A CASE STUDY OF THE EFFECTS OF SELECTED ARCHITECTURAL PARAMETERS ON THE ANNUAL ENERGY CONSUMPTION IN AN OFFICE BUILDING

UGO V. VELICOGNA

A Major Technical Report

in

the Centre

for

Building Studies

Faculty

of

Engineering

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering (Building)

at

Concordia University

Montreal, Quebec, Canada

September 1980

ABSTRACT

A CASE STUDY OF THE EFFECTS OF SELECTED ARCHITECTURAL PARAMETERS ON THE ANNUAL ENERGY CONSUMPTION IN AN OFFICE BUILDING

Ugo Velicogna, P.Eng.

Concordia University, 1980

This reports presents a case study of the effects of selected building envelope parameters on the annual energy consumption of an office building.

The major objective of this report is to evaluate the effects of wall insulation thickness, type and amount of glazing and lighting level on the energy consumption so that the architect can assess these alternatives as a first step toward designing an energy efficient building.

The energy consumption estimates for various enclosure treatments are obtained by using the "Architectural Building Concepts (ABC) Program" [1] which is a fast, easy-to-use computer program developed by Public Works Canada.

Different methods to analyze the cumulative effect of selected parameters are described. Each of the methods, which are illustrated graphically, can be used to assess at a glance the changes in energy consumption as a result of variations in one or more of the architectural parameters.

ACKNOWLEDGEMENTS

The author would like to acknowledge the guidance given to this work by Professor Mal Turaga from the Centre of Building Studies of Concordia University.

TABLE OF CONTENTS

LIST OF SYMBOLS

Af	floor area (SQ-FT)
Ag	glazing area (SQ-FT)
Ar	roof area (SQ-FT)
Aw	area of opaque wall (SQ-FT)
CCM	cloud cover modifier (dimensionless)
Cp	specific heat of air (BTU/lbs . DEG-F)
CD	clear double - type of glass
CT	clear triple - type of glass
Fc	space cooling factor (DEG-F . HR)
Fh	space heating factor (DEG-F . HR)
Foa	flow rate of outside air due to ventilation and infiltration (CFM)
Fr	refrigeration factor for system using outdoor air for cooling (DEG-F . HR)
fs	flow rate of supply air to the room (CFM)
Fs	space cooling factor at setback conditions (DEG-F . HR)
hoa	specific enthalpy of outdoor air (BTU/lbs)
hr	specific enthalpy of room air (BTU/lbs)
hs	specific enthalpy of supply air (BTU/lbs)
HVAC	heating, ventilation and air conditioning
q	heat gain to space per square feet (BTU/SQ-FT)
qr	mechanical cooling required per square foot (BTU/SQ-FT)
Qc	annual cooling requirement for space (BTU)
Qi	sum of internal heat gain rate (BTU/HR)
Qh	annual heating requirement (BTU)

Qr	annual requirement for refrigeration (BTU)
Qs	annual heating requirement at setback conditions (BTU)
RD	reflective double - type of glass
S	density of air (lbs/CU-FT)
SCg or SC	shading coefficient of glass (dimensionless)
SHGF	solar heat gain factors per hour (BTU/HR . SQ-FT)
toa	outdoor air temperature (DEG-F)
tr	room temperature (DEG-F)
ts	supply air temperature (DEG-F)
TD	tinted double - type of glass
Ug	U-value of glass (BTU/HR . SQ-FT . DEG-F)
Ur	U-value of roof (BTU/HR . SQ-FT . DEG-F)
Uw	U-value of wall (BTU/HR . SQ-FT . DEG-F)
VAV	variable air volume system
V	normalized parameter $\frac{Y}{X}$(HR . DEG-F/BTU)
Vo	normalized parameter for occupied period (HR . DEG-F/BTU)
Vu	normalized parameter for unoccupied period (HR . DEG-F/BTU)
W	normalized parameter $\frac{Z}{X}$(HR . DEG-F/BTU)
Wo	normalized parameter $\frac{Z}{X}$ for occupied period (DEG-F)
Wv	normalized parameter $\frac{Z}{X}$ for unoccupied period (DEG-F)
X	normalized parameter for transmission component (BTU/HR . DEG-F)
Xo	normalized parameter for occupied period (BTU/HR . DEG-F)
Xu	normalized parameter for unoccupied period (BTU/HR DEG-F)

Y	normalized parameter for solar component (dimensionless)
Z	normalized parameter for internal heat gain component (BTU/HR . SQ-FT)
Zo	normalized parameter for occupied period (BTU/HR . SQ-FT)
Zu	normalized parameter for unoccupied period (BTU/HR SQ-FT)
$\sum_{+VE}$	summation of all positive values
$\sum_{-VE}$	summation of all negative values

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Enclosure element components such as wall insulation and type and amount of glazing have an impact on the annual energy consumption of a building. Another item that has a considerable impact on the energy load of an office building is the level of the artificial lighting.

The decision on these architectural concepts is generally made at a very early stage of building design. At this time, the design alternatives are little more than rough sketches, and the architect tends to give very little consideration to the HVAC system design, or to the energy consumption of the building.

Experience has shown that the architectural design is often quite advanced by the time an energy analysis is performed. Consequently, while the energy analysis may be used to show that the architectural concepts chosen are unattractive from the energy consumption point of view, it is generally too late to change economically the physical characteristics of the building.

A number of proprietary and non-proprietary computer programs are currently available on the market to evaluate the energy consumption in buildings. Most of these programs are high technology based and require detailed architectural and HVAC system data as input, for this reason they are unsuitable for use at the conceptual design stage.

One of the primary requirements of any tool for the evaluation of enclosure treatments at an early design stage is that it can be easily and quickly used by architects to provide a first order estimate of energy requirements so that a comparison of various alternatives can be made. Once the basic enclosure elements are designed based on energy efficient performance, other structural, architectural and HVAC system details can be developed.

In this report the estimates of the annual energy consumption of a specific office building are determined for various enclosure combinations and lighting levels. The annual heating, cooling and total energy consumptions are estimated and plotted against each of the assumed variable architectural parameters in order to determine the relative effect of one parameter upon the building energy requirements. Then, the sensitivity of the total energy consumption to changes in wall conductivity, level of illumination and glazing percentage is analyzed. Finally, using the equivalent building thermal resistance [4], the effects of glazing percentage and wall insulation are combined and by superimposing the lighting level, the cumulative effect of all the architectural parameters upon the annual energy consumption is represented on a graph.

The intention of this report is to present, through a case study, a methodology to evaluate the energy consumption of an office building.

The energy consumption depends not only on the building architectural parameters, but also on the building geographical location, orientation, usage and the operating characteristics of various systems. For this reason, each building should be considered thermally unique and the graphs presented in this report should not be generalized and used to evaluate energy consumptions of other buildings.

CHAPTER 2

LITERATURE SURVEY

2.0 LITERATURE SURVEY

In this chapter a brief literature survey on the effects of enclosure elements on the energy consumption is presented.

In commercial and industrial buildings many different elements contribute to the overall heat gain and loss. The enclosure elements may represent a relatively small percentage of the total load. Consequently, in many instances, wall insulation by itself may be difficult to justify in economic terms in both existing and new buildings, particularly if the external wall has a reasonably low transmission coefficient (e.g. 0.16 - 0.20 BTU/HR.SQ-FT.DEG-F). Double glazing, on the other hand, with proper shading devices for the reduction of solar gains during the cooling season could be justified for certain weather conditions.

Ambrose [2] states that "there are many system design options and material selections for a building. To economise design time and costs it is therefore necessary to develop nationally recognised guidelines to assure minimum standards for building energy performance".

ASHRAE 90-75 [3] is one such standard which covers all phases of heating and air conditioning, including the maximum allowable heat flow through the exterior envelope. Section 4 of Ref. [3] establishes the minimum requirements for thermal design of major portions of the exterior envelope of a new building according to a defined building classification and for a particular climatic condition expressed in annual degree days.

In Ref. [3] buildings are classified into two types:

Type "A" which includes:

A-1 Detached one and two family dwellings.

A-2 All other residential buildings, three stories or less including multi-family dwellings, hotels and motels.

Type "B" which includes all other buildings not covered under the description of type "A" buildings.

Figures 15 and 16 show the minimum combined thermal transmittance value (U_o value) for the gross area of exterior walls using annual heating degree days for type "A" and type "B" buildings. The wall combined thermal transmittance value is defined as the sum of the products of the transmittance values of each wall component and their correspondence area, divided by the gross area of the exterior wall.

Rudoy and Duran [4] in their study, analyzed the effects of lighting, glazing percentage and type and wall insulation on annual heating and cooling load for a single zone office module. In terms of lighting intensity, Rudoy and Duran concluded that a reduction in lighting intensity (from 3.16 to 1.58 watts/SQ.FT) reduces the cooling load by 25% while the heating load is increased by 15%. They suggest that reduction of lighting level by using natural light combined with heat recovery would offer one of the best energy conservation options for office buildings. For the analysis of the effects of fenestration, the combined thermal transmittance value was used for three different types of glass. The results are shown in Figure 23. This analysis seems to indicate that the annual heating energy is not linearly related to the U-value and that the annual cooling energy is also not linearly related to the shading coefficient.

Spielvogel [5] in his study on the effects of increased insulation on energy consumption, indicated that, for some applications, the cooling load increases with the increase of wall insulation, probably because of reduction of exfiltration of the internal heat gains.

In general, most of the existing studies seem to indicate that energy conservation cannot be related to a single parameter but must depend on an interrelationship of a variety of factors. This may also mean that it is helpful to analyze each building at a given location to assess the real contribution of various energy conservation options before selecting the best method to economize energy.

The contribution of this report is to present a simple method which can be used to assess various options and combinations of several architectural parameters of an office complex in order to obtain an energy efficient building.

CHAPTER 3

A.B.C. PROGRAM DETAILS

3.0 PROGRAM DETAILS

3.1 Basic

The computer program used in this case study is entitled "Architectural Building Concepts (ABC) Program", Version 3.0 [1].

It was developed in 1978 by the Department of Public Works Canada because of a pressing need for a simple tool capable of analyzing the effects of basic architectural parameters on building energy consumption.

The ABC program does not perform heating or cooling energy calculations; instead it simply does a table lookup-interpolation from database of precomputed values to evaluate the energy consumption in a building.

The ABC program is meant to be used to assess alternatives and to aid in the optimum selection of architectural parameters of a building at the conceptual stages of design, when the design of the mechanical and electrical systems are not yet prepared.

3.2 Methodology Used

The heating and cooling requirements are affected to a great extent by architectural factors such as insulation, type and amount of glazing, building location and orientation, occupancy density and period, ventilation and infiltration rates.

To be able to generate a simplified energy calculation procedure it is necessary to group these factors into a small number of variables and assess their effects on the thermal loads.

The building construction characteristics can be described by the following equations:

$$X = \frac{Uw.Aw + Ur.Ar + Ug.Ag + 1.08\ Foa}{Af} \left(\frac{BTU}{HR.SQ\text{-}FT.DEG\text{-}F}\right) \quad \ldots\ldots(1)$$

where the coefficient X represents the normalized component directly affected by the outdoor air temperature.

$$Y = \frac{Ag.SCg}{Af} \text{ (dimensionless)} \qquad (2)$$

where the coefficient Y represents, in normalized form, the solar radiation through the windows.

$$Z = \frac{Qi}{Af} \text{ (BTU/HR.SQ-FT)} \qquad (3)$$

where the coefficient Z is the normalized form of the internal heat gains.

A further reduction in the number of variables can be obtained by determining the ratio of these coefficients thus:

$$V = \frac{Y}{X} \tag{4}$$

where V is now the ratio of solar coefficient to the transmission coefficient and

$$W = \frac{Z}{X} \tag{5}$$

where W is the ratio of internal heat gain coefficient to the transmission coefficient.

The heat gain per square foot of floor area for any given hour is the sum of transmission gains, solar heat gains and internal heat gains.

$$q = X(toa - tr) + Y(CCM \,.\, SHGF) + Z \tag{6}$$

dividing by X and substituting (4) and (5), equation (6) becomes

$$\frac{q}{X} = (toa - tr) + V(CCM \,.\, SHGF) + W \tag{7}$$

The annual heating requirement for the space is obtained by summing all negative hourly values of $\frac{q}{X}$ and multiplying by the floor area and X

$$Qh' = Af \,.\, X \,.\, \sum_{-ve} \frac{q}{X} \tag{8}$$

The annual cooling requirement for the space is obtained by summing all positive hourly values of $\frac{q}{X}$ and multiplying by the floor area and X

$$Qc = Af \cdot X \cdot \sum_{+ve} \frac{q}{X} \tag{9}$$

The value Qc is the annual heat which must be removed from the room.

Outdoor air is often used to provide "free-cooling" to the room; this is achieved by a variable air volume (VAV) system which maintains the room conditions at a pre-established temperature (tr) and enthalpy (hr) without using reheat. This ideal system was chosen for the ABC program. The system provides the necessary cooling by adjusting the flow of supply air (fs) which is assumed to be at constant temperature (ts) and enthalpy (hs)

$$q = 60 \cdot fs \cdot S \cdot Cp\ (tr - ts) \tag{10}$$

The amount of required refrigeration, or mechanical cooling, is dependent upon the outdoor air conditions.

- If toa $\leq$ ts, then the air supply conditions can be maintained by mixing without refrigeration.
- If toa $>$ ts and hoa $<$ hs then only sensible cooling is required and it can be defined by the equation

$$qr = 60 \,.\, S \,.\, Cp \,.\, fs \,.\, (toa - ts) \qquad (11)$$

By combining equation (11) and (10) and dividing by X

$$\frac{qr}{X} = \frac{(toa - ts)}{(tr - ts)} \frac{q}{X} \qquad (12)$$

- If toa $>$ ts and hoa $\leq$ hr, then the outdoor air must be mechanically cooled (sensible and latent cooling) to the supply air conditions.

The required cooling is defined by the equation

$$qr = S \,.\, 60\, fs\, (hoa - hs) \qquad (13)$$

which, combined with equation (10) and divided by X

$$\frac{qr}{X} = \frac{(hoa - hs)}{Cp(tr - ts)} \frac{q}{X} \qquad (14)$$

- If toa $>$ ts and hoa $>$ hr, then the room air is recirculated and cooled rather than cooling the outdoor air except for the portion of air which is included in X as ventilation air.

Similar to the above cases, the mechanical cooling required is.

$$qr = \frac{(hr - hs)}{Cp(tr - ts)} q \qquad (15)$$

or

$$\frac{qr}{X} = \frac{hr - hs}{Cp(tr - ts)} \frac{q}{X} \tag{16}$$

Finally the annual mechanical cooling requirement, Qr, is defined by

$$Qr = Af \,.\, X.\sum \frac{qr}{X} \tag{17}$$

where $\frac{qr}{X}$ is calculated by one of the equations (12), (14) and (16) above, dependent upon the outdoor air conditions. The algorithm presented in Figure 13 represents the sequence for the proper selection of the cooling factors at a specified outdoor air condition. The terms under summation in equations (8), (9) and (17) can be represented by

$$Fh = \sum_{-ve} \frac{q}{X}$$

$$Fc = \sum_{+ve} \frac{q}{X}$$

$$Fr = \sum_{+ve} \frac{qr}{X}$$

The factors Fh, Fc and Fr have units of ^{o}F . hr and are used to compute heating and cooling in a manner very similar to degree-day. An additional factor Fs is also used to compute heating when the room temperature is assumed to be "set back" to 65^{o}F during the unoccupied period. The data base is created by computing Fh, Fc, Fr and Fs for various values of V and W.

The proper values of V and W are chosen according to the location, the direction and the time schedule of the zone under consideration.

The organization of the data base for one particular location is divided into eight thermal blocks, one for each of eight cardinal directions and of two time schedules, day-time and night-time. An example of data base organization is shown in Table 27 [1].

The factors Fh, Fc, and Fr for day-time and night-time for a particular orientation and location are shown in Figures 17, 18, 19, 20, 21 and 22 1 .

3.3 Calculation Procedures

After the input data sequence is entered into the program and the calculation command is given, the following sequence of operations takes place:

- The coefficient X is calculated using equation (1) for the occupied (Xo) and unoccupied (Xu) period.
- The coefficient Y is calculated using equation (2).
- The coefficient Z is calculated using equation (3) for the occupied (Zo) and the unoccupied (Zu) period.
- The parameter V is calculated by using equation (4) for the occupied (Vo) and the unoccupied

(Vu) period, for the direction and location chosen.

- The parameter W is calculated by using equation (5) for the occupied (Wo) and the unoccupied (Wu) period, for the direction and location chosen.
- The values of Fh, Fc, Fr and Fs for each period are obtained by interpolation of the values given in the data base.
- The annual heating and cooling requirements are calculated for each time period.
- The combined heating and cooling are obtained from all the periods given into the program.

An algorithm of the above sequence of calculations is shown in Figure 14.

3.4 Program Limitations

One major simplification in the program is the assumption of an ideal HVAC system which can maintain pre-established room conditions without the use of reheat.

The derivation of the data base was made with the following assumptions.

- Building thermal mass effect is neglected and steady state equations are used.
- The analysis applies to one zone, which is considered to be independent of all other zones.
- All windows in one thermal zone are assumed to

face in the same direction.

- Internal heat gains, infiltration and ventilation rates are assumed to be constant during one time period (occupied/unoccupied period).
- All internal heat gains are assumed to be sensible and latent heat loads are neglected.
- Solar heat gain factors are computed for the 21st day of each month and include a cloud cover modifier which is read from the weather tape.
- Two systems are considered: The system without economizer simply meets the sensible cooling load. The system with the economizer is an ideal VAV system with enthalpy economizer.
- Three options of temperature settings were considered during the preparation of data base. The available settings are:

  1. 72°F for heating and 78°F for cooling.
  2. 72°F - 65°F for heating and 78°F for cooling (night set back option).
  3. 75°F for heating and cooling.

The program does not have a high degree of accuracy and should be used to compare only the relative energy consumption of one alternative with respect to another. For a more detailed energy estimate a more sophisticated program should be used.

3.5 Assessment to Date

The only assessment of the ABC program known to the writer was one study carried out by M. Turaga at the Centre for Building Studies, Concordia University, Montreal [6].

Turaga compared the results of the ABC program with the actual energy consumption of four buildings located in and around the City of Montreal. The buildings selected for the investigation were:

- An art museum with a floor area of 41,377 SQ-FT complete with oil heating and air conditioning system.
- A public library with a floor area of 16,498 SQ-FT with oil heating only (no mechanical ventilation and air conditioning system).
- An office building with a floor area of 146,568 SQ-FT with all electric heating and cooling system.
- A courthouse with floor area of 52,460 SQ-FT with electric heating and cooling system.

For the purpose of investigation, the energy consumption was divided into total electric and heating requirements. The total electric requirement includes lighting, equipment and electric service water heating energy. The heating requirements are essentially the heating produced by fuel oil, gas or from steam.

For the total electric consumption, the results indicated a close agreement between actual and estimated values for the museum, office building and courthouse, whereas a difference of 45% was noted for the library. One reason given for the large difference is that the proportion of electrical energy consumption compared to total consumption is low (19.3%).

In all cases the estimated values were found to be higher than the actual ones.

For the heating energy component, there was little agreement between the estimated and actual values. The explanation given for the disagreement was the lack of provisions in the program for simulating the actual mechanical systems (no re-heat); the program also does not consider the effects of heat transfer between the different zones of a given building.

Table 28 duplicates the summary of actual and estimated building energy requirements published by M. Turaga [7].

The analysis of the verification of the validity of the program concluded that:

- The program could be better suited for estimating the energy consumption in existing all-electric buildings and the accuracy decreases with the decrease of the percentage of the electric consumption when compared to the total energy consumption.

- The program may not be reliable for the estimation of total energy consumption in a building with a high percentage of non-electric heating consumption (oil, gas or steam).
- In general, the program could be used during the conceptual stages of a building design to evaluate alternatives and to aid in the optimum selection of basic architectural parameters.

CHAPTER 4

CASE STUDY

4.0 CASE STUDY

4.1 Building General Description

The office building selected for this analysis is located in the city of Edmonton, Alberta. It consists of a retail area on the lower floors and twenty-five storeys of offices.

The total gross floor area of the office space is 348,575 SQ-FT and total leasable floor is 322,787 SQ-FT.

Disregarding washrooms, stairwells and elevator areas, which are located in the central core of the building, each office floor has a net area of 12,912 SQ-FT.

Two mechanical rooms service the complex, one is located on the third floor, the other on the penthouse floor. The building outer envelope is a metal curtain wall with four inches of compressed glass fibre insulation. The glazing consists of double glazed sealed units with bronze solar glass outside and clear glass inside. The amount of glazing is 52 percent of the total envelope vertical area of the office floor levels.

The existing mechanical system consists of a variable air volume (VAV) system with economizer cycle used for cooling and ventilation. Secondary heating is obtained by hot water heated baseboard radiators located in the outer perimeter of the building.

