BUILDING ENVELOPE THERMAL PERFORMANCE STANDARD, THE TEXAS APPROACH

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In 1975, the State of Texas Legislature mandated that energy conservation standards be developed for new State buildings. The legislation called for the development of performance criteria and for guidelines for energy efficient design for different classes of state-owned or financed buildings. In response to this legislated mandate, the State Building Commission developed a standard which provided performance criteria for the building envelope and the building system components separately.

The State of Texas Building Energy Conservation Standard is divided into sections on the envelope, mechanical equipment, lighting, and service hot water. The standard is similar to ASHRAE 90-75 in the mechanical equipment and service hot water sections, but differs in the lighting and envelope sections. The building envelope section provided a new approach intended to address concerns expressed by the state's architects. It sets thermal performance of the shell by specifying an Energy Envelope Index (EEI) as a function of building size and location. The standard is structured such that compliance with the EEI may be determined by the architect early in the design. In fact, the EEI method has proved to be a useful tool, aiding the architect in initial design decisions. The EEI considers the influence of geometric factors, climatological variables such as temperature and solar irradiation, and the interaction of internal and envelope loads. The EEI calculations are extensions of standard procedures for estimating loads (such as those published by ASHRAE). These procedures are summarized in this paper and highlighted with examples.

It is felt that the State of Texas procedure was sufficiently innovative and flexible to meet the needs of both the State and the design professionals and to provide the workable performance-based standard required by the legislation.

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INTRODUCTION

In 1975, the 64th Texas Legislature enacted the Energy Conservation in Buildings Act. The purpose of the Act was

> to provide for the development of improved design, lighting, insulation, and architectural standards to promote efficient energy use in state buildings including buildings of state-supported institutions of higher education, to reduce wasteful or uneconomic consumption of energy by balancing the cost of energy procurement against the cost of energy conserving building practices to achieve the minimum lifetime cost for all new state buildings, including new buildings of state-supported institutions of higher education, measured by combined construction and operating costs, and to provide information to the public relating to energy saving uses, designs, constructing methods, and techniques for all new existing buildings.[1]

The State chose to enlist the aid and advice of an advisory committee selected from the professional design community and construction industry in the development and review of a standard for state buildings and as a model for cities' codes. The staff and the majority of the Model Code Advisory Committee felt that the most efficacious response to the legislation would be to use a draft of the NCS/BCS model code available at that time as a starting point for their work.

The state agencies charged with the task were somewhat constrained by the requirement of the Act to produce standards which would

> ...include both performance and procedural standards for maximum energy conservation allowed by the latest and most effective technology consistent with the requirement of public health and safety regulations and economic considerations.
>
> The standards shall be promulgated in terms of energy consumption allotments and shall take into consideration the various classes of building uses. Performance standards shall allow for design flexibility since only the total allotment of energy is prescribed.
>
> Procedural standards shall be directed toward specific design and building practices that produce good thermal resistance and low air leakage and toward requiring practices in the design of mechanical and electrical systems which conserve energy. The procedural standards shall address, when applicable, the following items:
>
> (1) insulation,
> (2) lighting, according to the lighting necessary for the tasks for which each area is intended to be used,
> (3) ventilation,
> (4) the potential use of new systems for saving energy in ventilation, climate control, and other areas, and
> (5) any other item which the State Building Commission deems appropriate.[2]

As the staff had a legislative mandate to produce standards which had seemingly contradictory requirements in that both performance and procedural standards were required, legislative intent was interpreted as intending to minimize any adverse impact of the new standards on the design process.

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[1] Subdivision 35 of Article 1175, Revised Civil Statutes of Texas, 1925.

[2] Subdivision 35 of Article 1175, Revised Civil Statutes of Texas, 1925.

A NEW APPROACH

A solution was sought whereby a new standard might be developed which would address the concerns of the specific group most impacted by each section of the standard. ASHRAE 90-75 was recognized as a valuable energy conservation design standard, yet some did not consider it to be suited to all the requirements of the law. ASHRAE 90-75 was as vigorously opposed by many architects as it was supported by many engineers. The solution to this lack of consensus seemed to be to use 90-75 as the basis for those sections most directly affecting the engineers and to develop a performance standard for the building shell which would reflect the energy impacts of the design alternatives available to architects.

The State Design Standard which grew out of this effort contains five (5) sections, covering the following:

1) building shell
2) mechanical system
3) mechanical equipment
4) service water heating
5) lighting

The mechanical systems, mechanical equipment, and service water heating sections are very similar to ASHRAE 90-75 and were considered acceptable by the engineering professionals.

The lighting section differs from 90-75 but follows a relatively standard approach. It provides for a lighting budget based on watts per square foot allowable for the different tasks within an area. The allowable power budgets for different standard tasks were compiled and listed in a tabular form. Additional requirements were included for switching and reduced levels of illumination during maintenance. Additional flexibility is provided by allowing some task areas to be designated in foot-candles with a maximum allowable budget of 3 watts per square foot. Exemptions were also granted for special purposes such as stage lighting.

The most novel (and most controversial) section of the standard is the section on the building shell. The development of this section grew out of the architectural profession's expressed concern that proposed code requirements for the building envelope, such as ASHRAE 90-75, were too prescriptive. The purpose of this paper is to describe the effort to provide a more flexible envelope standard which would meet these objections and yet be enforceable.

ENVELOPE ENERGY INDEX

The building shell section is based on compliance with what is called an Envelope Energy Index (EEI). The EEI is not intended to specify energy consumption, but to provide a comparative criteria for determining the relative energy efficiency of the building shell. The standard assures a minimal thermal performance of the shell by specifying an EEI as a function of building size and location. Standard EEI values were established by analyzing a prototypical building with a square floor plan and the optimum number of floors which would minimize the surface area of a building of a specified size. The wall and roof U-values used in the analysis were taken from ASHRAE 90-75. It was assumed that 30% of the wall area was single glazed and had a shading coefficient of one-half. These assumptions do not prescribe the shape or amount of glazing in a building; they simply establish a target EEI value. The point was to establish a minimum level of thermal performance. There are many combinations of building shape, orientation, and materials which will meet the EEI criteria in each building size range.

Compliance with the standard may be determined by the architect during the preliminary design. In fact, the EEI method may be a very useful design tool in aiding the architect in the initial design phase as shown in later examples. The EEI accounts for the influence of geometric factors, climatological variables associated with the location such as temperature and solar irradiation, and the effect of internal loads.

