be used instead of the rather "tedious" and "complex" calculations involved in the TF method. This chapter briefly describes the methodology of the CLTD/SCL/CLF method for cooling load calculations. The method is described in more detail in the new cooling and heating load calculation manual (McQuiston and Spitler, 1992).

ASHRAE sponsored research to compare the TFM and TETD/TA methods (Rudoy and Duran 1975, ASHRAE 1989). As part of their work on this project, Rudoy and Duran generated Cooling Load Temperature Differential (CLTD) data for the direct one-step calculation of the cooling load from the conduction heat gains through sunlit walls and roofs and through fenestration. They also developed Cooling Load Factors (CLFs) for similar one step calculations of solar loads through glass areas and for loads from internal sources.

This method has undergone revision after significant research carried out by Sowell (1985, 1988) and McQuiston and Harris (1988). A new method of categorizing of walls and roofs based upon their thermal response characteristics has been developed. Zones have been classified based on their thermal dynamic response using additional zone parameters that were hitherto not considered important, and CTF coefficients and weighting factors for these zone groups have been developed.

This huge database of CTF coefficients and weighting factors, recent research in the areas of solar radiation, solar heat gains through fenestration and rapid advancements

in the personal computing field prompted ASHRAE to fund a research project RP-626. The main objective of this project was to develop a new load calculation manual (McQuiston and Spitler 1992), incorporating the latest modifications to the CLTD/CLF method. Furthermore, both manual and computer-oriented versions were to be provided. The following sections describe how the inaccuracies in the earlier versions of the CLTD/CLF method have been eliminated.

The CLTD/CLF Method and GRP158

The CLTD/CLF method described in the ASHRAE GRP-158 is based on tabulated CLTD/CLF factors developed by Rudoy and Duran (1975). These CLTD/CLF factors, calculated using the TFM, are used for the calculation of the cooling loads for the various components which are then normalized for environmental and zone conditions. This is necessary because the TFM produces cooling loads for standard environmental conditions and zone types.

Walls and Roofs

The TFM was used to calculate cooling loads for 36 types of roofs and 96 types of walls. These cooling loads were based on the heat gain caused by outdoor air temperature and solar radiation under standard conditions of 40°N, July 21st, a maximum outdoor temperature of 95°F, daily temperature of 21°F, and an inside design temperature of 75°F for a single standard zone of medium type construction. The CLTDs were obtained by dividing the hourly cooling loads by the area of the roof or wall and its overall heat transfer coefficient

$$CLTD = Q / (U * A) \qquad (3.1)$$

where

Q =   The hourly cooling load   (Btu/hr)

U   =   Overall heat transfer coefficient   (Btu/hr-sq.ft.-°F)

A   =   Surface area   (sq.ft.)

CLTDs for the 96 types of wall constructions and 36 types of roofs were calculated. Walls were grouped into 7 different categories and CLTDs for 8 facing directions were tabulated. Roofs were grouped into 13 categories with suspended ceilings and 13 without and the CLTDs tabulated. In order to normalize these CLTDs for different latitudes, months, indoor and outdoor design conditions, the following equation was applied:

$$CLTD_{corr} = (CLTD + LM) * K + (78-T_R) + (T_M - 85) \qquad (3.2)$$

where

LM   =   The latitude month correction factor, Table 32 Chap. 26 ASHRAE H.O.F, 1989

K   =   Color adjustment factor applied after LM, equals 1 for dark colored surfaces or light surfaces in an industrial area; equals 0.5 for permanently light colored surfaces (rural areas)

T_R =   Inside design temperature, °F

T_M =   Mean temperature, °F   = T_O - DR / 2

T_O =   Outside design temperature, °F

DR   =   Mean daily range, °F

The original CLTD/CLF method however had a few drawbacks. First of all the number of walls and roofs studied and grouped together based on their thermal characteristics did not adequately represent all roof and wall constructions that are commonly in use. Besides, in the case where a particular roof or wall assembly did not match any representative surface in the group, complicated adjustments to the table CLTDs were required. This sometimes lead to questionable results. Another problem was

that corrections to the CLTDs for varying latitudes and design months sometimes led to significant inaccuracies in the cooling load values.

Fenestration

The cooling load through glass areas was divided into conductive and radiant portions. Cooling load due to conduction was calculated based on equation 3.1. The CLTDs for windows were tabulated in the same way as for roofs and walls with corrections for values of the daily average temperature and indoor design temperatures other than 85°F and 78°F respectively. Since the cooling load due to conduction through windows is a very small portion of the overall load, no latitude-month corrections were provided.

Calculation of the radiant cooling load involved the use of the shading coefficient (SC) which represents the ratio of the solar heat gain of the glass area to that of a reference glazing material (double strength, 1/8 in., sheet glass). Solar heat gains for each hour were determined for different fenestration orientations using the ASHRAE Clear Sky model. Then, using the weighting factor equation of the TFM, cooling loads were calculated for light, medium, and heavy zones with and without interior shading. A Cooling Load Factor (CLF) for each hour of the day was derived by dividing the hourly cooling load by the product of the maximum solar heat gain for the day, the shading coefficient, and the glass area

$$CLF = Q / (A * SC * SHGF_{max}) \qquad (3.3)$$

where

Q   = The cooling load for the reference glazing system   (Btu/hr)

$SHGF_{max}$ = Maximum solar heat gain factor, tabulated for all directions, months, and 0°N latitude to 60°N latitude   (Btu/hr)

A   = The glass area   (sq.ft.)

SC   = The shading coefficient

CLFs were tabulated for July 21 at 40°N latitude, and were considered to represent values for all the summer months at all northern latitudes. The tabulated CLFs, combined with the $SHGF_{max}$ were presumed to adequately account for the variation in the solar heat gain for other latitudes and design months. Thus, cooling loads for a particular latitude and design month were calculated by multiplying the corresponding $SHGF_{max}$ by the CLF calculated for July at 40°N latitude. This approximation caused erroneous results in the cooling loads calculated because the tabulated CLFs were significantly in error for other latitudes and design months, particularly for off-peak hours and for locations whose sunrise and sunset hours differ significantly from those of July 21, 40°N.

Occupancy, Lighting, and Equipment

The cooling loads for people, lighting, and equipment were calculated using the weighting factor equation of the TFM from unit heat gains and various operating schedules (2 hrs, 4 hrs, 6 hrs etc.) The hourly cooling load was determined as

$$Q = q_s * CLF + q_l \tag{3.4}$$

where

Q   = the cooling load   (Btu/hr)

q_s = Sensible heat gain   (Btu/hr)

q_l = Latent heat gain   (Btu/hr)

CLF   = The cooling load factor, equals cooling load since heat gain is unity

The cooling load factors for people and equipment were obtained using a single medium weight zone while those for lighting were determined using several zone types, light fixture types, and ventilation schemes.

Revisions to the CLTD/CLF Method

Research by Sowell (1985, 1988) and McQuiston and Harris (1988) as part of ASHRAE sponsored projects RP-359 and RP-472 has been described in the literature review section of Chapter I. The revised methodology resulting from their work successfully resolves many of the inaccuracies of the CLTD/CLF method and is described here.

As part of ASHRAE research project 626, a new way of arriving at the solar heat gains through fenestration has been introduced. This is done by using a new factor called the Solar Cooling Load (SCL). Although tabulating the CLF as a function of month and latitude would have solved the problem both $SHGF_{max}$ and CLF would now be functions of month and latitude creating an unnecessary step and other unnecessary tables. Instead, the SCL takes into account both the solar heat gain and the zone response for any latitude/month combination. The cooling load is calculated as

$$Q = A * SC * SCL \tag{3.5}$$

Accordingly, the method is now called the CLTD/SCL/CLF method.

Another area of significant improvement is a more accurate analysis of zone response using the weighting factors developed in ASHRAE-472. The weighting factors developed as part of this project account for important zone parameters hitherto not used in the earlier CLTD/CLF method.

New CLF data has been developed for the internal heat gain sources - people, lighting, and equipment (both hooded and unhooded). The printed tables in the Load Calculation Manual have been based on four representative zone types and the cooling loads obtained compare appreciably with those obtained by the TFM (Spitler et al., 1993).

A software program called CLTDTAB, which is provided with the new load calculation manual, produces custom SCL and CLF tables for any design month and

latitude, as well as for any zone type, without interpolation between latitudes as was required earlier. Using the method as a computer oriented one, the results of the zone response are closely comparable with those obtained with the TFM. By using the manual or semi-manual options, some accuracy is sacrificed by limiting the size of the printed tables available. Table VI explains how the CLTDTAB program generates the CLTD,SCL, and CLF tables using the general and specific options.

TABLE VI

THE CLTDTAB PROGRAM OPTIONS

GENERAL	SPECIFIC
1) Roofs - Roof CLTDs for 10 most common roof types are tabulated for the desired month, latitude, and zone parameters of the representative zone type	1) Roofs - Roof CLTDs for the desired roof type, month, latitude, and zone type are tabulated
2) Walls - Wall CLTDs for 15 most common wall types are tabulated for the desired month, latitude, and zone parameters of the representative zone type	2) Walls - Wall CLTDs for the desired wall type, month, latitude, and zone type are tabulated
3) Glass Areas - SCLs for four representative zone types - A,B,C, and D (LCM, 1992) are tabulated for 8 different directions and the horizontal	3) Glass Areas - SCLs for the particular zone for the 8 directions and the horizontal are tabulated for the desired month and latitude
4) No CLF tables are tabulated	4) CLFs for people (and unhooded equipment), lighting, and hooded equipment for the desired zone type are tabulated

By using the "zone specific" option, the results obtained by the CLTD/SCL/CLF method are nearly identical to those obtained by the revised TF method. Since the "general" option uses representative zone, roof, and wall types, the results obtained are not as accurate as those obtained by the revised TF method. The manual option of the CLTD/SCL/CLF method using the printed tables induces more errors since interpolation is required for other locations. Lindsey (1991) has tabulated the maximum percentage errors between the computer program values and printed table values for different representative roof and wall groups.

Spitler et al. (1993) describe the new load calculation manual and the revised CLTD/SCL/CLF method in their recent papers. Description of the software developed to access the CTF coefficients and weighting factors is made by Sowell (1992) while the CLTDTAB program and the procedures involved in generating the CLTD, SCL and CLF tables is described by Lindsey (1991), and a paper by Falconer et al. (1993).

CHAPTER IV

THE HVAC SOFTWARE PROGRAM

As part of this project, a software program has been developed in order to calculate the cooling loads for a building based on the revised Transfer Function Method. This program, written in the C-programming language, executes under Microsoft WINDOWS™ as a user-interactive, menu driven program. In addition to cooling load calculations, the program also performs calculations of the heat extraction rates for desired zones, and the heating load for the building based upon steady state heat transfer. An elaborate explanation of the graphical user interface and operation of the program appears in the Users Reference Manual accompanying the software (Hodson, 1992). Different aspects of the user-interface and the structure of the program are discussed by Song (1992). This chapter attempts to give an overview of the program, including the technical calculations.

Program Hierarchy

The program, which hereafter is called "HVAC", has a hierarchical data structure and interface. The highest level item is a building for which the loads are to be calculated. A building contains one or more zones which are each maintained at a uniform temperature. Each of these zone contains one or more rooms which may have heat gains due to walls, roofs, partition(s), people, lighting, equipment, and infiltration. Figure 4.1 shows the hierarchy that has been used for the program.
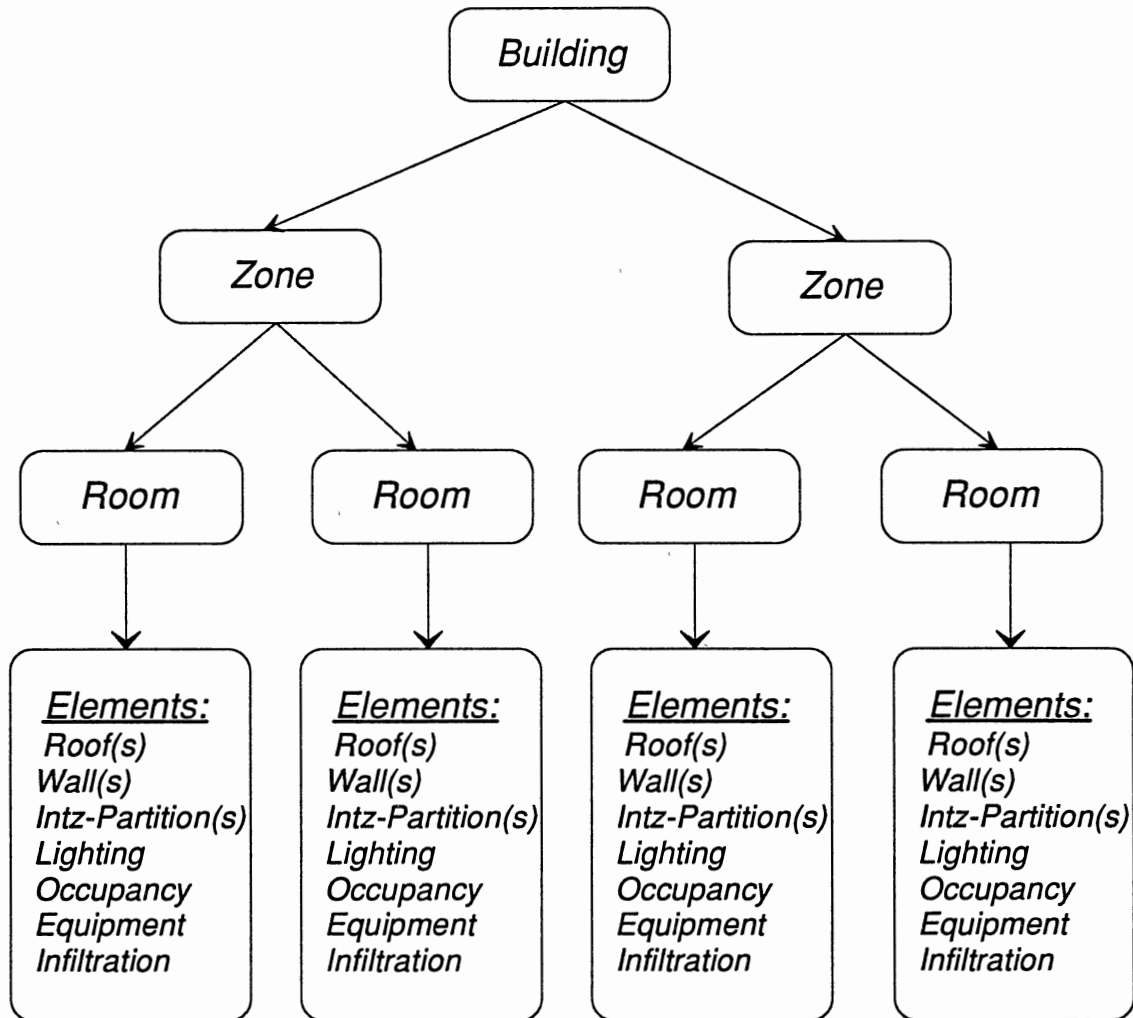
Figure 4.1: Hierarchy of the HVAC software program

Each component shown in the figure is represented as a user-identifiable icon in the program. The program allows the user to provide a distinct name to each component. The following sections describe each component and its required input details.

Building

Besides a user given name, each building has a Location name. The calculations to be performed (cooling load, heat extraction rate, and heating load) are set in the main dialog box. The design day requirements and outdoor conditions for summer (cooling load option) and winter (heating load option) are entered in the "Location" dialog box. Table VII shows the input required for this dialog box.

The average air temperature is the daily average air temperature for the location during the coldest winter months while the ground amplitude is the amplitude of variation of the ground temperature from the daily average air temperature. These parameters are required to calculate the heat losses through basements and floors. Values of the average air temperature for various locations in the U.S. are available in Table 3.5 in Chapter 3 of the Heating and Cooling Load Calculation Manual (1992), while Figure 4 in Chapter 25 of the ASHRAE Handbook of Fundamentals (1989) shows the lines of constant amplitude of the ground temperature.

Zones

Each building consists of one or more zones. A typical zone dialog box contains input for the inside design conditions for summer and winter. The default inside conditions for summer are 75°F dry bulb and 50% RH while those for winter are 70°F and 30% RH. The design wet bulb temperature can be entered instead of the relative humidity.

Heat extraction rate calculations are carried out on a zone-by-zone basis. Table VIII shows the input details for a typical heat extraction dialog box, which is brought up at the zone level by the "File-Heat Extraction" menu.

Heat extraction rates are required to be re-calculated if any design information has been modified *after* calculation has been done.

TABLE VII

INPUT DETAILS FOR THE "LOCATION" DIALOG BOX AT THE "BUILDING" LEVEL

Name	Units	Comments
City	-	}
State	-	} Default settings are for
Latitude	Deg. & Min.	} Stillwater, Oklahoma*
Longitude	Deg. & Min.	}
Time Zone		}
Atmospheric Pressure	lbf/in^2	} Default - 14.696 lbf/in^2 (Used to
		} calculate the specific humidities)
TIME -		
Local Solar Time	-	}
OR		} Default settings are Daylight
Local Clock Time	-	} Savings Time (Local Clock Time)
(Std. or Daylight		}
Savings Time)		}
SUMMER DESIGN		}
CONDITIONS		}
Month	-	} Default settings are based on the
Day	-	} 2½% design conditions for the 21st
Design Dry Bulb Temp.	°F	} of June for Stillwater, Oklahoma*
Mean Coincident Wet		} (ASHRAE H.O.F, 1989)
Bulb Temp.	°F	}
Daily Mean Range	°F	}
WINTER DESIGN		
CONDITIONS		}
Design Dry Bulb Temp.	°F	}
Wet Bulb Temperature	°F	} Default settings are based on the
Relative Humidity	-	} 99% design conditions for Stillwater,
Average Air Temperature	°F	} Oklahoma * (ASHRAE H.O.F, 1989)
Ground Amplitude	°F	}

* In case user wishes to change the default setting , the "save as default" button should be clicked after different data have been entered in the "Location" dialog box

In addition, the heating load calculations require details about the level of the walls of the room with respect to ground level in order to determine heating loads for above and below grade walls. Table IX shows the 5 available choices for wall levels. Depending upon the choice selected, the user is prompted to input either the floor U-Factor or the Perimeter heat loss factor along with the slab perimeter adjoining the non air-conditioned areas and accordingly, the heating load is calculated (using either the floor area or slab perimeter with the corresponding U-Factor).

TABLE IX

INPUT DETAILS FOR THE "WALL PARAMETERS"
DIALOG BOX AT THE "ROOM" LEVEL

Name	Units	Comments
WALL LEVEL	ft.	
1) Above Grade		} Floor U - Factor required
2) On Grade		} Slab Perimeter and Perimeter
		} U - Factor required
3) Less than 3' below grade		} Heights above and below grade, Slab
		} Perimeter and Perimeter U - Factor reqd.
4) More than 3' below grade		} Heights above and below grade and
		} Floor U - Factor required
5) Completely below grade		} Floor U - Factor required

NOTE : Refer to Table XV for heating load calculation for walls

Heat Gain Elements

The elements, some or all of which are present in rooms, are the sources of the heat gains which result in cooling and heating loads. Basically, there are seven types of

elements that contribute to the heat gains: roofs or ceilings, walls, inter-zone partitions, people, lighting, equipment, and infiltration.

Table X shows the input details required to specify roofs and walls. The roof or wall type and U-Factor for the roof/wall can either be specified directly or be obtained by setting the roof/wall type. Setting the roof/wall type means selecting the construction materials that make up the roof or wall, its mass location, principal material, and the secondary material (for walls) or the presence/absence of suspended ceiling (for roofs) from the "Roof Type" or "Wall Type" dialog box. Once these are selected, the program then automatically determines the appropriate roof/wall type from the database and the corresponding CTF coefficients for the calculation of the heat gains. The data for different construction materials are available in Table 11 of Chapter 26 of the ASHRAE Handbook of Fundamentals, 1989.

TABLE X

INPUT DETAILS FOR THE "ROOF" OR "WALL"
DIALOG BOX AT THE "ELEMENT" LEVEL

Name	Units	Comments
Facing Direction	Deg.	} Usually for walls - Measured clockwise from the North direction
Tilt	Deg.	} Tilt from the horizontal.
Roof/Wall Type	-	} Can either be input directly or details can
Actual U-Factor	$Btu/hr\text{-}ft^2$	} be entered at the "Roof (Wall) Type" } dialog box
Absorptance	-	} Solar Absorptance (Default : 0.9)
Area	ft^2	} Can be entered directly or as a } combination of the length and breadth

Roofs and walls may have glass areas in the form of skylights or doors and windows. Details for these glass areas are entered in the "Glass Areas" dialog box. Table XI shows the input requirements to calculate cooling loads through glass areas. Information about the awning/overhang if present is used for shading calculations.

TABLE XI

INPUT DETAILS FOR THE "GLASS AREAS" DIALOG
BOX AT THE "ROOF" or "WALL" LEVEL

Name	Units	Comments
Width of glass	ft.	
Height of glass	ft.	
Shading Coefficient	-	
Glass U-Factor	$Btu/hr\text{-}ft^2$	
AWNING/OVERHANG		
Overhang length (a)	ft.	}
Glass to Overhang (b)	ft.	} Required to calculate the shaded and
Overhang protrusion (c)	ft.	} unshaded glass areas for each hour
Reveal depth (d)	ft.	}

Inter-zone partitions are basically walls that separate zones maintained at different temperatures, and calculation of the cooling load is based on steady state heat transfer. Input information required to calculate the heat gain for a partition are the Area (ft^2) and U-Factor ($Btu/hr\text{-}ft^2$) of the partition and the temperature of the adjacent zone (°F).

People, lighting, and equipment form the sources of internal heat gain. These heat gains are made up of convective and radiant heat gain. The user specifies these fractions

the default values of which are 30% convective-70% radiant for people and equipment and 41% convective-59% radiant for lighting. These values can be changed depending upon the heat gain. Accordingly, the program normalizes the weighting factors for the zone, as explained in Chapter II. Tables XII, XIII, and XIV show the input requirements for the people, lighting, and equipment elements. These are entered in the "People Information", "Light Information", and "Equipment Information" dialog boxes.

Infiltration is entered as the number of air changes per hour (ACH). This indicates the maximum design infiltration rate. The total infiltration rate is calculated as:

$$V = ACH * Room\ Volume \qquad (4.1)$$

where the room volume is determined from the room height and its floor area.