This analysis is performed on only the portion of building allocated to offices between the mechanical rooms on the third floor and the penthouse floor. Other portions of the building were not considered.

Heat losses, or gains, through the mechanical rooms were disregarded.

4.2 Building Data

The architectural parameters required by the ABC program for the computation of the annual energy consumptions are divided into two groups. The first group consists of all parameters which are assumed constant or are pre-selected by the program; these are:

thermal zoning and floor area,
ventilation and infiltration rates,
occupancy period and population density, and
indoor-outdoor air temperature.

The second group consists of all parameters which are treated as variable; they are:

wall insulation,
type of glazing,
percentage of glazing, and
level of illumination.

4.3 Building Constant Parameters

Thermal Zoning

The plan of a typical office floor is shown in Figure 1. Each floor is divided into an interior zone, or core, plus one perimeter zone facing each cardinal direction.

The depth of the perimeter zone is approximately 20 feet. Each zone of the perimeter, for proper computer analysis, is thermally homogeneous; that is, the zone must "see" the same thermal loads affected by lights, people, solar transmission, ventilation, infiltration, etc. Furthermore, the windows of each perimeter zone face in the same cardinal direction.

Table 1 lists the constant architectural parameters of each of the zones considered. The listed values of floor area and wall area are the total of the 25 storeys.

Ventilation and Infiltration

The ventilation and infiltration rates for occupied and unoccupied periods are calculated according to recommended ASHRAE procedures [9] and are listed in Table 1.

The selected ventilation requirement is the minimum quantity of outdoor air supplied by a HVAC system with the economizer cycle and is 42,745 CFM (or approximately 24 CFM per person) during the occupied period. No ventilation is assumed for the unoccupied period.

The infiltration rate is assumed constant throughout the year and is calculated by the crack method used for high rise building. The infiltration rate is calculated for the existing 52 percent glazing and it is assumed unchanged also for all other alternatives with different glazing percentage. This assumption is based on the fact that the change in infiltration rate due to different glazing types and percentages is negligible when compared to the amount of ventilation required.

Occupancy Period and People Density

For the purpose of this analysis, the annual occupancy period is selected to be five days per week. The program automatically considers the occupancy period from 7:00 a.m. to 7:00 p.m., for 52 weeks per year. During the occupied period the area/people ratio is assumed to be 180 SQ-FT per person.

Night and weekends are considered unoccupied periods.

Indoor and Outdoor Air Temperatures

The selection of indoor and outdoor temperatures is restricted to the values existing in the data base.

For indoor temperatures, the program computes and prints values of annual heating requirements for two sets of conditions.

1. Constant operation, which assumes 72°F during occupied and unoccupied periods, and
2. "Setback" operation, which assumes 72°F during occupied period and 65°F during unoccupied period.

The computation of cooling requirements is based on a constant indoor temperature of 78°F.

The outdoor temperatures used by the program are provided by the Environment Canada Weather Data tape for the City of Edmonton. This data is derived on the reference year concept [8] and is based on the normalized hourly values of data gathered during a number of years.

4.4 Building Variable Parameters

The four architectural parameters chosen as variables for this study are: wall insulation, level of illumination, type and amount of glazing.

These parameters were selected because of their major effects on the energy requirements of a building. Also, they must be defined at the early stages of design when mechanical equipment is not yet finalized.

Wall Insulation

The external wall of the existing building is a metal curtain type with a four-inch thick compressed glass fibre insulation.

This study will consider, in addition to the existing wall, two other options. Namely:

- an opaque wall with 2 inches of insulation, and
- an opaque wall with 6 inches of insulation.

The U-Values of all alternatives mentioned above are the values for summer and winter conditions also taking into consideration the outside film coefficient (air velocity: 15 MPH for winter, 7.5 MPH for summer).

The selected wall U-Values are listed in Table 2.

Type and Amount of Glazing

The four types of glazing used in this study are:

clear double,
tinted double,
reflective double, and
clear triple.

For each of the above types of glazing, an average year-round U-Value and shading coefficient is calculated. Draperies are not taken into consideration in shading coefficients of glazing. The U-Values and shading coefficients are listed in Table 3. The amount of glazing, as a percentage of the total external wall (opaque wall plus glazing) was originally set for the existing building at 52%.

This analysis will consider, in addition to 52%, two additional options of 32% and 72% of glazing.

Illumination Level

Three illumination levels were selected for the occupied period (7 a.m. - 7 p.m.; 5 days per week) and one reduced illumination level for the unoccupied period (nights and weekends). The selected lighting levels are considered as the total wattage rating of the installed luminaires divided by the office floor area. Localized task lighting could also be considered, providing the wattage per unit area of the office space is maintained unchanged.

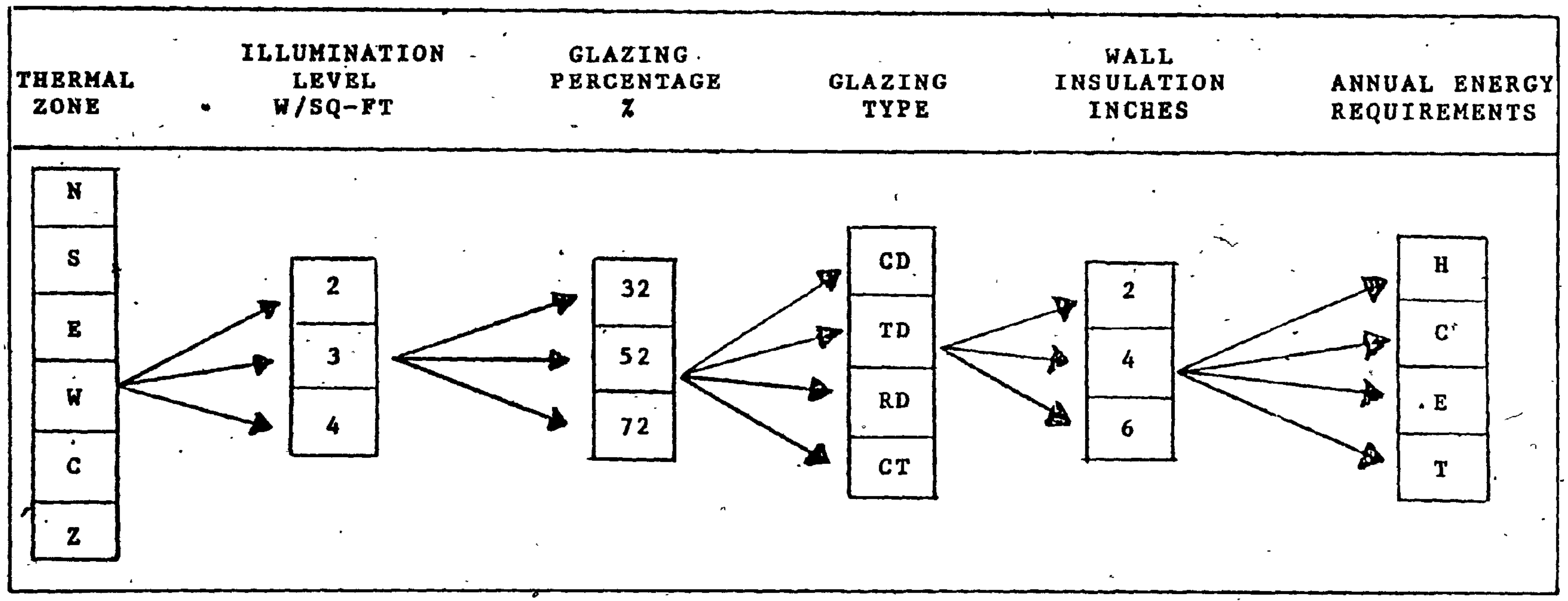
Table 4 summarizes the illumination levels.

4.5 Variations Considered

The annual energy required for heating (H), cooling (C) and illumination level (E) as well as their equivalent total (T) was computed for each of the variations schematically represented below, namely:

5 thermal zones (N'S'E'W'C) and their sum (Z),
3 levels of illumination (2,3 and 4 W/SQ-FT),
3 glazing percentages (32, 52 and 72%),
4 types of glazing (CD, TD, RD, CT),
3 thicknesses of insulation (2", 4" and 6").

There were 648 computer runs to satisfy 108 variations for all possible combinations of different architectural parameters. Computer runs and variations are summarised in the following page.



VARIATIONS CONSIDERED

CHAPTER 5

ANALYSIS OF RESULTS

5.0 ANALYSIS OF RESULTS

A sample of the results obtained from the ABC program is shown in Appendix C and a summary of the computed annual energy consumptions is presented in Tables 5 to 13. All consumptions are referred to the office building operating with an economizer (VAV) and with a night time temperature setback of 65°F.

One way to analyze the results is to represent in graphical form the annual energy consumption for heating, cooling and the total, including lighting, as direct effects of changes of one single architectural parameter. Figures 2, 3 and 4 show the effects of different wall conductivities, or insulation thickness, on the building's energy consumption. Figure 2 shows that the heating requirement increases with the increase of wall conductivity and that clear triple glass requires less building heating than the other types of glass considered. Calculations indicate that at a wall U-value of 0.06 BTU/HR.SQ-FT.DEG-F, or 4" insulation, the annual energy consumption of the building, with clear double glass, is 33.3% higher than the consumption of the building with clear triple glass. An inspection of Figure 2 reveals that the four glazing lines have the same slope and that the lines are straight. The constant line slopes show that changes in heating load due to different wall conductivities are independent of the glazing types. The linearity of the lines is the result of the computation method used by the ABC program. This linearity is in partial disagreement with the conclusions put forward by Rudoy and Duran in their studies [4]. It can be seen in Figure 3 that the cooling energy consumption declines with the decrease in wall insulation. A similar result was obtained by Spielvogel [5] and mentioned also by Rudoy [4].

One possible explanation is that high wall thermal conductivity, or little insulation, helps to dissipate through the walls the heat generated within the space. This effect is noticeable in this study because in office buildings, the internal heat loads are relatively high when compared to transmission loads.

It is interesting to note that the sequential order of the glazing lines in Figure 3 is different from what appears in Figure 2. These figures indicate that the building heating energy consumption is at the minimum with clear triple glass and that the cooling consumption is less with reflective double glass. This was expected because the clear triple glass has a low thermal conductivity which minimizes heat losses by conduction. Similarly, the reflective double glass has a high value of shading coefficient which prevents the radiant solar energy from entering the building.

Figures 5, 6 and 7 show the effects of varying the percentage of glazing on the heating, cooling and total annual energy consumption of the building. In all three figures it is clear that the energy consumption is directly proportional to the amount of glazing. This result was expected because in the

ABC program the amount of glazing is treated as one of the factors required for the computation of the wall equivalent thermal conductivity. A typical calculation of wall equivalent U-value is presented in Appendix D.

A confirmation that the glazing percentage is directly related to the wall equivalent U-value can be deducted from Figure 5. Here, by extrapolating the four glazing lines to a hypothetical point correspondent to zero glazing, the four lines seem to coincide. At this point the wall equivalent U-value is equal to the U-value of the opaque wall.

It should be mentioned that in Figure 6 the relative position of the glazing lines is not the same as the position appearing in Figure 3. In Figure 6 the annual cooling consumption increases with the increase of glazing percentage whereas, in Figure 3, it decreases with the increase of U-values. One possible explanation is that in Figure 6 the annual cooling consumption is affected not only by the thermal conductivity of the glass but also by the glass shading coefficient. In this particular case the effect of the shading coefficient appears more pronounced than the thermal conductivity because during the cooling period, which is mainly in summer, the shading coefficient helps to control the amount of radiant solar energy entering the building. This explanation is substantiated also by the relative position of the four glazing lines which are positioned in the same order as their respective shading coefficients.

Figures 8, 9 and 10 show the effects of various levels of illumination on the building's annual heating, cooling and total energy consumptions at constant glazing percentage and wall conductivity. Figure 8 indicates that the annual heating decreases with the increase of the level of illumination. This was expected because the heat radiated by artificial lights contributes to the heating of the office space. Conversely, the same heat produces a substantial increase in cooling energy requirement as can be seen in Figure 9. When heating, cooling and lighting requirements are combined, as shown in Figure 10, the total annual energy load increases with the increased illumination level and the increase is more pronounced at high lighting levels. These results are in agreement with the results published by Rudoy [4].

Another way to analyze the results is to investigate the sensitivity of the building energy requirements affected by changes in architectural parameters. In Figure 11 the energy requirements, as well as the architectural parameters, are expressed as percentage variations from a base case. The base case being the architectural parameters actually used in the existing building, namely 4" insulation, 52% glazing and 3 watts/SQ-FT illumination and the energy requirement computed using these basic parameters. The sensitivity of each architectural parameter is represented by the slope of the curves. In Figure 11 it can be seen that at equal percentages changes of architectural parameters, the energy consumption of the building is more sensitive to changes of the wall conductivity than to changes of glazing percentage or of illumination level. As an example a 10% increase of wall conductivity produces a 5% increase in annual energy consumption, whereas a 10% increase in illumination level produces a 2% increase in energy load. Because of the northern location of the building, the heating energy consumption is by far greater than the cooling energy, consequently it appears logical that the wall conductivity has a much higher impact on the energy consumption than the other variables.

Figure 11 can also be used to analyze the effects on the energy load resulting from simultaneous changes of two parameters. As one example, it can be seen that by increasing the wall U-value by 10% (which is equivalent to the reduction of wall insulation from 4" to 2") the annual energy load remains unchanged if, at the same time, the amount of glazing is reduced by 14.8% (which is equivalent to changing the glazing percentage from 52% to 44.3%). This graphical analysis was compared with the results obtained from a computer run made with the same modified parameters. The difference between the two results was less than 1%

Figure 11 can also be used to estimate the change required by one architectural parameter to produce a predetermined reduction, or increase, in energy consumption. It can be shown graphically that in order to obtain a 50% reduction in energy consumption the level of illumination should be reduced by 26.5% or from 3 W/SQ-FT used in the base case to 2.23 W/SQ-FT. Again this graphical solution was compared with the results obtained from a computer run. The difference between the two results was approximately 0.2%.

A graph similar to the one in Figure 11 could be made at the early stages of a building design. Such a graph could be of invaluable help to architects and engineers to evaluate a variety of different combinations of basic architectural parameters and could facilitate the selection of the most effective combination of parameters.

A third way to analyze the results is to represent in graphical form the percentage variation of the annual energy consumption as a function of all variable parameters considered in this study. Figure 12 is such a graph. Here the type of glazing and the level of illumination are represented by different curves, whereas the glazing percentage, the wall U-value and glass U-value are grouped into one equivalent U-value represented by the abscissa.

A sample calculation for the determination of the equivalent wall U-value is shown in Appendix D and all calculated equivalent U-values are tabulated in Table 26.

Figure 12 indicates that clear triple glass at 2 W/SQ-FT illumination level is the most energy saving alternative at any value of wall thermal conductivity. Conversely, the highest energy loss is obtained when the level of illumination is 4 W/SQ-FT and the glass type is reflective double. It appears reasonable that the most economical combination of alternatives, from the energy saving point of view, is the clear triple glass which has the lowest thermal conductivity and 2 W/SQ-FT which is the minimum level of illumination considered in this study. Conversely, the clear double glass at 4 W/SQ-FT should produce the highest amount of energy loss. The main reason that the reflective double glass appears to have the highest energy consumption is that it has the lowest shading coefficient which prevents the winter solar radiation from entering the room and producing useful heat gain. This figure, similar to Figure 11, can be made at the early stages of building design and be used for a preliminary selection of architectural parameters when energy conservation is one of the designer's main objectives.

CHAPTER 6

CONCLUSIONS

6.0 CONCLUSIONS

The ABC program was used to estimate the annual energy consumption of each of the different values of the selected architectural parameters. A typical print-out of one computer run is shown in Appendix C and the results of all computations are summarized in Tables 2 to 13.

The results were analyzed in three stages. In the first stage the heating, cooling and total energy consumption was plotted against wall U-values, glazing percentages and illumination levels and for each of the four types of glazing considered. In this way the effects of one single architectural parameter were analyzed upon each of the major components of the total annual energy consumption. In the second stage a sensitivity analysis was carried out to determine which of the architectural parameters had the greatest effect on the total annual energy consumption of the building. Finally, in the third stage, all selected architectural parameters were plotted against the energy consumption. In this way it was possible to identify the best combination of architectural parameters for an energy efficient building.

It was shown that the annual heating load rose with the increase of wall thermal conductivity and glazing percentage and declined with the increase of illumination level. Similarly, the annual cooling load increased with the increase in illumination level and glazing percentage, but declined with the increase of wall U-value. One possible explanation for this last conclusion was that high wall thermal conductivity helped to dissipate the heat generated within the building.

As for the type of glass, the clear triple glazing was shown to produce the minimum heating consumption because of low thermal conductivity which reduced heat transmission losses. Conversely, the reflective double glazing yielded the minimum cooling consumption because of a low shading coefficient which prevented the radiant solar energy from entering the building.

When cooling, heating and lighting loads were summed together to form the total annual energy consumption, it was evident that the major contributors to the building consumption were the heating and lighting loads because of the high latitude in which the building was located.

An example of the sensitivity of the annual energy consumption to percentage variations in architectural parameters showed that the wall U-value was the major building element affecting changes in energy loads. This suggests that to reduce the estimated energy consumption the architect should first decrease the wall U-value.

Figure 12 indicated that the minimum level of illumination and glass with low U-values was the best alternative for an energy efficient building located at high latitudes. This figure suggested also that glass with low shading coefficient should be avoided because it rejects the radiant solar energy which could favorably contribute to the heating of the enclosure.

REFERENCES

1 ABC Program: Engineering Manual and User's Manual Version 3, March 1980 by Public Work Canada, Design and Construction Technology.

2 E.R. AMBROSE, P.E.

"Handbook of Energy Conservation for Mechanical Systems in Building". Article 18, p.p. 90 to 94. Van Nostrand Reinhold, 1978.

3 ASHRAE STANDARD 90-75. Energy Conservation in New Building Design, 1975.

4 W. RUDOY and F. DURAN

Effect of building envelope parameters on annual heating/cooling load. ASHRAE Journal, July 1975.

5 I.G. SPIELVOGEL

More insulation can increase energy consumption. ASHRAE Journal, Vol. 16, No. 1, p. 61, 1974.

6 M. TURAGA

"Final Report of the Project on the Verification of the Effectiveness of Selected Energy Conservation Strategies on the "Ideal" Energy Consumption on Commercial Buildings." Centre for Building Studies, Concordia University, December 1979.

7 M. TURAGA, D.M. SANDER and P.E. DUMOUCHEL

"A simplified computer assisted energy calculation procedure for the evaluation of building architectural concepts." Centre for Building Studies, Concordia University, 1979.

8 "Computer Aided Building Energy Systems Analysis Using Meriwether Energy Systems Analysis Program", Reference Manual - Department of Public Work Canada, 1976.