The EEI method employs standard procedures for estimating heating/cooling loads. However, in this procedure these loads are estimated on a daily rather than hourly basis, and are correlated with daily average temperature. A number of studies have shown that the average dry bulb temperature provides a reasonable single measure method for correlating envelope loads. It was felt computerized methods providing for multiple measure correlations would be too complex for practical application. Utilizing daily loads minimized the complexity of the calculation procedure. Additionally, the use of daily loads compensates for the effects of mass or thermal capacitance. The procedures for including solar and internal loads are also simplified. (The hourly design load for sizing equipment must be calculated separately as this procedure will not provide appropriate loads for that purpose.)

CALCULATION PROCEDURE

The thermal performance of any particular building envelope may be represented graphically as a function of BTU's transferred and daily average temperature as shown in Figure 1. Research has indicated that the daily load is roughly a linear function of average daily temperature, and therefore its variation may be approximated by specifying two points. Daily loads are calculated for two days--one for a summer day representative of average conditions in July, and one for a winter representative of average conditions in January.

The daily loads are determined by using daily sums of the total equivalent temperature differences and solar heat gain factors described in the ASHRAE Handbook of Fundamentals, 1972. The TETD and SHGF values must be corrected for percent possible sunshine, surface color coefficient, and an ambient dry bulb temperature profile different from that on which the Handbook tables are based. This must be done since daily envelope loads are to be compared on the basis of average conditions rather than peak load conditions. The correction procedure, however, is very simple and is outlined below.

Terms:

Q_D = Daily load

ETD = Equivalent temperature difference ^oF

I_T = Total irradiation on a surface Btu/hr.

I_{DT} = Total daily irradiation on a surface Btu/day

A_p = Area of perimeter spaces

t_o = Outside air temperature ^oF

t_{oa} = Outside air temperature average

t_i = Inside air temperature ^oF

$\propto/h$ = Color correction factor

%S = Percent possible sunshine

SC = Shading coefficient for windows (include both internal and external shading)

Load for Roof and Walls:

Equivalent temperature difference

$$ETD = t_o - t_i + \propto/h\ (I_T)\ \%S$$

Daily sum $\quad \Sigma ETD = (t_{oa} - t_i)\ 24 + \propto/h\ (I_{DT})\ \%S$

Daily load for wall or roof $\quad Q_D = UA\ (\Sigma ETD)$

Load for Windows:

Transmission $\quad Q_T = U_g A_g\ (t_{oa} - t_i)\ 24$

Solar $Q_S = A_g I_{DT}$ (SC) (%S)

Daily load for glass $Q_{Dg} = Q_T + Q_S$

Internal Loads:

In this procedure, only the internal load in the perimeter zones will be assumed to interact with the building envelope. For calculation purposes, the perimeter zones will be assumed to be 15 feet deep.

Internal Loads:

Lights $QL = (\text{watts/ft.}^2) \times (3.413) \times A_p \times (\text{hours of operation})$

Equipment Q_E = (same form as lights)

People $Q_p = (A_p/150) \times (400 \text{ Btu/hr}) \times (\text{hours of occupancy})$

This assumes an occupancy of one person per 150 square feet.

Total Daily Load $Q_{DT} = Q_D + Q_{Dg} + (Q_L + Q_E + Q_p)$

The Energy Conservation Manual has a standard data sheet and a calculation form to facilitate the calculations. Additional calculation aids are provided in the manual, including thermal resistance of building materials and shading factor nomographs.

A series of graphs provides the index as a function of building size for each of 15 climatological areas of the state. Once an EEI has been established from the appropriate graph for a particular building size and location, a proposed building design may be checked for compliance. An architect may evaluate his building during the preliminary stages by calculating Q_{DT} for January and July and establishing a building load line. A preliminary comparison can then be made between the proposed building and the standard by taking the January and July values from the appropriate graph for the same size building and location.

Typically, visual inspection will indicate if the proposed building is in compliance. If visual inspection proves indecisive, compliance may be determined by using the end points to express the proposed building load line in equation form $Y = aX + b$, where Y is BTU's per day and X is average monthly temperature. Simple substitution into the equation of the average monthly temperatures for X will yield Q_{DT} at that temperature for the other ten months. The Q_{DT} for each month multiplied by the number of days in each month is then summed to provide an index value to compare with the EEI taken from an appropriate graph such as Figure 2. If the summation for 12 months is less than the EEI determined from the graph, the building complies; if it is greater, modifications of the building shell are required.

The architect may establish a baseline for comparing design alternatives by plotting the standard building envelope load line using graphs of the January and July values. After plotting the design standard, visual selection of superior designs is possible as shown in the following examples.

EXAMPLES

As previously mentioned, the EEI standard also works as a design tool to guide the designer in making a more efficient envelope. The usefulness of this method is best demonstrated by graphically displaying performance differences caused by design parameter changes. Although this method is not as precise as some would desire, it indicates, in a relative manner, how different design decisions impact energy requirements.

For example, in Figure 3, the addition of insulation is demonstrated by the dashed line which has a flatter slope and lower monthly average temperature intercept. This example demonstrates a principle of over-insulation. The increased insulation retains more internal load below 69^{o}F where the line intercepts. The area between the two lines above or below the horizontal axis represents the increased or decreased load due to design changes. In the example shown in Figure 3, the savings in air conditioning at temperatures above 69^{o}F and below 48^{o}F are less than the increased air conditioning load between 48 ^{o}F and 69^{o}F.

As an additional example, consider a simple one-story building, 200 feet long by 60 feet wide and 12 feet high. The building is oriented with the long axis north-south (i.e., major exposure east and west) and has 30% single glass on all four sides with no shade. Wall and roof U-values are assumed to be 0.10 Btu/hr-ft^{2}-^{o}F. The impacts of varying these design parameters can be seen by plotting loads and calculating EEI values.

The results of six options are shown in Table 1 and Figures 4 - 9 for a building located in Austin, Texas. The solid black line is the plot of the state standard; the dashed line is the plot of the example building.

TABLE 1

EEI COMPARISON OF DESIGN ALTERNATIVES

Case No.	Description	EEI	Fig. No.
1	Base, 200' x 60' x 12'	644,755,700	4
2	2-story -- 142' x 43' x 24'	771,006,230	5
3	Aspect ratio 150' x 80' x 12'	565,710,784	6
4	Orientation east-west	532,759,750	7
5	% glass reduction to 10%	464,517,950	8
6	Shading increase SF = 0.15	445,239,050	9
	EEI--Standard, 110' x 110' x 12'	546,000,000	

In Figure 4 the base line building is compared to the standard. The building would not comply due to the solar load on the east and west glass. Figure 7 shows what happens by rotating the building 90 degrees. The building now complies and has a lower EEI than the standard although the building has more surface area. The standard was developed using a square floor plan; therefore, a rectangular building with the same glass area and U-values normally will comply if oriented east-west and will not comply if oriented north-south. The north-south oriented building can come into compliance by the addition of insulation, shading for glass as shown in Figure 9, or by reducing the glass area as shown in Figure 8.