TABLE XII

INPUT DETAILS FOR THE "PEOPLE INFORMATION" DIALOG
BOX AT THE "ELEMENT" LEVEL

Name	Units	Comments
Peak occupancy	-	
Sensible heat gain/person	Btu/hr	} Default: 250 Btu/hr
Latent heat gain/person	Btu/hr	} Default: 200 Btu/hr
Radiant Fraction of heat gain	-	} Default: 0.70
Convective Fraction of heat gain	-	} Default: 0.30
SCHEDULE		
Schedule for people	-	

TABLE XIII

INPUT DETAILS FOR THE "LIGHT INFORMATION" DIALOG
BOX AT THE "ELEMENT" LEVEL

Name	Units	Comments
TOTAL INSTALLED LIGHTING		
Heat Gain/Area	W/ft^2	
OR		
Total Heat Gain with	Btu/hr	} Lighting Multiplier is for multiple
Lighting Multiplier		} light elements with the same heat
		} gain data
Radiant Fraction of heat gain	-	} Default: 0.59
Convective Fraction of heat gain	-	} Default: 0.41
SCHEDULE		
Schedule for lighting	-	

TABLE XIV

INPUT DETAILS FOR THE "EQUIPMENT INFORMATION"
DIALOG BOX AT THE "ELEMENT" LEVEL

Name	Units	Comments
Sensible heat gain	Btu/hr	
Latent heat gain	Btu/hr	
Equipment Multiplier		} Equipment Multiplier is for multiple
		} Equipment elements with the same
		} heat gain data
Radiant Fraction of heat gain	-	} Default: 0.70
Convective Fraction of heat gain	-	} Default: 0.30
SCHEDULE		
Schedule for Equipment	-	

Internal sources of heat gains (people, lights, and equipment) and infiltration require the use of a schedule in order to determine the hourly heat gains. A schedule is a set of 24 hourly fractional multipliers used to determine the hourly heat gain of a particular element. For people, lighting, and equipment, the schedule indicates the fraction of the total peak heat gain for the particular hour. Default schedules are available and can be modified or a completely new schedule may be generated and saved into the schedule library.

Calculations and Output

Once all input data for the entire building have been entered, cooling and/or heating load calculations can be carried out by using the "Calculate" menu option at the Building level.

Before calculating the heat gains for any element, the program determines the outside specific humidity, equation of time, declination, and the coefficients of the solar model - A, B, and C for the date of calculation. It then determines the various solar angles for each hour of the day (at half past the hour) required to estimate the solar radiation loads. It then calculates the heat gains and cooling loads for each element one by one, using the database for walls and roofs by selecting the appropriate wall/roof with its conduction transfer coefficients and the weighting factors that correspond to the heat transfer response of the zone. Figure 4.2 shows a schematic of the working of the software program for cooling load calculations.

In case the user wishes to examine intermediate calculations, they can be written to files by using the "File-Preferences" menu option. The intermediate files are named as DATA.CLD and DATA.XTR for cooling load and heat extraction rates respectively where DATA is the name of the data file. The program also has an "Auto Save" feature which prevents the loss of data by saving all data before calculation is performed (when

Preliminary Calculations for the Building (Eqn. of Time, declination, solar angles)

For each Zone

Preliminary Zone Calculations and Lookups

For each Room

Preliminary Room Calculations / Lookups

SUM = 0

For each Element

Calculate heat gain

SUM = SUM+heat gain

Continued ...

```
┌─────────────────────────────┐
│    Calculate Cooling Load    │
│     for each element type     │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│         ROOM LOAD            │
│  CALCULATIONS / SUMMATION    │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────────────┐
│            ZONE LOAD                  │
│     CALCULATIONS / SUMMATION          │
│                and                    │
│ Heat Extraction Calculations (if required) │
└─────────────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│        BUILDING LOAD          │
│  CALCULATIONS / SUMMATION     │
└─────────────────────────────┘
```

Figure 4.2: Flow chart of the HVAC program.

the "Calculate" menu item is invoked). The data is saved into the DATA.BAK file. This is useful because the user does not have to change his original data file in case he was performing only a test run.

Plots of the cooling loads can be examined on screen at all levels, from the Building up to each Element and printed out if required. After the heating load has been calculated, a dialog box containing the summary for the building pops up. Heating loads for individual zones can be viewed within this dialog box using the "Zone" option.

The heat extraction calculations can be performed after the cooling load calculations are done and the details for the heat extraction rates in the particular zone are entered. Plots of the heat extraction and the space air temperature can be viewed on screen at the "Zone" level.

The program also provides an option to print the results for the entire building. The "Print" menu option is available at every level and hard copies of the results at any level can be obtained. Thus, the user may print out an elaborate report of the building loads beginning with each element or just a summary of the loads at the level he desires.

Heating Load Calculations

Heating load calculations are performed by the HVAC program using the steady state heat transfer equation $Q = U * A * \Delta T$. Table XV shows how the individual heating loads are determined.

TABLE XV

CALCULATION OF INDIVIDUAL HEATING LOADS
BY THE "HVAC" PROGRAM

Heating Load For	Equation	Comments
1)Roofs, Walls*, Glass Areas, and Floors above exterior space	$Q = U*A* (T_i - T_o)$	
2) Floors on Grade	$Q = U'*P* (T_i - T_o)$	} U' is the perimeter heat loss } factor and P is the slab perimeter } measured in feet
3)Walls* and Floors below grade (a) Less than 3ft. below grade	$Q = U'*P* (T_i - T_o)$	
(b) More than 3ft.		

TABLE XV (Continued)

Heating Load For	Equation	Comments
below grade	$Q = U*A* (T_i - T_g)$	} T_g is the ground temperature } which is calculated from the } average air temp. and the ground } amplitude
(c) Completely below grade	$Q = U*A_T* (T_i - T_g)$	} A_T is the total wall area
4) Infiltration Sensible	$Q_S = 1.10*CFM (T_i - T_0)$	
Latent	$Q_S = 4840*CFM*(W_i - W_0)$	} W_i and W_0 are the inside and } outside specific humidities

* Please refer to table IX for wall levels.

CHAPTER V

ZONE DESCRIPTIONS

In order to study the results of the revised Transfer Function Method and compare them with those of the CLTD/SCL/CLF Method, three "fictitious" test zones were selected. They are:

1) Retail Store: A single story rectangular zone with 2 exterior walls-one with an exterior glass window, a roof and sources of internal load. The walls are made of heavy construction material.

2) Office Premises: An office area with an adjoining computer room. These are two mid-floor zones each at different temperatures. Exposed glass areas are externally shaded by means of awnings.

3) Office in a High Rise Building: This is a top-floor office area with curtain walls and a carpeted floor. Glass forms a major portion of the exterior surfaces.

Following is a brief description of the zones and sample cooling load calculations by the two methods.

Test Zone1 - Retail Store

This zone is a 70 ft. by 30 ft. corner zone, a retail store in a shopping mall located in Stillwater, Oklahoma (Latitude 36'10", Longitude 97'05"). Figure 5.1 shows the plan and elevation views of this test zone. It has two exterior walls, the East and South Walls.
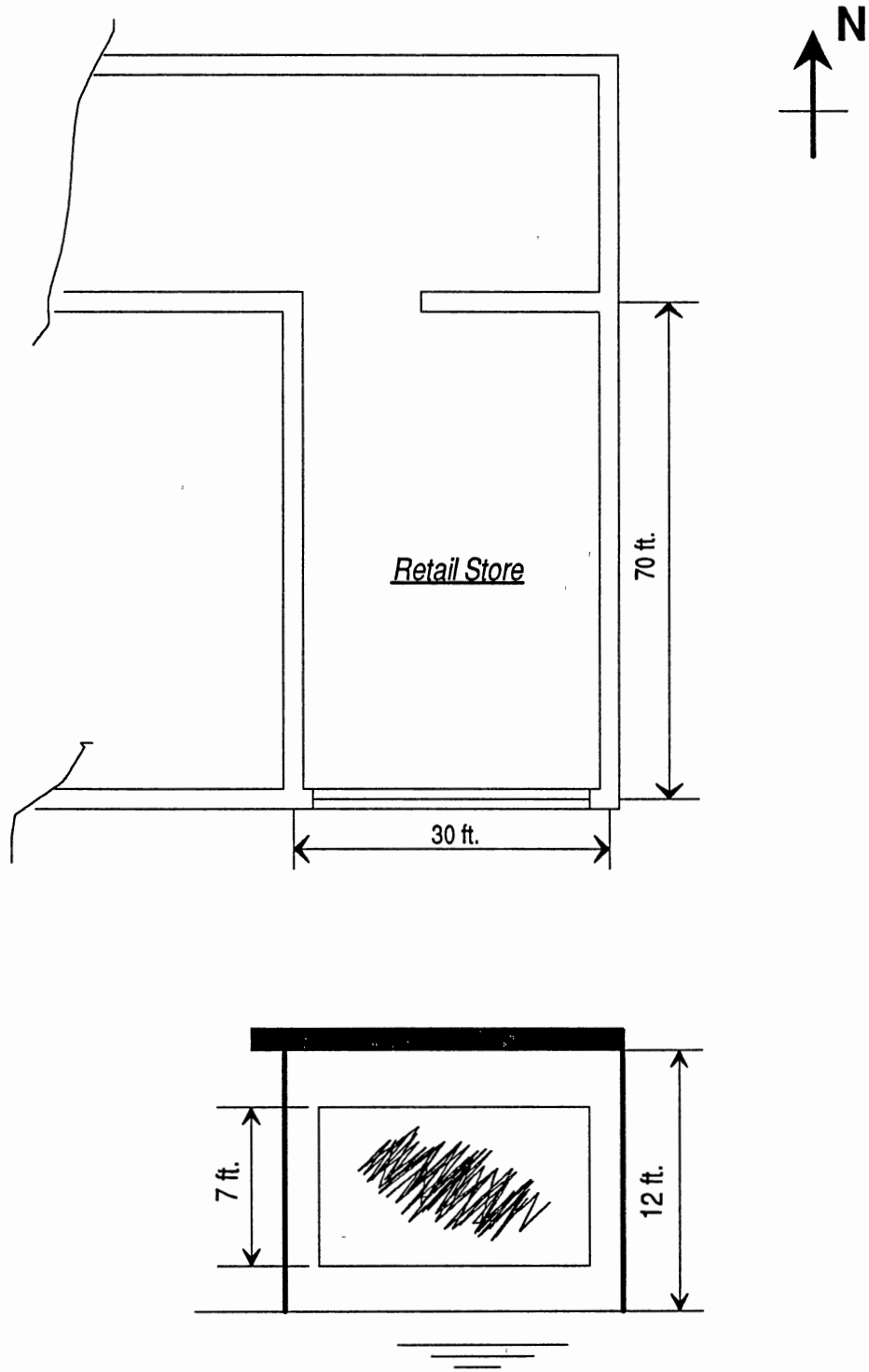
Figure 5.1: Plan and Elevation views of
the Retail Store

The 70 ft east wall has no exposed glass surfaces. However, the south wall has a 30 ft. by 7 ft. high display window with no interior shading (shading coefficient of the glass is 0.55 and its U-factor is 0.81 Btu/hr-sq.ft-°F). The north and west walls are interior walls that adjoin other stores. The exterior walls are made of 4 in. face brick, 8 in. concrete block, 0.75 in. polystyrene insulation with 1 in. furring strips (2 in. in width, spaced 16 in. o.c.), and 0.5 in. dry wall. The roof of the zone is constructed from built up roofing, rigid roof deck insulation, 2 in. concrete on a corrugated metal deck, and a suspended ceiling. The interior walls are constructed from 0.5 in. dry wall and steel studs. The floor of the zone is a 4 in. concrete slab on grade. The peak occupancy of the store is about 15 people at times between 9 a.m. to 9 p.m. The fluorescent lights are on from 8 a.m. to 10 p.m. There is no heat generating equipment in the zone and the infiltration rate is taken to be 1.5 air changes per hour.

Test Zone 2 - Office Premises

This test zone is actually two zones - an office area and an adjoining computer area which are maintained at 74 °F and 70 °F respectively. This office premise is on a middle floor in a multi-story building in St. Louis, Missouri (Latitude 38'39", Longitude 90'38"). Figure 5.2 depicts this test zone. The equipment room is not air-conditioned. Exterior glass areas are shaded externally by means of awnings (Figure 5.3). The floors above and below these zones are air-conditioned. Assuming that the temperature on the floors above and below remain constant throughout the day, the ceiling and floor are treated as inter-zone partitions with steady state heat transfer across them. The exterior walls of the office area are made of exterior finish, 8 in. light weight concrete block and moderate insulation (R=4.5 °F-ft^2-hr/Btu). The east wall of the computer room is constructed of exterior finish, 4in. face brick, 8 in. light wt. concrete block (filled) with an air space in between. The computer room adjoins other office areas which are
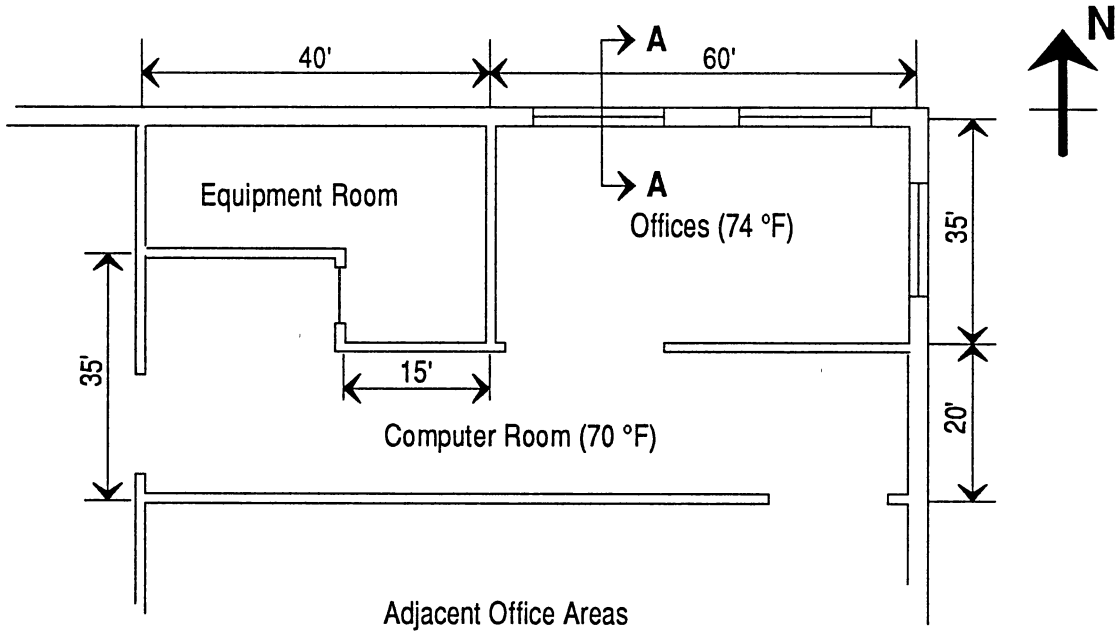
Figure 5.2: Test Zone 2 - Office Premises
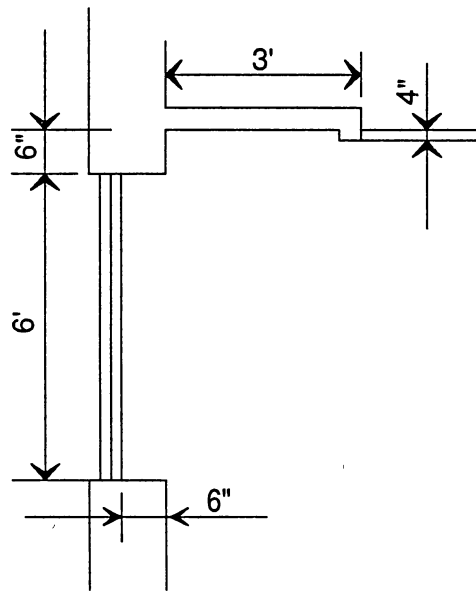
Figure 5.3: View of Window at
section A-A

100'

80'

Air Space

2" Granite Finish
on Steel Structure

Suspended
Ceiling

Gypsum Board

7 ft. Glass Window
with glass frame

Carpeted Floor
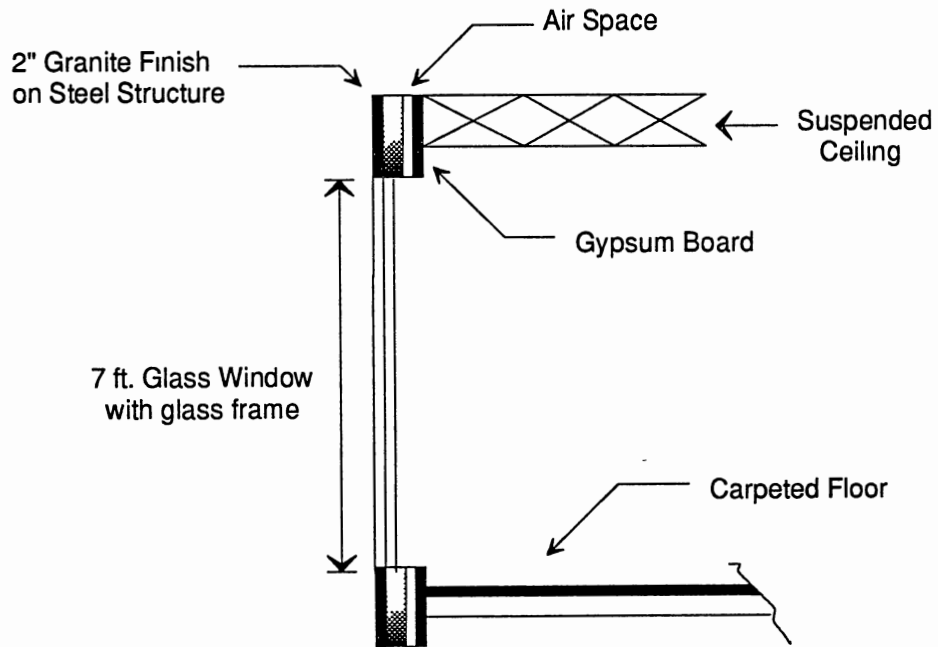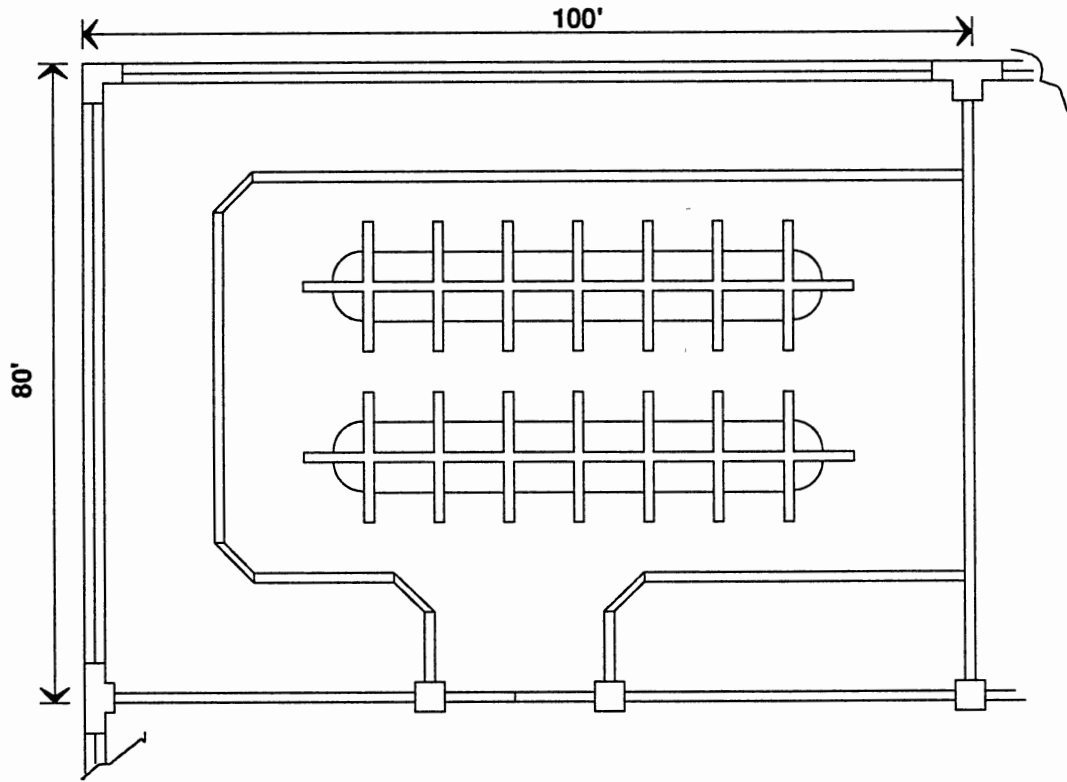
Figure 5.4: Test Zone 3 - Top Story Office premises

controlled at different temperatures and has electronic and computer machinery operating throughout the day.

Schedules for people, lighting, and equipment for the office area are typical of an 8 to 6 office area whereas those for the computer area extend to a greater part of the day, since the equipment within it operates throughout the day. The internal heat generating sources for the two areas are:

	OFFICE	COMPUTER ROOM
1) Occupancy	80 (8 a.m - 6 p.m.)	5 (8 a.m - 8 p.m.)
2) Lighting	1.9 W/ft^2 (8 a.m - 6 p.m.)	1.5 W/ft^2 (All 24 hrs)
3) Equipment	8000 Btu/hr sens. } 8 a.m to	25000 Btu/hr sens. }All 24
	1600 Btu/hr latent } 6 p.m.	5500 Btu/hr latent }hours

Infiltration calculations are based on 2 ACH (7a.m - 7 p.m.) for the office area and 1.5 ACH (All 24 hours) for the computer room.

Test Zone 3 - Top Story Office

This test zone is a huge office area situated on the top floor of a high rise building in La Crosse, Wisconsin (Latitude 43'52", Longitude 91'15"). The office is maintained at 75 °F. It has two exterior walls, one facing the north and the other facing the west. The walls are of curtain type (light weight) with polished granite facing bolted onto a steel structure on the outside and dry wall on the inside. Glass forms a major portion of the exterior facade. No external shading exists for the glass areas. The roof of this zone is made of 6" concrete with medium insulation and a vapor barrier. The flooring of the zone is heavily carpeted. Figure 5.4 shows views of this zone.

Schedules for people (occupancy - 300), lighting (2.5 W/ft^2), and equipment (70000 Btu/hr sensible and 6000 Btu/hr latent) for the office area are on from 8 a.m. to 6

p.m. and off at other times. The air-conditioning system is on from 7 a.m. to 7 p.m. and infiltration calculations are based on 2 air changes per hour.

Sample cooling load calculations for test zone 1 (The Retail Store) using both methods are available in appendix A. Cooling load calculations for the other two test zones by both methods are carried out along similar lines and compared. Comparison tables and plots for these zones are available in the appendixes B and C. The results of the different tests are discussed in chapter 6.