9 ASHRAE Handbook, 1977 Fundamentals, Chapter 21.

APPENDIX A

TABLES

THERMAL ZONE	FLOOR AREA		ENVELOPE AREA		VENTILATION CFM/SQ – FT		INFILTRATION CFM/SQ – FT		PEOPLE
	SQ-FT	%	SQ-FT	%	OCCUPIED	UNOCCUPIED	OCCUPIED	UNOCCUPIED	SQ-FT/ PERSON
NORTH	64906	20.1	43610	26.8	.103	0	.062	.062	180
SOUTH	64906	20.1	43610	26.8	.165	0	.062	.062	180
EAST	54250	16.8	37717	23.2	.140	0	.074	.074	180
WEST	54250	16.8	37717	23.2	.156	0	.074	.074	180
CORE	84475	26.2	-	-	.110	0	.047	.047	180
TOTAL	322787	100	162654	100	-	-	-	-	-

TABLE 1 - SUMMARY OF INPUT DATA: CONSTANT PARAMETERS

CODE	INSULATION THICKNESS (INCHES)	U-VALUE BTU/HR·SQ-FT·DEG-F
R 2	2	.114
R 3	4	.060
R 4	6	.040

TABLE 2 - SELECTED U-VALUES OF OPAQUE WALL

	U-VALUE BTU/HR·SQ-FT·DEG-F	SHADING COEFFICIENT (DIMENSIONLESS)
CLEAR DOUBLE	.49	.88
TINTED DOUBLE	.43	.58
REFLECTIVE DOUBLE	.40	.38
CLEAR TRIPLE	.31	.71

TABLE 3 - SELECTED U-VALUES AND SHADING COEFFICIENTS OF GLAZING

CODE	LEVEL OF ILLUMINATION WATTS/SQ.-FT. OF FLOOR	
	OCCUPIED	UNOCCUPIED
W 2	2	.15
W 3	3	.15
W 4	4	.15

TABLE 4 - SELECTED LEVELS OF ILLUMINATION

ILLUMINATION	GLAZING	GLAZING TYPE	WALL CONDUCTANCE	ANNUAL ENERGY CONSUMPTION 1 LIGHTS KWH	2 HEATING MBTU	3 COOLING TON-HR	4 (1+2+3) TOTAL KWH
3 W/SQ-FT	52%	CD	R2	3 302 249	15 460 815	270 307	9 612 527
			R3	3 302 249	14 402 893	270 982	9 199 911
			R4	3 302 249	14 013 288	271 232	9 047 956
		TD	R2	3 302 249	14 618 874	216 014	9 229 318
			R3	3 302 249	13 534 594	216 689	8 806 405
			R4	3 302 249	13 129 821	216 942	8 648 528
		RD	R2	3 302 249	14 400 588	179 686	9 107 714
			R3	3 302 249	13 276 371	180 361	8 669 199
			R4	3 302 249	12 861 518	180 611	8 507 381
		CT	R2	3 302 249	11 849 713	241 517	8 173 012
			R3	3 302 249	10 807 191	242 192	7 766 412
			R4	3 302 249	10 425 576	24[illegible] 442	7 617 579

TABLE 5 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 3 W/SQ-FT, 52% Glazing

		Glazing Type	Wall Conductance	Annual Energy Consumption			
				1	2	3	4 (1+2+3)
				LIGHTS KWH	HEATING MBTU	COOLING TON-HR	TOTAL KWH
ILLUMINATION: 3 W/SQ-FT	GLAZING: 32%	CD	R2	3 302 249	12 859 795	210 084	8 536 181
			R3	3 302 249	11 335 571	211 040	7 941 679
			R4	3 302 249	10 779 442	211 395	7 724 775
		TD	R2	3 302 249	12 418 181	176 675	8 330 250
			R3	3 302 249	10 726 907	177 713	7 670 569
			R4	3 302 249	10 290 755	177 985	7 500 453
		RD	R2	3 302 249	12 322 849	154 319	8 270 651
			R3	3 302 249	10 743 834	155 275	7 654 744
			R4	3 302 249	10 165 756	155 630	7 429 265
		CT	R2	3 302 249	10 632 018	192 369	7 648 156
			R3	3 302 249	9 143 930	193,326	7 067 772
			R4	3 302 249	8 599 360	193 680	6 855 382

TABLE 6 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 3 W/SQ-FT, 32% Glazing

ILLUMINATION	GLAZING	GLAZING TYPE	WALL CONDUCTANCE	ANNUAL ENERGY CONSUMPTION 1 LIGHTS KWH	2 HEATING MBTU	3 COOLING TON-HR	4 (1+2+3) TOTAL KWH
3 W/SQ-FT	72%	CD	R2	3 302 249	18 159 594	330 501	10 727 034
			R3	3 302 249	17 545 330	330 894	10 487 457
			R4	3 302 249	17 318 194	331 040	10 398 869
		TD	R2	3 302 249	16 834 176	255 479	10 134 220
			R3	3 302 249	16 203 055	255 873	9 888 059
			R4	3 302 249	16 045 613	255 869	9 826 548
		RD	R2	3 302 249	16 502 024	205 029	9 954 011
			R3	3 302 249	15 856 415	205 423	9 702 189
			R4	3 302 249	15 617 613	205 569	9 609 044
		CT	R2	3 302 249	13 163 057	290 642	8 735 212
			R3	3 302 249	12 558 283	291 036	8 499 343
			R4	3 302 249	12 335 387	291 181	8 412 411

TABLE 7 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 3 W/SQ-FT, 72% Glazing

ILLUMINATION	GLAZING	GLAZING TYPE	WALL CONDUCTANCE	ANNUAL ENERGY CONSUMPTION			
				1	2	3	4 (1+2+3)
				LIGHTS KWH	HEATING MBTU	COOLING TON-HR	TOTAL KWH
2 W/SQ-FT	52%	CD	R2	2 292 387	16 712 975	231 936	9 053 466
			R3	2 292 387	15 627 418	232 608	8 630 051
			R4	2 292 387	15 226 005	232 858	8 473 484
		TD	R2	2 292 387	15 934 936	177 649	8 695 228
			R3	2 292 387	14 816 884	178 318	8 259 116
			R4	2 292 387	14 404 164	178 567	8 098 130
		RD	R2	2 292 387	15 846 643	136 848	8 619 934
			R3	2 292 387	14 685 349	137 512	8 166 923
			R4	2 292 387	14 257 986	137 759	8 000 216
		CT	R2	2 292 387	13 041 261	203 142	7 590 269
			R3	2 292 387	11 970 622	203 817	7 172 685
			R4	2 292 387	11 575 125	204 067	7 018 429

TABLE 8 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 2 W/SQ-FT, 52% Glazing

ILLUMINATION	GLAZING	GLAZING TYPE	WALL CONDUCTANCE	ANNUAL ENERGY CONSUMPTION			
				1	2	3	4 (1+2+3)
				LIGHTS KWH	HEATING MBTU	COOLING TON-HR	TOTAL KWH
2 W/SQ-FT	32%	CD	R2	2 292 387	14 115 916	171 722	7 978 677
			R3	2 292 387	12 553 743	172 677	7 369 349
			R4	2 292 387	11 978 836	173 031	7 145 108
		TD	R2	2 292 387	13 750 240	138 313	7 802 412
			R3	2 292 387	12 142 422	139 269	7 175 253
			R4	2 292 387	11 550 030	139 623	6 944 181
		RD	R2	2 292 387	13 726 783	115 956	7 770 891
			R3	2 292 387	12 094 442	116 912	7 134 152
			R4	2 292 387	11 492 097	117 267	6 899 193
		CT	R2	2 292 387	11 864 378	154 006	7 081 368
			R3	2 292 387	10 307 641	154 962	6 474 165
			R4	2 292 387	9 734 028	155 316	6 250 429

TABLE 9 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 2 W/SQ-FT, 32% Glazing

ILLUMINATION	GLAZING	GLAZING TYPE	WALL CONDUCTANCE	1 LIGHTS KWH	2 HEATING MBTU	3 COOLING TON-HR	4 (1+2+3) TOTAL KWH
2 W/SQ-FT	72%	CD	R2	2 292 387	19 378 304	292 148	10 154 924
			R3	2 292 387	18 749 124	292 541	9 909 520
			R4	2 292 387	18 516 468	292 686	9 818 775
		TD	R2	2 292 387	18 191 720	216 979	9 616 201
			R3	2 292 387	17 543 434	217 370	9 363 330
			R4	2 292 387	17 305 842	217 515	9 270 657
		RD	R2	2 292 387	17 865 158	166 687	9 438 333
			R3	2 292 387	17 205 992	167 077	9 181 211
			R4	2 292 387	16 962 174	167 221	9 086 104
		CT	R2	2 292 387	14 302 437	252 280	8 132 102
			R3	2 292 387	13 679 968	252 673	7 889 319
			R4	2 292 387	13 451 119	252 819	7 800 063

TABLE 10 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65^{o}F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 2 W/SQ-FT, 72% Glazing

				ANNUAL ENERGY CONSUMPTION		
		GLAZING TYPE	WALL CONDUCTANCE	1	2	3	4 (1+2+3)
				LIGHTS KWH	HEATING MBTU	COOLING TON-HR	TOTAL KWH
ILLUMINATION: 4 W/SQ-FT	GLAZING: 52%	CD	R2	4 312 111	14 490 456	308 656	10 281 654
			R3	4 312 111	13 463 971	309 331	9 881 319
			R4	4 312 111	13 089 668	309 581	9 735 343
		TD	R2	4 312 111	13 599 192	254 366	9 879 180
			R3	4 312 111	12 559 417	255 041	9 473 653
			R4	4 312 111	12 175 753	255 291	9 324 020
		RD	R2	4 312 111	13 323 881	218 037	9 735 297
			R3	4 312 111	12 248 141	218 713	9 315 721
			R4	4 312 111	11 851 097	218 963	9 160 861
		CT	R2	4 312 111	10 974 501	279 869	8 879 313
			R3	4 312 111	9 968 866	280 545	8 487 125
			R4	4 312 111	9 600 943	280 795	8 343 641

TABLE 11 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 4 W/SQ-FT, 52% Glazing

ILLUMINATION	GLAZING	GLAZING TYPE	WALL CONDUCTANCE	ANNUAL ENERGY CONSUMPTION 1 LIGHTS KWH	2 HEATING MBTU	3 COOLING TON-HR	4 (1+2+3) TOTAL KWH
4 W/SQ-FT	32%	CD	R2	4 312 111	11 884 422	248 448	9 203 365
			R3	4 312 111	10 419 624	249 404	8 632 078
			R4	4 312 111	9 884 595	249 759	8 423 417
		TD	R2	4 312 111	11 398 903	215 039	8 980 281
			R3	4 312 111	9 901 961	215 996	8 396 438
			R4	4 312 111	9 372 507	216 350	8 189 954
		RD	R2	4 312 111	11 254 731	192 684	8 901 604
			R3	4 312 111	9 747 137	193 640	8 313 598
			R4	4 312 111	9 214 776	193 994	8 105 978
		CT	R2	4 312 111	9 714 861	230 733	8 338 082
			R3	4 312 111	8 329 004	231 690	7 797 636
			R4	4 312 111	7 819 186	232 044	7 598 823

TABLE 12 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65^{O}F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 4 W/SQ-FT, 32% Glazing

		Glazing Type	Wall Conductance	Annual Energy Consumption 1 Lights KWH	2 Heating MBTU	3 Cooling TON-HR	4 (1+2+3) Total KWH
ILLUMINATION: 4 W/SQ-FT	GLAZING: 72%	CD	R2	4 312 111	17 149 878	368 864	11 380 800
			R3	4 312 111	16 547 149	369 257	11 145 729
			R4	4 312 111	16 325 691	369 403	11 059 360
		TD	R2	4 312 111	15 852 036	293 693	10 798 610
			R3	4 312 111	15 242 568	294 087	10 560 908
			R4	4 312 111	15 017 746	294 233	10 473 224
		RD	R2	4 312 111	15 387 359	243 392	10 566 777
			R3	4 312 111	14 764 399	243 786	10 323 804
			R4	4 312 111	14 533 965	243 932	10 233 928
		CT	R2	4 312 111	12 268 723	329 004	9 434 053
			R3	4 312 111	11 686 341	329 397	9 206 931
			R4	4 312 111	11 471 667	329 543	9 123 212

TABLE 13 - SUMMARY OF COMPUTER OUTPUT, SET BACK (65°F) WHEN UNOCCUPIED, SYSTEM WITH ECONOMIZER (VAV), 4 W/SQ-FT, 72% Glazing

TINTED DOUBLE

LIGHTS 2 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	7 802 -11.401	8 695 -1.261	9 616 9.158
	4"	7 175 -18.521	8 259 -6.212	9 363 6 325
	6"	6 944 -21.145	8 098 -8.040	9 270 5.269

TABLE 14: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

CLEAR DOUBLE

LIGHTS 2 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	7 979 -9.391	9 053 2.805	10 154 15.308
	4"	7 369 -16.318	8 630 -1.999	9 909 12.526
	6"	7 145 -18.862	8 473 -3.782	9 818 11.492

TABLE 15: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

REFLECTIVE DOUBLE

LIGHTS 2 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	7 770 -11.765	8 619 -2.124	9 438 7.177
	4"	7 134 -18.987	8 166 -7.268	9 181 4.258
	6"	6 899 -21.656	8 000 -9.153	9 086 3.180

TABLE 16: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

CLEAR TRIPLE

LIGHTS 2 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	7 081 19.589	7 590 -13.809	8 132 -7.654
	4"	6 474 -26.482	7 172 -18.556	7 889 -10.413
	6"	6 250 -29.026	7 018 -20.304	7 800 -11.424

TABLE 17: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

TINTED DOUBLE

LIGHTS 3 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	8 330 -5.405	9 229 4.804	10 134 15.081
	4"	7 670 -12.900	8 806 BASE RUN	9 888 12.287
	6"	7 500 -14.831	8 648 -1.794	9 826 11.583

TABLE 18: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

CLEAR DOUBLE

LIGHTS 3 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	8 536 -3.066	9 612 9.153	10 727 21.815
	4"	7 942 -9.811	9 199 4.463	10 487 19.089
	6"	7 725 -12.276	9 047 2.737	10 398 18.079

TABLE 19: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

REFLECTIVE DOUBLE

LIGHTS 3 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	8 270 -6.087	9 107 3.418	9 954 13.037
	4"	7 654 -13.082	8 669 -1.556	9 702 10.175
	6"	7 429 -15.637	8 507 -3.395	9 609 9.119

TABLE 20: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

CLEAR TRIPLE

LIGHTS 3 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	7 648 -13.150	8 173 -7.188	8 735 -.806
	4"	7 068 -19.737	7 766 -11.810	8 499 -3.486
	6"	6 855 -22.155	7 617 -13.502	8 412 -4.474

TABLE 21: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

TINTED DOUBLE

LIGHTS 4 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	8 980 1.976	9 879 12.185	10.798 22.621
	4"	8 396 -4.656	9 473 7.574	10 560 19.918
	6"	8 189 -7.007	9 324 5.882	10 473 18.930

TABLE 22: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

CLEAR DOUBLE

LIGHTS 4 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	9 203 4.508	10.281 16.750	11 380 29.230
	4"	8 632 -1.976	9 881 12.208	11 145 26.561
	6"	8 423 -4.349	9 735 10.550	11 059 25.585

TABLE 23: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

REFLECTIVE DOUBLE

LIGHTS 4 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	8 901 1.079	9 735 10.550	10 566 19.986
	4"	8 313 -5.598	9 315 5.780	10.323 17.227
	6"	8 105 -7.960	9 160 4.020	10 233 16.205

TABLE 24: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

CLEAR TRIPLE

LIGHTS 4 W/SQ-FT		GLAZING PERCENTAGE		
		32%	52%	72%
INSULATION	2"	8 338 -5.315	8 879 0.829	9 434 7.132
	4"	7 797 -11.458	8 487 -3.623	9 206 4.542
	6"	7 598 -13.718	8 343 -5.258	9 123 3.600

TABLE 25: TOTAL ANNUAL ENERGY REQUIREMENT (KWH x 1000) AND ITS PERCENTAGE DIFFERENCE FROM BASE RUN.

TINTED DOUBLE

INSULATION	GLAZING PERCENTAGE 32%	52%	72%
2"	.215	.278	.342
4"	.178	.252 BASE RUN	.326
6"	.165	.243	.321

CLEAR DOUBLE

INSULATION	GLAZING PERCENTAGE 32%	52%	72%
2"	.234	.309	.385
4"	.198	.284	.370
6"	.184	.274	.364

REFLECTIVE DOUBLE

INSULATION	GLAZING PERCENTAGE 32%	52%	72%
2"	.206	.263	.320
4"	.169	.237	.305
6"	.155	.227	.300

CLEAR TRIPLE

INSULATION	GLAZING PERCENTAGE 32%	52%	72%
2"	.177	.216	.255
4"	.140	.190	.240
6"	.126	.180	.234

TABLE 26: EQUIVALENT U-VALUES (BTU/HR. SQ-FT. DEG-F) OF TOTAL WALL (OPAQUE WALL AND GLAZING) FOR DIFFERENT GLAZING TYPES, INSULATION THICKNESSES, AND GLAZING PERCENTAGES.

LOCATION

DAYTIME	NIGHTTIME
NORTH (F_h,F_c,F_r,F_s)	NORTH (F_h,F_c,F_r,F_s)
NORTHEAST (F_h,F_c,F_r,F_s)	NORTHEAST (F_h,F_c,F_r,F_s)
EAST (F_h,F_c,F_r,F_s)	EAST (F_h,F_c,F_r,F_s)
SOUTH EAST (F_h,F_c,F_r,F_s)	SOUTHEAST (F_h,F_c,F_r,F_s)
SOUTH (F_h,F_c,F_r,F_s)	SOUTH (F_h,F_c,F_r,F_s)
SOUTHWEST (F_h,F_c,F_r,F_s)	SOUTHWEST (F_h,F_c,F_r,F_s)
WEST (F_h,F_c,F_r,F_s)	WEST (F_h,F_c,F_r,F_s)
NORTHWEST (F_h,F_c,F_r,F_s)	NORTHWEST (F_h,F_c,F_r,F_s)

TABLE 27. ORGANIZATION OF DATA BASE [1]

		**ACTUAL ENERGY CONSUMPTION		SIMULATED ENERGY CONSUMPTION		% DIFFERENCE		TOTAL ENERGY CONSUMPTION		ANNUAL EQUIVALENT ENERGY CONSUMPTION			
BLDG TITLE	FLOOR AREA FT²	* (A) TOTAL ELEC KWH	(B) HEATING KWH	* (C) TOTAL ELEC KWH	(D) HEATING KWH	ELEC	HEATING	ACTUAL KWH	SIMULATED KWH	(E) ACTUAL	(F) SIMULATED	% DIFF	REMARKS
#1	41,377	1,779,069	2,175,413	1,878,301	28,759	- 4.99	+ 98.68	3,958,498	1,907,060	95.67	46.09	-51.83	OIL HEATING/AIR CONDTN.
#2	16,498	123,089	515,751	178,857	388,957	-45.31	+ 24.58	638,840	567,814	38.70	34.42	+11.06	NO A/C OR MECHANICAL VENTILATION
#3	146,568	6,326,189	--	6,349,214	--	- 0.36	--	6,326,189	6,349,214	43.16	43.30	- 0.32	ALL ELECTRIC
#4	52,461	2,105,920	--	2,350,607	--	-11.62	--	2,105,920	2,350,607	40.18	44.80	-11.50	ALL ELECTRIC

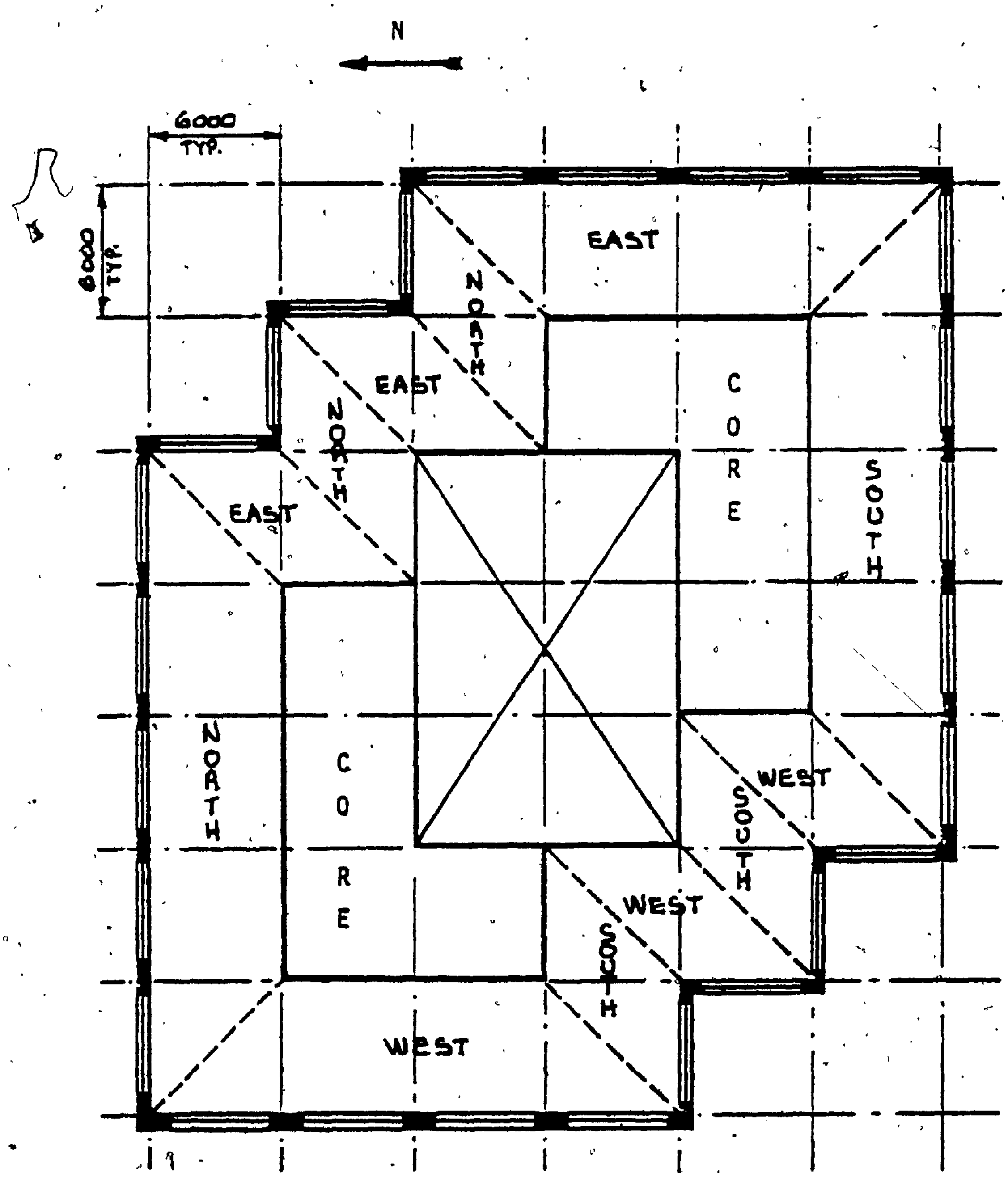
* Includes Lighting Equipment and Service Water Heating (Electric)
** Actual Energy Consumption is Based on Records for the Period of April 1978 to March 1979

TABLE 1 - SUMMARY OF ACTUAL AND ESTIMATED BUILDING ENERGY REQUIREMENTS

TABLE 28. ACTUAL AND ESTIMATED BUILDING ENERGY REQUIREMENTS [7]

APPENDIX B

FIGURES



Number of office floors	:	25
Total gross floor area	:	348 575 SQ-FT
Total net floor area	:	322 787 SQ-FT

FIG. 1 - OFFICE BUILDING, TYPICAL FLOOR AREA

GLAZING: 52%

ILLUMINATION: 3 W/SQ-FT.