There exists no unique set of modifications assuring compliance for a given structure. The designer is therefore free to choose combinations of modifications using the additional criteria of cost effectiveness, esthetics, etc. For example, Figure 6 shows the results of changing the aspect ratio, that is, "squaring up" the building. Although Case Three is still out of compliance, it is much closer than Case One, as shown below:

	EEI (Btu)	Excess above EEI (Btu)	Percent
Standard	546,000,000	0	0%
Case 1	644,755,700	98,755,700	18%
Case 3	565,710,784	19,710,784	3%

The Case Three building only exceeds the EEI 3%, whereas the Case One building exceeds the standard by 18%.

The worst offender is the two-story building. For the same gross square footage of space, the envelope surface is significantly greater, resulting in a higher EEI and therefore requiring more conservation efforts. The EEI standard penalizes inefficient geometries by requiring a more efficient envelope.

In general, the graphs of the EEI tell the characteristics of the envelope. By looking at a proposed design on the graph, the necessary corrective action can be identified by considering the following relationships:

1.	Change in the U-values	---	changes the slope
	increase U	---	yields increased slope
	decrease U	---	yields decreased slope
2.	Change in the internal load	---	causes vertical shift in the line
3.	Changes in fenestration area or placement and shading	---	causes a vertical shift and changes in the slope

The particular site and building utilization will determine what elements in the design can be changed to affect compliance.

The usefulness of the EEI method can also be seen by looking at three typical building uses: Retail, Office, and School. The same single-story example building was utilized to compare three variations of each building use.

The combination of component values selected for comparisons of the retail example is shown in Table 2.

TABLE 2

RETAIL STORE

Case	U_{wall}	U_{roof}	U_{glass}	% glass of total wall	glass location	shade coeff.	EEI
R1	0.10	0.10	1.10	25%	west	1.00	786,696,400
R2	0.10	0.06	1.10	25%	west	0.15	462,415,150
R3	0.10	0.10	0.55	25%	west	0.31	495,430,900

Case R2 varies from R1 by the addition of more roof insulation and adding an awning for shading the west glass. Case R3 incorporates double glazed reflective glass. This retail design is typical of strip centers which have a glass wall facing the business traffic. The EEI of R2 and R3 are not significantly different and both are in compliance; however, in most retail applications, the commercial advantage of the glass exposure would be nullified if reflective glass were used.

The combination of component values and the EEI for the office building examples is shown in Table 3. The office examples incorporate an equal percentage of glass on all walls, each wall having equal glass area. The percentage of glass and the shading coefficient are varied. Case O2 uses reflective double glass with only 10% glazing and Case O3 incorporates shading with 30% glazing.

The fenestration area and shading coefficient have a significant impact on the EEI and overshadow the contribution of wall and roof U-values. This

TABLE 3 OFFICE BUILDING							
Case	U_{wall}	U_{roof}	U_{glass}	% glass	glass location	shade coeff.	EEI
01	0.10	0.10	1.10	20%	all sides	1.00	451,205,100
02	0.10	0.10	0.55	10%	all sides	0.31	339,679,100
03	0.10	0.10	1.10	30%	all sides	0.15	493,975,300

accurately reflects where the design emphasis should be placed. The primary design concern in most Texas climates is for cooling. However, the EEI approach would reflect the passive solar heating impact during the winter season.

The combination of component values and the resulting EEI's for the school buildings are shown in Table 4. All the school examples have been rotated 90 degrees resulting in major exposure facing north and south. The north-south location of glass is typical of school designs where classrooms are located on both sides of a middle corridor. The impact of shading the glass is shown to be more important than reducing the fenestration area. The right tradeoffs for this building in Austin, Texas, would not be the same in another climate.

TABLE 4 SCHOOLS							
Case	U_{wall}	U_{roof}	U_{glass}	% glass	glass location	shade coeff.	EEI
S1	0.08	0.08	1.10	30%	N/S	1.00	493,333,600
S2	0.10	0.10	1.10	30%	N/S	0.15	402,900,000
S3	0.10	0.10	0.55	10%	N/S	0.31	450,175,200

The examples are illustrative of the usefulness of the EEI approach to building envelope design. The tradeoffs are quantified for the designer to allow consideration of multiple options quickly and inexpensively.

Manual calculations take only about 30 minutes once all the data are collected. Additional iterations only take 10 to 15 minutes since some of the calculations usually remain the same.

CONCLUSIONS

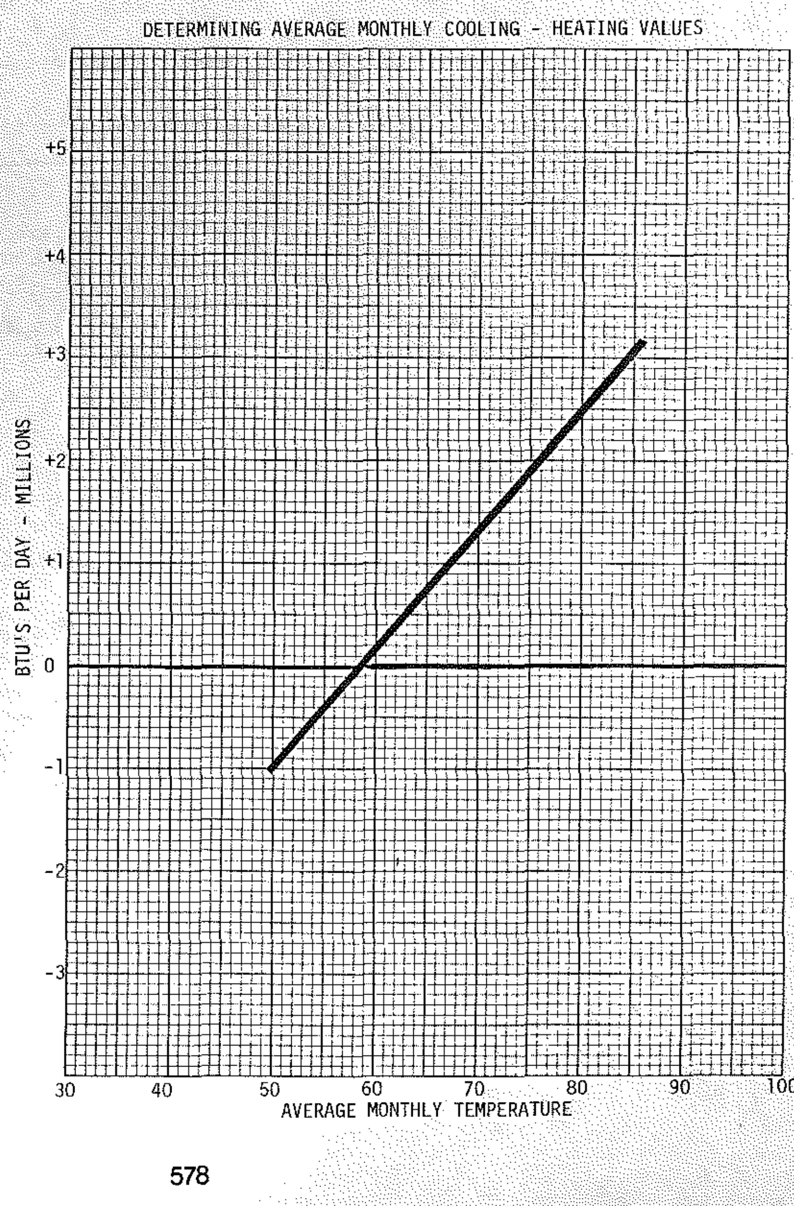
The Envelope Energy Index provides a quick and inexpensive method for the designer to evaluate options when preparing a new building concept. The approach accounts for local climate and encourages design tradeoff by selection of the glazing area, shading, insulation values, orientation, aspect ratio and height. Compliance with the standard is easily and quickly checked before construction.