CHAPTER VI

RESULTS AND DISCUSSION

This chapter describes the results of the comparison tests carried out on the test zones using the revised Transfer Function and CLTD/SCL/CLF methods. The CLTD/SCL/CLF method is intended to give results very close to those of the revised TF method. However, there are certain inherent limitations in the CLTD/SCL/CLF method. These limitations are expected to cause some differences in the results obtained by the two methods. The "manual" mode of the CLTD/SCL/CLF method has further limitations.

It was found that there are minor differences between the implementations of the HVAC program and the CLTDTAB program. These are enumerated in Table XVI. In order to have an accurate comparison between the two methods, the following changes were implemented:

1) The CLTDTAB source code was modified to include the contribution of the Y factor.

2) A version of the HVAC (TFM) software that calculated the cooling loads at the hour was prepared and used for the comparison tests.

3) All factors used in the load calculations were kept consistent for the two methods. The following values were used:

$$h_o = 3.0 \text{ Btu/hr-ft}^2\text{-}°F$$

$$\varepsilon = 0.9$$

$$\delta R = 20.0 \text{ Btu/hr-ft}^2$$

TABLE XVI

IMPLEMENTATION DIFFERENCES BETWEEN THE "HVAC" AND "CLTDTAB" PROGRAMS

HVAC Program	CLTDTAB Program	Effect
1) All Cooling Loads are calculated at half past the hour	1) All Cooling Loads are calculated at the hour	Due to the difference in the time of calculation, all solar calculations are different
2) The Y - Factor is included in the calculations for solar radiation through vertical surfaces: if $\cos \theta > -0.2$ $Y = f(\cos \theta)$ else $Y = 0.45$ $I_{ds} = C*I_{DN}*Y$ This is an Anisotropic model of diffuse sky radiation	2) The Y-Factor is not used. Instead, the following relation is used: $I_{ds} = C*I_{DN}* [1+\cos(tilt)] / 2$ Thus for vertical surfaces, $[1+\cos(tilt)] / 2 = 0.5$ This is an Isotropic model of diffused radiation	Differences in the solar radiations for vertical surfaces resulted in largely differing values of sol-air temperatures by the two methods (Max. difference observed: 63.03 °F ; 155.31°F by the revised TF method & 92.28 °F by the CLTD/SCL/CLF method)
3) Absorbed solar heat gains through glass areas are converted into cooling loads by using "conduction" Weighting Factors	3) All absorbed solar heat gains through glass areas are assumed to form instantaneous cooling load	Since the magnitude of the absorbed cooling loads is small, the difference in these cooling loads (± 2 to 3 %) did not have any major effect on the total cooling load
4) Values used for some constants were: $h_o = 4.0$ Btu/hr-ft^2-°F $\varepsilon = 1.0$ $\delta R = 20.1$	4) Corresponding values used were: $h_o = 3.0$ Btu/hr-ft^2-°F $\varepsilon = 0.9$ $\delta R = 20.0$	Differences in the inward flowing fraction (N_i) and the sol-air temperatures resulted in moderately different cooling load values (2 to 4 %) by the two methods

The methodological differences to be investigated include:

1) The use of the CLTDs, the SCLs and CLFs generated by the CLTDTAB program that are tabulated with a small number of significant digits thereby inducing some round-off error.

2) Use of the CLTD/SCL/CLF method for dates other than the 21st of the month which requires interpolation. This may induce some error.

3) Use of the CLTDTAB program while interpolating for different latitudes.

4) Use of shaded and unshaded SCLs to calculate cooling loads through externally shaded glass areas.

An exhaustive number of cooling load comparison tables and plots were obtained for each of the test zones, some of which are reproduced here for discussion. Others are found in the appendix.

In addition to the above comparison tests, the CLTD correction equation developed by Rudoy and Duran (1975) was checked for its validity for varying outside and inside temperatures and daily ranges. The equation is given as:

$$CLTD_{corr} = (CLTD_{table} + LM) * K + (78 - T_R) + (T_M - 85) \qquad (6.1)$$

where

LM = The latitude month correction factor

K = The color adjustment factor

T_R = Inside design temperature, °F

T_M = Mean temperature, °F = $T_O - DR / 2$

T_O = Outside design temperature, °F

DR = Mean daily range, °F

The above correction equation can be approximated analytically to be a function of the outside and inside temperatures and the mean daily range. Conduction heat transfer is driven by the sol-air temperatures, and the inside temperature.

Thus,

$$q_{cond} = f(T_i, T_o)$$

Assuming that the inside zone temperature remains constant, we can define T_o' such that

$$T_o' = T_o - T_i$$

Then,

$$q_{cond} = f(T_o')$$

Furthermore, the following cosine fit can be applied to approximate the temperature profile of (T_o') for the day:

$$T_o' = (T_{max}' - DR/2) * [A + B \cos (2\pi (h - h_{Tmax}) / 24)]$$

where

T_{max}' = the maximum value of T_o' for the day (°F)

DR = the mean daily range (°F)

A, B = constants for the curve fit

h = the hour under consideration

h_{Tmax} = the hour that corresponds to the maximum value of T_o'

Thus, as long as the profile of the temperature difference T_o' remains constant, the temperature correction depends upon the term ($T_{max}' - DR/2$), which is same as the correction given by Rudoy and Duran.

Outside temperatures varying from 85°F to 105°F in steps of 5°F, inside design temperatures from 50°F to 75°F in steps of 5°F, and mean daily ranges varying from 15°F to 25°F in steps of 2°F were used to compare the results. Cooling load values obtained by the revised TF and CLTD/SCL/CLF methods for varying values of the outside temperature, inside temperature, and the mean daily range were nearly identical (maximum error - 0.06 to 0.09 %). A change in the parameter (T_o, T_i, or DR) resulted only in a shift of the cooling load profile by a proportional value, while the overall profile remained the same.

Effect of inherent round-off error from tables

The CLTDTAB program generates custom tables containing the CLTDs for commonly used roofs and walls, and SCL/CLF data for four representative zone types using the "General" option. If the "Zone Specific" option is used then data pertaining to the particular zone type is obtained. The CLTDs are in the form of integer numbers for each hour while the SCLs and CLFs are tabulated with an accuracy of two decimal places. Due to this round off, the potential difference in the values of the cooling loads for roofs and walls using the table CLTDs and those obtained by using the revised TF method is ±0.5 times the UA value of the particular surface. For the SCLs and CLFs the difference is ±0.005 times the corresponding heat gain.

Keeping all other variables the same and using the "Zone Specific" option for the CLTDTAB program, cooling loads were determined by using both the table as well as the non-rounded values (obtained by debugging the CLTDTAB code) of the CLTDs. Using the non-rounded values of the CLTDs is equivalent to using the revised TF method. It was found that for almost every case for each hour, the difference in cooling load values was within the maximum error specified above.

Table XVII shows these calculations for the retail store roof while Fig. 6.1 shows a plot of the cooling loads obtained by the two methods. The minimal differences in the cooling loads using the non-rounded CLTDs and the TF Method is attributed to very small differences in the solar angles values and calculations thereafter.

Cooling loads by the two methods were then calculated based on the actual design conditions and actual U-factors for the exterior surfaces (for the earlier test, the U-factor of the representative wall/roof from the grouping tables was used). The calculated cooling loads compared satisfactorily with cooling loads obtained by the revised TF method with differences within the error range.

TABLE XVII

COOLING LOADS FOR THE RETAIL STORE ROOF BY THE
REVISED TF AND THE CLTD/SCL/CLF METHODS

Time	TF Method	CLTD Method			Using non-rounded Values of CLTDs		
		CLTD	Load	Difference	$CLTD_{NR}$.	Load	Difference
1	28288.37	32	28513.43	225.06	31.7447	28285.95	-2.420
2	25177.71	28	24949.25	-228.46	28.2538	25175.40	-2.311
3	22242.23	25	22276.12	33.89	24.9598	22240.30	-1.932
4	19480.59	22	19602.98	122.39	21.8606	19478.77	-1.818
5	16895.23	19	16929.85	34.62	18.9593	16893.58	-1.646
6	14523.10	16	14256.72	-266.39	16.2972	14521.53	-1.566
7	12838.88	14	12474.63	-364.25	14.4071	12837.37	-1.510
8	12512.91	14	12474.63	-38.28	14.0413	12511.43	-1.484
9	13775.12	15	13365.67	-409.45	15.4577	13773.50	-1.618
10	16527.30	19	16929.85	402.55	18.5462	16525.49	-1.807
11	20505.45	23	20494.03	-11.42	23.0106	20503.47	-1.977
12	25351.57	28	24949.25	-402.32	28.4490	25349.33	-2.239
13	30647.10	34	30295.52	-351.58	34.3916	30644.45	-2.647
14	35928.05	40	35641.79	-286.26	40.3182	35925.32	-2.732
15	40725.73	46	40988.06	262.33	45.7023	40722.79	-2.938
16	44609.82	50	44552.24	-57.59	50.0612	44606.77	-3.053
17	47212.65	53	47225.37	12.72	52.9822	47209.51	-3.141
18	48262.38	54	48116.41	-145.97	54.1601	48259.07	-3.310
19	47609.76	53	47225.37	-384.39	53.4278	47606.56	-3.202
20	45335.56	51	45443.28	107.72	50.8757	45332.52	-3.037
21	42067.44	47	41879.10	-188.34	47.2083	42064.71	-2.735
22	38527.55	43	38314.92	-212.63	43.2357	38524.94	-2.609
23	34996.87	39	34750.74	-246.13	39.2735	34994.44	-2.426
24	31569.19	35	31186.56	-382.63	35.4270	31567.04	-2.149

NOTE : 1) All loads are in Btu/hr
2) To = 95°F, Ti = 78°F, Mean daily range = 21°F
3) U-factor used = 0.424307 (U- factor of representative roof # 8)
4) Maximum Error Range = ± 0.5 *U*A = ± 0.5*0.424307*2100 = ± 445.52 Btu/hr

Similar tests were carried out for glass areas without external shading, lighting, occupancy, and equipment to study the effects of using the table SCLs and CLFs as against their actual values, with acceptable results (see Appendix A). However, since the

CLTDTAB program does not generate the CLFs for *odd* hour schedules (1hr, 3 hrs, 5 hrs etc.), accurate comparisons for internal sources with odd hour schedules could not be carried out. Interpolation of the CLFs does not yield correct results.

Thus it can be concluded that a reasonable degree of accuracy is maintained by when reading off CLTD values from the tables.
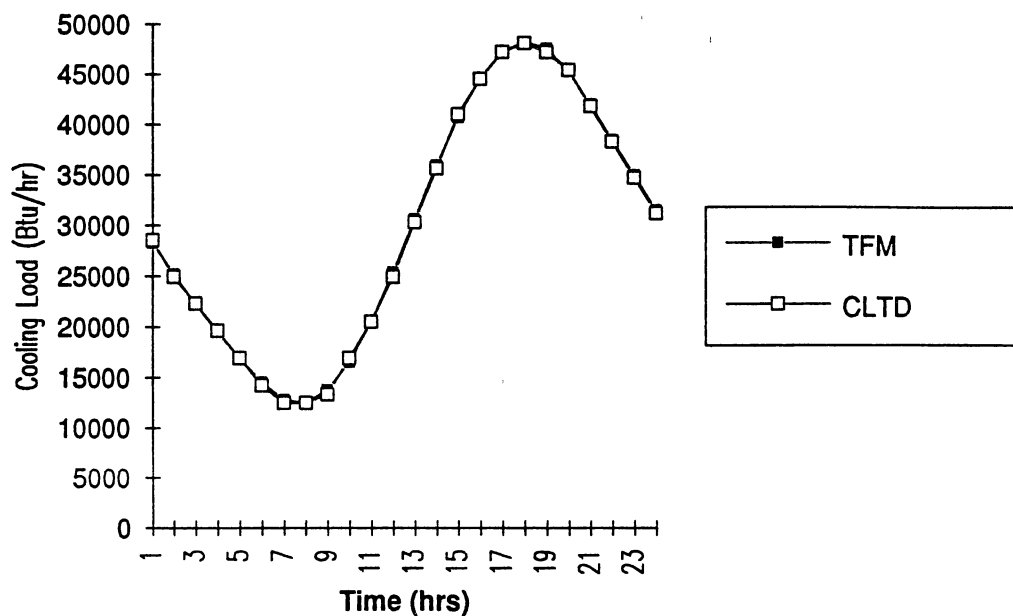
Figure 6.1:Cooling loads by the revised TF and CLTD/SCL/CLF
Methods for the Retail Store Roof.

Effect of using CLTD/SCL/CLF tables

for dates other than the 21st

The CLTDTAB program generates data only for the 21st of any month of the year. The "HVAC" software program however, is capable of calculating the cooling

loads for any day of the year. This is done by linear interpolation of the A, B, and C solar model coefficients.

To examine the effect of using the CLTD/SCL/CLF data for days other than the 21st, cooling loads for the 6th of the month, which is about midway between the 21st days of the preceding and next months, were calculated by the TF Method. These loads were compared with the cooling loads obtained by using the CLTD/SCL/CLF data (which are for the 21st of that month).

Of the three test zones, the retail store being driven by the roof, two walls and an exposed glass area was used for the study since it has a greater percentage of exterior surface areas. An important point to be noted is that the comparison was based on the assumption that the outdoor design conditions are the same for both the 6th and the 21st of the month, which actually may not be the case. Table XVIII shows the differences in the cooling loads obtained.

It is seen that the increase in the difference of the cooling loads by using CLTD/SCL/CLF data for the 6th is small compared to the magnitude of the load (maximum difference = 0.7% for hour 13). With the outside design temperatures being the same for the two days, the difference in the cooling loads is attributed to difference in the beam and diffuse radiations incident on the exterior surfaces of the zone for the 6th and the 21st. This can be easily noticed as the differences are greater during the daytime and smaller before sunrise and after sunset. Thus, the CLTD/SCL/CLF method may be used for cooling load calculations with reasonable accuracy for days other than the 21st for similar outside design conditions.

TABLE XVIII

COOLING LOADS FOR THE RETAIL STORE
FOR THE 6th OF JULY

Time	TF Method (for the 6th)	TF Method (for the 21st)	CLTD Method	Difference for the 6th	Difference for the 21st	Increase in Difference
1	28136.87	28105.63	27790.76	-346.11	-314.87	31.24
2	25750.16	25695.75	25326.26	-423.90	-369.49	54.41
3	23593.95	23543.25	23401.04	-192.91	-142.21	50.70
4	21713.26	21647.71	21564.14	-149.12	-83.57	65.55
5	20236.74	20217.27	20071.60	-165.14	-145.67	19.47
6	20008.52	20015.12	19929.40	-79.12	-85.72	-6.60
7	20623.65	20606.64	20357.24	-266.41	-249.40	17.01
8	22413.27	22389.05	22541.86	128.59	152.81	24.22
9	28756.11	28660.47	28699.22	-56.89	38.75	95.64
10	39080.20	38888.50	39081.97	1.77	193.47	191.70
11	45123.09	44851.28	45046.72	-76.37	195.44	271.81
12	50856.24	50505.85	50404.59	-451.65	-101.26	350.39
13	55342.14	54976.68	54872.24	-469.90	-104.44	365.46
14	58414.63	58103.42	57844.00	-570.63	-259.42	311.21
15	60080.10	59813.68	59687.66	-392.44	-126.02	266.42
16	60442.37	60299.60	60107.38	-334.99	-192.22	142.77
17	59738.30	59605.15	59251.59	-486.71	-353.56	133.15
18	57610.62	57516.27	57183.47	-427.15	-332.80	94.35
19	54382.28	54302.26	53724.24	-658.04	-578.02	80.02
20	51118.44	51041.20	50705.92	-412.52	-335.28	77.24
21	47950.48	47869.64	47379.07	-571.41	-490.57	80.84
22	42525.71	42469.85	41864.83	-660.88	-605.02	55.86
23	33507.79	33426.74	32910.45	-597.34	-516.29	81.05
24	30655.35	30597.85	30197.09	-458.26	-400.76	57.50

NOTE : 1)To = 96 °F, Ti = 75 °F, DR = 24 °F
2)All loads are in Btu/hr

Use of the CLTDTAB program

while interpolating for different

Latitudes

The new load calculation manual (1992) contains CLTD and SCL data for northern latitudes of 24, 36, and 48 degrees to be used for manual calculations. In order to calculate the loads for locations at other latitudes, while using the printed tables, interpolation is required. Alternatively, the CLTDTAB program can be used to generate a set of tables for the particular latitude.

To compare the differences resulting from interpolation of the latitude, the table values of the CLTDs for 36°N and 48°N were used to interpolate for values corresponding to a latitude of 42°N. To keep all other values the same while performing the comparisons, cooling loads determined by the TF Method were based on design conditions of 95°F outside, 78°F inside and a mean daily range of 21°F. Cooling loads for the exterior east wall of the Office from test zone 2 were calculated by both methods and compared. Table XIX shows the interpolated values of the CLTDs vis-a-vis those obtained by using the general option of the CLTDTAB for 42°N. The cooling loads obtained by the TF method are tabulated for comparison. As can be seen the maximum percent difference in the cooling loads obtained by interpolation is about 6.15 % at 8 hrs.

Similar comparison tests were carried out using the values of 24°N, 36°N, and 48°N to interpolate for intermediate latitudes and calculate the cooling loads by the CLTD/SCL/CLF method. The maximum percent difference observed due to interpolation ranged between 6 to 8 %.

Table XX shows the results of the comparison of the cooling loads for the east wall of the office area of test zone 2 using extrapolated CLTDs for 6°N from the tabulated values for 24°N and 36°N. This is an extreme test case and large differences in cooling load values are observed. These are partly due to the fact that with the CLTD

TABLE XIX

COOLING LOADS FOR 42°N LATITUDE USING
INTERPOLATION FOR CLTDs

Time	TFM	CLTD METHOD							
	Cooling Load	CLTD 36° N	CLTD 48° N	CLTD(42) Interpol.	Load_1	Difference (Load_1 - TFM)	CLTDs for 42 deg using CLTDTAB	Load_2	Difference (Load_2 - TFM)
1	941.03	17	17	17	950.30	9.27	16	894.4	-46.63
2	816.28	15	15	15	838.50	22.22	14	782.6	-33.68
3	702.20	12	13	12.5	698.75	-3.45	11	614.9	-87.30
4	598.04	11	11	11	614.90	16.86	10	559.0	-39.04
5	503.33	9	9	9	503.10	-0.23	8	447.2	-56.13
6	423.10	7	8	7.5	419.25	-3.85	7	391.3	-31.80
7	431.06	7	9	8	447.20	16.14	7	391.3	-39.76
8	655.75	11	14	12.5	698.75	43.00	12	670.8	15.05
9	1050.68	18	21	19.5	1090.05	39.37	20	1118.0	67.32
10	1488.41	26	28	27	1509.30	20.89	29	1621.1	132.69
11	1864.84	33	35	34	1900.60	35.76	35	1956.5	91.66
12	2117.21	37	39	38	2124.20	6.99	40	2236.0	118.79
13	2217.28	39	41	40	2236.00	18.72	41	2291.9	74.62
14	2187.05	39	40	39.5	2208.05	21.00	40	2236.0	48.95
15	2105.64	37	38	37.5	2096.25	-9.39	38	2124.2	18.56
16	2021.45	36	37	36.5	2040.35	18.90	36	2012.4	-9.05
17	1943.44	35	35	35	1956.50	13.06	35	1956.5	13.06
18	1864.20	33	34	33.5	1872.65	8.45	33	1844.7	-19.50
19	1772.99	32	32	32	1788.80	15.81	31	1732.9	-40.10
20	1659.20	30	30	30	1677.00	17.80	29	1621.1	-38.10
21	1520.39	27	27	27	1509.30	-11.10	26	1453.4	-66.99
22	1370.15	24	25	24.5	1369.55	-0.60	24	1341.6	-28.55
23	1220.29	22	22	22	1229.80	9.51	21	1173.9	-46.39
24	1076.37	19	20	19.5	1090.05	13.68	18	1006.2	-70.17

NOTE : To = 95 °F, T$_1$ = 78 °F, DR = 21 °F

U = 0.3 Btu/hr-ft^2-°F, Area = 2100 ft^2

Load_1 = U $*$ Area $*$ CLTD$_{42(Interpolated)}$

Load_2 = U $*$ Area $*$ CLTD$_{42(CLTDTAB)}$

TABLE XX

COOLING LOADS FOR 6°N LATITUDE USING
EXTRAPOLATION FOR CLTDs

Time	TFM			CLTD METHOD					
	Cooling Load	CLTD 24° N	CLTD 36° N	CLTD(6) Extrapol.	Load_1	Difference (Load_1 - TFM)	CLTDs for 6 deg using CLTDTAB	Load_2	Difference (Load_2 - TFM)
1	857.70	15	17	12	670.80	-186.90	14	782.6	-75.10
2	743.06	13	15	10	559.00	-184.06	12	670.8	-72.26
3	637.53	11	12	9.5	531.05	-106.48	10	559.0	-78.53
4	540.61	9	11	6	335.40	-205.21	9	503.1	-37.51
5	452.00	8	9	6.5	363.35	-88.65	7	391.3	-60.70
6	372.01	6	7	4.5	251.55	-120.46	6	335.4	-36.61
7	304.51	6	7	4.5	251.55	-52.96	5	279.5	-25.01
8	330.66	10	11	8.5	475.15	144.49	6	335.4	4.75
9	590.88	17	18	15.5	866.45	275.57	11	614.9	24.02
10	1004.55	25	26	23.5	1313.65	309.10	20	1118.0	113.45
11	1419.71	33	33	33	1844.70	424.99	27	1509.3	89.60
12	1732.74	37	37	37	2068.30	335.56	33	1844.7	111.96
13	1894.62	39	39	39	2180.10	285.48	35	1956.5	61.88
14	1918.98	39	39	39	2180.10	261.12	35	1956.5	37.52
15	1882.74	37	37	37	2068.30	185.56	34	1900.6	17.86
16	1834.03	36	36	36	2012.40	178.37	33	1844.7	10.67
17	1781.93	34	35	32.5	1816.75	34.82	32	1788.8	6.87
18	1718.68	33	33	33	1844.70	126.02	31	1732.9	14.22
19	1631.52	31	32	29.5	1649.05	17.53	29	1621.1	-10.42
20	1514.89	28	30	25	1397.50	-117.39	27	1509.3	-5.59
21	1382.43	26	27	24.5	1369.55	-12.88	24	1341.6	-40.83
22	1245.87	23	24	21.5	1201.85	-44.02	22	1229.8	-16.07
23	1111.06	20	22	17	950.30	-160.76	19	1062.1	-48.96
24	980.94	18	19	16.5	922.35	-58.59	17	950.3	-30.64

NOTE : T_o = 95 °F, T_i = 78 °F, DR = 21 °F
U = 0.3 Btu/hr-ft^2-°F, Area = 2100 ft^2
Load_1 = U * Area * $CLTD_{6(Extrapolated)}$
Load_2 = U * Area * $CLTD_{6(CLTDTAB)}$

values for both 24°N and 36°N being identical for some hours, extrapolation for 6°N yields the same value. The maximum percent difference due to extrapolation in this case was 23.1% for hour 11.