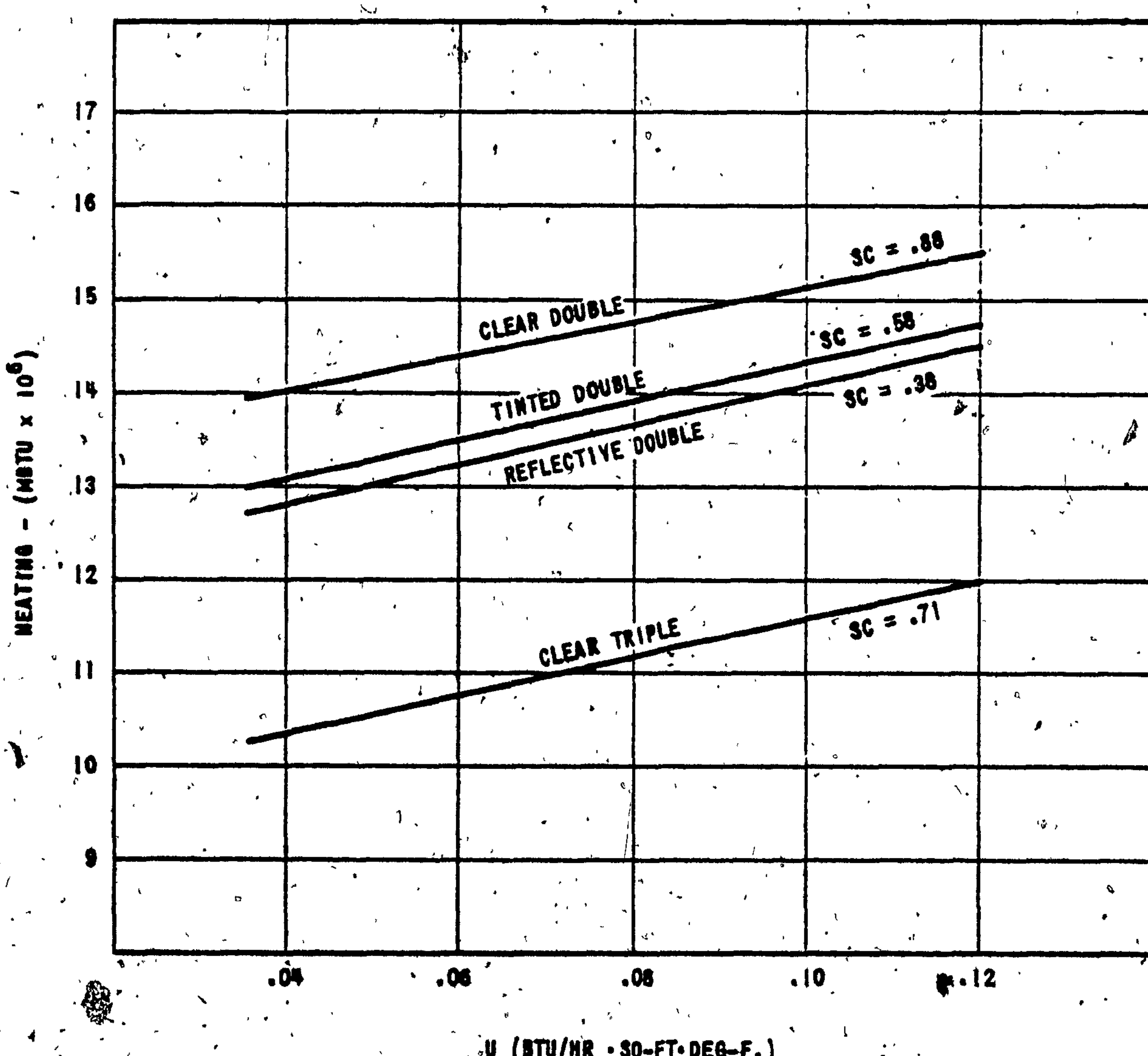


FIG. 2 - ANNUAL HEATING (MBTU) VERSUS WALL CONDUCTIVITY (U) AND TYPE OF GLAZING

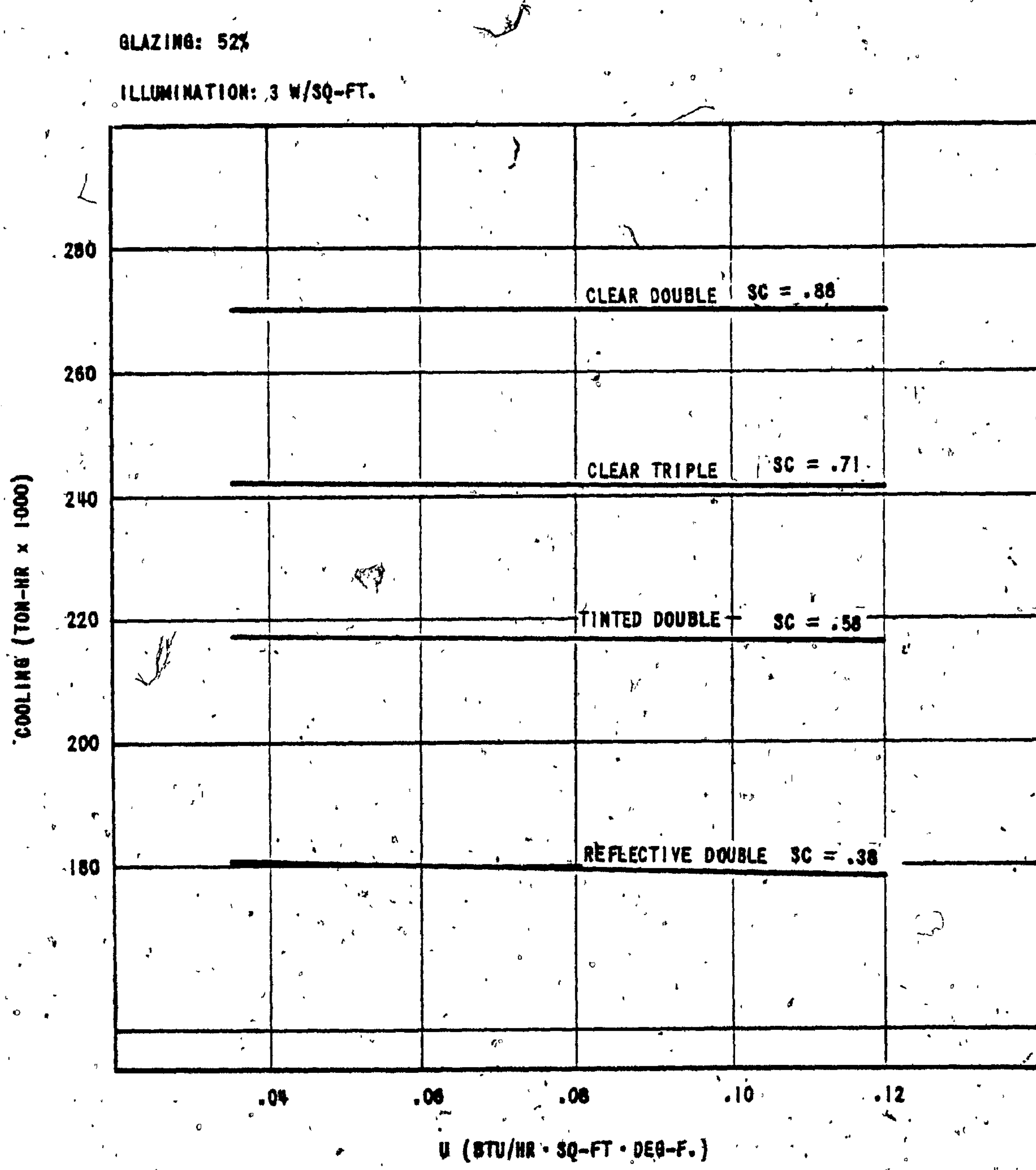


FIG. 3 - ANNUAL COOLING (TON-HR) VERSUS WALL CONDUCTIVITY (U) AND TYPE OF GLAZING

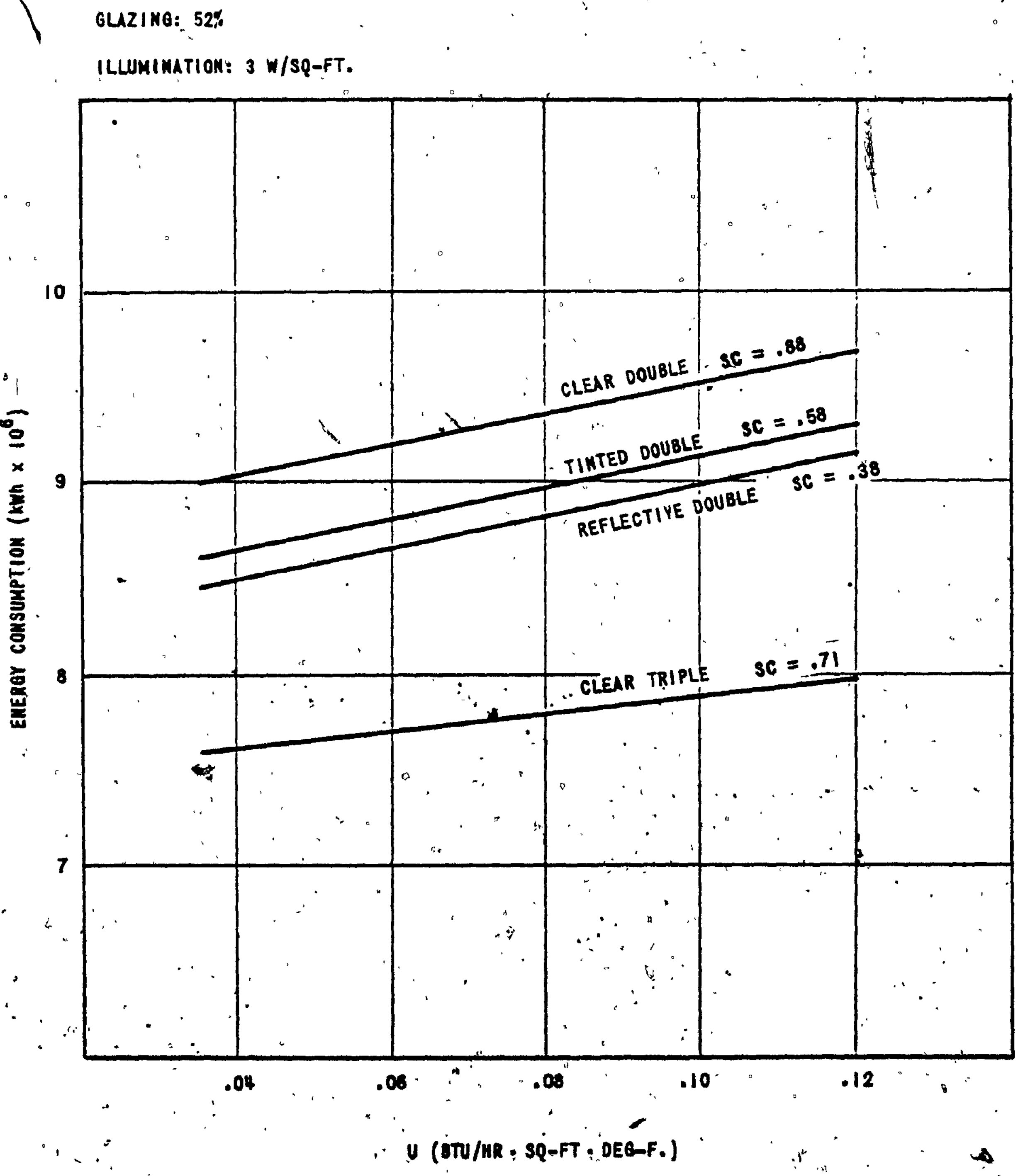


FIG. 4 - TOTAL ANNUAL ENERGY CONSUMPTION (kWh) VERSUS WALL CONDUCTIVITY (U) AND TYPE OF GLAZING

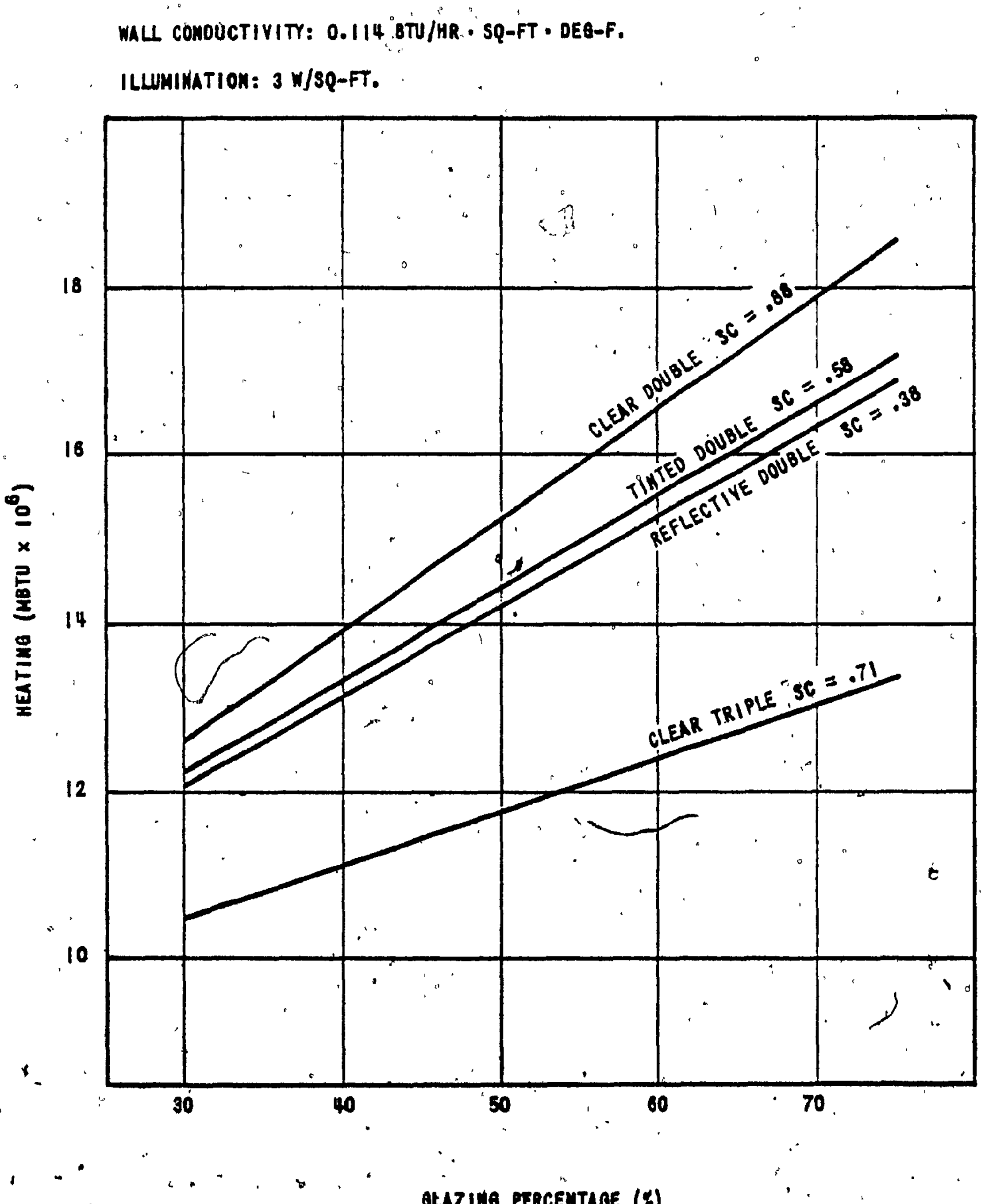


FIG. 5 - ANNUAL HEATING (MBTU) VERSUS PERCENTAGE (%) AND TYPE OF GLAZING

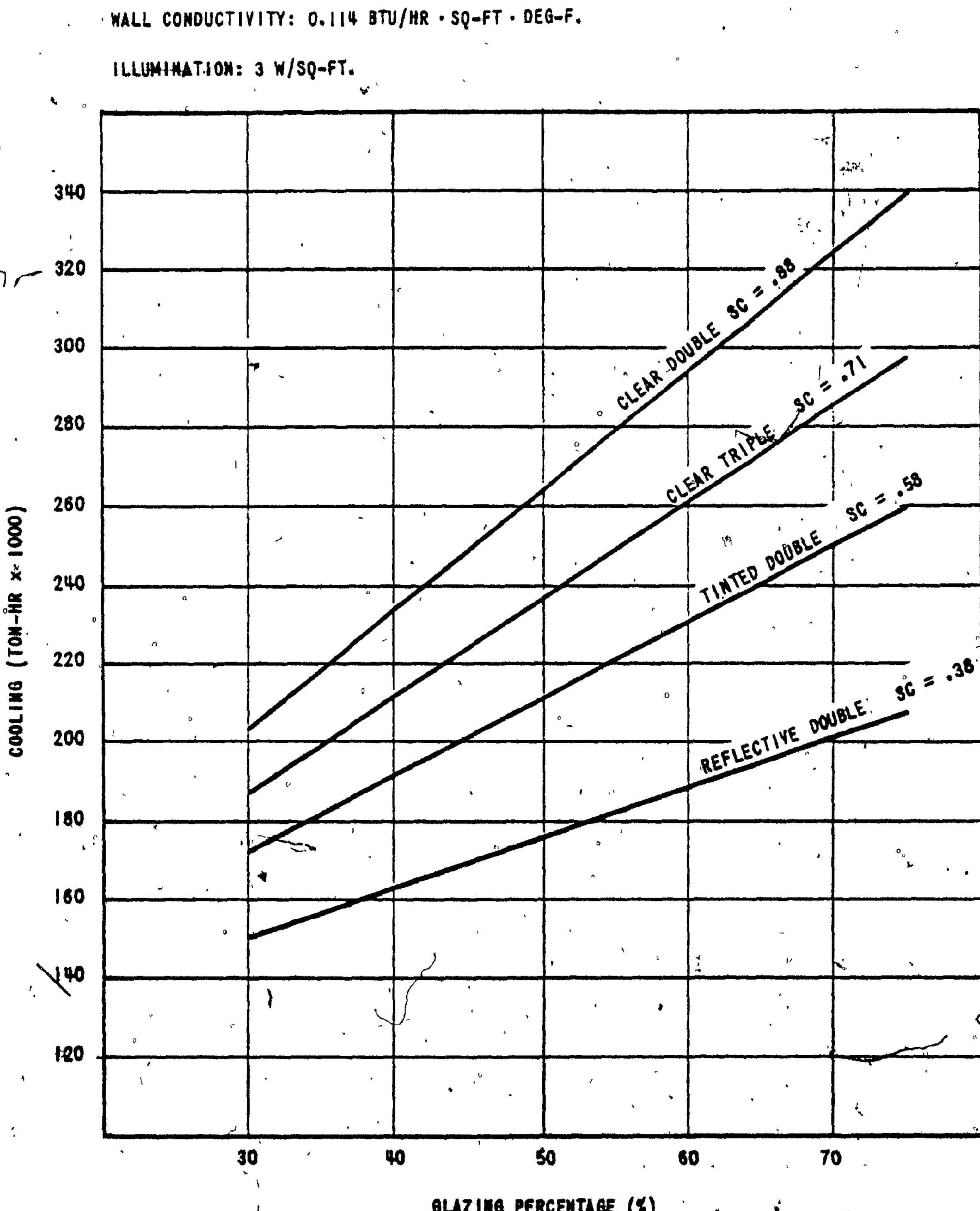


FIG. 6 - ANNUAL COOLING (TON-HR) VERSUS PERCENTAGE AND TYPE OF GLAZING

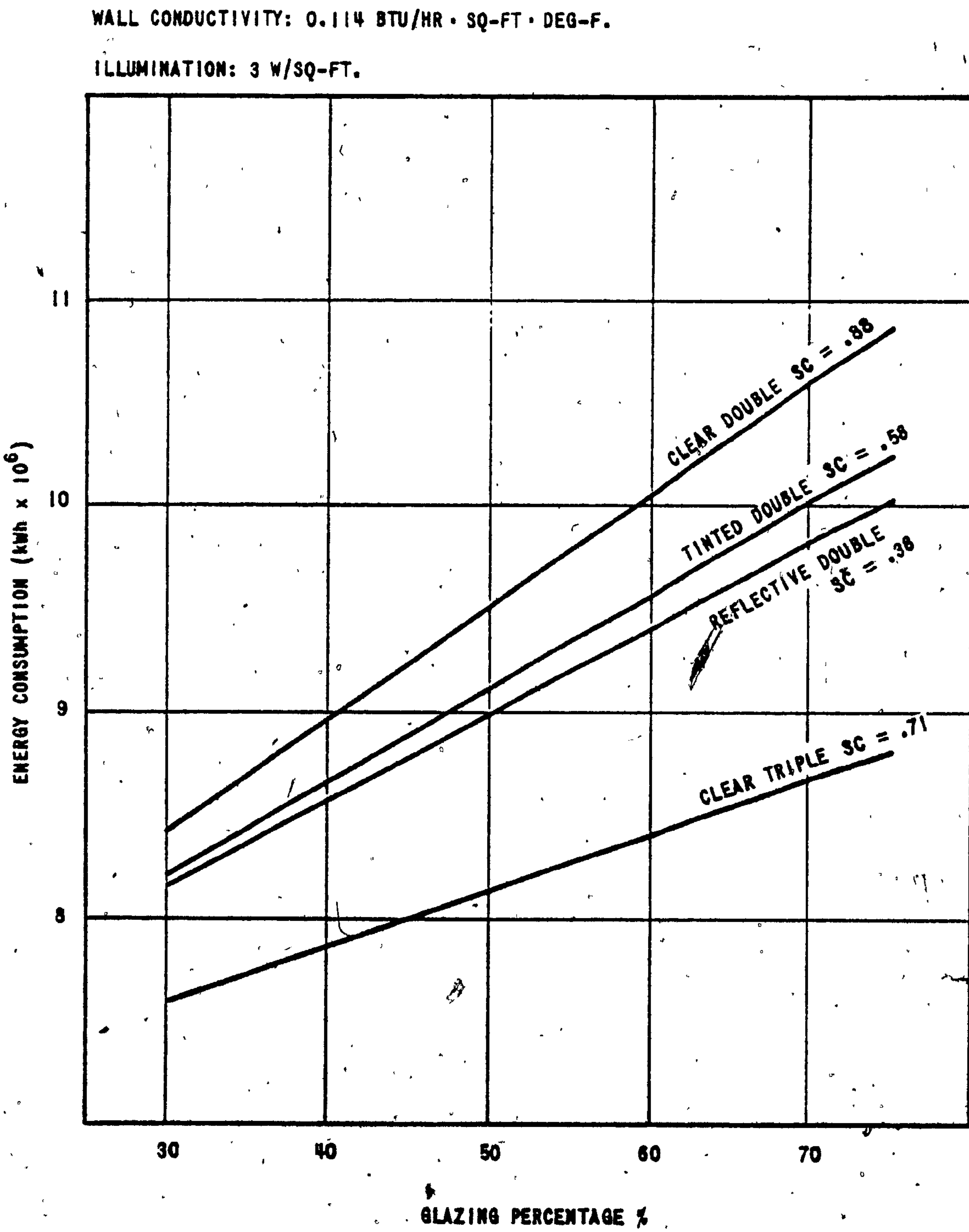