The approach lacks the ability to account for seasonal changes in temperature control, the dynamic performance of high mass structures, and the results of shut down during unoccupied periods. These shortcomings do not restrict the utilization of any energy conservation opportunity. Further, the EEI approach does not limit the consideration of innovative options due to a high cost of proving compliance by alternative methods, e.g. Chapter 11, ASHRAE 90-75.

Though the standard has been adopted in Texas for state buildings only, it is not rigidly enforced. No formal submittal is required at this time. However, some architects are providing the completed calculation sheets and state staff members are reviewing plans and checking for compliance on buildings under the authority of the Facilities and Construction Division of the State Purchasing and General Services Commission.

Experience indicates nearly all building plans submitted are complying with the present EEI standards. Changes in the indices are anticipated in the future to encourage more efficient design.

This approach toward energy conservation design standards has admittedly evolved from controversy and is founded in compromise. Amendments and updating will be necessary, but this procedure has provided a precedent for performance standards which can be quantitatively determined and satisfied before construction. In addition, this procedure causes little or no obstruction to the design and construction process.



TYPICAL BUILDING LOAD LINE
FIG. 1

ALLOWABLE EEI FOR BUILDINGS - AUSTIN

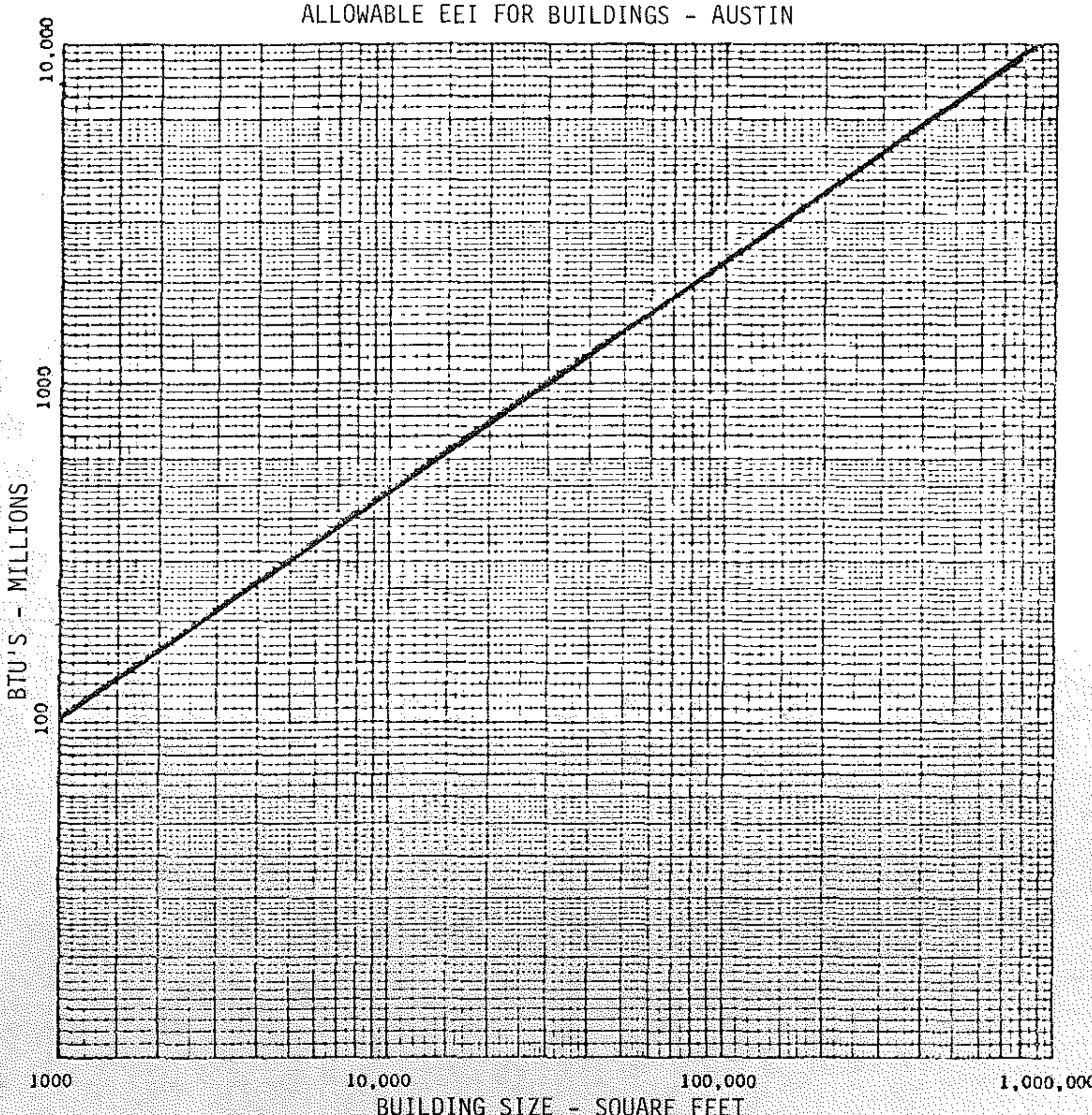


FIG. 2

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

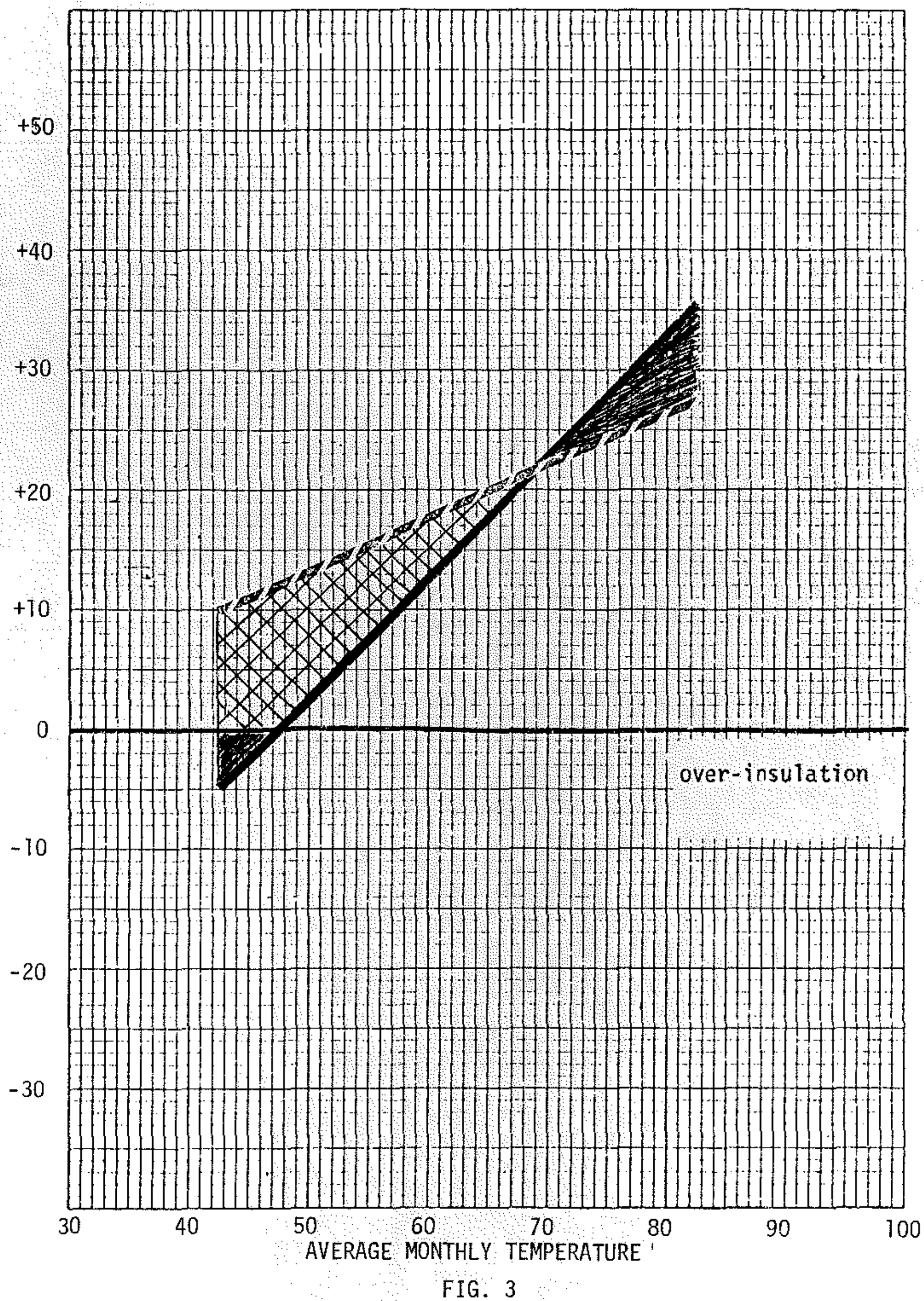


FIG. 3

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

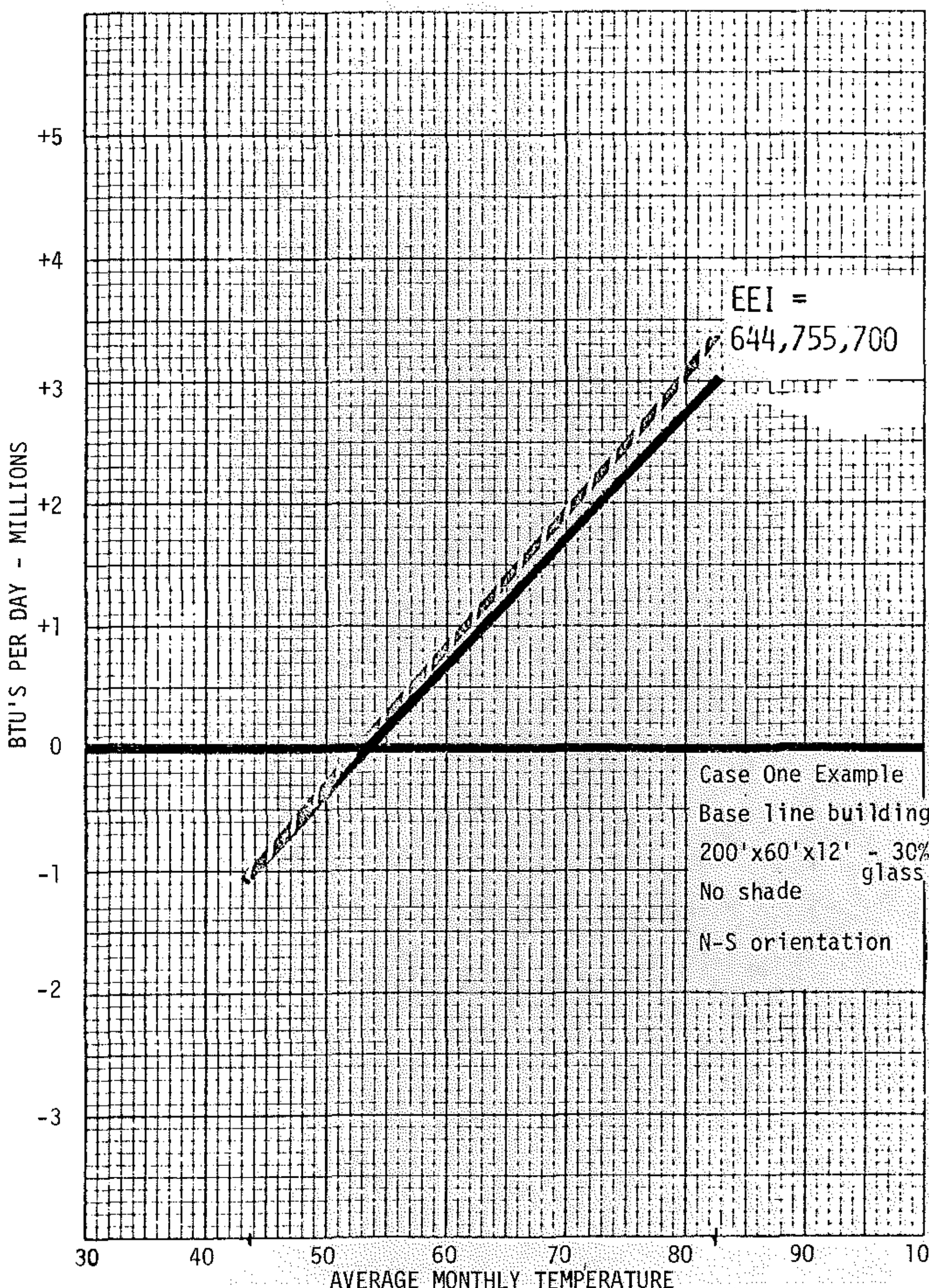


FIG. 4

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