Use of shaded and unshaded

SCLs for solar heat gains through

Fenestration

To calculate the cooling load due to the radiant heat gain through fenestration by the CLTD/SCL/CLF method, a new factor called the Solar Cooling Load (SCL) is used. This factor, described in chapter III takes into account both the solar heat gain and the zone response for any latitude/month combination.

As pointed out earlier, the CLTDTAB program employs weighting factors to convert the transmission heat gains only (SOLAR WFs). The heat gains due to absorption are not converted to cooling load. Rather, they are assumed to directly represent instantaneous cooling loads. This assumption is acceptable because for all cases the magnitudes of the absorbed cooling loads are very small (2 to 3% of the total glass load). There are two other important differences between the methodologies of the revised TF and CLTD/SCL/CLF methods:

1) In the CLTD/SCL/CLF method, calculation of cooling loads through the shaded area of glass areas is based on the SCLs determined for a north facing glass surface at that location, which is assumed to represent a fully shaded glass surface, since it is almost never reached by the direct rays of the sun.

2) The CLTD/SCL/CLF method employs shaded and unshaded SCLs to calculate the cooling loads through the respective shaded and unshaded areas. The shaded SCLs represent a glass area that is completely shaded throughout the day while the unshaded SCLs represent a glass area that is completely unshaded throughout the day. In reality,

the shaded and unshaded glass areas may continuously vary during the day. Thus, the CLTD/SCL/CLF method is incapable of correctly accounting for the past history of varying shaded and unshaded glass areas.

In order to study the effect of the use of the north facing glass for shaded areas and the shaded and unshaded SCLs, test zone 2 (the office premises) was used to compare results obtained by the two methods. Besides this test zone, other cases of exterior shaded windows were examined and the results for some important cases are described in the following paragraphs.

The office of test zone 2 has three glass areas - two identical ones facing the north and the other, similar to the first two, facing the east. Cooling loads for these glass areas (only one of the north facing glass windows was considered) were calculated using the two methods (all parameters including the date of calculation, latitude, and the zone parameters were kept same for both methods) and compared. Figures 6.2 and 6.3 show the cooling loads obtained by the two methods for the north and east glass areas.

From figure 6.2 (cooling load for north facing window for the office area) it can be seen that there is an abrupt change in the cooling load profile for the CLTD/SCL/CLF Method for some hours early morning and late evening. This is because with the sun rising due north of east and setting due north of west, the window is actually subjected to beam radiation (I_D) from the sun during these hours, and remains partially unshaded. The SCLs for the shaded area in the CLTD/SCL/CLF Method are based on a north facing glass area and thus the effect of the beam radiation is included in the calculations of the transmitted and absorbed cooling loads through the shaded areas too.
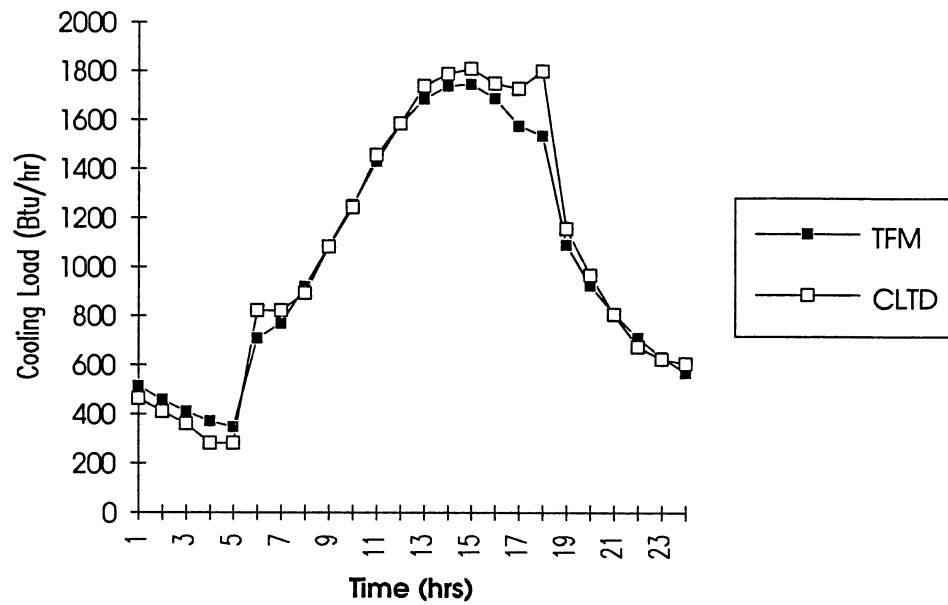
Figure 6.2: Cooling loads for the north window of test zone 2 by the
revised TF and CLTD/SCL/CLF methods
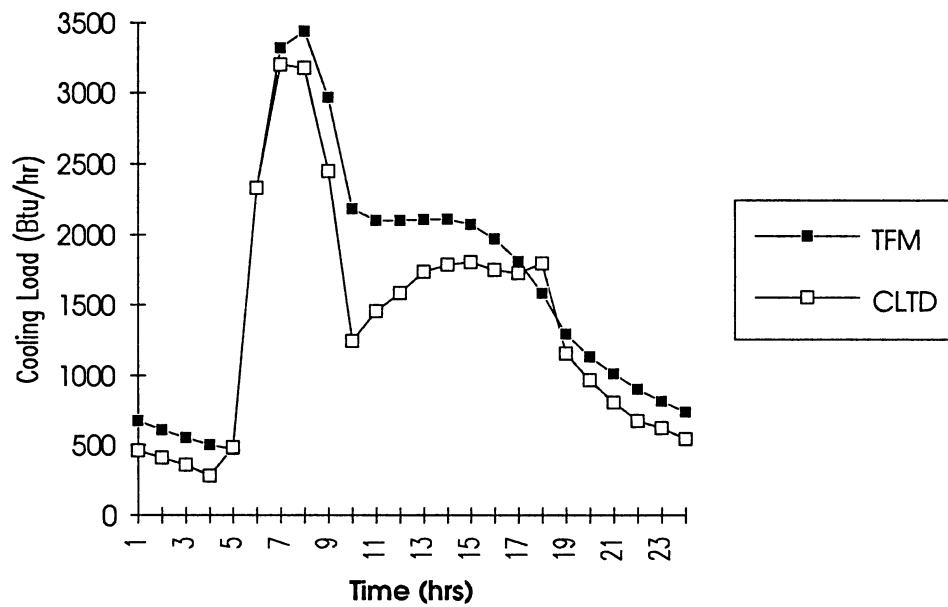
Figure 6.3: Cooling loads for the east window of test zone 2 by the
revised TF and CLTD/SCL/CLF methods
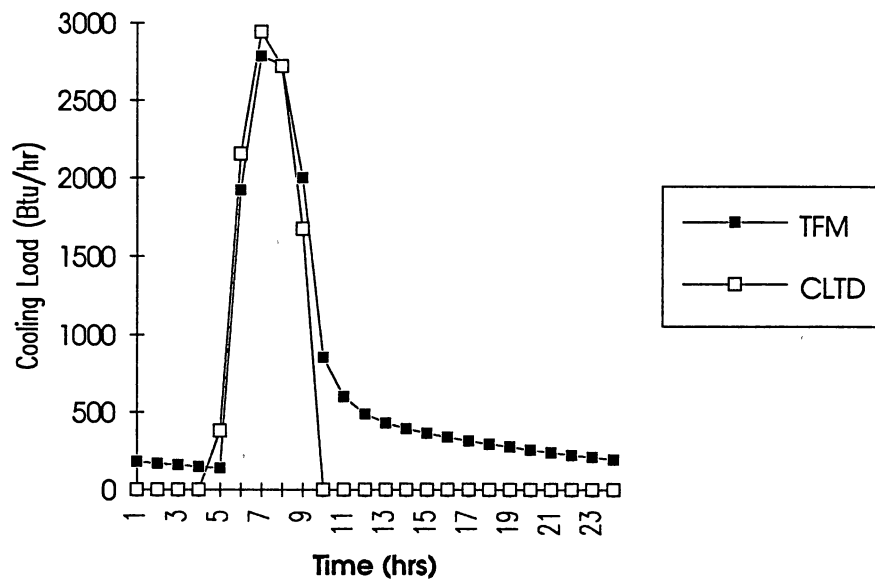
Figure 6.4:Transmitted cooling loads through the unshaded
area of the east window of test zone 2

The revised TF Method however, performs calculations of the transmitted and absorbed solar heat gains based on the shaded and unshaded portions and the facing direction of the glass area. Since accurate heat gains are obtained this way, the cooling loads determined by using the weighting factors are an accurate representation of the past history of the heat gains for the day. Appendix D shows plots of the transmitted cooling loads through the shaded and unshaded areas of the north and east glass areas.

Figure 6.3 is an example that shows the inability of the CLTD/SCL/CLF method to accurately account for the varying shaded and unshaded glass area. This can explained more clearly with respect to the tables XXXVII and XXXVIII from APPENDIX D and figure 6.4. At hour 10, the east facing glass area is completely shaded after having been partly shaded for the previous 5 hours. The cooling load for hour 10 predicted by the

CLTD/SCL/CLF method is based on a window that has been completely shaded for the entire day. Therefore, the load predicted by the CLTD/SCL/CLF method is considerably less than that predicted by the revised TF method, which correctly accounts for the beam radiation transmitted through the window earlier in the day.

To further analyze the effect of exterior shading, the cooling load profiles by the two methods were studied for externally shaded arbitrary facing glass areas at different latitudes. Tests were carried out to check the severity of the use of the shaded SCLs (north facing glass) for the shading calculations for glass areas at the equator. Generally, it is not recommended that these SCLs be used for latitudes below 24 °N on account of beam radiation being present for some hours at these latitudes for north facing glass (Load Calculation Manual - 1979, 1992).

Figure 6.6 shows the cooling load profiles obtained by the two methods for a southwest facing window. This exterior shading details for this window are shown in figure 6.5. The window is 5' in width and 4' high (U-factor = 0.82, shading coefficient = 0.58, To = 95 °F, Ti = 75 °F, DR = 21 °F) and is located at 0 °N latitude (the equator).
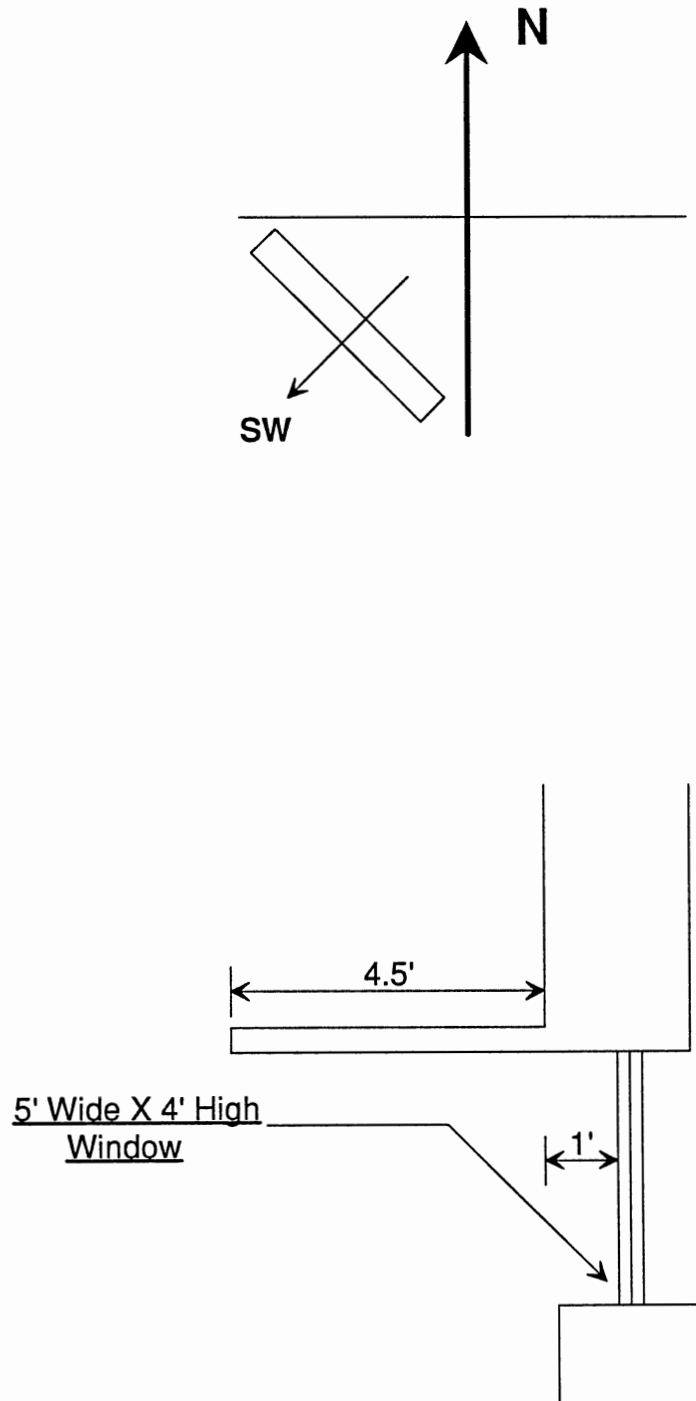
Figure 6.5: An externally shaded south west facing
window

Figure 6.6:Cooling loads for the SW facing window at 0 °N by the
revised TF and CLTD/SCL/CLF methods

Figure 6.7:Transmitted cooling loads through the shaded area of the
SW facing window at 0 °N

Figure 6.8:Transmitted cooling loads through the unshaded area of
the SW facing window at 0 °N

This configuration represents a somewhat extreme case of external shading. The awkward behavior of the cooling load profile obtained by the CLTD/SCL/CLF method is due to

1) the contribution of the beam radiation to the SCLs calculated for the shaded glass area (north orientation) and

2) The inability of the CLTD/SCL/CLF method to correctly account for the past history of the varying areas of the shaded and unshaded portions of the glass areas in the cooling load calculations.

As seen in figure 6.7, the transmitted cooling loads through the shaded portion of the glass area by the two methods shows great variations with differences as much as 200% for some hours. This deviation of the cooling load profile from that obtained by the TF method is a result of the beam radiation on a north facing glass area for these

hours and the corresponding heat gain being included in the SCL calculation for north (shaded) facing glass.

Figure 6.8 shows the transmitted cooling loads by the two methods through the unshaded areas. Since the south west facing window is shaded for most of the day except for a few hours in the evening, the cooling load profiles show an increase towards the evening. However, the cooling load calculations by the CLTD/SCL/CLF method are based only on the respective shaded and unshaded areas at the hour of calculation and do not account for the variation in these areas for the hours that preceded this hour. Thus, the cooling load profile obtained does not accurately represent the actual load. On the other hand, the TF method accounts for these changes during the conversion of the heat gains into the corresponding cooling loads and thus the cooling load profile is more normalized. This is why the cooling load profile by the CLTD/SCL/CLF method (figure 6.8) shows a sudden rise in the cooling load from previous values of zero whereas that for the TF method shows a more gradual increase from earlier positive values of the load.

Another test was carried out for a south west facing glass area (5 ft. wide by 4 ft. in height) at 24 °N latitude. The temperatures selected were 95 °F on the outside and 75 °F on the inside. The daily range was set at 21 °F. External shading details are the same as shown in figure 6.5. A "heavy" zone was selected (no interior shade, no furniture, no suspended ceiling, and vinyl tile for the floor) in order to obtain the most extreme possible effect. It was found that with this configuration of the window, it remained completely shaded throughout the day except at hour 18. The TF code was modified such that the glass area remained *totally unshaded* at this hour. The CLTDTAB code was modified so as to calculate the SCLs for shaded areas also. Using these separate values of the shaded and unshaded SCLs cooling loads were determined for the window and compared with those obtained by the revised TF method.

Figure 6.9 shows the cooling load profiles obtained by the two methods. On observing the plots in figures 6.10 and 6.11, it can be concluded that while the TF

method successfully takes into consideration the past history of changing shaded and unshaded areas of the window, the CLTD/SCL/CLF does not. Hence an abrupt change in the cooling load profile is noticed.

Appendix E shows the cooling loads obtained by the two methods for a typical case of external shading. The cooling load plots indicate the typical errors that may be encountered with the use of the CLTD/SCL/CLF method for externally shaded glass areas. Both the inability of the CLTD/SCL/CLF method to account for the past history of the varying shaded/unshaded areas and the effect of the use of the North facing glass SCLs for shaded glass areas are noticeable.
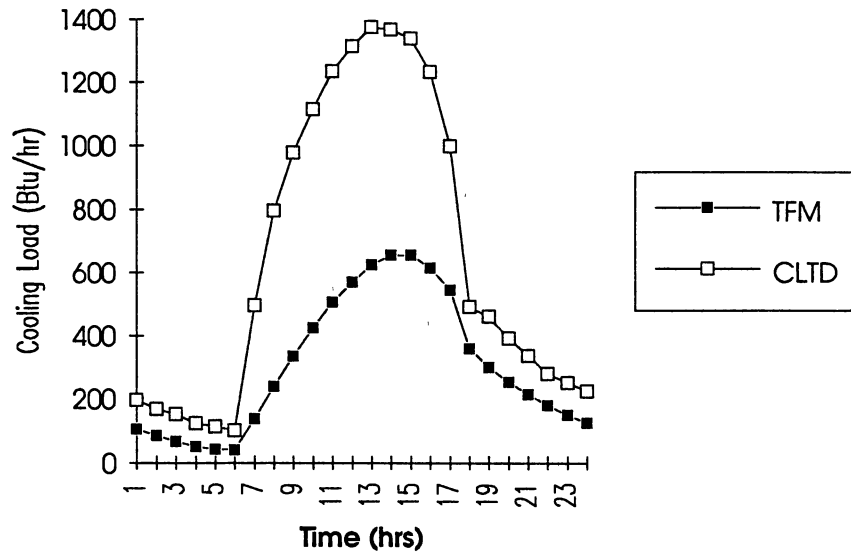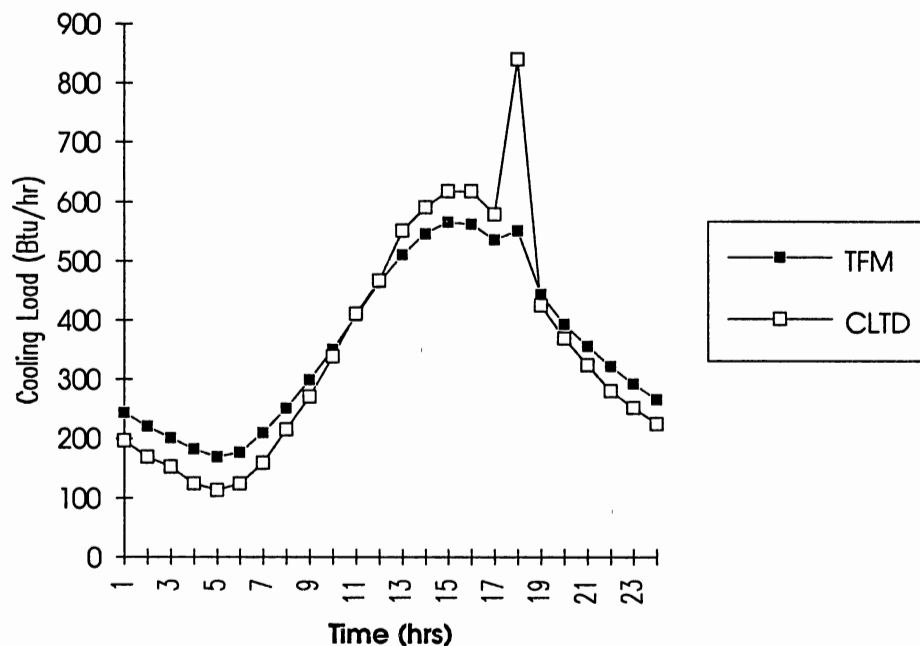