FIG. 7 - TOTAL ANNUAL ENERGY CONSUMPTION (kWh) VERSUS PERCENTAGE (%) AND TYPE OF GLAZING

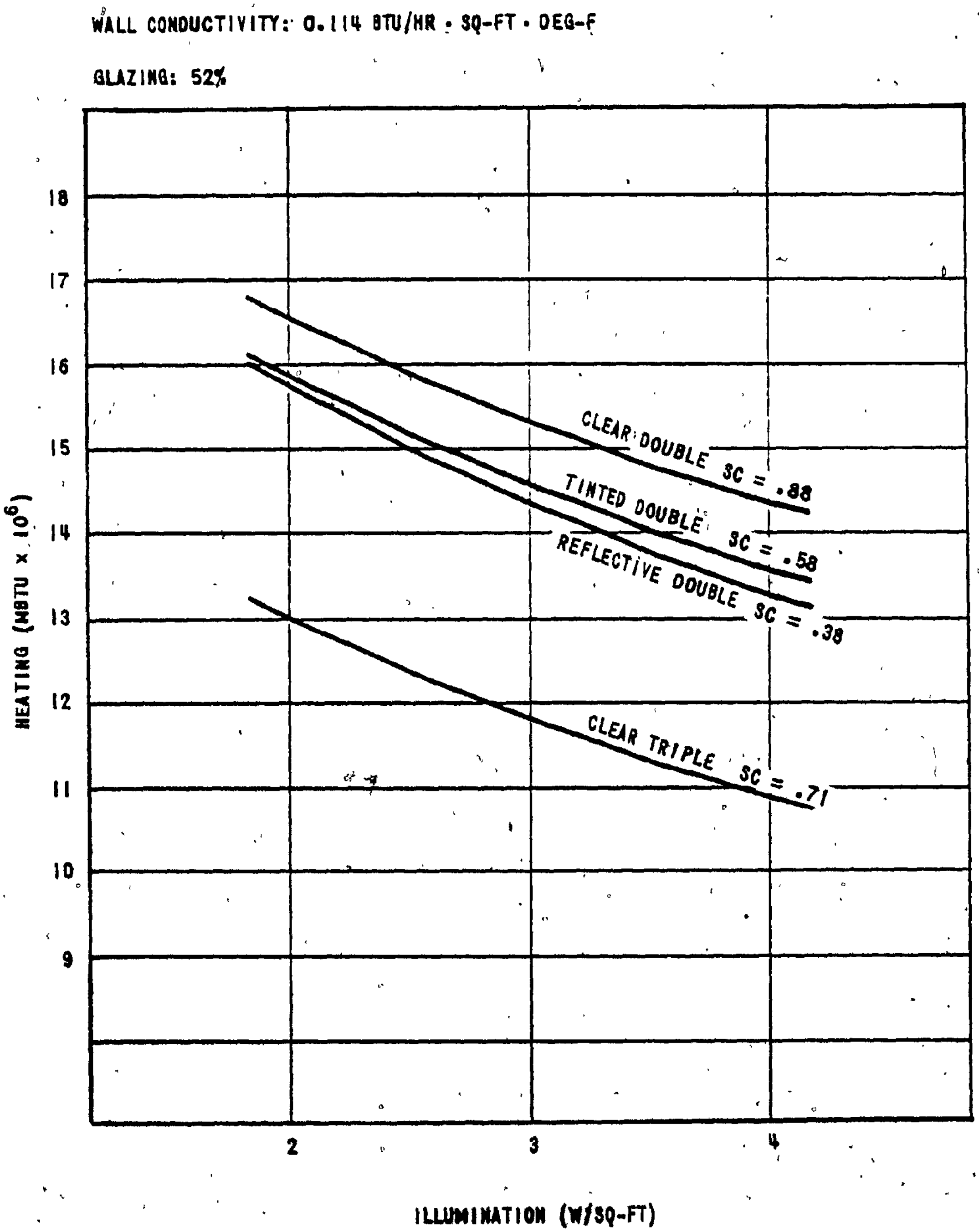


FIG. 8 - ANNUAL HEATING (MBTU) VERSUS ILLUMINATION LEVEL (W/SQ-FT) AND TYPE OF GLAZING

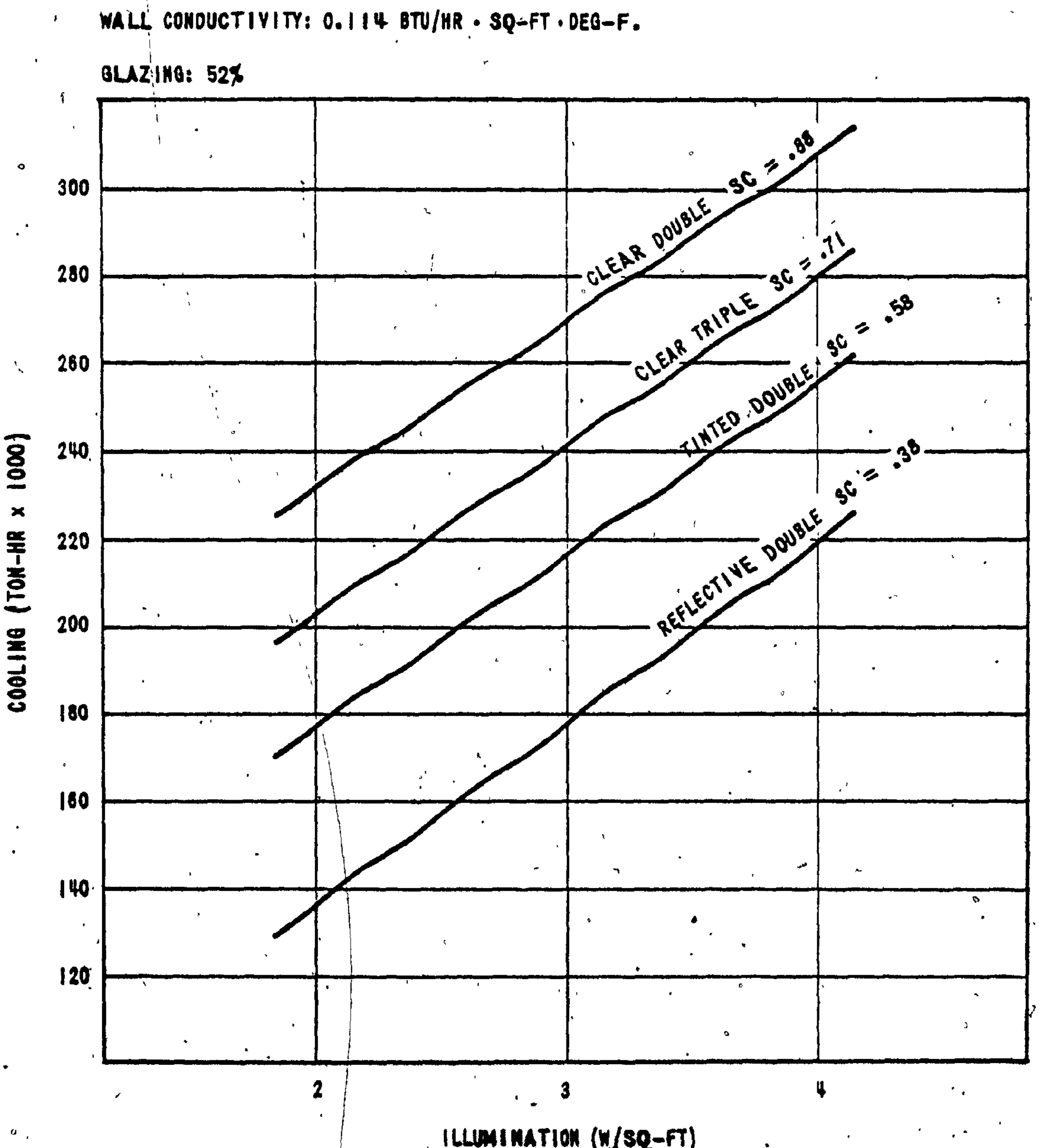


FIG. 8 - ANNUAL COOLING (TON-HR) VERSUS ILLUMINATION LEVEL (W/SQ-FT) AND TYPE OF GLAZING

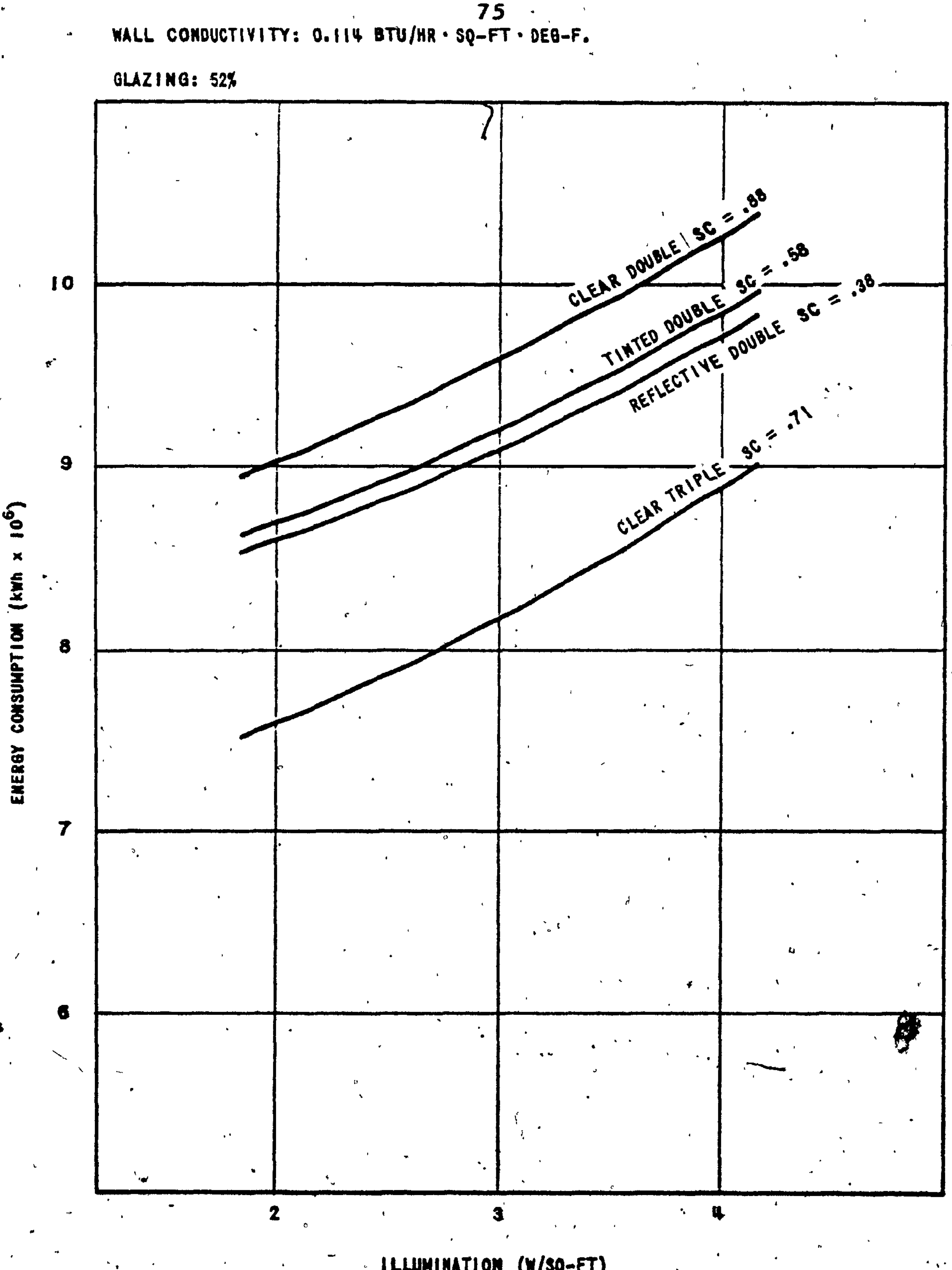


FIG. 10 - TOTAL ANNUAL ENERGY CONSUMPTION (kWh) VERSUS ILLUMINATION LEVEL (W/SQ-FT) AND TYPE OF GLAZING

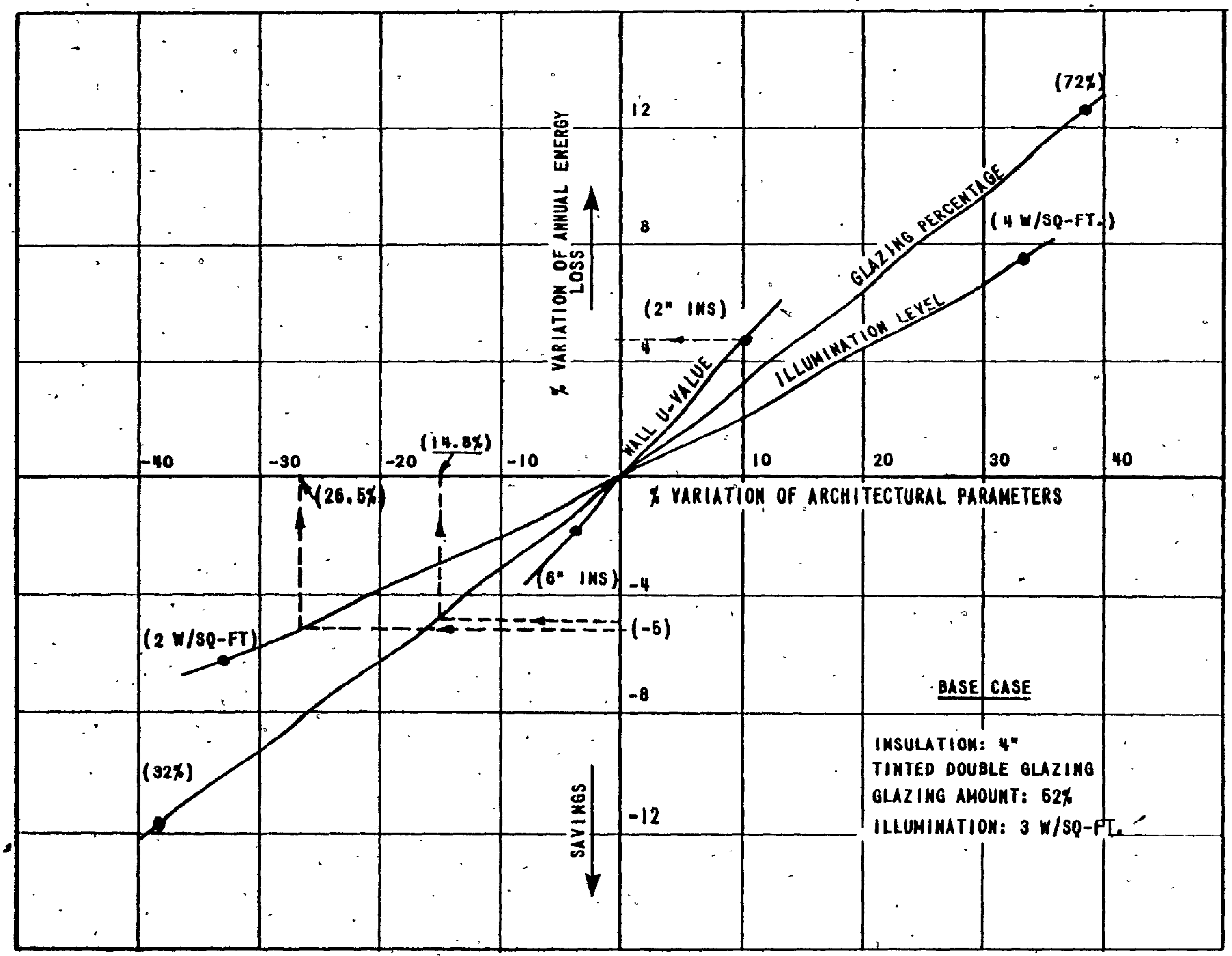


Figure 11 - % VARIATION OF ANNUAL ENERGY REQUIREMENTS VS % VARIATION OF ARCHITECTURAL PARAMETERS. ALL VARIATIONS ARE REFERED TO THE BASE CASE