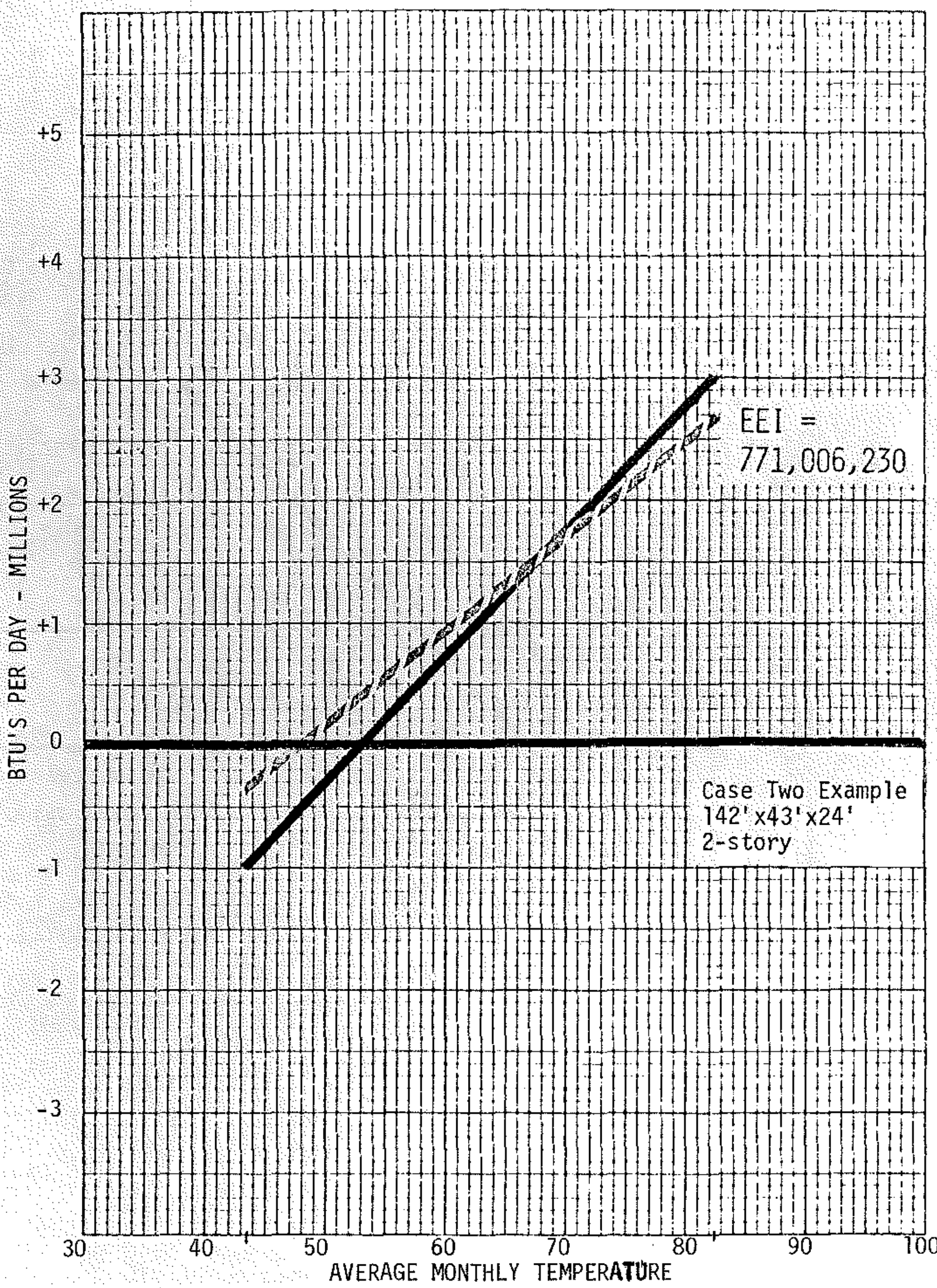


FIG. 5

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

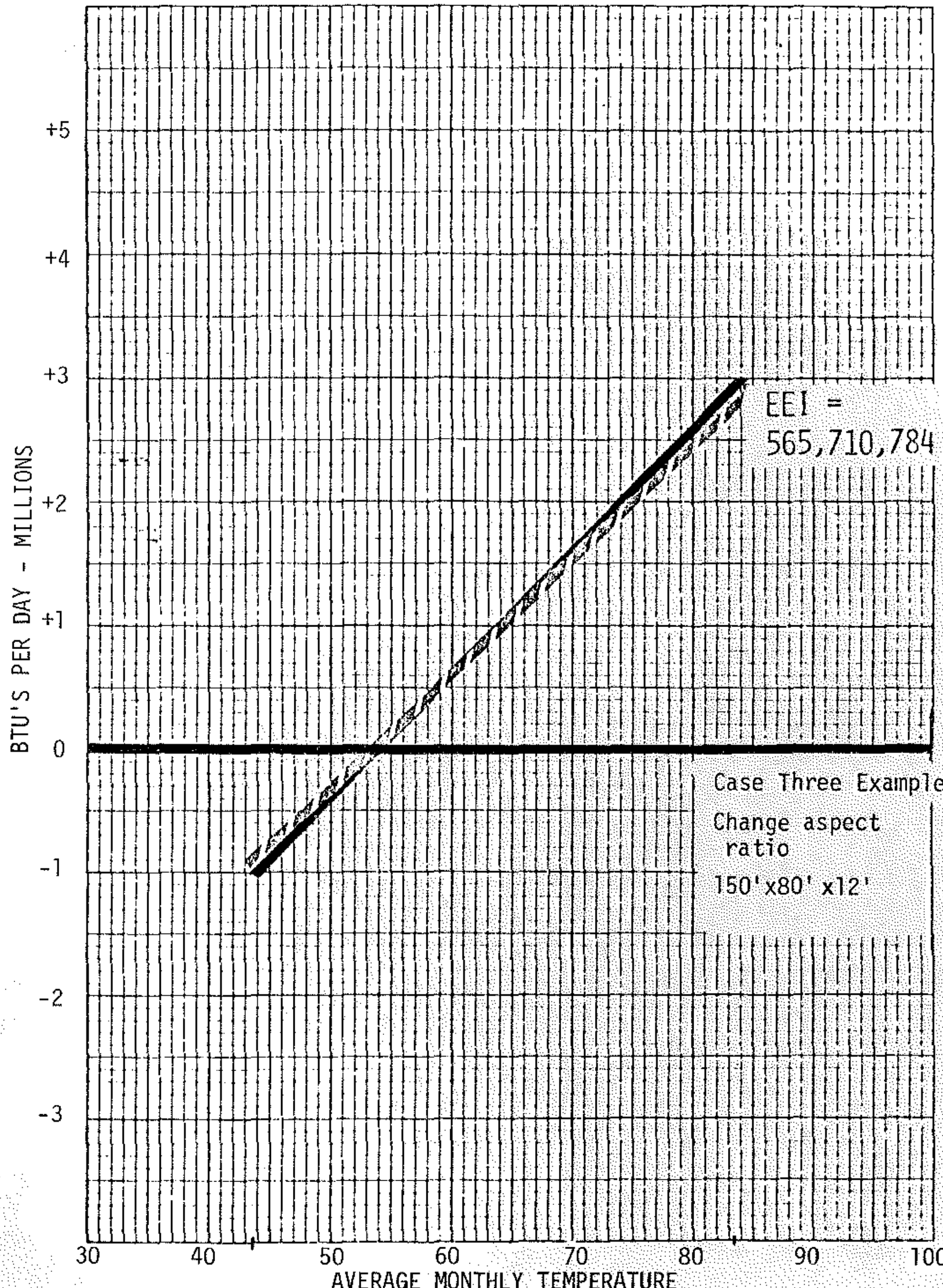


FIG. 6

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

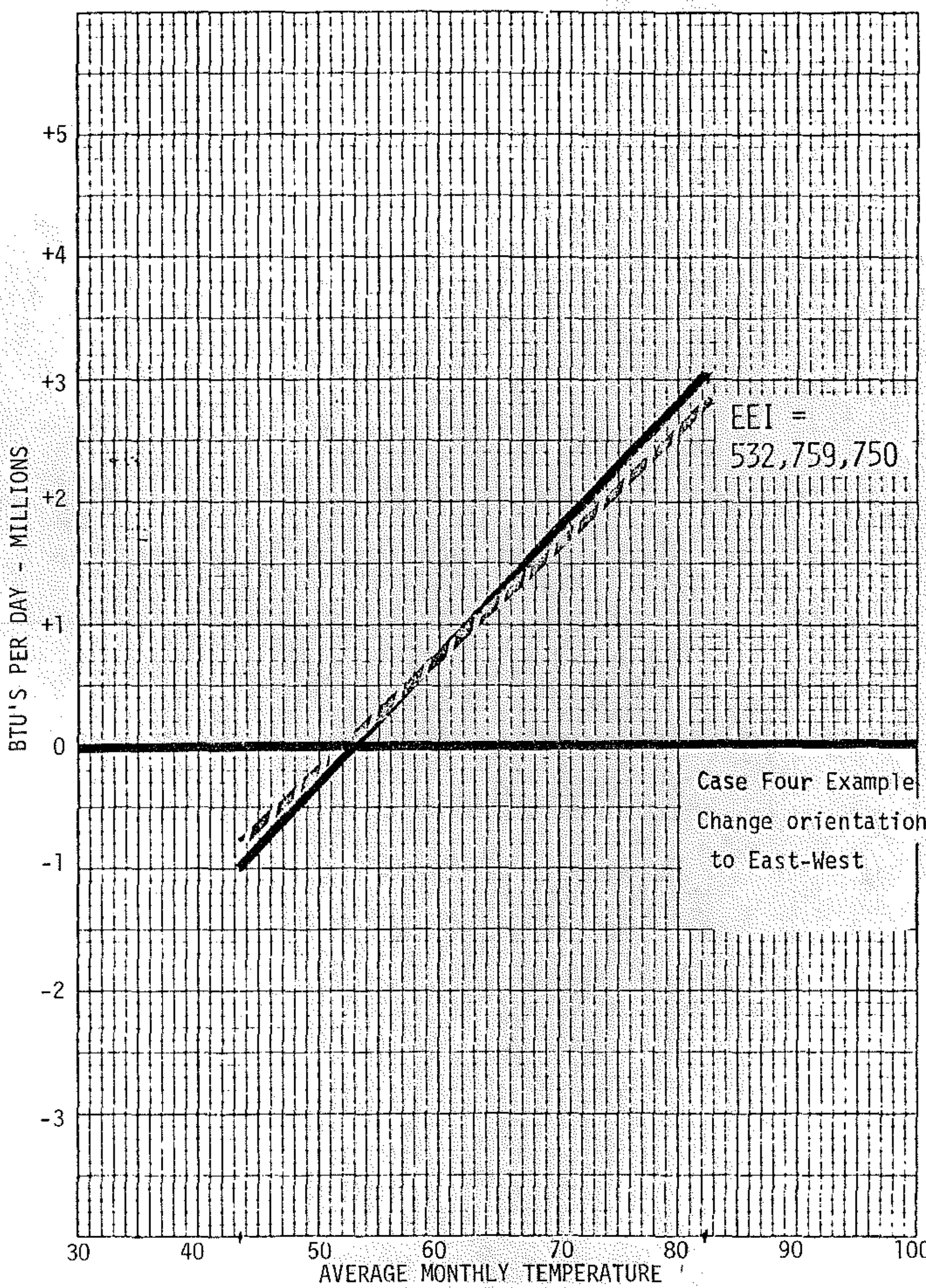


FIG. 7

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

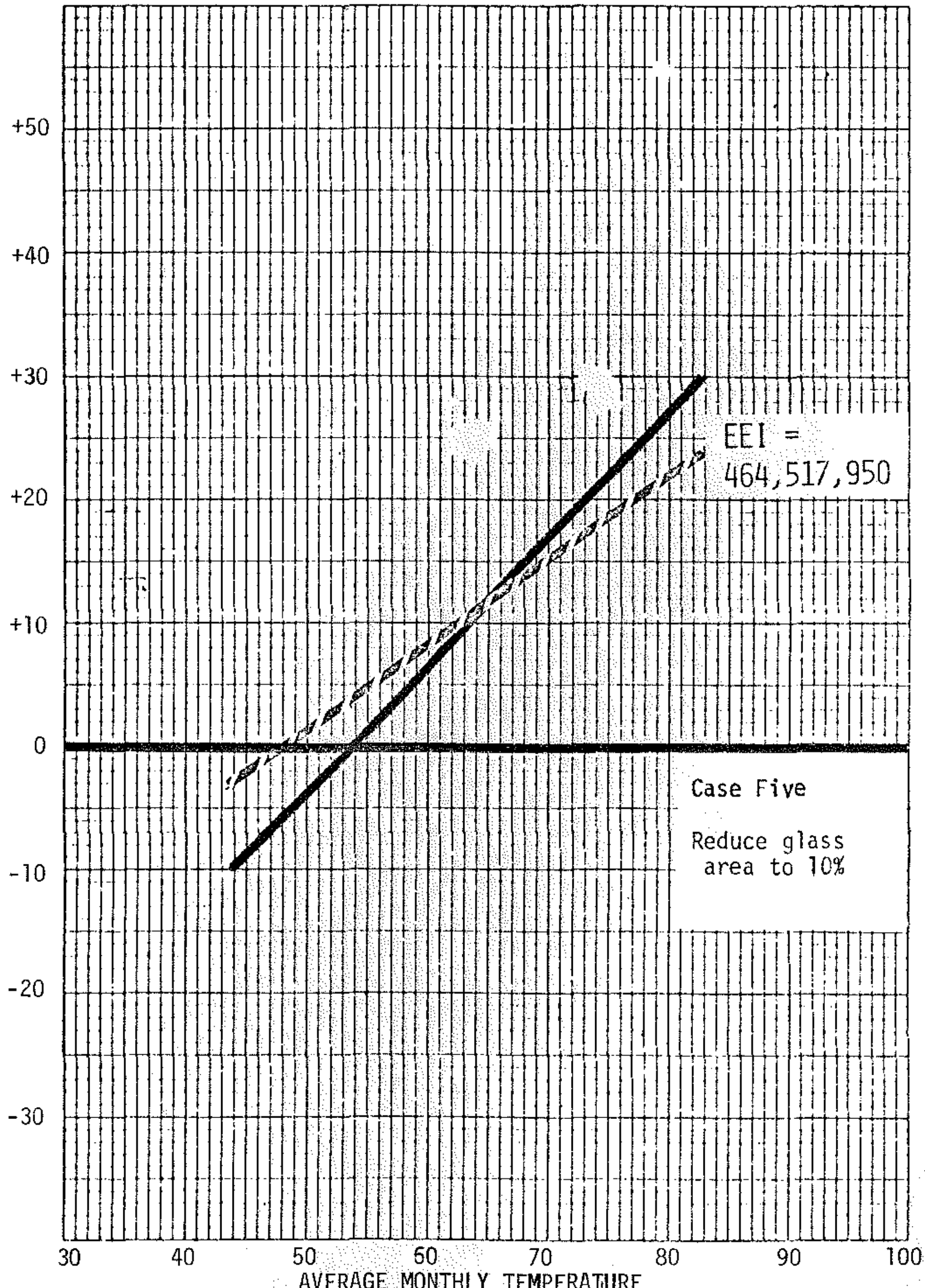


FIG. 8

DETERMINING AVERAGE MONTHLY COOLING - HEATING VALUES

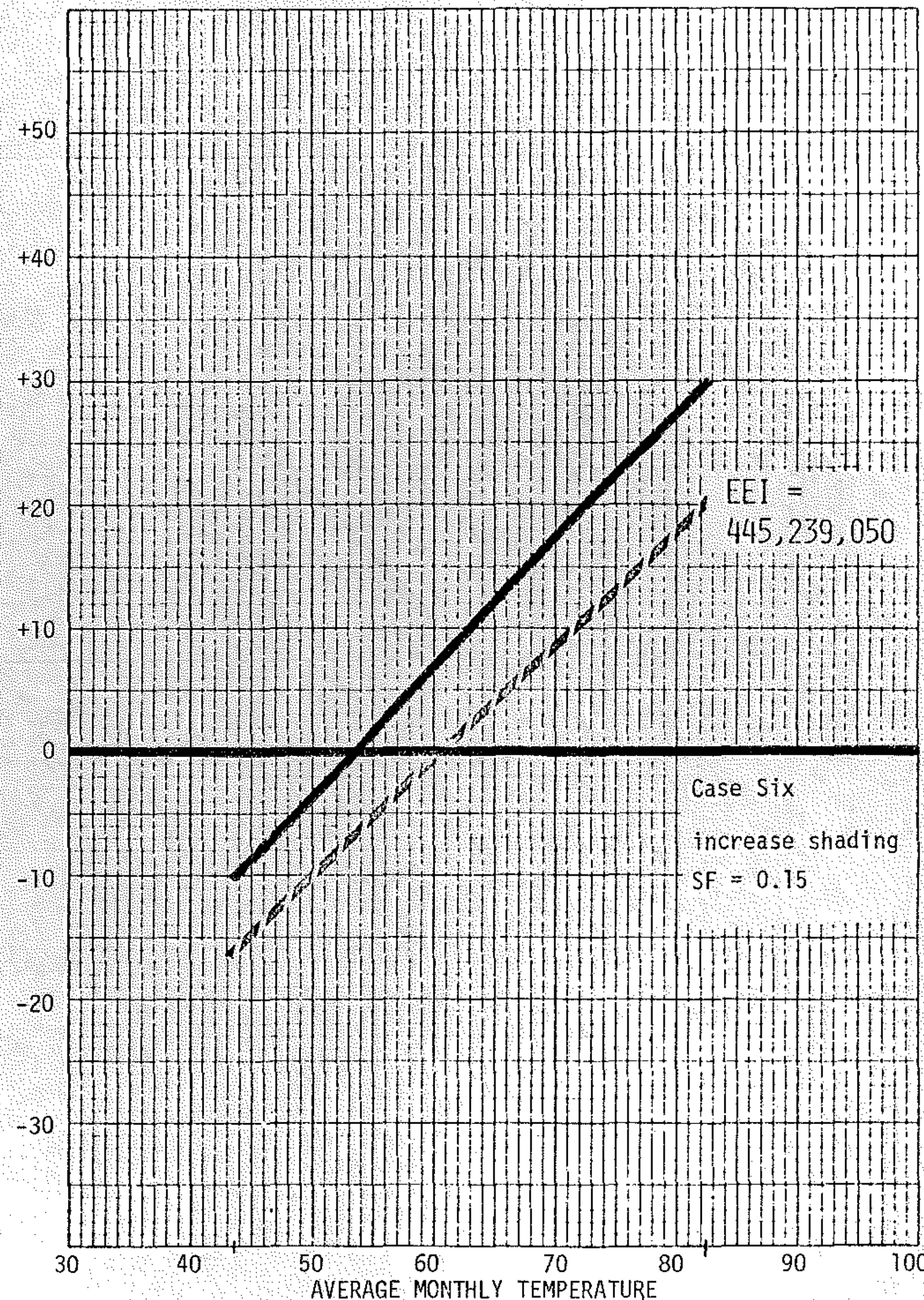


FIG. 9