Figure 6.9: Cooling loads for the SW facing window at 24 °N by the revised TF and CLTD/SCL/CLF methods
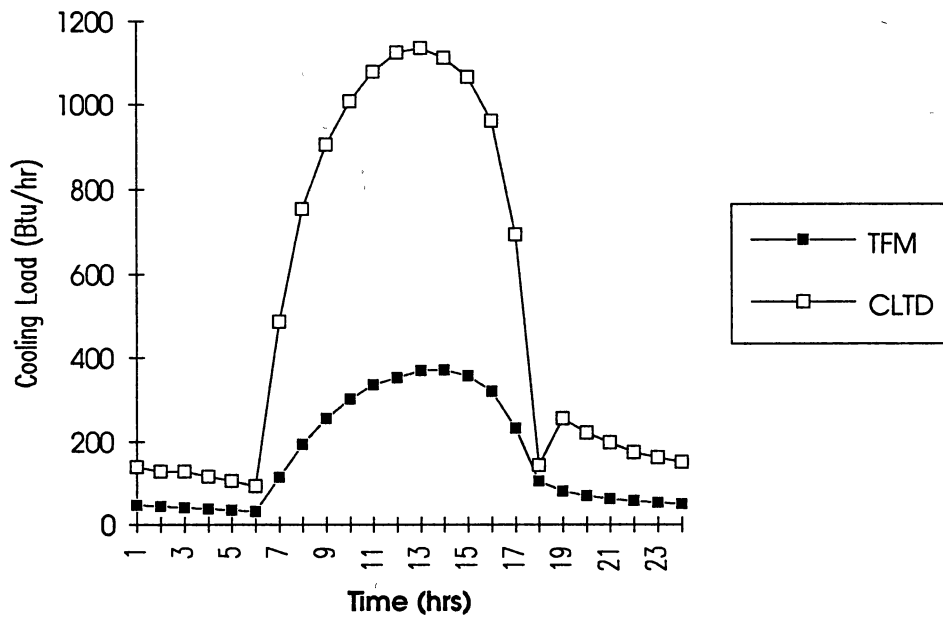
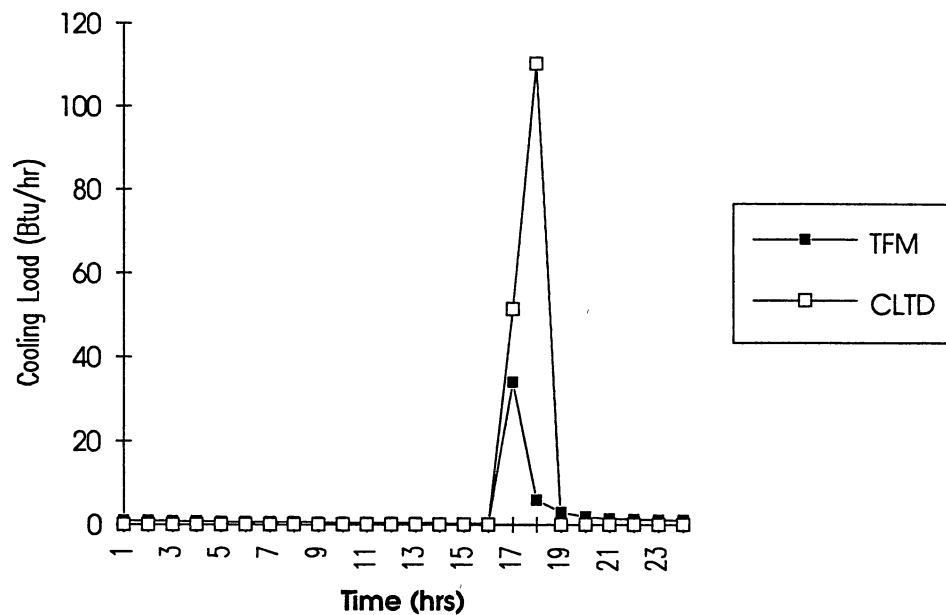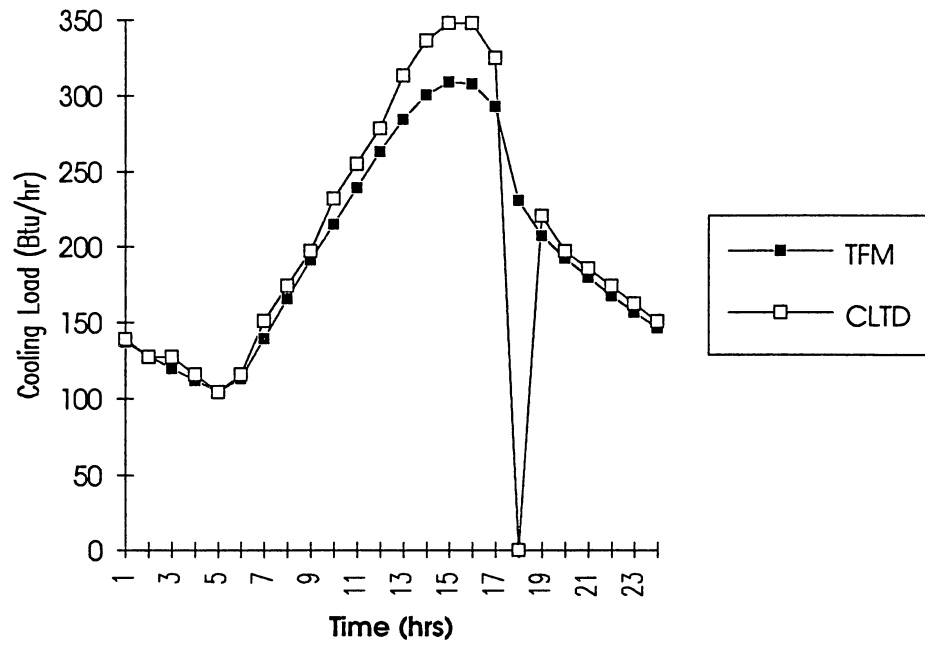Figure 6.10: Transmitted cooling loads through the shaded area of the
SW facing window at 24 °N
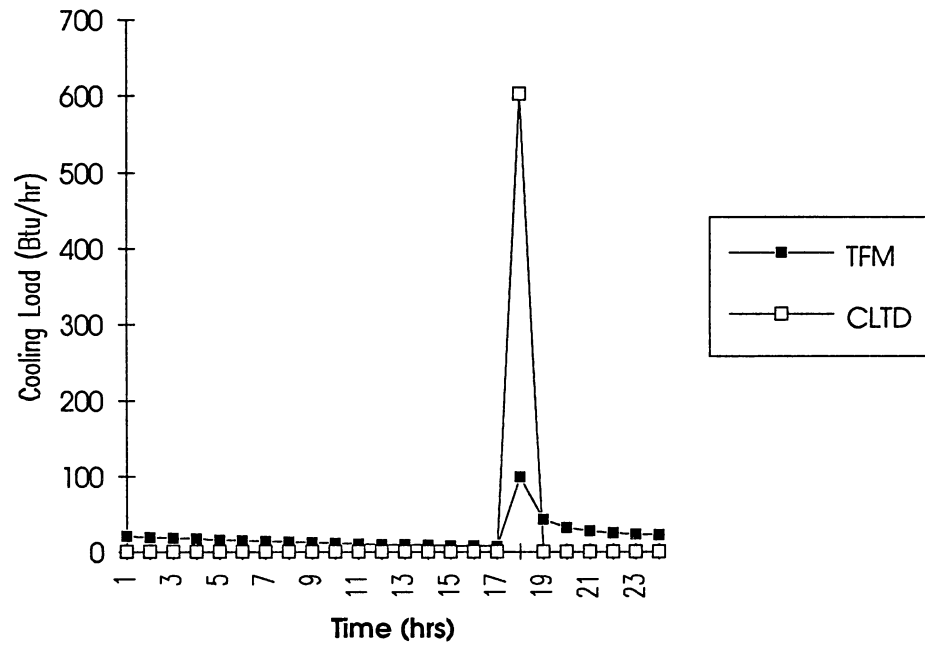
Figure 6.11: Transmitted cooling loads through the unshaded area of the
SW facing window at 24 °N

From the tests carried out on the use of the SCLs for externally shaded glass areas, two important conclusions can be drawn:

1) A north facing window does not always accurately represent a completely shaded glass area throughout the day and significant inaccuracies in the cooling loads are obtained in some cases, especially locations near the equator.

2) For the case of a glass window where shading caused by overhangs or awnings exists and *varies* during the day, the application of the tabulated solar cooling loads (both the shaded and unshaded) does not yield accurate cooling loads. This is because these SCLs are calculated based on the assumption that the same condition prevails throughout the day i.e the unshaded SCLs represent a glass area that is *unshaded throughout the day* while the shaded SCLs represent a glass area that is fully *shaded throughout the day*. Since the shaded and unshaded areas change their respective sizes, the cooling load is not proportional to the total glass area, rather it is dependent on the past history of the changing shaded and unshaded areas. The heat storage effect due to these varying areas and their sizes needs to be taken into account during calculation of the cooling loads. However, in the CLTD/SCL/CLF method, it is not possible to generate SCL tables for varying areas because of the number of combinations that exist.

Todorovic and Curcija in their paper (1984) explained a possible way of determining the cooling loads through glass areas accounting for the varying shaded and unshaded areas. Their method, called the "Negative Cooling Load Method" first calculates the cooling loads as if the glass area is completely unshaded. These loads are then corrected to account for the effect of shading by using "negative storage factors". These negative storage factors were tabulated for 8 directions for light, medium, and heavy zones based on July 21, 40 °N latitude.

Table XXI summarizes the results of the various tests carried out to examine the differences between the two methods.

TABLE XXI

SUMMARY OF COMPARISON TESTS

TEST	RESULT
1) Using the rounded table values of the CLTDs, SCLs, and CLFs for cooling load calculations	Differences in the loads obtained by using the table CLTDs for exterior roofs, walls, and the SCLs for glass areas without external shading were within the error range. Marginal differences in loads using the CLFs for internal sources (0.5 to 1%).
2) Using the table values of the CLTDs to calculate the cooling loads for dates other than the 21st	Cooling loads calculated by the two methods showed small differences for same outside design conditions (1%)
3) Using the CLTDTAB program while interpolating for different latitudes	Small differences in the cooling loads calculated by the two methods (6 to 8%).
4) (a) Using the SCLs for north facing glass as an approximation for shaded glass. (b) Using the shaded and unshaded SCLs to calculate cooling loads through externally shaded glass areas	(a) Use of the north (shaded) SCLs for locations near the equator showed considerable differences in the cooling load values (Maximum difference observed = 120% for 0°N SW facing window). Moderate differences were found for latitudes farther north (12%) (b) Large differences were observed in the transmitted cooling loads through glass areas that were unshaded for some part of the day (Maximum difference observed = 200% for 0°N SW facing window). The CLTD/SCL/CLF cooling load profile showed its inherent inability to correctly account for the previous history of heat gains due to the varying shaded and unshaded areas. (Max. difference observed = 43% for east glass of test zone 2)

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This chapter contains the conclusions that are drawn from the preceding chapters and some recommendations for work that can be carried out on the subject in the future.

Conclusions

1) A comprehensive software program, currently called HVAC, has been developed. This program calculates the cooling loads for a given building based on the revised Transfer Function Method and is a user-friendly software working under a graphical user interface (Microsoft WINDOWS™). In addition to performing cooling load calculations, the HVAC software program calculates the heat extraction rates for zones of interest and heating loads for buildings.

2) The results of the comparison of the two methods, the revised TF and the CLTD/SCL/CLF method, have brought forward many points:

   a) The CLTDTAB program used to generate custom tables for the CLTD/SCL/CLF method calculates the cooling loads at the hour rather than at half past the hour. The HVAC program however, calculates the cooling loads at half the hour which is considered to be an adequate representation of the hour. In order to have consistency in the comparison, a version of HVAC which calculated the cooling loads at the hour was prepared and cooling loads compared.

   b) The results of the comparison of the two methods have validated the CLTD/SCL/CLF method as a fairly accurate method for manual calculations of cooling loads. Cooling loads obtained by the this method compared reasonably

with those obtained by the TF method for the various comparison tests that were carried out (except for some cases where glass areas were externally shaded).

c) Differences in cooling loads through externally shaded glass areas were observed. These were considerable for glass areas located near the equator. The SCLs calculated for north facing glass and being used to determine cooling loads through shaded areas did not give correct results for all cases and for glass areas near the equator. This is due to the fact that for locations near the equator (latitudes less than 24 °N) north facing surfaces are exposed to sunlight, and hence beam radiation, for some hours. It can thus be concluded that it is not quite appropriate to use the SCLs of the north facing glass for shaded calculations near the equator. This has also been recommended by the Load Calculation Manual (1992).

d) The cooling load profiles for the cooling loads due to transmitted heat gains for the glass areas that receive direct sunlight for only some hours showed deviations on account of the inherent inability of the CLTD/SCL/CLF method to correctly account for the past history of heat gains due to varying shaded and unshaded glass areas. This is because the SCLs are calculated on the basis that the same condition prevailed throughout the day - i.e. the unshaded SCLs represent a glass area that is *unshaded throughout the day* and the shaded SCLs represent a glass area that is *shaded throughout the day*. Hence, while the cooling load profile of the revised TF method showed a gradual change in the cooling load, that for the CLTD/SCL/CLF method shows an abrupt shift for the hour(s) of change from shaded to unshaded.

e) Calculations of the cooling loads for heat gains due to internal sources using the CLFs from the tables for *even* hour schedules (2hrs, 4 hrs, 6 hrs etc.) resulted in closely matching values with those obtained by the TF method. However, no table values are available for *odd* hour schedules (3 hrs, 5 hrs, 7 hrs etc.). Interpolation for these values does not give correct values of the CLFs.

Recommendations

Following are some recommendations aimed at further improvement of the HVAC software program and research in the area of cooling load calculation:

1) Like most software programs, the HVAC software has room for enhancement in a number of areas with a view to make it more user-oriented:

   (a) The HVAC program uses the X-Y shading concept to determine the shaded and unshaded glass areas. Walton (1979) and McCluney (1990) have developed shading algorithms for complex geometries. It is suggested that one of these algorithms be employed for the HVAC program.

   (b) The current version uses default values for various parameters like the coefficients of heat transfer at the outside (h_o) and inside surfaces (h_i), emissivity (ε), ground reflectance (ρ_g), and the long wave radiation difference (δR). It is suggested that rather than restraining the program to use these default values, the software can be modified so as to allow the user to enter values that would suit his design specifications.

   (c) While the program has a "Save as Default" feature, a library of locations with their design conditions would make an excellent feature. This would save the user from having to refer to the Handbook for design conditions and type them in every time he performs load calculations for a different location.

2) The HVAC program has been tested for its correctness in determining cooling loads. Comparison tests have been carried out with the CLTD/SCL/CLF method. It is suggested that comprehensive tests with major energy (and load calculation) programs like BLAST be carried out. This will prove beneficial in further validating the software program, and in general the revised TF method.

3) The current CLTDTAB program calculates unshaded SCLs for 9 facing directions (8 vertical + 1 horizontal). SCLs for the north facing glass are used for

calculations through shaded glass areas. There are two possible ways of representing the cooling loads through glass areas:

(a) Calculate the SCLs for a shaded north facing glass area to be used for approximating all shaded glass areas.

(b) Calculate both shaded and unshaded SCLs for the surface for each facing direction *separately* and use them for calculations.

Either option can be used for cooling load calculations. However, it should be noted that the current CLTDTAB program does not account for the Y - factor for vertical surfaces. It is suggested that the SCL calculations be based on the anisotropic model of diffuse sky radiation (inclusion of the Y - factor) and SCLs tabulated for all 9 directions.

4) There are several differences in implementation between the HVAC and CLTDTAB programs. Following are a list of suggested modifications to the CLTDTAB program:

(a) All calculations, including the solar radiation calculations be based on half past the hour.

(b) Include the Y- factor in the calculations for solar radiation through vertical surfaces.

(c) As mentioned above, shaded and unshaded SCLs be calculated separately for all facing directions and used for cooling load calculations.

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APPENDIXES

APPENDIX A

SAMPLE COOLING LOAD CALCULATIONS

FOR TEST ZONE 1

Sample Cooling Load Calculation for the Retail Store

using the revised TF Method

Determination of the Room Parameters

Table XXII shows the fourteen room parameters that define the Retail Store.

TABLE XXII

ZONE PARAMETERS FOR THE
RETAIL STORE

No.	Parameter	Choice # (Closest match)	Description
1	Zone Geometry	1	100 ft x 20 ft.
2	Zone Height	2	10 ft.
3	# of Ext. Walls	2	2
4	Zone Location	1	Single-Story
5	Interior Shade	3	0 percent
6	Furniture	1	With
7	Ext. Wall Constrn.	4	Heavy wall with Moderate Insulation
8	Partition Type	1	5/8 in. Gyp-Air-5/8 in. Gyp
9	Mid Flr. Type	1	8 in. Conc.
10	Slab Type	2	4 in. Slab on 12 in. Soil
11	Ceiling Type	1	3/4 in. Acoustic Tile & Air Space
12	Roof Type	2	LW w/o suspended ceiling
13	Floor Covering	2	Vinyl Tile
14	Glass Percent	3	10

Once the fourteen room parameters have been selected, the weighting factors for the zone are determined using the Weighting Factor routines.

Determination of the Wall CTF Coefficients

      The exterior wall of the store is categorized as shown in table XXIII.
The location of the thermal mass of the wall, the 8 in. heavy weight concrete block is outside with respect to the insulation, hence the mass location is "mass out"
The corresponding resistance range No. 9 [table 2.6(a) of the LCM].

TABLE XXIII

CATEGORIZATION OF THE RETAIL
STORE WALL

Code Letter	Description	R - Value (hr-sq.ft.-°F/Btu)
A0	Outside Surface Resistance	0.33
A2	4 in. Face Brick	0.43
B1	Airspace Resistance	0.91
C8	8 in. HeavyWeight Concrete Block	1.11
B2	1 in. Insulation	3.33
E1	3/4 in. Plaster or Gypsum (closest to dry wall)	0.15
E0	Inside Surface Resistance	0.69
	TOTAL RESISTANCE	6.95

The primary and secondary wall materials are the 8 in. HW Concrete Block (C8) and the 4 in. face brick (A2).

When these parameters are passed to the *wget* routine, a wall type of 17 is returned with the following CTF coefficients and a U- factor of 0.1439 Btu / hr-sq.ft.-F

n	b_n	d_n
0	0.000000	1.000000
1	0.000005	-2.008750
2	0.000134	1.371200
3	0.000436	-0.378967
4	0.000300	0.039616
5	0.000051	-0.001647
6	0.000002	0.000023

These CTF coefficients need to be unnormalized based upon the ratio of the actual U-factor of the wall and the U-factor that corresponds to the matching wall type. The actual U-factor of the wall is calculated to be 0.15 Btu / hr-sq.ft.-F as compared to 0.04232 Btu / hr-sq.ft.-F. Thus, the ratio is:

$$U_{actual} / U_{wall\ type} = 0.1439 / 0.04232 = 3.331$$

The unnormalized CTF coefficients are multiplied by this ratio and are tabulated as follows:

n	b_n	d_n
0	0.000000	1.000000
1	0.000017	-2.008750
2	0.000446	1.371200
3	0.001452	-0.378967
4	0.000999	0.039616
5	0.000170	-0.001647
6	0.000007	0.000023

and

$$\sum c_n = \sum b_n = 0.003091$$

Determination of the Roof CTF Coefficients

The roof of the store is categorized in a manner similar to the wall as shown in table XXIV.

Mass Location: "mass in" as the 2 in. heavy weight concrete is on the inside with respect to the insulation.

The corresponding resistance range is No. 2 [table 2.7(a) of the LCM].

The primary roof material is the 2 in. HW Concrete (C12).

The CTF coefficients before and after unnormalization are as shown in table XXV.

TABLE XXIV

CATEGORIZATION OF THE RETAIL
STORE ROOF

Code Letter	Description	R - Value (hr-sq.ft.-°F/Btu)
A0	Outside Surface Resistance	0.33
E2	1/2 in. Slag	0.05
E3	3/8 in. Felt and Membrane	0.29
B2	1 in. Insulation	3.33
C12	2 in. HW Concrete	0.17
A3	Corrugated Metal Deck	0.00
E4	Ceiling Air Space	1.00
E5	Acoustic Tile	1.79
E0	Inside Surface Resistance	0.69
	TOTAL RESISTANCE	7.65

Roof type selected : 8 (from *rget* routine)

U- factor : 0.4243 Btu / hr-sq.ft.-°F

Actual U - factor : 0.1226 Btu / hr-sq.ft.-°F

Ratio : 0.1226 / 0.4243 = 0.289

TABLE XXV

CONDUCTION TRANSFER COEFFICIENTS
FOR THE WALL

n	Conduction CTF coefficients		d_n
	b_n		
	Before Unnormalization	After Unnormalization	
0	0.000984	0.000284	1.000000
1	0.019384	0.005602	-1.102350
2	0.020827	0.006022	0.207496
3	0.002189	0.000633	-0.002865
4	0.000015	0.000004	0.000002
5	0.000000	0.000000	0.000000
6	0.000000	0.000000	0.000000

and

$$\sum c_n = \sum b_n = 0.012545$$

Calculation of the heat gains

Solar radiation intensity. The following steps show the calculation of the solar intensities and the sol-air temperatures for the South Wall of the store for the time period 09:00 hrs to 10:00 hrs for the 21st of June (The calculations are based on 10:00 hrs)

Solar Time	=	10:00 hrs
Hour Angle (h)	=	- 0.25 deg / min * (2 * 60)
	=	- 30.0 degrees
		(SIGN CONVENTION: Hour angles are negative for Local Solar Times before noon)
Declination angle (δ)	=	+23.45* degrees (table 2-2)
Solar altitude angle (β)	=	sin⁻ [(cos 36 cos 23.45 cos -30.0) + (sin 36 sin 23.45)]
	=	61.24 degrees
Solar Azimuth angle (ϕ)	=	cos⁻ [(sin β sin l - sin δ) / cos β cos l]
	=	72.45 degrees

According to the sign convention, if the hour angle is negative, the angle ϕ is also taken as negative, hence

ϕ	=	-72.45 degrees
Wall Facing angle	=	180 degrees (facing South)
Wall Azimuth angle (ψ)	=	0 degrees

According to the sign convention, if the surface faces east of south (Wall Facing angle <= 180) then ψ is negative. However, here ψ = 0 degrees

Wall Solar Azimuth angle (γ)	=	abs(ϕ - ψ)

---

* Note that all values calculated here may differ slightly from those tabulated using the HVAC program on account of round - off during calculations. For example, the value of declination calculated by the HVAC program is 0.4086 radians or 23.41 degrees.