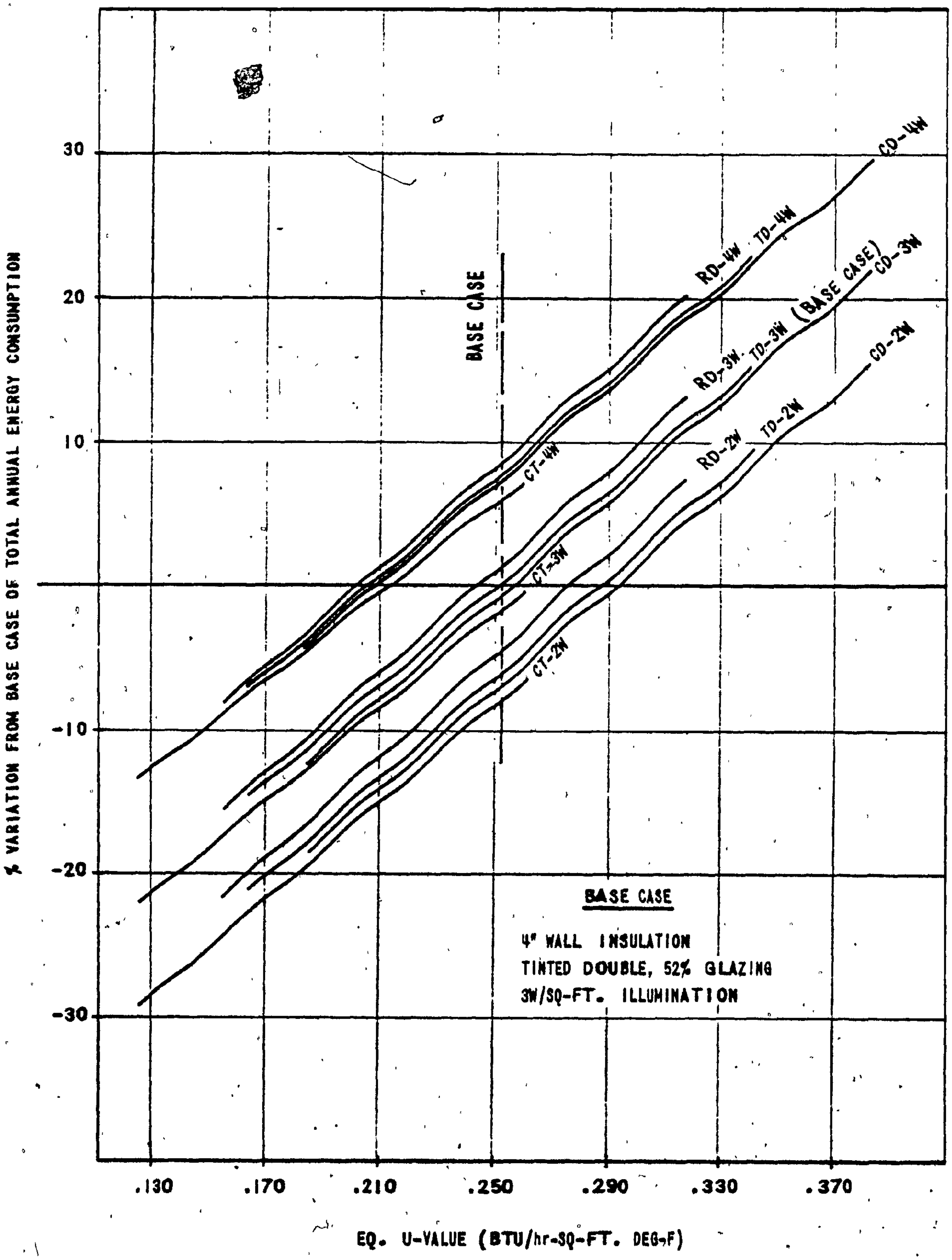


FIGURE 12 - % VARIATION FROM BASE CASE OF TOTAL ANNUAL ENERGY CONSUMPTION VERSUS WALL EQUIVALENT U-VALUE

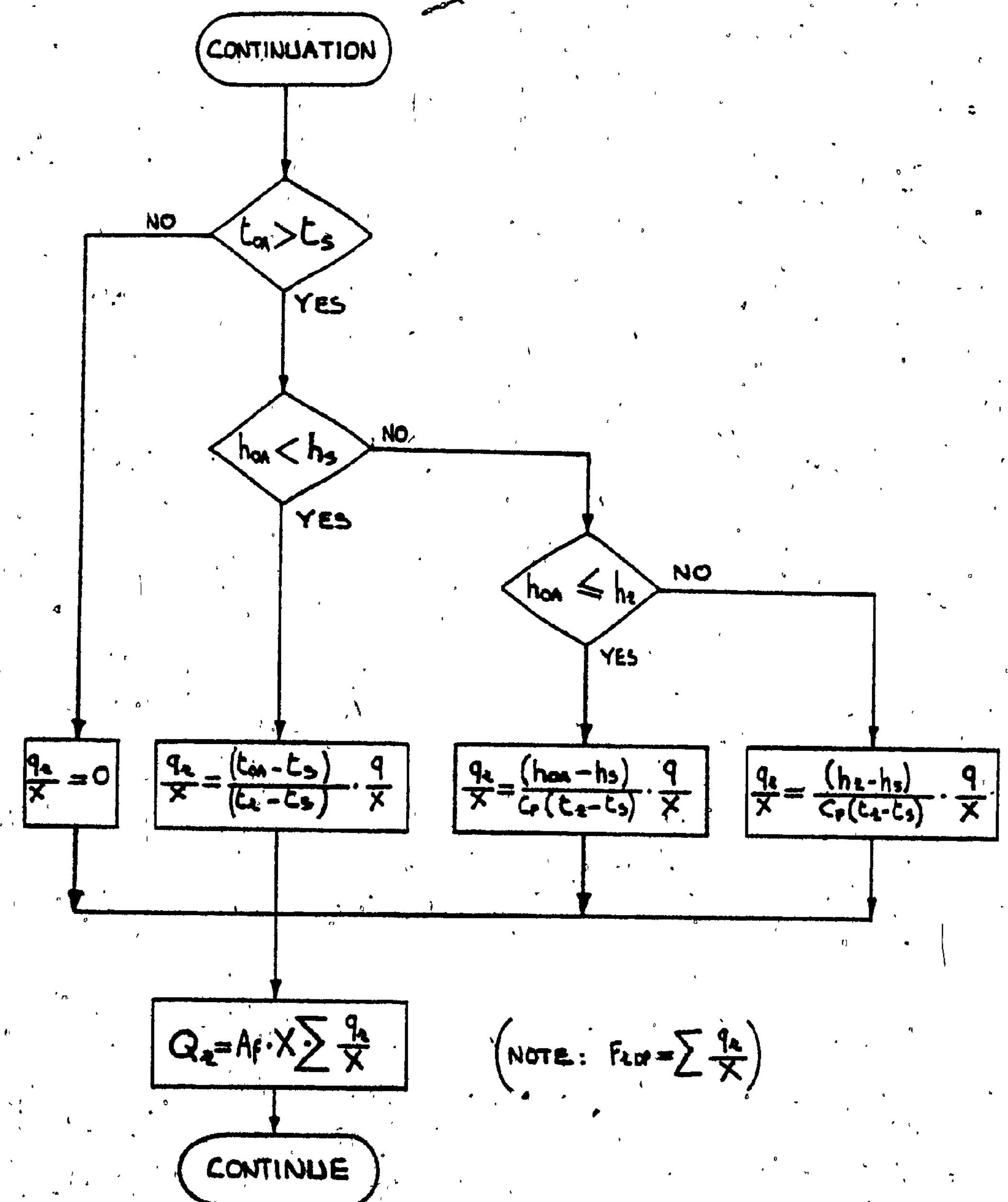


FIG. 13: ALGORITHM FOR CALCULATION OF MECHANICAL REFRIGERATION.

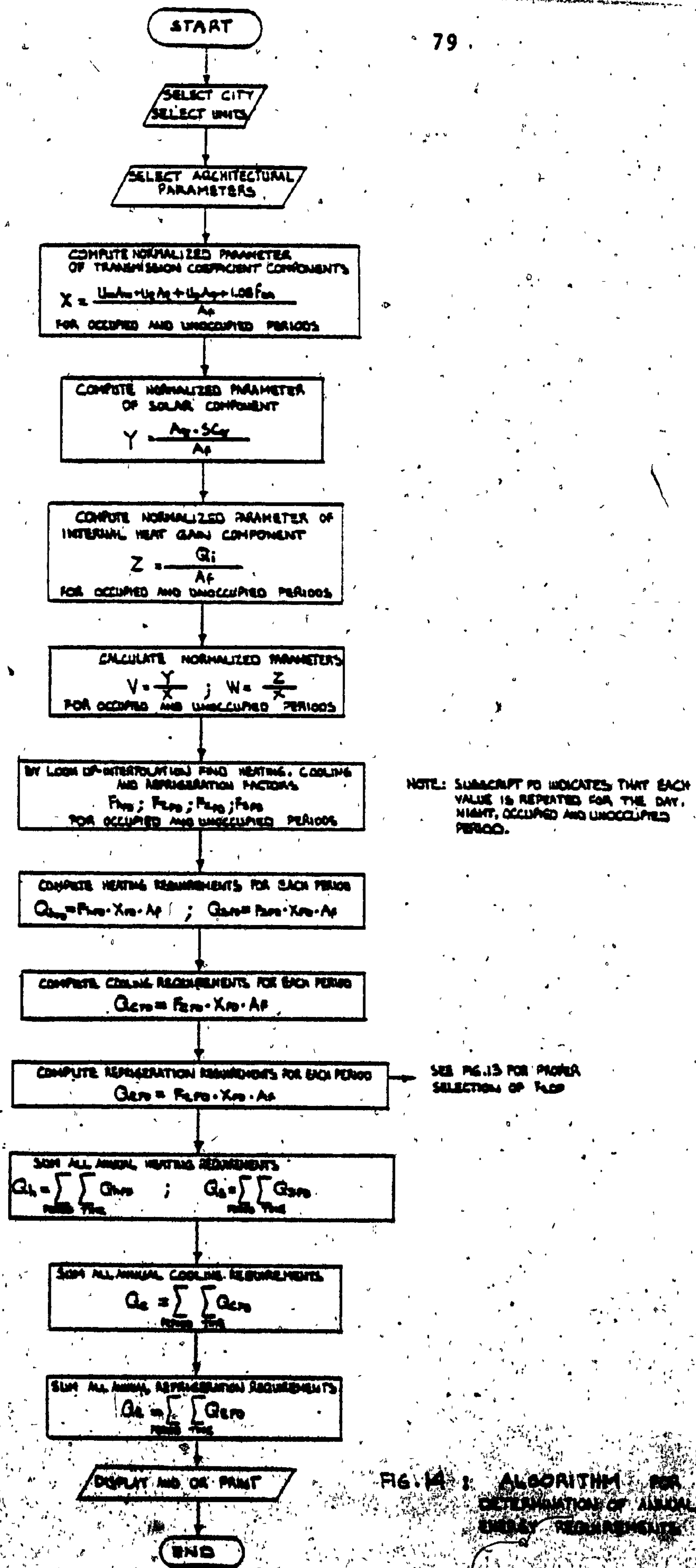


FIG. 14 : ALGORITHM FOR DETERMINATION OF ANNUAL ENERGY REQUIREMENTS

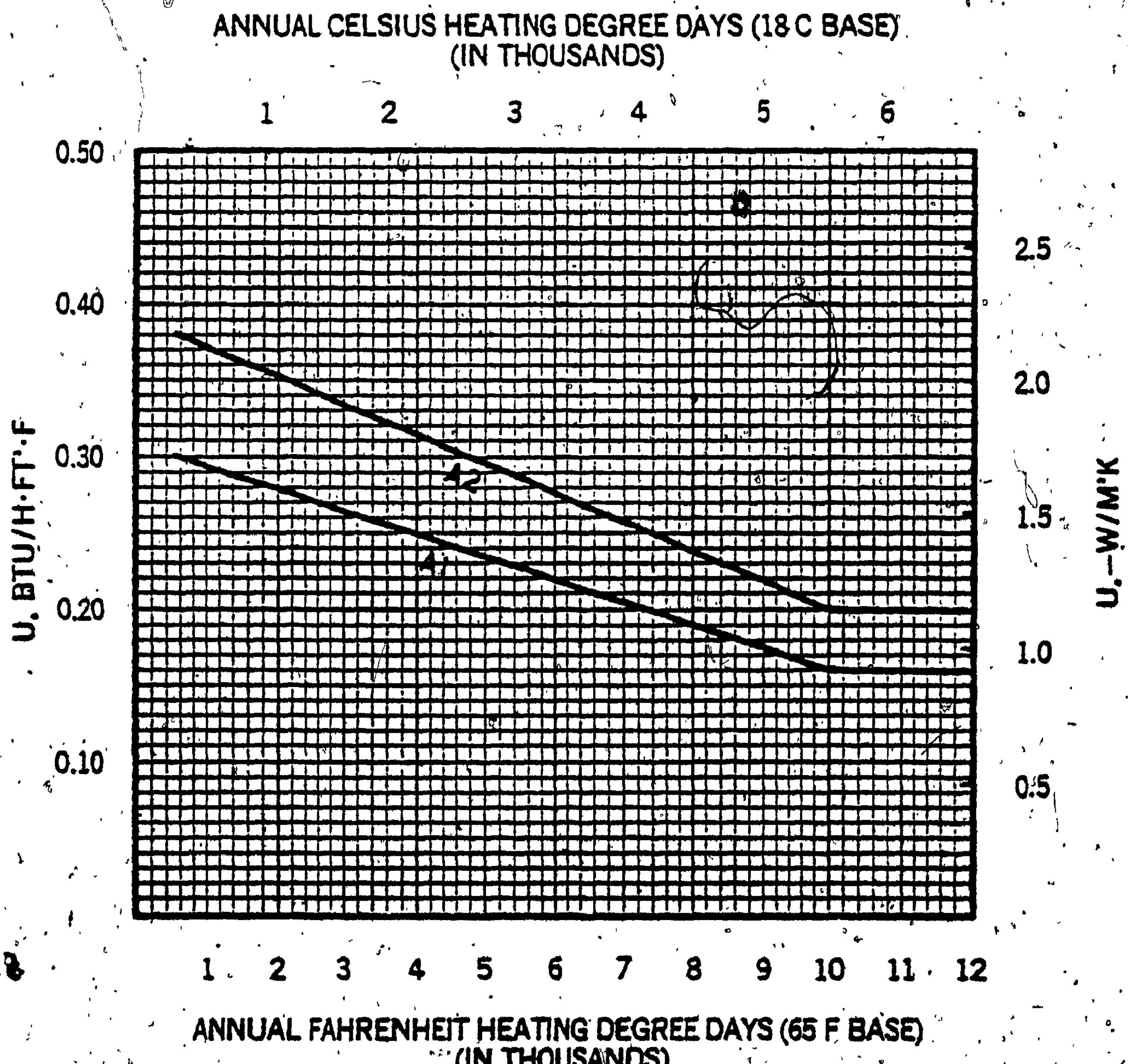
U₀ WALLS—TYPE "A" BUILDINGS

TYPE A BUILDINGS SHALL INCLUDE:

A 1 DETACHED ONE AND TWO FAMILY DWELLINGS

A 2 ALL OTHER RESIDENTIAL BUILDINGS, THREE STORIES OR LESS, INCLUDING BUT NOT LIMITED TO:

MULTI-FAMILY DWELLINGS
HOTELS AND MOTELS



U_o WALLS—HEATING—TYPE—"B" BUILDING

FOR ALL BUILDINGS NOT COVERED BY PARA. 4.3

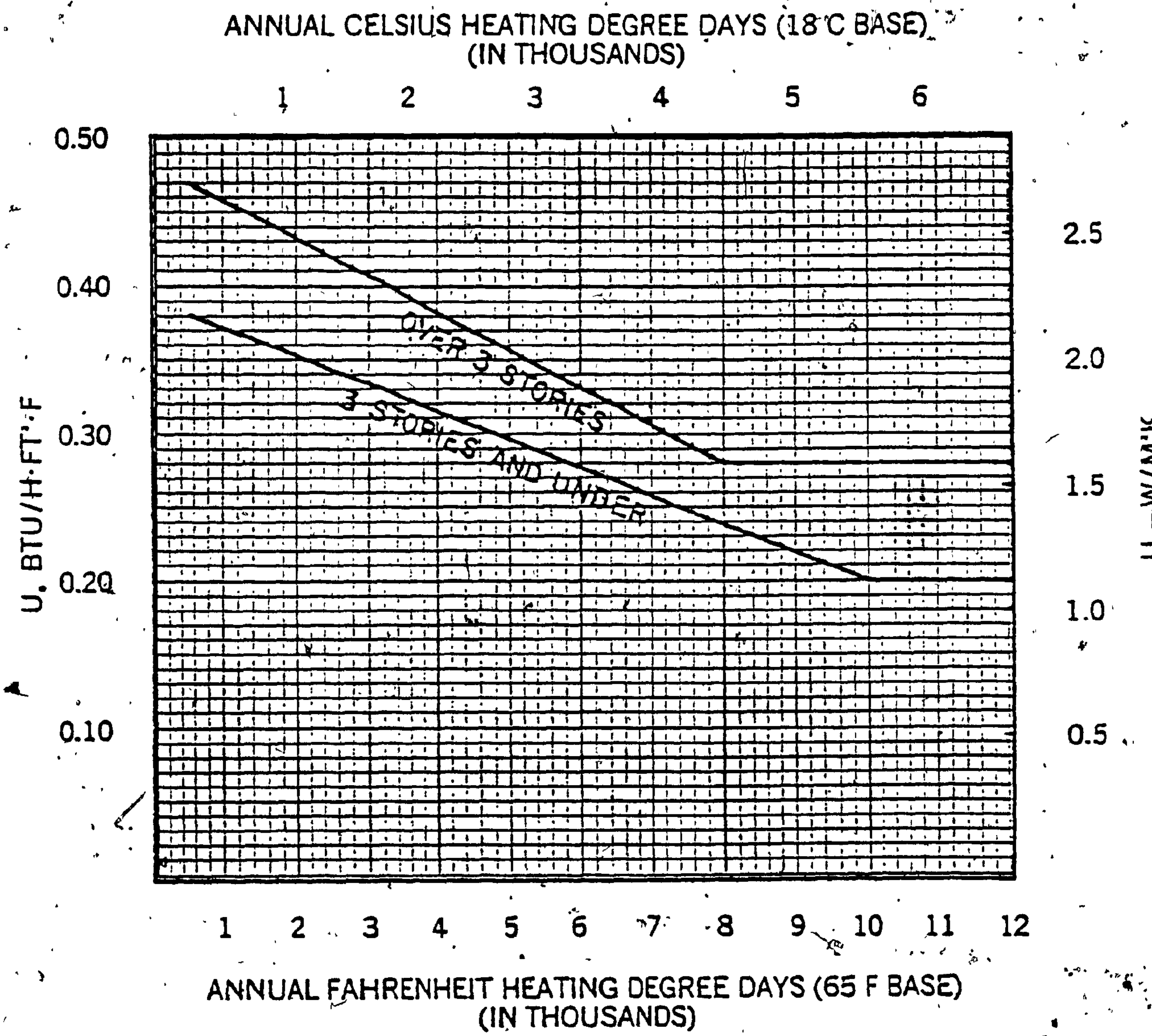


FIG. 16 - U_o WALLS - TYPE "B" BUILDING [3]

HEATING FACTOR: DAYTIME
LOCATION: MONTREAL, QUEBEC
ORIENTATION: SOUTHEAST

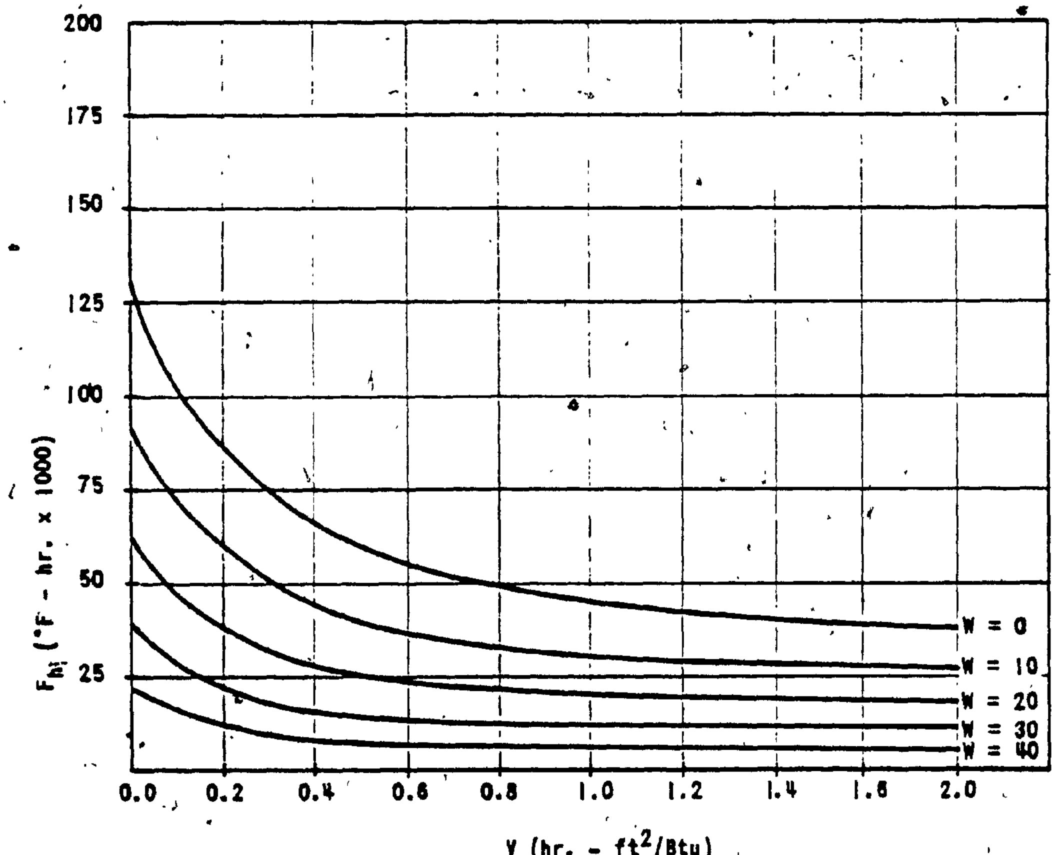


Figure 17: PLOT OF HEATING FACTOR, F_h, VERSUS PARAMETERS V AND W FOR "DAYTIME" PERIOD (7 am - 7 pm)