	=	abs(-72.45 - 0)
	=	72.45 degrees
Angle of incidence (θ)	=	$\cos^-[\cos\beta\cos\gamma]$
	=	81.66 degrees
Direct Normal Intensity (I_{DN})	=	$A\,e^{(-B/\sin\beta)}$

where

A	=	346.3 (Table II)
B	=	0.185 (Table II)
C	=	0.137 (Table II)

Hence

I_{DN}	=	$346.3\,e^{(-0.185/\sin 61.24)}$
	=	280.42 Btu / hr-ft^2
Direct Intensity (I_D)	=	$I_{DN}\cos\theta$
	=	40.67 Btu / hr-ft^2
Ratio (Y)	=	$0.55 + 0.437\cos\theta + 0.313\cos^2\theta$
	=	0.620
Diffuse Intensity (Id)	=	Ids + Idg
	=	$C\,Y\,I_{DN} + 0.5*I_{DN}(C + \sin\beta)*\rho g$
	=	$0.137 * 0.620 * 280.42 + 0.5 *$
		$280.42 * (0.137 + 0.8766) * 0.2$
	=	52.24 Btu / hr-ft^2
Total Solar Intensity (I_t)	=	$I_D + I_d$
	=	92.91 Btu / hr-ft^2
Sol-Air Temperature (t_e)	=	$t_o + \alpha\,I_t / h_o - \varepsilon\,\delta R / h_o$
	=	82.56 + 0.9 * 92.91 / 3.0 - 0.0

(Note: t_o is the outside hourly summer DBT calculated using the percent daily range - table 2.9 of the LCM)

$$= \quad 110.43\ °F$$

Calculation of the hourly heat gains due to conduction. Once the hourly sol-air temperatures for the surface have been determined as shown in the earlier section, using the b_n, c_n, and d_n CTF coefficients, the hourly heat gains due to conduction are calculated using equation 2.32:

$$q_{e,\theta} = A \left[\sum_{n=0} b_n\, {}^{(t_{e,\theta}\, -\, n\delta)} - \sum_{n=1} d_n\, \{{}^{(q_{e,\theta}\, -\, n\delta)}/A\} - t_{rc} \sum_{n=0} c_n \right]$$

Thus, given that the design zone temperature is 75°F , the conduction heat gains for the East facing wall are calculated. Note that the heat flux terms are initially assumed to be zero. The above equation is used successively until convergence is reached for the 24 hour periods. The results are as shown in table XXVI:

TABLE XXVI

SOL-AIR TEMPERATURES AND CONDUCTION
HEAT GAINS FOR SOUTH WALL

Time (hr)	Sol-Air Temp (°F)	Conduction Heat Gain (Btu/hr)
1	75.12	502.068
2	73.92	474.834
3	72.96	444.471
4	72.24	412.327
5	72.12	379.389
6	77.15	346.364
7	81.91	313.839
8	87.06	282.714
9	97.71	254.917
10	110.66	232.845

$$= \quad 6484.41 \text{ Btu} / \text{hr}$$

$$\text{ASHGF} \quad = \quad I_D \sum_{j=0}^{5} a_j [\cos\theta]^j + I_d * 2 \sum_{j=0}^{5} a_j / (j+2)$$

$$= \quad 40.67 * 0.06384 + 52.24 * 0.05436$$

$$= \quad 5.436 \text{ Btu} / \text{hr-ft}^2$$

$$\text{ASHG} \quad = \quad \text{ASHGF} * SC * Ni * A$$

$$= \quad 5.436 * 0.55 * 0.327 * 210$$

$$= \quad 205.314 \text{ Btu} / \text{hr}$$

Conversion of the heat gains
into cooling loads

Once the hourly heat gains for all components of the zone have been calculated, the corresponding hourly cooling loads due to the individual components have to be calculated. For this purpose, we use equation 2.1 in conjunction with the appropriate weighting factors. The following section shows the application of the weighting factors to the lighting heat gains calculated for the retail store in order to convert the heat gains into cooling loads:

5000 Btu/hr of fluorescent lighting is on from 8 a.m. until 10 p.m. Using the 14 room parameters for the retail store, the following WF coefficients were obtained from the database:

$$v0 \quad = \quad 0.611160$$

$$v1 \quad = \quad -0.672670$$

$$v2 \quad = \quad 0.129870$$

$$w1 \quad = \quad -1.197180$$

$$w2 \quad = \quad 0.265540$$

Now, assuming the initial values of the cooling loads and the previous values of the heat gains to be zero, equation 2.1 is used successively until convergence is reached for the 24 hour time period. The results of the convergence with the final cooling loads is as depicted in table XXVII. Note that the cooling loads converge by around 5th or 6th day:

TABLE XXVII

THE CONVERGING PROCESS FROM HEAT GAINS
TO COOLING LOADS FOR THE LIGHTING

Time	COOLING LOAD (Btu/hr)					
(hr)	1st Iteration	2nd Iteration	3rd Iteration	4th Iteration	5th Iteration	6th Iteration
1	0.00	1111.36	1206.50	1214.76	1215.48	1215.54
2	0.00	994.52	1080.45	1087.91	1088.56	1088.62
3	0.00	895.51	973.12	979.86	980.44	980.49
4	0.00	808.00	878.10	884.18	884.71	884.76
5	0.00	729.53	792.84	798.33	798.81	798.85
6	0.00	658.82	716.00	720.96	721.40	721.43
7	0.00	595.01	646.65	651.13	651.52	651.56
8	0.00	537.39	584.03	588.08	588.43	588.46
9	3055.80	3541.15	3583.28	3586.94	3587.25	3587.28
10	3350.79	3789.15	3827.20	3830.50	3830.79	3830.81
11	3541.86	3937.78	3972.14	3975.12	3975.38	3975.40
12	3692.28	4049.86	4080.89	4083.58	4083.82	4083.84
13	3821.62	4144.57	4172.60	4175.03	4175.24	4175.26
14	3936.51	4228.20	4253.51	4255.71	4255.90	4255.92
15	4039.72	4303.16	4326.03	4328.01	4328.19	4328.20
16	4132.78	4370.70	4391.36	4393.15	4393.30	4393.32
17	4216.77	4431.66	4450.31	4451.93	4452.07	4452.08
18	4292.61	4486.70	4503.54	4505.00	4505.13	4505.14
19	4361.11	4536.40	4551.61	4552.94	4553.05	4553.06
20	4422.97	4581.29	4595.03	4596.22	4596.33	4596.34
21	4478.84	4621.83	4634.24	4635.32	4635.41	4635.42
22	4529.31	4658.45	4669.66	4670.63	4670.72	4670.72
23	1519.08	1635.72	1645.85	1646.72	1646.80	1646.81
24	1265.25	1370.60	1379.74	1380.54	1380.60	1380.61

Conversion of the other types
of heat gains into cooling loads

The transmitted solar heat gains (TSHGs) are converted into cooling loads by using the SOLAR Weighting Factors, whereas the absorbed solar heat gains (ASHGs) are converted into cooling loads using the CONDUCTION Weighting Factors. This is because the absorbed solar heat gains are conducted through the glass area into the space, where it is later convected and radiated in a manner similar to the heat conduction that takes place through walls and roofs. Hence the response is similar.

The heat gains due to internal equipment or occupancy are converted into the corresponding cooling loads using the OCCUPANT or EQUIPMENT Weighting Factors. The Weighting Factors are the same for both types. This is because the heat gains from both people and equipment are split into 70% radiant and 30% convective.

The heat gains from Lighting, as shown in the retail store problem earlier, uses the LIGHTING Weighting Factors. The light heat gain is split into 59% radiant and 41% convective.

The Total Cooling Load - Summation
of the hourly cooling loads

Once all the hourly cooling loads have been determined for each type of heat gain, including the heat gain due to infiltration which forms an instantaneous cooling load, the loads for each hour for each zone is added up to obtain the total hourly cooling load for the building. Peak loads for each room, zone and the building can be determined and the air-conditioning machinery designed/selected suitably. However, if the zone temperatures vary significantly, the heat extraction rate, one of the added features of the Transfer Function Method, can be carried out.

Cooling Load Calculation using the "CLTD/SCL/CLF" Method

The calculations of the cooling loads using the CLTD/SCL/CLF Method are based on the tables generated by the CLTDTAB program. Option 2 (the specific option) was used and the Retail Store details entered so as to obtain the CLTDs, SCLs and CLFs. These values were then used to calculated the individual loads.

Cooling Load Due to Heat Gain
through Roofs and Walls

The calculations for the cooling loads for the roof of the retail store for the time period 09:00 hrs to 10:00 hrs are as under:

Roof Area	=	2100 ft^2
Roof U-Factor	=	$0.1226 \text{ Btu / hr-ft}^2$
CLTD from table	=	$19°F$
Corrected CLTD	=	$CLTD + (78 - T_1) + (T_m - 85)$
	=	$19 + (78 - 75) + (84 - 85)$
	=	$21°F$
		$[T_m = T_0 - \text{Daily Range}/2$
		$= 96 - 24/2 = 84°F]$
Cooling Load q	=	$U * A * CLTD$
	=	$0.1226 * 2100 * 21$
	=	5406.66 Btu / hr

Cooling Load Due To Heat Gain
Through Windows

The heat gain through glass areas is divided into the radiant and conductive portions. The conduction cooling load is calculated as

$$q_{cond} = U * A * CLTD$$

while that due to solar radiation is calculated as

$$q_{rad} = A * SC * SCL$$

Thus,

$$q_{Total} = q_{cond} + q_{rad}$$

The cooling load through the south glass of the retail store for the time period 09:00 hrs to 10:00 hrs is calculated as follows:

Window Area	=	210 ft^2
Window U-Factor	=	0.81 Btu / hr-ft^2
Glass shading coeff.	=	0.55
CLTD from table	=	4°F
Corrected CLTD	=	4 + (78 - 75) + (84 - 85) =6°F
$q_{conduction}$	=	0.81 * 210 * 6
	=	1020.6 Btu/hr
SCL from table	=	35
$q_{radiant}$	=	210 * 0.55 * 35
	=	4042.5 Btu/hr
Total Load, q_{Total}	=	1020.6 + 4042.5
		5063.1 Btu/hr

Cooling Loads due to Internal Heat Gain

The cooling load calculations involving the internal heat gain sources utilize the cooling load factor (CLF). The CLF is the fraction of the sensible heat gain that appears as cooling load for the hour under consideration.

The internal cooling loads for the retail store for the time period 09:00 hrs to 10:00 hrs are calculated as follows:

Cooling Load Due to Lights   =   Sensible Gain $* F_u * F_s * CLF$

(Assuming Unvented Ceiling Plenum)

where

$F_u = 1.0$, $F_s = 1.20$

CLF = 0.77 from the CLF table

Now, in the HVAC program, the sensible heat gain entered is inclusive of the ballast factor (Fs).

Hence,

q_{Lights} =   5000 * 1.0 * 0.77

          =   3850.00 Btu/hr

Cooling Load from People   = $q_{Sensible} + q_{Latent}$

where

$q_{Sensible}$ =   Number of People $* q'_s * F_d * CLF$

          = $15 * 250 * 1.0 * 0.69$

          =   2587.50 Btu/hr (Delayed Load)

q_{Latent} =   Number of People $* q'_l * F_d$

          =   15*20*1.0 Btu/hr

          =   3000 Btu/hr

Hence,

q_{Total} =   5587.50 Btu/hr

Cooling Loads due to

Infiltration

The calculation of the cooling load due to infiltration is the same as calculated by the TFM.

Infiltration Sensible Load	=	1.1 * CFM * ΔT * Hour Fraction
	=	1.1 * 630 * (77.4 - 75) * 1.0
	=	1663.2 Btu/hr
Infiltration Latent Load	=	4840 * CFM * ΔW * Hour Fraction
	=	4840 * 630 * (0.013 - 0.0092) * 1.0
	=	11586.96 Btu/hr
Total Infiltration Load	=	1663.2 + 11586.96
	=	13250.16 Btu/hr

Tables XXVIII, XXIX, and XXX show the cooling load comparisons for the south glass window, people, lighting of the retail store respectively while figures A.1, A.2, and A.3 depict the plots of the same. Table XXXI shows the total cooling loads for the retail store calculated by both methods and the difference in these load values. Figure A.4 depicts the plot of these total cooling loads.

TABLE XXVIII

COMPARISON OF THE COOLING LOADS BY THE REVISED TF AND
CLTD/SCL/CLF METHODS FOR THE SOUTH WINDOW
OF THE RETAIL STORE

Hour	TF Method	CLTD Method	Difference
1	1734.31	1665.30	-69.01
2	1444.89	1379.70	-65.19
3	1188.44	1209.60	21.16
4	966.62	924.00	-42.62
5	818.77	808.50	-10.27
6	1328.45	1386.00	57.55
7	1920.10	1848.00	-72.10
8	2613.75	2765.70	151.95
9	3533.16	3683.40	150.24
10	4972.23	5063.10	90.87
11	6492.20	6612.90	120.70
12	7623.09	7530.60	-92.49
13	8084.48	8040.90	-43.58
14	7880.94	7749.00	-131.94
15	7278.00	7110.60	-167.40
16	6774.52	6648.60	-125.92
17	6185.52	6016.50	-169.02
18	5369.15	5268.90	-100.25
19	4302.48	4120.20	-182.28
20	3708.73	3549.00	-159.73
21	3214.17	3093.30	-120.87
22	2761.42	2522.10	-239.32
23	2367.50	2236.50	-131.00
24	2033.10	1950.90	-82.20

MAXIMUM PERCENT DIFFERENCE = 9.5% at 22 hrs

TABLE XXIX

COMPARISON OF THE COOLING LOADS BY THE REVISED TF AND
CLTD/SCL/CLF METHODS FOR THE
RETAIL STORE PEOPLE

Hour	TF Method	CLTD Method	Difference
1	755.13	750.00	-5.13
2	679.89	675.00	-4.89
3	613.09	600.00	-13.09
4	553.11	562.50	9.39
5	499.06	487.50	-11.56
6	450.31	450.00	-0.31
7	406.32	412.50	6.18
8	366.64	375.00	8.36
9	330.83	337.50	6.67
10	5597.60	5587.50	-10.10
11	5791.79	5775.00	-16.79
12	5906.86	5925.00	18.14
13	5994.86	6000.00	5.14
14	6070.10	6075.00	4.90
15	6136.90	6150.00	13.10
16	6196.89	6187.50	-9.39
17	6250.94	6262.50	11.56
18	6299.69	6300.00	0.31
19	6343.67	6337.50	6.17
20	6383.36	6375.00	-8.36
21	6419.17	6412.50	-6.67
22	4152.40	4162.50	10.10
23	958.21	975.00	16.79
24	843.14	825.00	-18.14

MAXIMUM PERCENT DIFFERENCE = 0.31% at 12 hrs

TABLE XXX

COMPARISON OF THE COOLING LOADS BY THE REVISED TF AND
CLTD/SCL/CLF METHODS FOR THE
RETAIL STORE LIGHTING

Hour	TF Method	CLTD Method	Difference
1	1215.54	1200	-15.54
2	1088.62	1100	11.38
3	980.50	1000	19.50
4	884.76	900	15.24
5	798.85	800	1.15
6	721.43	700	-21.43
7	651.56	650	-1.56
8	588.46	600	11.54
9	3587.28	3600	12.72
10	3830.81	3850	19.19
11	3975.40	4000	24.60
12	4083.84	4100	16.16
13	4175.26	4200	24.74
14	4255.92	4250	-5.92
15	4328.20	4350	21.80
16	4393.32	4400	6.68
17	4452.08	4450	-2.08
18	4505.14	4500	-5.14
19	4553.06	4550	-3.06
20	4596.34	4600	3.66
21	4635.42	4650	14.58
22	4670.72	4650	-20.72
23	1646.81	1650	3.19
24	1380.61	1400	19.39

MAXIMUM PERCENT DIFFERENCE = 0.59% at 13 hrs
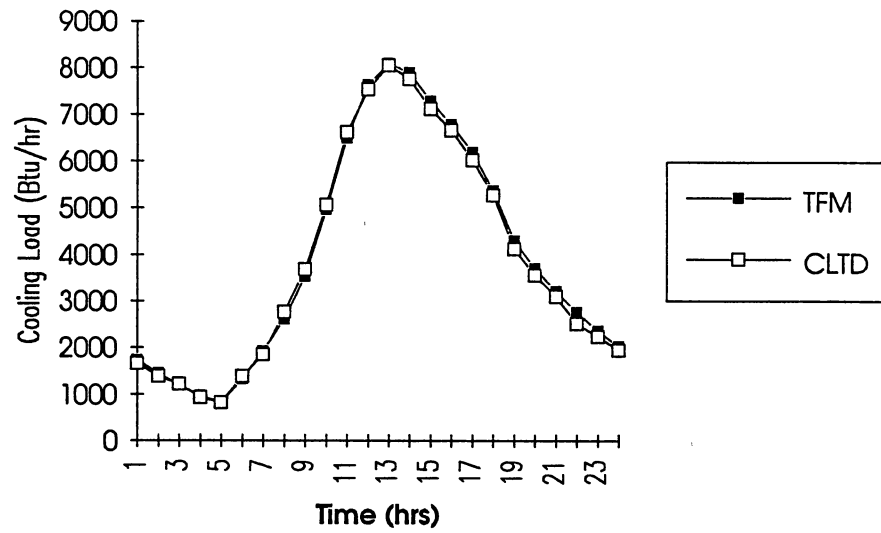
Figure A.1: Total glass cooling loads for the south window of
the Retail Store by the revised TF and the
CLTD/SCL/CLF Methods
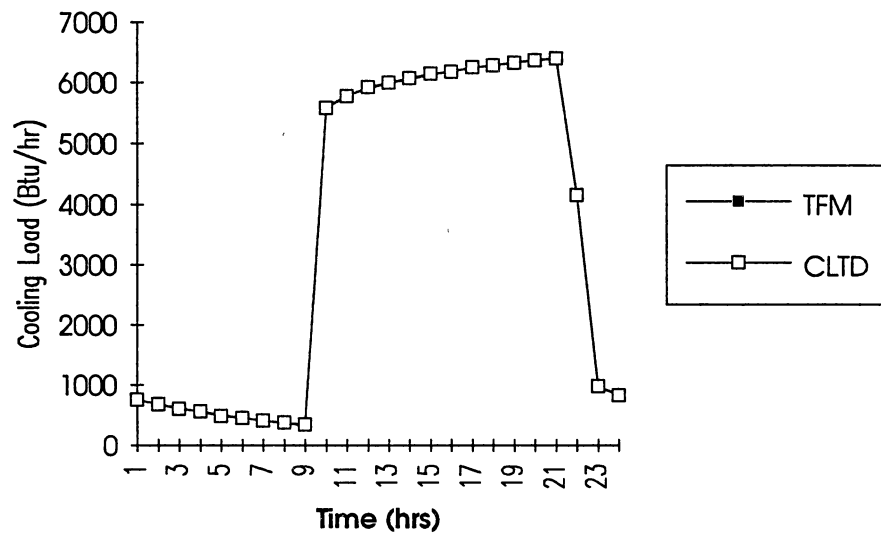
Figure A.2: Cooling loads for the people of the Retail Store by
the revised TF and the CLTD/SCL/CLF
Methods

Figure A.3: Cooling loads for the lighting of the Retail Store by the revised TF and the CLTD/SCL/CLF Methods

TABLE XXXI

COOLING LOADS FOR THE RETAIL STORE BY THE
REVISED TF AND THE CLTD/SCL/CLF
METHODS

Hour	TOTAL COOLING LOAD (Btu/hr)		
	By TF Method	By CLTD Method	Difference
1	28105.63	27790.76	-314.87
2	25695.75	25326.26	-369.49
3	23543.25	23401.04	-142.21
4	21647.71	21564.14	-83.57
5	20217.27	20071.60	-145.67
6	20015.12	19929.40	-85.72
7	20606.64	20357.24	-249.40
8	22389.05	22541.86	152.81
9	28660.47	28699.22	38.75
10	38888.50	39081.97	193.47
11	44851.28	45046.72	195.44
12	50505.85	50404.59	-101.26
13	54976.68	54872.24	-104.44
14	58103.42	57844.00	-259.42
15	59813.68	59687.66	-126.02
16	60299.60	60107.38	-192.22
17	59605.15	59251.59	-353.56
18	57516.27	57183.47	-332.80
19	54302.26	53724.24	-578.02
20	51041.20	50705.92	-335.28
21	47869.64	47379.07	-490.57
22	42469.85	41864.83	-605.02
23	33426.74	32910.45	-516.29
24	30597.85	30197.09	-400.76

NOTE : To = 96°F, Ti = 75°F, Mean daily range = 24°F

Figure A.4: Total cooling loads for the Retail Store by the revised
TF and the CLTD/SCL/CLF Methods

APPENDIX   B

COOLING LOAD RESULTS FOR TEST ZONE 2

TABLE XXXII

COMPARISON OF THE COOLING LOADS BY THE REVISED TF AND
CLTD/SCL/CLF METHODS FOR
TEST ZONE 2

	Office Area			Computer Room			Total Load		
Time	TFM	CLTD	Difference	TFM	CLTD	Difference	TFM	CLTD	Difference
1	11616.13	11233.95	-382.18	94126.67	93222.93	-903.75	105742.8	104456.9	-1285.92
2	10797.18	10367.61	-429.57	93230.88	92387.50	-843.38	104028.1	102755.1	-1272.95
3	10054.17	9538.97	-515.20	92501.46	91716.65	-784.82	102555.6	101255.6	-1300.01
4	9383.03	9054.67	-328.36	91939.34	91210.38	-728.95	101322.4	100265.1	-1057.32
5	8803.50	8638.28	-165.22	91709.73	91033.29	-676.43	100513.2	99671.6	-841.66
6	10933.26	10846.51	-86.74	91977.59	91349.97	-627.62	102910.9	102196.5	-714.37
7	11737.98	11718.92	-19.06	92743.53	92160.41	-583.12	104481.5	103879.3	-602.18
8	43049.42	42482.61	-566.81	94178.42	93629.19	-549.23	137227.8	136111.8	-1116.04
9	90687.96	89921.85	-766.11	98038.89	97568.83	-470.06	188726.9	187490.7	-1236.17
10	95765.55	94561.29	-1204.26	100608.50	100087.60	-520.82	196374.1	194648.9	-1725.16
11	100961.70	100083.00	-878.66	103519.60	102910.60	-609.00	204481.3	202993.6	-1487.70
12	105536.80	104823.10	-713.68	106282.20	105569.00	-713.16	211819.0	210392.1	-1426.90
13	108951.60	108362.90	-588.68	108388.80	107556.60	-832.27	217340.4	215919.5	-1420.90
14	111290.30	110949.70	-340.60	109822.60	108885.80	-936.81	221112.9	219835.5	-1277.40
15	112420.60	112140.50	-280.11	110406.40	109392.00	-1014.36	222827.0	221532.5	-1294.50
16	112136.80	111869.90	-266.83	109973.70	108910.80	-1062.89	222110.5	220780.7	-1329.80
17	110851.10	110997.90	146.80	108858.70	107771.20	-1087.52	219709.8	218769.1	-940.70
18	108809.70	109470.20	660.47	107067.80	105973.20	-1094.60	215877.5	215443.4	-434.10
19	60502.64	60515.26	12.62	104934.80	103846.10	-1088.75	165437.4	164361.4	-1076.08
20	17456.57	17496.70	40.13	102791.30	101718.90	-1072.36	120247.9	119215.6	-1032.27
21	15857.87	15784.58	-73.29	99228.10	98108.47	-1119.64	115086.0	113893.1	-1192.92
22	14577.85	14162.47	-415.39	97482.28	96412.59	-1069.69	112060.1	110575.1	-1485.07
23	13475.51	13296.13	-179.39	96085.88	95070.90	-1014.99	109561.4	108367.0	-1194.36
24	12500.30	12315.09	-185.22	95023.45	94058.37	-965.09	107523.8	106373.5	-1150.29

MAXIMUM PERCENT DIFFERENCE (For Total Load) = 0.89% at 10 hrs
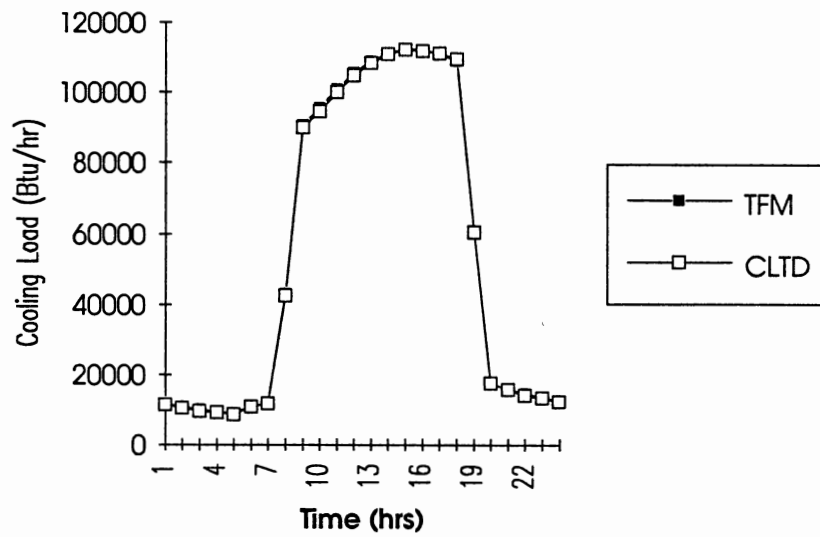
Figure B.1: Total cooling loads for the office area of test
zone 2 by the revised TF and the
CLTD/SCL/CLF Methods
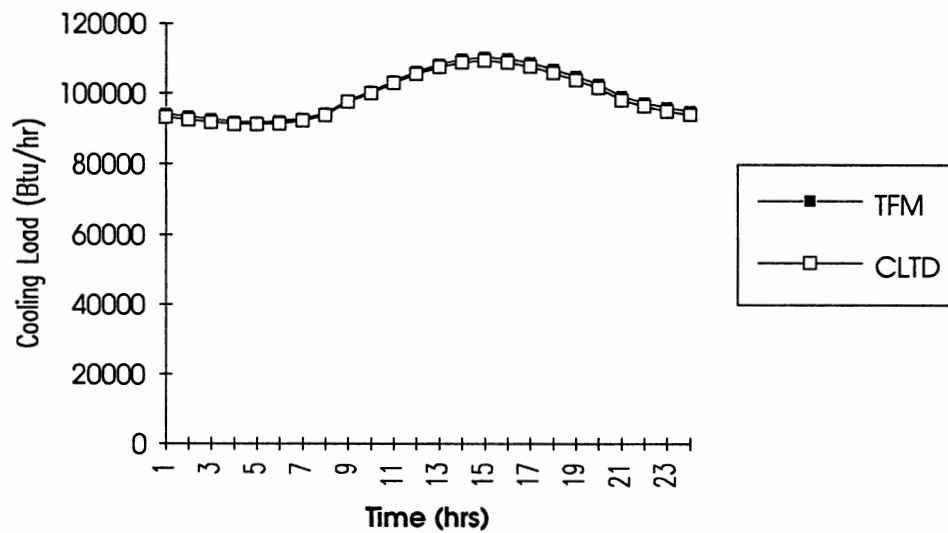
Figure B.2: Total cooling loads for the computer room of test
zone 2 by the revised TF and the
CLTD/SCL/CLF Methods
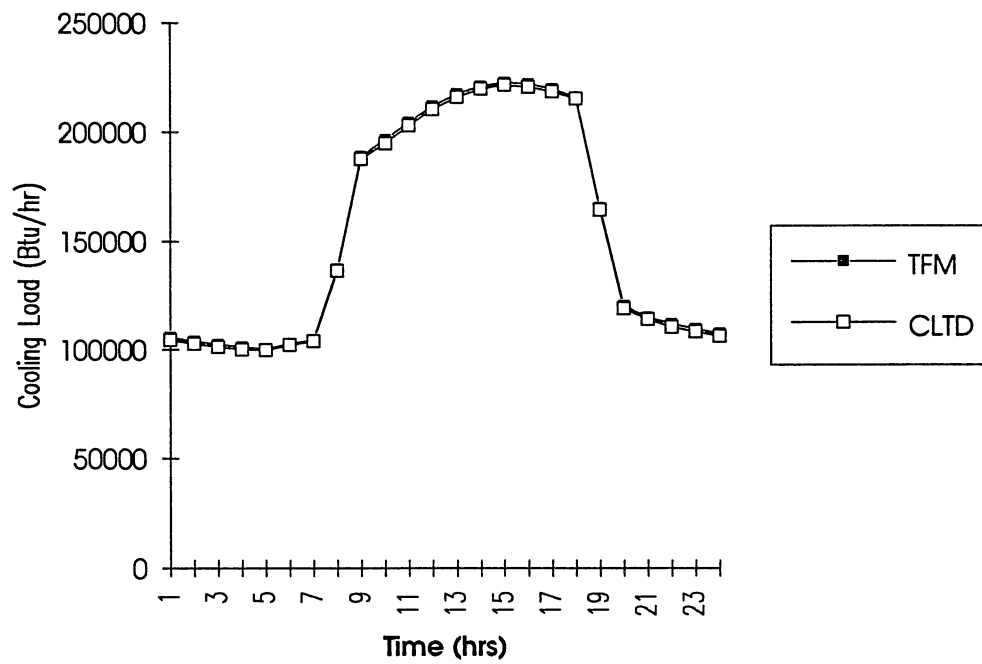
Figure B.3: Total cooling loads for test zone 2 by the revised
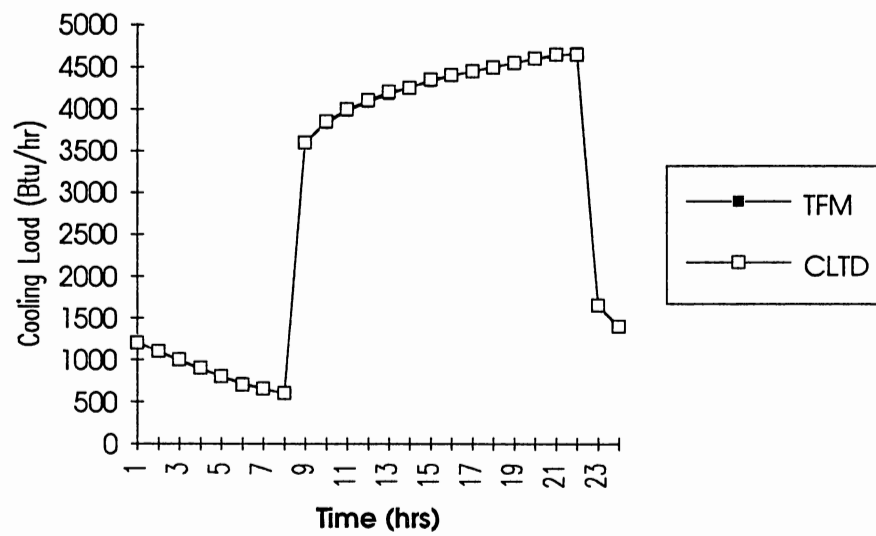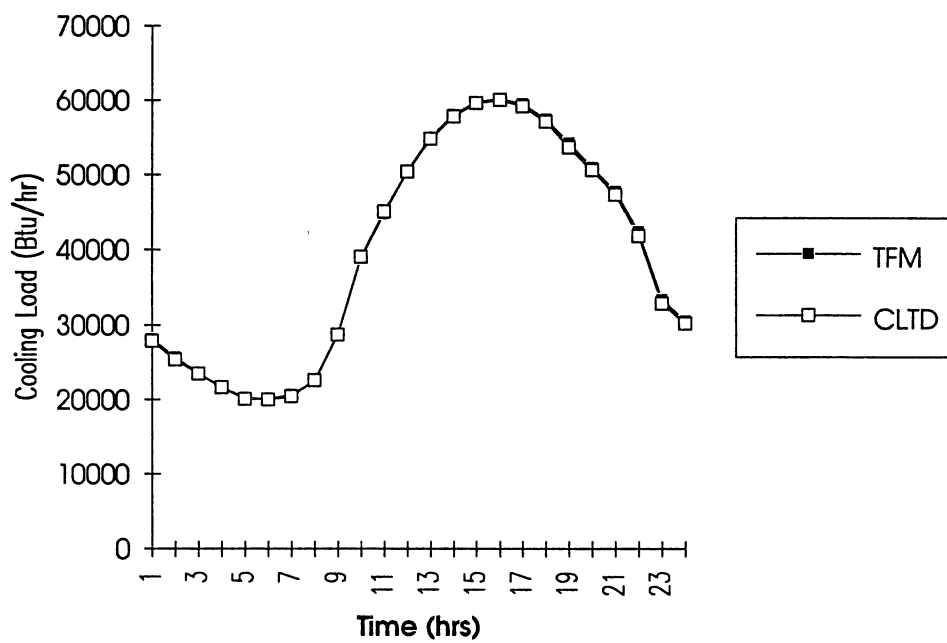TF and the CLTD/SCL/CLF Methods

APPENDIX   C

COOLING LOAD RESULTS FOR TEST ZONE 3

TABLE XXXIII

COMPARISON OF THE COOLING LOADS BY THE REVISED TF AND
CLTD/SCL/CLF METHODS FOR
TEST ZONE 3

Hour	TF Method	CLTD Method	Difference
1	23727.80	25064.10	1336.27
2	18187.19	20197.50	2010.30
3	13306.43	16302.10	2995.63
4	9020.04	10774.60	1754.56
5	8215.07	10153.90	1938.81
6	16304.08	18431.40	2127.30
7	18162.08	19995.40	1833.29
8	76105.56	78510.50	2404.96
9	316300.80	317950.00	1649.15
10	357195.20	357393.00	198.21
11	389149.30	387936.00	-1212.95
12	416000.80	413677.00	-2323.41
13	444173.00	440399.00	-3773.60
14	474906.30	469881.00	-5025.75
15	498809.70	493044.00	-5765.51
16	511363.50	505740.00	-5623.16
17	511820.10	505743.00	-6077.10
18	498220.30	493823.00	-4397.71
19	226218.00	221687.00	-4531.09
20	170058.70	169175.00	-883.77
21	62460.47	61864.00	-596.49
22	47748.47	46903.20	-845.23
23	37673.75	38874.10	1200.37
24	30021.13	31695.40	1674.30

MAXIMUM PERCENT DIFFERENCE = 1.20% at 17 hrs

Figure C.1: Total cooling loads for Test Zone 3 by the
revised TF and the CLTD/SCL/CLF
Methods

APPENDIX D

COOLING LOAD COMPARISONS FOR EXTERNALLY
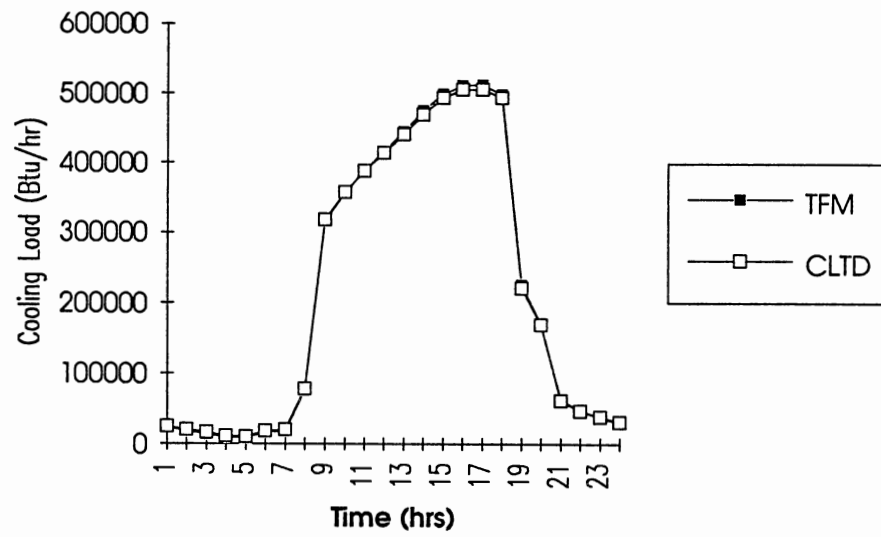
SHADED GLASS AREAS

TABLE XXXIV

COOLING LOADS BY THE REVISED TF METHOD FOR THE
NORTH WINDOW OF OFFICE AREA (TEST ZONE 2)

Time	I_D	I_d	Shd Area	TSHG Shd	T_load Shd	Unshd Area	TSHG Unshd	T_load Unshd	T_total	Q_cond	Q_Total
1	0	0	60	0	183.51	0	0	19.41	202.91	307.07	512.58
2	0	0	60	0	171.34	0	0	18.08	189.42	266.96	458.79
3	0	0	60	0	160.02	0	0	16.87	176.88	232.85	411.99
4	0	0	60	0	149.45	0	0	15.75	165.20	205.19	372.50
5	0.088	0.025	6.495	0.065	139.62	53.505	2.302	15.73	155.35	190.31	347.66
6	40.960	19.000	31.550	239.490	236.83	28.445	554.550	260.44	497.26	195.08	708.86
7	26.120	29.850	60	715.610	464.11	0	0	69.17	533.28	220.61	767.79
8	0	36.490	60	874.580	587.74	0	0	41.58	629.31	273.62	919.42
9	0	41.390	60	992.090	682.25	0	0	30.56	712.81	355.21	1086.64
10	0	44.540	60	1067.600	752.25	0	0	25.57	777.82	453.98	1251.98
11	0	47.400	60	1136.300	814.22	0	0	22.81	837.03	569.18	1427.81
12	0	48.370	60	1159.500	854.04	0	0	20.93	874.97	682.49	1579.78
13	0	47.400	60	1136.300	868.35	0	0	19.41	887.76	773.83	1683.87
14	0	44.540	60	1067.600	855.60	0	0	18.08	873.68	840.42	1735.57
15	0	41.390	60	992.090	831.62	0	0	16.87	848.49	874.78	1743.69
16	0	36.490	60	874.580	783.51	0	0	15.75	799.26	869.32	1687.26
17	26.120	29.850	60	715.610	708.93	0	0	14.71	723.64	834.46	1574.30
18	40.960	19.000	31.550	239.490	483.91	28.445	554.550	260.20	744.11	770.38	1534.52
19	0.088	0.025	6.495	0.065	325.58	53.505	2.302	70.07	395.65	688.95	1090.31
20	0	0	60	0	275.72	0	0	41.73	317.45	603.16	924.91
21	0	0	60	0	247.34	0	0	30.62	277.95	526.64	808.26
22	0	0	60	0	227.36	0	0	25.59	252.95	455.25	711.50
23	0	0	60	0	211.04	0	0	22.83	233.87	395.33	632.23
24	0	0	60	0	196.65	0	0	20.93	217.58	347.78	568.16

NOTE : 1) U-factor = 0.84, SC = 0.5, Glass area = 60 ft^2

2) To = 94°F, Ti = 74°F, DR = 18°F

3) I_D = Beam Radiation, I_d = Diffuse Radiation, TSHG = Transmitted heat gain

4) T_load = Cooling load due to transmitted heat gain

5) Q_cond = Cooling load due to conduction heat gain

6) Q_Total is inclusive of the cooling loads due to absorbed heat gains

TABLE XXXV(a)

SAMPLE TABLES OBTAINED BY EXECUTING THE SHADEC PROGRAM FOR SHADOW LENGTHS DUE TO EXTERNAL SHADING (HORIZONTAL PROJECTIONS)

Shadow Lengths for Building Exterior Projections
May 21st

HORIZONTAL PROJECTION   38 Deg North Latitude
Shadow Length Foot per Foot Projection, Sh/P

Solar Time	N	NE	E	SE	S	SW	W	NW
5	0.045	0.020	0.021	0.055	*	*	*	*
6	0.781	0.246	0.224	0.444	*	*	*	*
7	3.358	0.554	0.443	0.722	*	*	*	*
8	*	1.034	0.714	0.985	29.407	*	*	*
9	*	1.978	1.105	1.291	5.260	*	*	*
10	*	5.055	1.813	1.718	3.680	*	*	*
11	*	*	3.807	2.459	3.200	28.406	*	*
12	*	*	*	4.353	3.078	4.353	*	*
13	*	*	*	28.406	3.200	2.459	3.807	*
14	*	*	*	*	3.680	1.718	1.813	5.055
15	*	*	*	*	5.260	1.291	1.105	1.978
16	*	*	*	*	29.407	0.985	0.714	1.034
17	3.358	*	*	*	*	0.722	0.443	0.554
18	0.781	*	*	*	*	0.444	0.224	0.246
19	0.045	*	*	*	*	0.055	0.021	0.020

TABLE XXXV(b)

SAMPLE TABLES OBTAINED BY EXECUTING THE SHADEC
PROGRAM FOR SHADOW LENGTHS DUE TO EXTERNAL
SHADING (VERTICAL PROJECTIONS)

Shadow Lengths for Building Exterior Projections
May 21st

VERTICAL PROJECTION   38 Deg North Latitude
Shadow Width Foot per Foot Projection, Sw/Pv

Solar Time	N	NE	E	SE	S	SW	W	NW
5	2.165	0.368	0.462	2.717	*	*	*	*
6	3.487	0.554	0.287	1.804	*	*	*	*
7	7.578	0.767	0.132	1.304	*	*	*	*
8	*	1.050	0.024	0.953	41.203	*	*	*
9	*	1.532	0.210	0.653	4.761	*	*	*
10	*	2.943	0.493	0.340	2.030	*	*	*
11	*	*	1.190	0.087	0.841	11.553	*	*
12	*	*	*	1.000	0.000	1.000	*	*
13	*	*	*	11.553	0.841	0.087	1.190	*
14	*	*	*	*	2.030	0.340	0.493	2.943
15	*	*	*	*	4.761	0.653	0.210	1.532
16	*	*	*	*	41.203	0.953	0.024	1.050
17	7.578	*	*	*	*	1.304	0.132	0.767
18	3.487	*	*	*	*	1.804	0.287	0.554
19	2.165	*	*	*	*	2.717	0.462	0.368

TABLE XXXVI

COOLING LOADS BY THE CLTD/SCL/CLF METHOD FOR THE NORTH WINDOW OF OFFICE AREA (TEST ZONE 2)

| Time	Sh/P	Sh	Actual Sh	Sv/Pv	Sv	Unshd Area	Shad Area	SCL	Q_unsh	SCL North	Q_shd	CLTD	CLTD Corr	Q_cond	Total Load
1	0	0	0	0	0	0	60	7	0	7	210	1	5	252.0	462.0
2	0	0	0	0	0	0	60	7	0	7	210	0	4	201.6	411.6
3	0	0	0	0	0	0	60	7	0	7	210	-1	3	151.2	361.2
4	0	0	0	0	0	0	60	6	0	6	180	-2	2	100.8	280.8
5	0.05	0.16	0	2.17	1.08	53.52	6.48	6	160.56	6	19.44	-2	2	100.8	280.8
6	0.78	2.73	2.48	3.49	1.74	29.05	30.95	24	348.56	24	371.45	-2	2	100.8	820.8
7	3.36	11.75	11.50	7.58	3.79	0	60	24	0	24	720	-2	2	100.8	820.8
8		0	0		0	0	60	23	0	23	690	0	4	201.6	891.6
9		0	0		0	0	60	26	0	26	780	2	6	302.4	1082.4
10		0	0		0	0	60	28	0	28	840	4	8	403.2	1243.2
11		0	0		0	0	60	30	0	30	900	7	11	554.4	1454.4
12		0	0		0	0	60	31	0	31	930	9	13	655.2	1585.2
13		0	0		0	0	60	31	0	31	930	12	16	806.4	1736.4
14		0	0		0	0	60	31	0	31	930	13	17	856.8	1786.8
15		0	0		0	0	60	30	0	30	900	14	18	907.2	1807.2
16		0	0		0	0	60	28	0	28	840	14	18	907.2	1747.2
17	3.36	11.75	11.50	7.58	3.79	0	60	29	0	29	870	13	17	856.8	1726.8
18	0.78	2.73	2.48	3.49	1.74	29.05	30.95	33	479.26	33	510.74	12	16	806.4	1796.4
19	0.05	0.16	0	2.17	1.08	53.52	6.48	15	401.40	15	48.60	10	14	705.6	1155.6
20	0	0	0	0	0	0	60	12	0	12	360	8	12	604.8	964.8
21	0	0	0	0	0	0	60	10	0	10	300	6	10	504.0	804.0
22	0	0	0	0	0	0	60	9	0	9	270	4	8	403.2	673.2
23	0	0	0	0	0	0	60	9	0	9	270	3	7	352.8	622.8
24	0	0	0	0	0	0	60	8	0	8	240	2	6	302.4	542.4
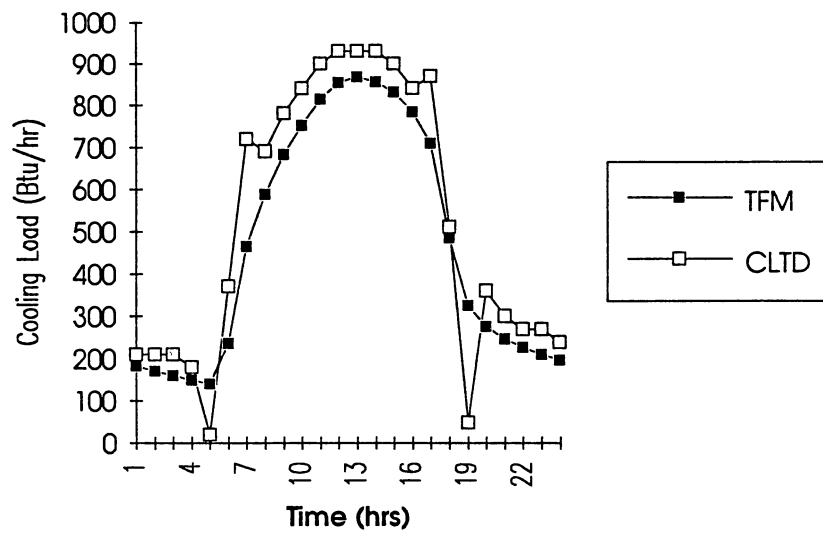
Figure D.1: Transmitted cooling loads for the shaded
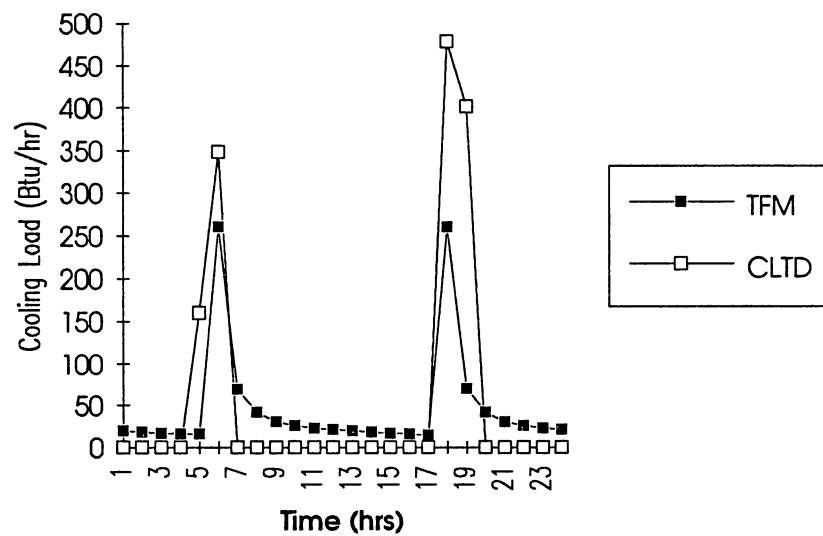portion of the north window of office area
(Test Zone 2)