HEATING FACTOR: NIGHT-TIME
LOCATION: MONTREAL, QUEBEC
ORIENTATION: SOUTHEAST

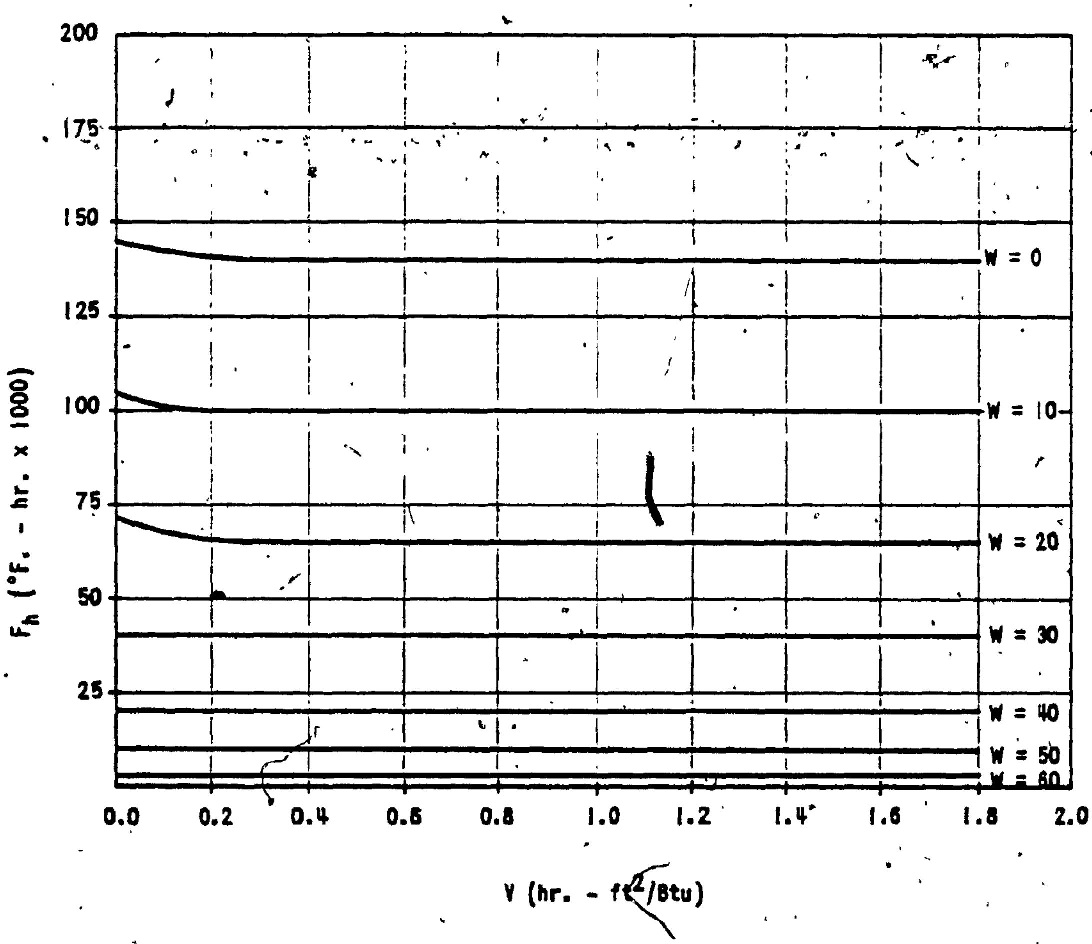


Figure 18: PLOT OF HEATING FACTOR, F_h, VERSUS PARAMETERS V AND W FOR "NIGHTTIME" PERIOD (7 am - 7 pm)

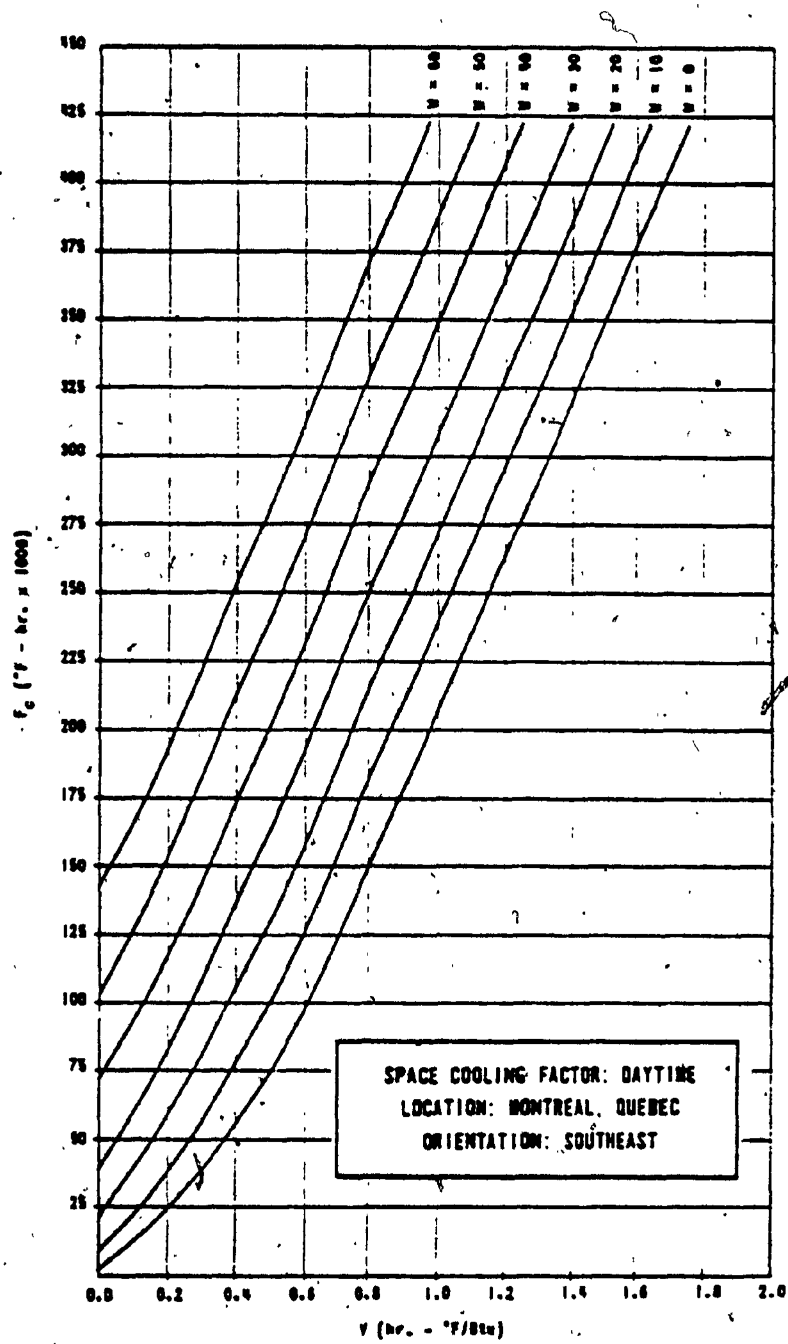


Figure 19: PLOT OF SPACE COOLING FACTOR, F_c, VERSUS PARAMETERS V AND W FOR "DAYTIME" PERIOD (7 am - 7pm)

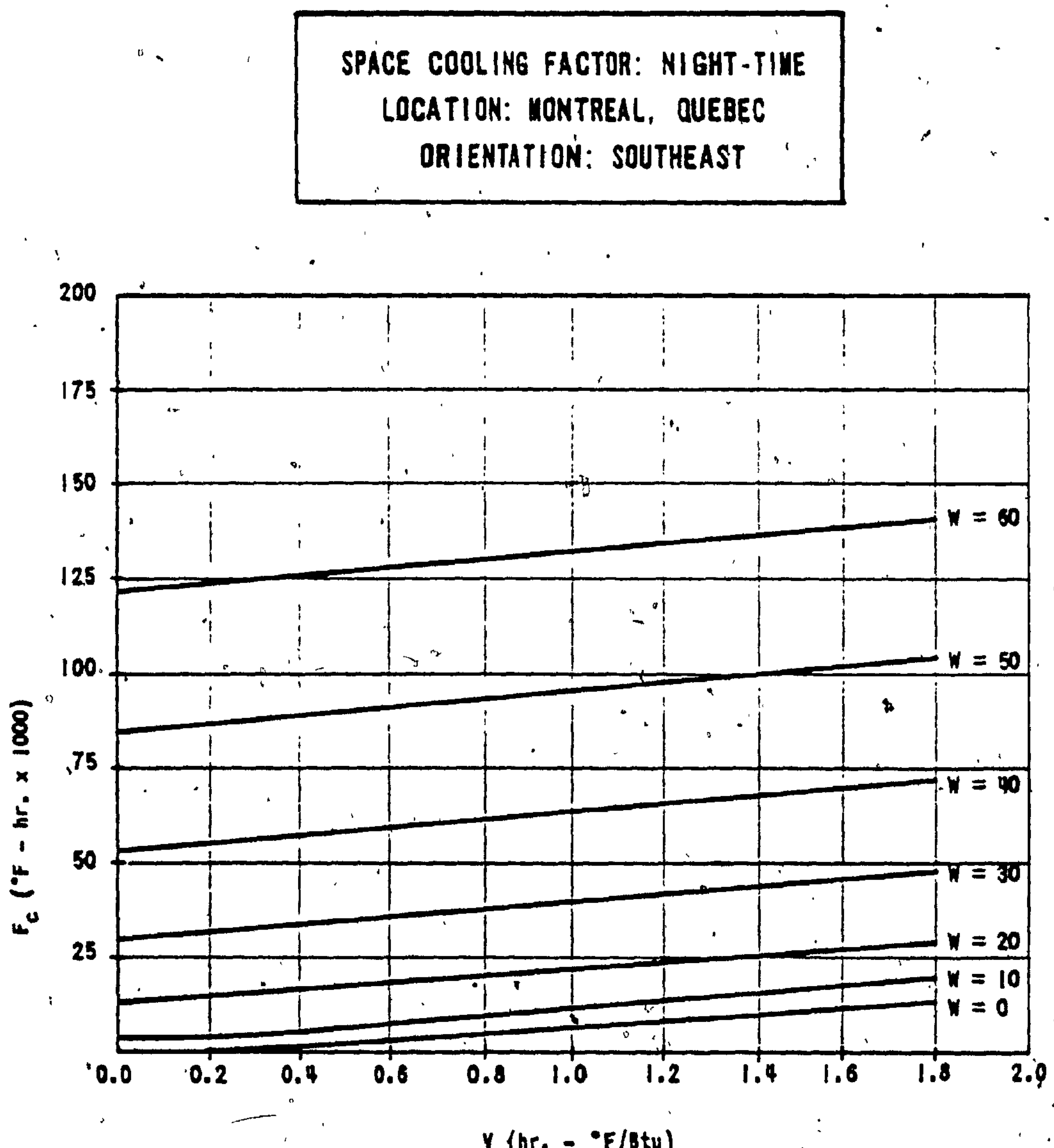


Figure 20: PLOT OF SPACE COOLING FACTOR, F_C, VERSUS PARAMETERS V AND W FOR "NIGHTIME" PERIOD (7 pm - 7 am)

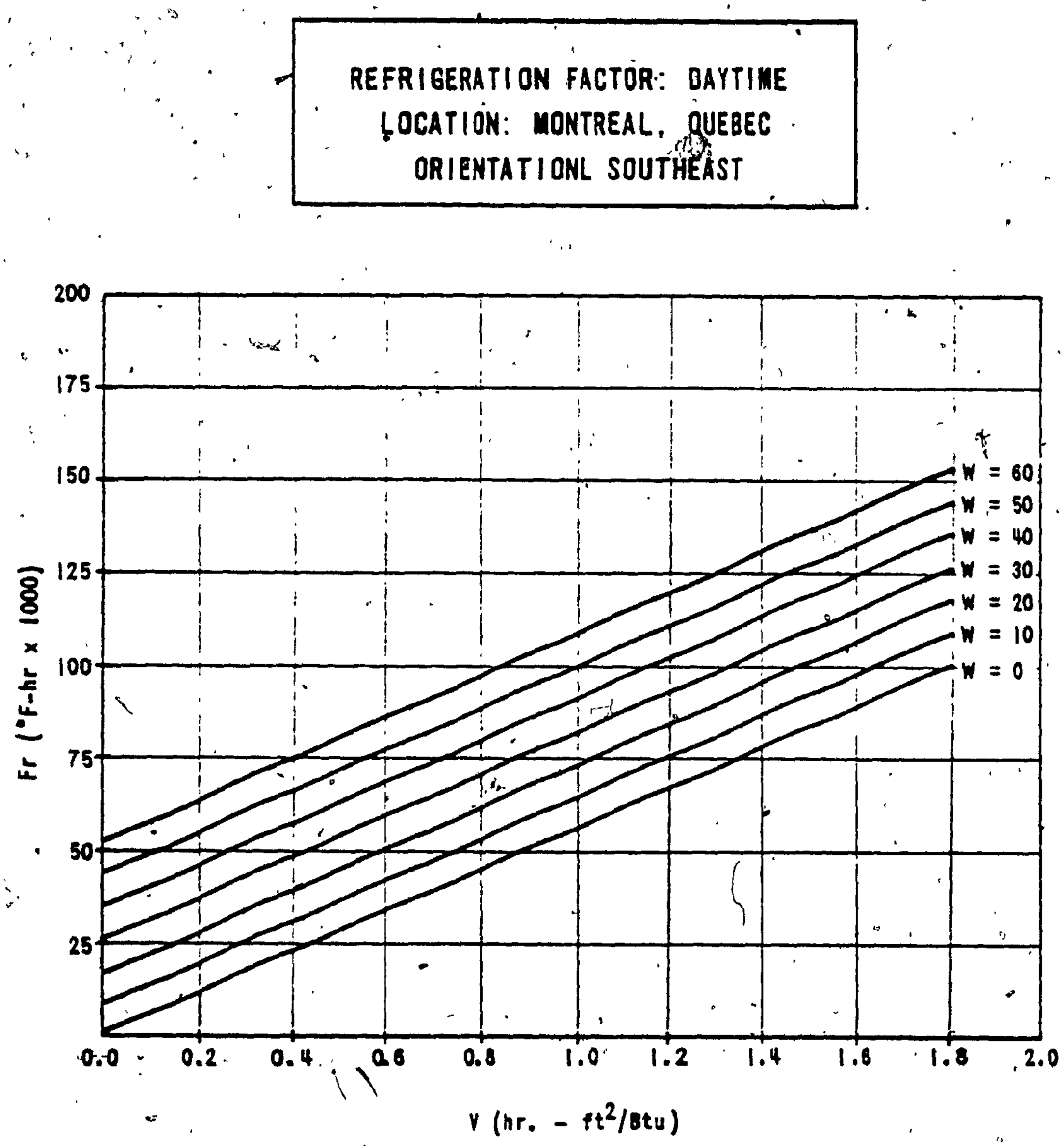


Figure 21 : PLOT OR REFRIGERATION FACTOR, F_r, VERSUS PARAMETERS V AND W FOR "DAYTIME" PERIOD (7 am - 7 pm)

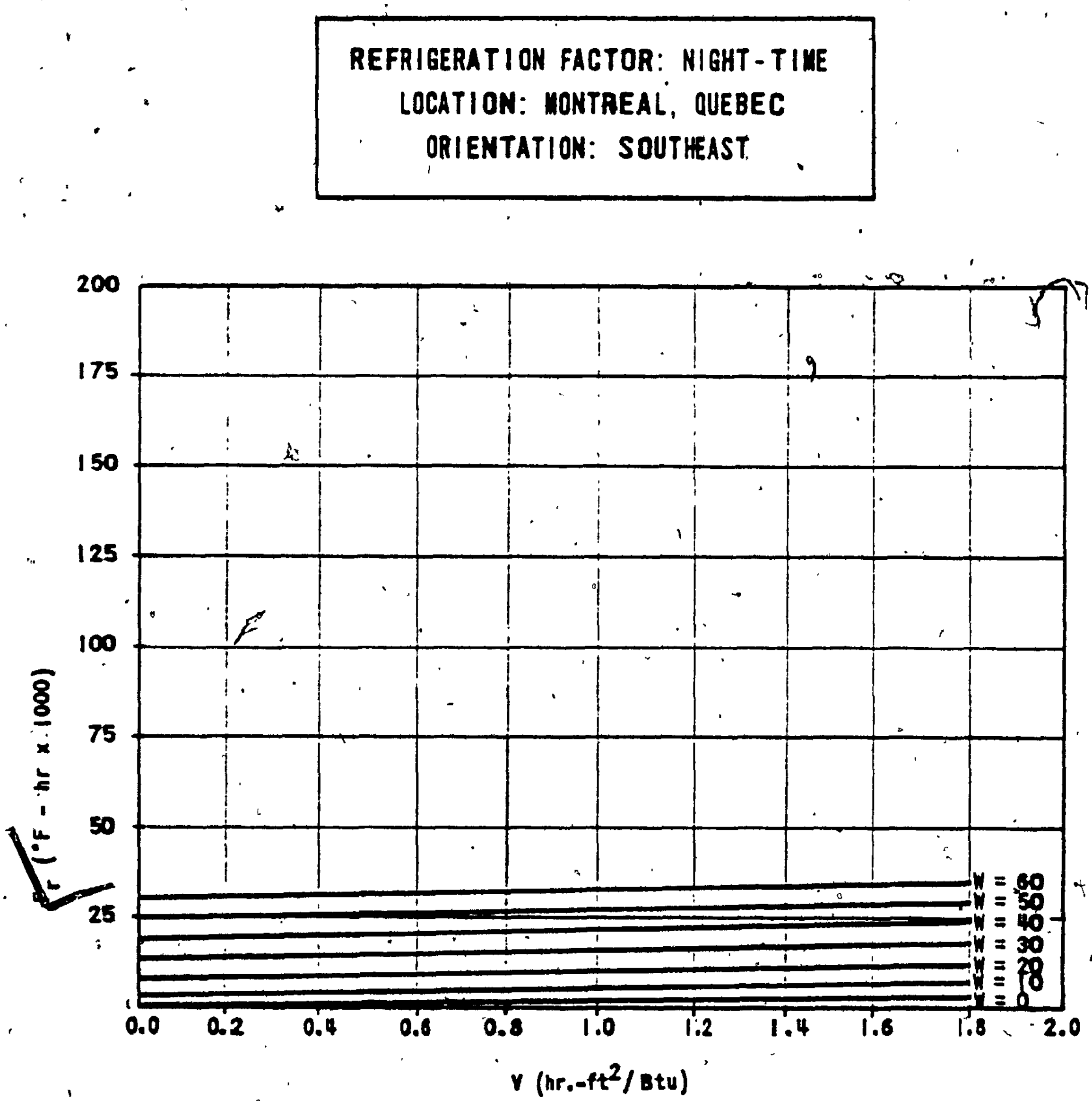


Figure 22 : PLOT OF REFRIGERATION FACTOR, F_r, VERSUS PARAMETERS V AND W FOR "NIGHTTIME" PERIOD (7 pm - 7 am)

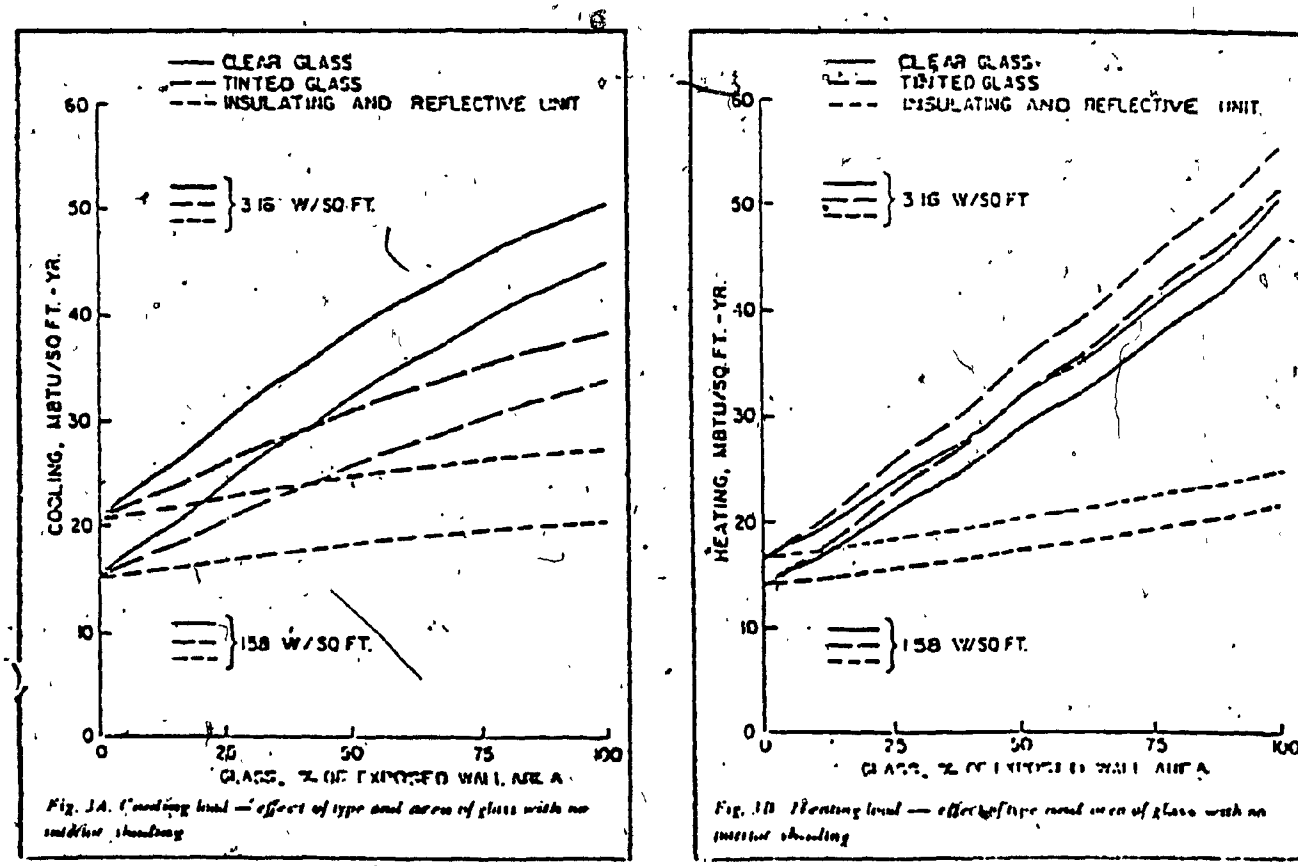


FIG. 23 - COOLING AND HEATING LOADS - EFFECT OF TYPE AND AREA OF GLASS WITH NO INTERIOR SHADING. [4]

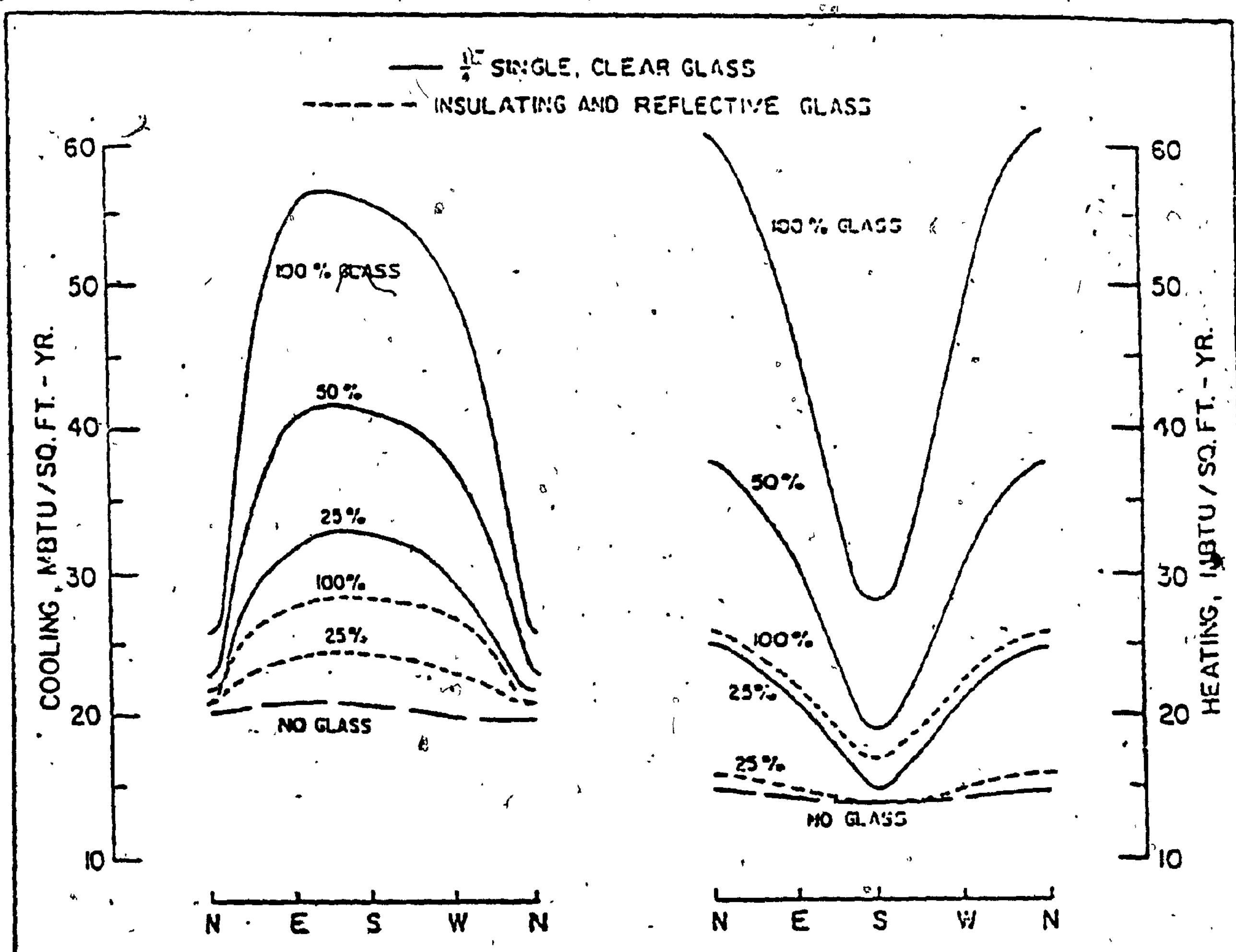


Fig. 1. Effect of orientation and type and extent of glass

FIG. 24 - EFFECT OF ORIENTATION AND TYPE AND AREA OF GLASS [4]

APPENDIX C

"ABC" PROGRAM

TYPICAL COMPUTER PRINT-OUT

- BASE CASE -

```
PUBLIC WORKS CANADA 'ABC' PROGRAM-VERSION 3.0

PROJECT
EFFECTS OF ARCHITECTURAL PARAMETERS ON ENERGY CONSUMPTION IN BUILDINGS

***ZONE NUMBER 1
ZONE:  CW3G00NGRO
MULT:  ZONE MULTIPLIER=  1.0
AREA:  FLOOR AREA=      84475. (SQ-FT)
DIRX:  DIRECTION=    INTR
ROOF:  ROOF AREA=           0. (SQ-FT) ;U-VALUE= 0.000 (BTU/HR SQ-FT DEG-F)
TIME:  OCCUPIED PERIOD=  5 DAYS/WEEK ;   0 NIGHTS/WEEK
     UNOCCUPIED PERIOD=  2 DAYS/WEEK ;   7 NIGHTS/WEEK
LITE:  OCCUPIED=  3.00 (WATT/SQ-FT)    ;UNOCCUPIED=   .15 (WATT/SQ-FT)
PEOP:  OCCUPIED=  180. (SQ-FT/PERSON)  ;UNOCCUPIED=    0. (SQ-FT/PERSON)
VENT:  VENTILATION REQUIREMENTS:
       OCCUPIED=  .110 (CFM/SQ-FT)     ;UNOCCUPIED= 0.000 (CFM/SQ-FT)
       INFILTRATION RATE
       OCCUPIED=  .047 (CFM/SQ-FT)     ;UNOCCUPIED=  .047 (CFM/SQ-FT)

***USING DATA FILE: EDM
   -EDMONTON REFERENCE YEAR, STANDARD SOLAR, TSTAT=72-78 F.

** ANNUAL REQUIREMENT **
ELECTRICITY (LIGHTS):           864215. (KWH)  ;       10.23 (KWH/SQ-FT)

** CONSTANT OPERATION **
HEATING:                        867219. (MBTU) ;       10.27 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=     111695. (TON-HR);       1.32 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=   31602. (TON-HR);        .37 (TON-HR/SQ-FT)

** SETBACK (65 F.) WHEN UNOCCUPIED **
HEATING:                        722421. (MBTU) ;        8.55 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=     111125. (TON-HR);       1.32 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=   31095. (TON-HR);        .37 (TON-HR/SQ-FT)
```

PUBLIC WORKS CANADA 'ABC' PROGRAM-VERSION 3.0

PROJECT.
EFFECTS OF ARCHITECTURAL PARAMETERS ON ENERGY CONSUMPTION IN BUILDINGS

***ZONE NUMBER 2
ZONE: NWGG52TDR3
MULT: ZONE MULTIPLIER= 1.0
AREA: FLOOR AREA= 64906.(SQ-FT)
DIRX: DIRECTION= NORT
WALL: WALL AREA= 43610.(SQ-FT) ;U-VALUE= .060 (BTU/HR SQ-FT DEG-F)
WIND: WINDOW AREA= 52. % ;U-VALUE= .430 (BTU/HR SQ-FT DEG-F)
;SHADING COEF.= .58
ROOF: ROOF AREA= 0.(SQ-FT) ;U-VALUE= 0.000 (BTU/HR SQ-FT DEG-F)
TIME: OCCUPIED PERIOD= 5 DAYS/WEEK , 0 NIGHTS/WEEK
UNOCCUPIED PERIOD= 2 DAYS/WEEK , 7 NIGHTS/WEEK
LITE: OCCUPIED= 3.00 (WATT/SQ-FT) ,UNOCCUPIED= .15 (WATT/SQ-FT)
PEOP: OCCUPIED= 180. (SQ-FT/PERSON) ,UNOCCUPIED= 0. (SQ-FT/PERSON)
VENT: VENTILATION REQUIREMENTS:
OCCUPIED= .103 (CFM/SQ-FT) ,UNOCCUPIED= 0.000 (CFM/SQ-FT)
INFILTRATION RATE
OCCUPIED= .062 (CFM/SQ-FT) ,UNOCCUPIED= .062 (CFM/SQ-FT)

***USING DATA FILE. EDM
-EDMONTON REFERENCE YEAR, STANDARD SOLAR, TSTAT=72-78 F.

** ANNUAL REQUIREMENT **
ELECTRICITY (LIGHTS): 664016. (KWH) ; 10.23 (KWH/SQ-FT)

** CONSTANT OPERATION **
HEATING: 3971376. (MBTU) ; 61.19 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER= 81952. (TON-HR); 1.26 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)= 36875. (TON-HR); .57 (TON-HR/SQ-FT)

** SETBACK (65 F.) WHEN UNOCCUPIED **
HEATING: 3447518. (MBTU) ; 53.12 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER= 73970. (TON-HR); 1.14 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)= 31828. (TON-HR); .49 (TON-HR/SQ-FT)

PUBLIC WORKS CANADA 'ABC' PROGRAM-VERSION 3.0

PROJECT:
EFFECTS OF ARCHITECTURAL PARAMETERS ON ENERGY CONSUMPTION IN BUILDINGS

```
***ZONE NUMBER 3
ZONE:  SWGG52TDR3
MULT:  ZONE MULTIPLIER=   1.0
AREA:  FLOOR AREA=      64906. (SQ-FT)
DIRX:  DIRECTION=   SOUT
WALL:  WALL AREA=        43610. (SQ-FT) ;U-VALUE=  .060 (BTU/HR SQ-FT DEG-F)
WIND:  WINDOW AREA= 52. %               ;U-VALUE=  .430 (BTU/HR SQ-FT DEG-F)
                                        ;SHADING COEF:= .58
ROOF:  ROOF AREA=            0. (SQ-FT) ;U-VALUE= 0.000 (BTU/HR SQ-FT DEG-F)
TIME:  OCCUPIED PERIOD=    5 DAYS/WEEK ;   0 NIGHTS/WEEK
     UNOCCUPIED PERIOD=    2 DAYS/WEEK ;   7 NIGHTS/WEEK
LITE:  OCCUPIED=  3.00 (WATT/SQ-FT)     ;UNOCCUPIED=   .15 (WATT/SQ-FT)
PEOP:  OCCUPIED=  180. (SQ-FT/PERSON)   ;UNOCCUPIED=    0. (SQ-FT/PERSON),
VENT:  VENTILATION REQUIREMENTS:
       OCCUPIED=  .165 (CFM/SQ-FT)      ;UNOCCUPIED= 0.000 (CFM/SQ-FT)
       INFILTRATION RATE
       OCCUPIED=  .062 (CFM/SQ-FT)      ;UNOCCUPIED=  .062 (CFM/SQ-FT)

***USING DATA FILE: EDM
   -EDMONTON REFERENCE YEAR, STANDARD SOLAR, TSTAT=72-78 F.

** ANNUAL REQUIREMENT **
ELECTRICITY (LIGHTS):              664016. (KWH)   ;      10.23 (KWH/SQ-FT)

** CONSTANT OPERATION **
HEATING:                          3561602. (MBTU)  ;      54.87 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=        278430. (TON-HR);       4.29 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=      80437. (TON-HR);       1.24 (TON-HR/SQ-FT)

** SETBACK (65 F.) WHEN UNOCCUPIED **
HEATING:                          3069170. (MBTU)  ;      47.29 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=        216630. (TON-HR);       3.34 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=      63651. (TON-HR);        .98 (TON-HR/SQ-FT)
```

PUBLIC WORKS CANADA 'ABC' PROGRAM-VERSION 3.0

```
PROJECT:
EFFECTS OF ARCHITECTURAL PARAMETERS ON ENERGY CONSUMPTION IN BUILDINGS

***ZONE NUMBER  4
ZONE:  EW3CS2T0R3
MULT:  ZONE MULTIPLIER=   1.0
AREA:  FLOOR AREA=      54250.(SQ-FT)
DIRX:  DIRECTION=    EAST
WALL:  WALL AREA=       37717.(SQ-FT) ;U-VALUE=  .060 (BTU/HR SQ-FT DEG-F)
WIND:  WINDOW AREA= 52. %            ;U-VALUE=  .430 (BTU/HR SQ-FT DEG-F)
                                      ;SHADING COEF.= .58
ROOF   ROOF AREA=           0.(SQ-FT) ;U-VALUE= 0.000 (BTU/HR SQ-FT DEG-F)
TIME:  OCCUPIED PERIOD=   5 DAYS/WEEK ;   0 NIGHTS/WEEK
     UNOCCUPIED PERIOD=   2 DAYS/WEEK ,   7 NIGHTS/WEEK
LITE   OCCUPIED=  3.00 (WATT/SQ-FT)    ,UNOCCUPIED=   .15 (WATT/SQ-FT)
PEOP   OCCUPIED=  130. (SQ-FT/PERSON)  ,UNOCCUPIED=    0. (SQ-FT/PERSON)
VENT   VENTILATION REQUIREMENTS.
       OCCUPIED=  .140 (CFM/SQ-FT)     ;UNOCCUPIED= 0.000 (CFM/SQ-FT)
       INFILTRATION RATE
       OCCUPIED=  .074 (CFM/SQ-FT)     ;UNOCCUPIED=  .074 (CFM/SQ-FT)

***USING DATA FILE. EDM
   -EDMONTON REFERENCE YEAR, STANDARD SOLAR, TSTAT=72-78 F.

** ANNUAL REQUIREMENT **
ELECTRICITY (LIGHTS):              555001. (KWH)   ;       10.23 (KWH/SQ-FT)

** CONSTANT OPERATION **
HEATING:                          3532017. (MBTU)  ;       65.11 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=        160089. (TON-HR);        2.95 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=      42084. (TON-HR);         .78 (TON-HR/SQ-FT)

** SETBACK (65 F.) WHEN UNOCCUPIED **
HEATING:                          3075778. (MBTU)  ;       56.70 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=        126291. (TON-HR);        2.33 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=      35234. (TON-HR);         .65 (TON-HR/SQ-FT)
```

PUBLIC WORKS CANADA 'ABC' PROGRAM-VERSION 3.0

PROJECT
EFFECTS OF ARCHITECTURAL PARAMETERS ON ENERGY CONSUMPTION IN BUILDINGS

```
***ZONE NUMBER  5
ZONE:  WW3052TDR3
MULT:  ZONE MULTIPLIER=  1.0
AREA:  FLOOR AREA=      54250. (SQ-FT)
DIRX:  DIRECTION=   WEST
WALL:  WALL AREA=       37717. (SQ-FT) ;U-VALUE=  .060 (BTU/HR SQ-FT DEG-F)
WIND:  WINDOW AREA= 52 %              ;U-VALUE=  .430 (BTU/HR SQ-FT DEG-F)
                                      ;SHADING COEF: = .58
ROOF:  ROOF AREA=           0. (SQ-FT) ;U-VALUE= 0.000 (BTU/HR SQ-FT DEG-F)
TIME.  OCCUPIED PERIOD=   5 DAYS/WEEK ;    0 NIGHTS/WEEK
     UNOCCUPIED PERIOD=   2 DAYS/WEEK ;    7 NIGHTS/WEEK
LITE.  OCCUPIED=  3.00 (WATT/SQ-FT)     ;UNOCCUPIED=   .15 (WATT/SQ-FT)
PEOP:  OCCUPIED=  180. (SQ-FT/PERSON)  ;UNOCCUPIED=     0. (SQ-FT/PERSON)
VENT:  VENTILATION REQUIREMENTS:
       OCCUPIED=  .156 (CFM/SQ-FT)      ;UNOCCUPIED= 0.000 (CFM/SQ-FT)
       INFILTRATION RATE
       OCCUPIED=  .074 (CFM/SQ-FT)      ;UNOCCUPIED=  .074 (CFM/SQ-FT)

***USING DATA FILE:  EDM
   -EDMONTON REFERENCE YEAR, STANDARD SOLAR, TSTAT=72-78 F.

** ANNUAL REQUIREMENT **
ELECTRICITY (LIGHTS):               555001. (KWH)   ;       10.23 (KWH/SQ-FT)

** CONSTANT OPERATION **
HEATING:                           3681518. (MBTU)  ;       67.86 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=         172082. (TON-HR);        3.17 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=       73800. (TON-HR);        1.36 (TON-HR/SQ-FT)

** SETBACK (65 F.) WHEN UNOCCUPIED **
HEATING:                           3219709. (MBTU)  ;       59.35 (MBTU/SQ-FT)
COOLING:
-SYSTEM WITHOUT ECONOMIZER=         130740. (TON-HR);        2.41 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=       54881. (TON-HR);        1.01 (TON-HR/SQ-FT)
```

PUBLIC WORKS CANADA 'ABC' PROGRAM-VERSION 3.0

PROJECT.
EFFECTS OF ARCHITECTURAL PARAMETERS ON ENERGY CONSUMPTION IN BUILDINGS

*** BUILDING TOTAL- SUM OF ZONES ***

1 CW3G00NGRO
2 NW3G52TDR3
3 SW3G52TDR3
4 EW3G52TDR3
5 WW3G52TDR3

***USING DATA FILE: EDM
-EDMONTON REFERENCE YEAR, STANDARD SOLAR, TSTAT=72-78 F.

** ANNUAL REQUIREMENT **

ELECTRICITY (LIGHTS):	3302249. (KWH)	;	10.23 (KWH/SQ-FT)

** CONSTANT OPERATION **

HEATING.	15613730. (MBTU)	;	48.37 (MBTU/SQ-FT)
COOLING.			
-SYSTEM WITHOUT ECONOMIZER=	804247. (TON-HR);		2.49 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=	264798. (TON-HR);		.82 (TON-HR/SQ-FT)

** SETBACK (65 F.) WHEN UNOCCUPIED **

HEATING:	13534594. (MBTU)	;	41.93 (MBTU/SQ-FT)
COOLING:			
-SYSTEM WITHOUT ECONOMIZER=	658755. (TON-HR);		2.04 (TON-HR/SQ-FT)
-SYSTEM WITH ECONOMIZER (VAV)=	216689. (TON-HR);		.67 (TON-HR/SQ-FT)

APPENDIX D

SAMPLE CALCULATION FOR THE DETERMINATION OF WALL EQUIVALENT U-VALUE

APPENDIX D

SAMPLE CALCULATION FOR THE DETERMINATION OF WALL EQUIVALENT U-VALUE, U_{EQ}

$$U_{EQ} = U_G \times PC_G + U_W \times (1 - PC_G)$$

where

U_G = U-value of glazing

U_W = U-value of opaque wall

PC_G = percentage of glazing with respect to total wall

Example

For the base run

U_G = 0.43 BTU/HR.SQ-FT.DEG-F

U_W = 0.06 BTU/HR.SQ-FT.DEG-F

PG_G = 52% or 0.52

then

$$U_{EQ} = (0.43) \times (.52) + (.06) \times (1 - .52)$$

$$= .252 \text{ BTU/HR.SQ-FT.DEG-F}$$