Figure D.2: Transmitted cooling loads for the unshaded
portion of the north window of office area
(Test Zone 2)

TABLE XXXVII

COOLING LOADS BY THE REVISED TF METHOD FOR THE
EAST WINDOW OF OFFICE AREA (TEST ZONE 2)

Time	I_D	I_d	Shd Area	TSHG Shd	T_load Shd	Unshd Area	TSHG Unshd	T_load Unshd	T_total	Q_cond	Q_Total
1	0	0	60	0	177.07	0	0	183.12	360.19	307.07	671.45
2	0	0	60	0	165.33	0	0	171.04	336.36	266.96	607.23
3	0	0	60	0	154.40	0	0	159.76	314.15	232.85	550.64
4	0	0	60	0	144.21	0	0	149.22	293.42	205.19	502.01
5	0.191	0.036	1.386	0.02	134.70	58.61	5.75	141.93	276.63	190.31	470.18
6	144.000	29.910	6.239	74.55	158.94	53.76	4032.10	1922.79	2081.74	195.08	2329.80
7	205.300	47.490	13.37	253.63	237.79	46.63	5072.10	2784.90	3022.68	220.61	3317.47
8	210.400	55.780	22.54	502.23	362.64	37.46	4240.60	2727.22	3089.87	273.62	3440.77
9	183.000	58.800	36.36	854.13	549.13	23.64	2375.90	2002.33	2551.46	355.21	2969.50
10	133.800	58.400	60	1399.80	842.03	0	0	851.79	1693.82	453.98	2182.70
11	70.400	55.860	60	1339.10	898.04	0	0	598.98	1497.01	569.18	2097.60
12	0	52.150	60	1250.20	900.29	0	0	488.81	1389.10	682.49	2100.67
13	0	47.400	60	1136.30	871.56	0	0	431.18	1302.74	773.83	2103.47
14	0	44.540	60	1067.60	850.69	0	0	393.61	1244.30	840.42	2110.23
15	0	39.870	60	955.78	808.05	0	0	364.37	1172.42	874.78	2070.76
16	0	33.500	60	803.03	740.07	0	0	339.16	1079.22	869.32	1969.49
17	0	25.310	60	606.62	643.50	0	0	316.36	959.86	834.46	1811.91
18	0	14.230	60	341.16	505.55	0	0	295.34	800.89	770.38	1584.36
19	0	0.016	60	0.37	319.77	0	0	275.80	595.57	688.95	1291.78
20	0	0	60	0	268.04	0	0	257.59	525.63	603.16	1135.04
21	0	0	60	0	239.38	0	0	240.59	479.97	526.64	1012.27
22	0	0	60	0	219.64	0	0	224.72	444.36	455.25	904.82
23	0	0	60	0	203.73	0	0	209.90	413.63	395.33	813.80
24	0	0	60	0	189.78	0	0	196.05	385.83	347.78	738.11

TABLE XXXVIII

COOLING LOADS BY THE CLTD/SCL/CLF METHOD FOR THE EAST WINDOW OF OFFICE AREA (TEST ZONE 2)

| Time	Sh/P	Sh	Actual Sh	Sv/Pv	Sv	Unshd Area	Shad Area	SCL	Q_unsh	SCL North	Q_shd	CLTD	CLTD Corr	Q_cond	Total Load
1	0	0	0	0	0	0	60	17	0	7	210	1	5	252.0	462.0
2	0	0	0	0	0	0	60	16	0	7	210	0	4	201.6	411.6
3	0	0	0	0	0	0	60	15	0	7	210	-1	3	151.2	361.2
4	0	0	0	0	0	0	60	14	0	6	180	-2	2	100.8	280.8
5	0.02	0.07	0	0.46	0.23	58.61	1.39	13	380.99	6	4.16	-2	2	100.8	486.0
6	0.22	0.78	0.53	0.29	0.14	53.88	6.12	80	2155.03	24	73.49	-2	2	100.8	2329.3
7	0.44	1.55	1.30	0.13	0.07	46.69	13.31	126	2941.14	24	159.78	-2	2	100.8	3201.7
8	0.71	2.50	2.25	0.02	0.01	37.47	22.54	145	2716.21	23	259.15	0	4	201.6	3177.0
9	1.11	3.87	3.62	0.21	0.11	23.58	36.43	142	1673.81	26	473.53	2	6	302.4	2449.7
10	1.81	6.35	6.10	0.49	0.25	0	60	123	0	28	840	4	8	403.2	1243.2
11	3.81	13.32	13.07	1.19	0.60	0	60	91	0	30	900	7	11	554.4	1454.4
12	0	0	0	0	0	0	60	65	0	31	930	9	13	655.2	1585.2
13	0	0	0	0	0	0	60	57	0	31	930	12	16	806.4	1736.4
14	0	0	0	0	0	0	60	53	0	31	930	13	17	856.8	1786.8
15	0	0	0	0	0	0	60	49	0	30	900	14	18	907.2	1807.2
16	0	0	0	0	0	0	60	45	0	28	840	14	18	907.2	1747.2
17	0	0	0	0	0	0	60	40	0	29	870	13	17	856.8	1726.8
18	0	0	0	0	0	0	60	34	0	33	990	12	16	806.4	1796.4
19	0	0	0	0	0	0	60	27	0	15	450	10	14	705.6	1155.6
20	0	0	0	0	0	0	60	24	0	12	360	8	12	604.8	964.8
21	0	0	0	0	0	0	60	22	0	10	300	6	10	504.0	804.0
22	0	0	0	0	0	0	60	21	0	9	270	4	8	403.2	673.2
23	0	0	0	0	0	0	60	19	0	9	270	3	7	352.8	622.8
24	0	0	0	0	0	0	60	18	0	8	240	2	6	302.4	542.4
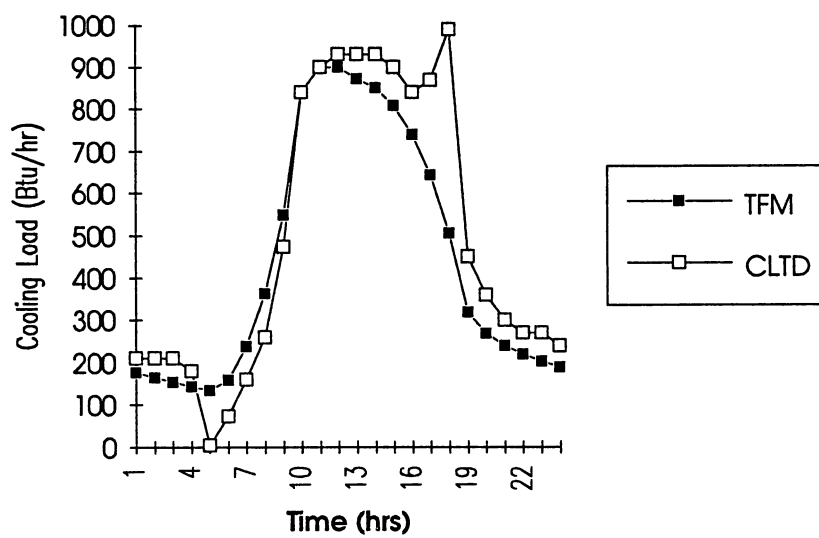
Figure D.3: Transmitted cooling loads for the shaded
portion of the east window of office area
(Test Zone 2)

APPENDIX E

COOLING LOAD COMPARISONS FOR TYPICALLY

SHADED GLASS AREAS

Cooling Load Calculations by the revised TF and the CLTD/SCL/CLF

methods for typically shaded glass areas

Cooling loads were calculated for a typical case of external shading. Figure E.1 shows the exterior shading details for this glass area. The window is 4' in width and 6' high (U-factor = 0.81, Shading coefficient = 0.55). The design conditions assumed were those of Stillwater, Oklahoma (Latitude = 36 °N). Cooling loads for 8 facing directions of this window were calculated by both methods and compared. Figures E.2 through E.9 show the plots of the cooling loads for these 8 facing directions. These figures indicate the kind of typical errors that may be encountered by using the CLTD/SCL/CLF method for externally shaded glass areas. While the cooling load plots of the North East (fig. E.3) East (fig. E.4), and South East (fig E.5) facing glass show the inability of the CLTD/SCL/CLF method to account for the past history of the varying shaded/unshaded areas, that for South (fig. E.6), South West (fig. E.7) and North West (fig. E.9) show the effect of the use of the North facing glass SCLs to represent a completely shaded glass area. Table XXXIX shows the maximum percent differences between the two methods for the 8 facing directions.
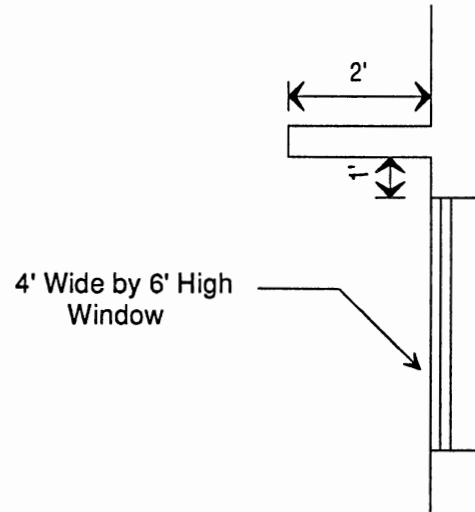
Figure E.1: Typically exterior shaded
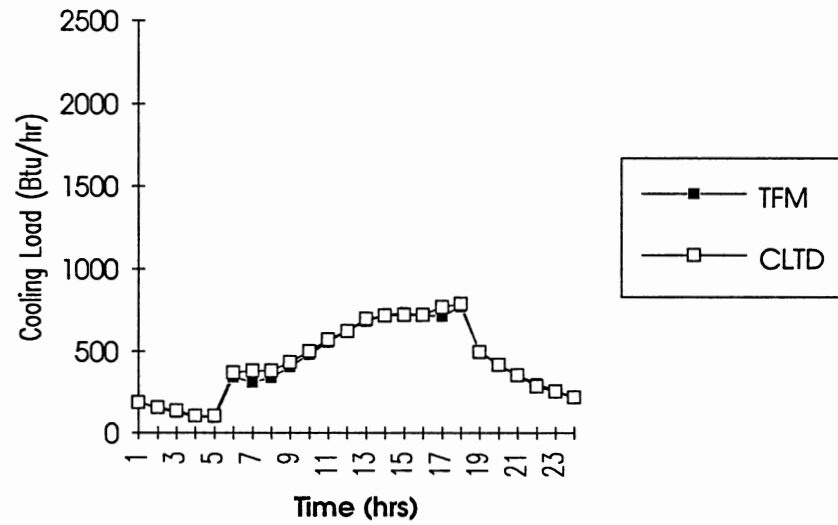glass window

Figure E.2: Cooling loads for North facing window (36°N) by
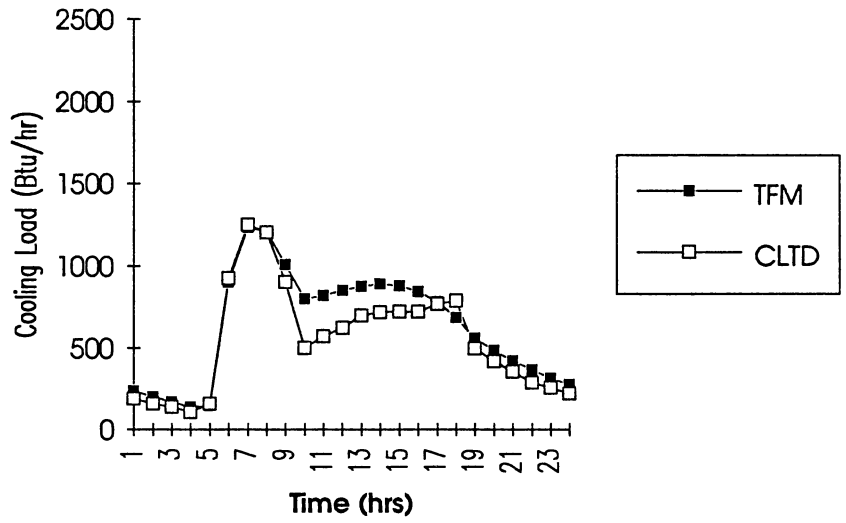the revised TF and CLTD/SCL/CLF Methods

Figure E.3: Cooling loads for NE facing window (36°N) by
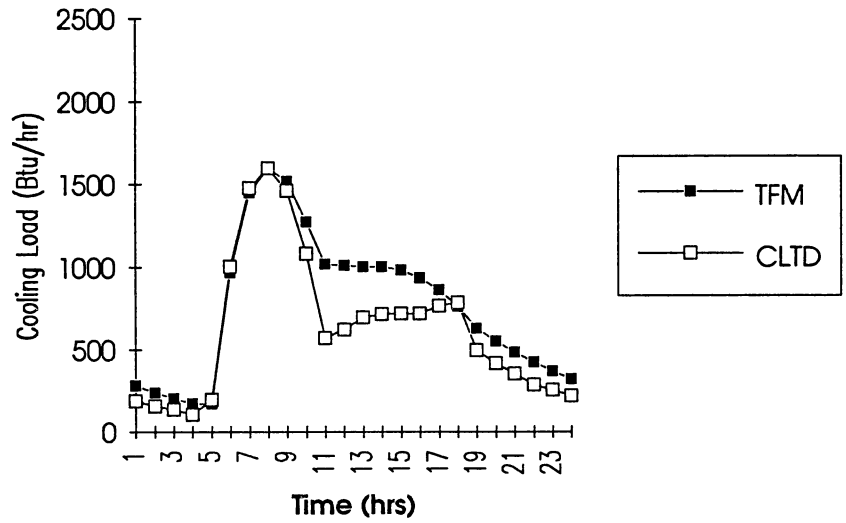the revised TF and CLTD/SCL/CLF Methods

Figure E.4: Cooling loads for East facing window (36°N) by
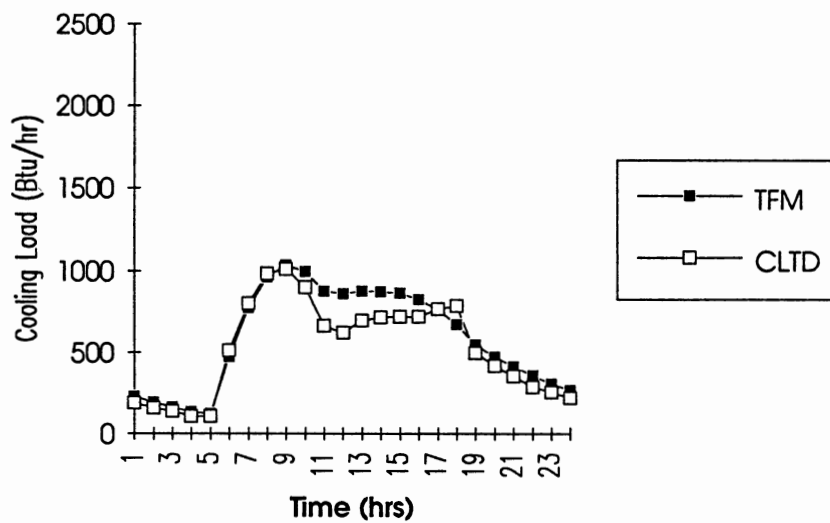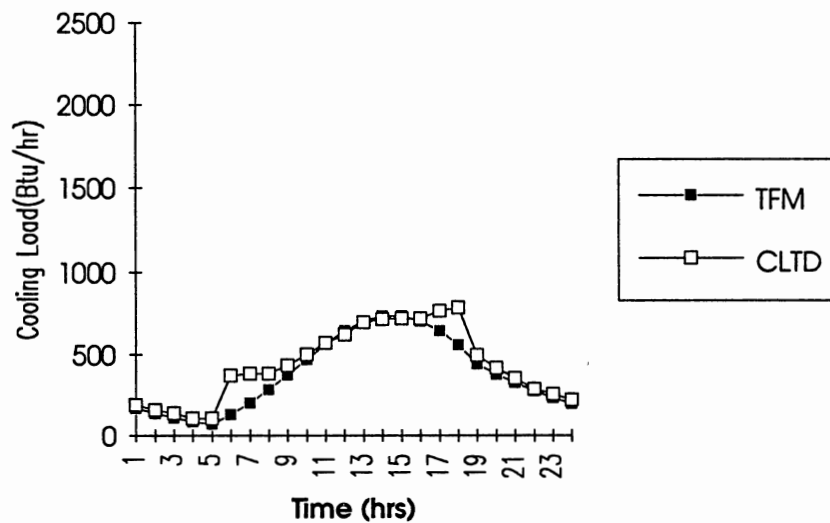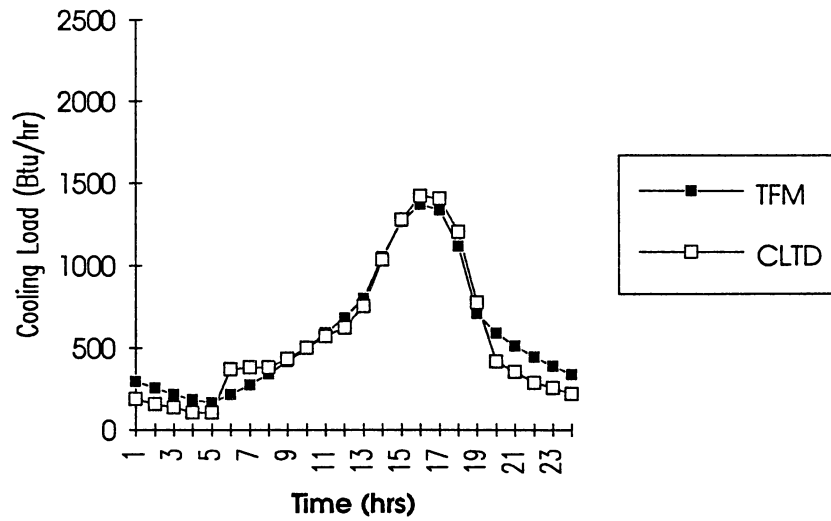the revised TF and CLTD/SCL/CLF Methods

Figure E.5: Cooling loads for SE facing window (36°N) by
the revised TF and CLTD/SCL/CLF Methods

Figure E.6: Cooling loads for South facing window (36°N) by
the revised TF and CLTD/SCL/CLF Methods

Figure E.7: Cooling loads for SW facing window (36°N) by
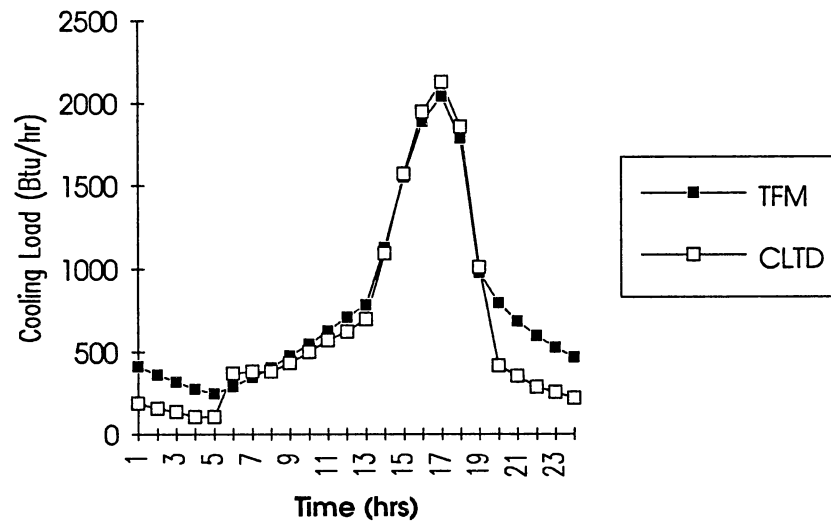the revised TF and CLTD/SCL/CLF Methods

Figure E.8: Cooling loads for West facing window (36°N) by
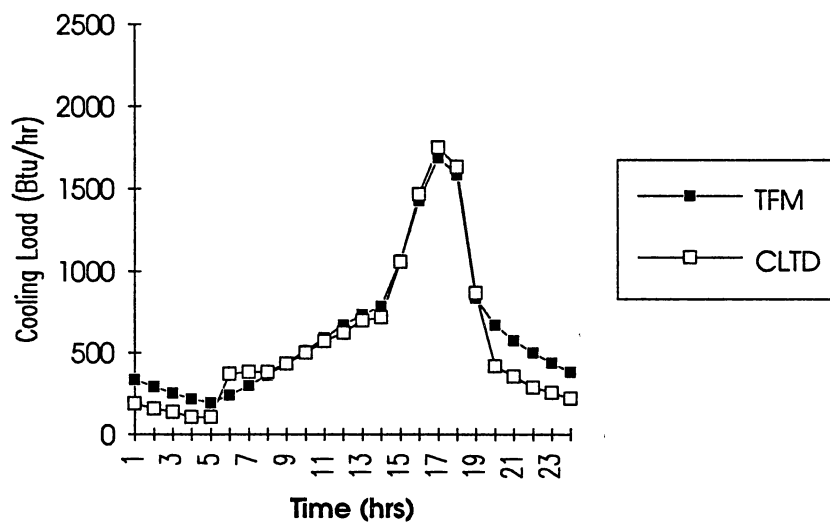the revised TF and CLTD/SCL/CLF Methods

Figure E.9: Cooling loads for NW facing window (36°N) by
the revised TF and CLTD/SCL/CLF Methods

TABLE XXXIX

MAXIMUM PERCENT DIFFERENCES FOR THE
TYPICALLY SHADED GLASS AREA

Facing Direction	Maximum % Difference and Hour
1) North	18.59 % at 0007 hrs.
2) North East	37.52 % at 0010 hrs.
3) East	43.99 % at 0011 hrs.
4) South East	27.59 % at 0012 hrs.
5) South	64.06 % at 0006 hrs.
6) South West	41.26 % at 0006 hrs.
7) West	54.16 % at 0001 hrs.
8) North West	43.51 % at 0001 hrs.

VITA

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