# A THERMAL PERFORMANCE DESIGN
# OPTIMIZATION STUDY FOR
# SMALL ALASKAN RURAL SCHOOLS

by

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# Preface

In the spring of 1979 the Department of Transportation and Public Facilities determined that if its mission as planner and builder of State buildings was to be responsibly fulfilled in a period of uncertain energy economics an extensive investigation into the relevance of Building Energy Performance Standards for the Alaskan environment would be necessary.

Work began immediately and quickly became the major focus of the Department's Energy and Buildings research program. The task proved to be ominous. Of the thermal standards in existance or under development at the national level none had addressed either the climatic or economic complexities of building construction and operation in the Alaskan environment. By 1979 the rhetoric of energy conservation and appropriate thermal standards had taken on political implications which were expressed in a form not unlike religious feeling with its advocates and adversaries, soaring far above the economic ground on which any rational approach for a relevant solution would eventually be based. But this was quite natural since the baseline data for determining just what constituted a "properly built building" from an energy consumption standpoint did not then exist for Alaska and still does not exist in a universally comprehendible form.

By the spring of 1980 a contract had been established which brought together a team of University of Alaska research faculty, professionals from the Alaskan design community, and Research Engineers from the DOTPF who would work to develop a data base of the technical design and economic criteria for State buildings which would, in turn, form the basis for the rational development of an Alaskan Buildings Energy Performance Standard. At the same time the Alaska Legislature was in the process of amending Public Law to add this responsibility to the mission of the Department.

During the past year this task of developing the data base has been completed. A data base has now been established along with an analytical method for rationally determining what the energy performance of a building should be based on the climatic and economic implications of various regions of the State. The data base, the analytical tools, and the design solutions are presented in this report. But an Energy Performance Standard is not contained herein. The reasons for this are discussed in the text.

So what has been accomplished so far and what is the value of this report?

1. It shows the economic implications of various design solutions as a function of levels of energy conservation on a state-wide basis for comparative purposes.

2. It illuminates the complexities and anomalies of building energy consumption economics for the State of Alaska which warns against over simplified solutions to the "energy problem".

3. It identifies those areas where hard policy is lacking with respect to energy conservation and provides a way of evaluating the ramifications of various policy decisions.

4. It provides stabilized ground on which the rhetoric of energy conservation may continue.

5. When it has been thoroughly reviewed, discussed, criticized, and modified, it can become a major component in the foundation of a relevant Building Energy Performance Standard for Alaskan public buildings.

This report is the result of phase one of the Department's development of a "...Thermal and Lighting standard adapted to cold region environs" as set forth in Public Law AS 44.42.020. By the necessity of fixed funding and available manpower, the scope to date has been limited. Renewable energy resources and their economic implications are yet to be addressed, as are waste heat recovery, and the question of conflicts between energy conscious design and existing building codes. The entire subject of Energy Conservation for large, load dominated buildings awaits investigation. The job is by no means complete.

To aid the Department in the work which remains to be done we would invite comment and criticism of this report by all who read it. Those interested in accomodating us in our need for input may write to the address indicated below.

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## TABLE OF CONTENTS

1.0 Summary 1

2.0 Introduction 2

- 2.1 Purpose 3
- 2.2 Scope 4

3.0 A Discussion of Thermal Standards 5

- 3.1 Recent Federal Government Studies 5
- 3.2 Requirements for Standards in Alaska 15

4.0 Life Cycle Cost Evaluation Technique 17

- 4.1 Prototype Building 20
- 4.2 Envelope Design Alternatives 27
- 4.3 Mechanical System Design Alternatives 32
- 4.4 Electrical System Design Alternatives 46
- 4.5 Cost Estimating 49
  - 4.5.1 Construction Costs for Thermal Envelopes 49
  - 4.5.2 Construction Costs for Mechanical and Electrical Systems 52
  - 4.5.3 Analysis of Maintenance Costs 57
- 4.6 Statewide Climate and Costs Regions 59
- 4.7 Thermal Modeling Techniques 62
- 4.8 Methods of Economic Analysis 66
  - 4.8.1 Analysis of First Costs and Renovation Costs 68
  - 4.8.2 Analysis of Maintenance and Operations Costs 70

TABLE OF CONTENTS (continued)

4.8.3 Analysis of Annual Energy Consumption 72

4.9 LCC Computer Model "MAIN" 74

5.0 Analysis of Results 77

5.1 Description of Life Cycle Cost Model Results 77

5.2 Selection of Least Life Cycle Cost Design Alternatives 112

6.0 Conclusions and Recommendations 117

6.1 Conclusions 117

6.2 Recommendations 119

7.0 References 120

8.0 Appendices

Appendix 1: Electrical Systems Design

Appendix 2: Climate Data

Appendix 3: Listing of Analysis Program

Appendix 4: Listing of Program Variables

Appendix 5: Energy Use Summary

Appendix 6: Life Cycle Cost Summary

# LIST OF TABLES

| TABLE NO. | TITLE | PAGE NO. |
|---|---|---|
| 1 | Prototype Building Characteristics | 23 |
| 2 | Occupancy/Ventilation Schedule | 24 |
| 3 | Ventilation Schedule | 26 |
| 4 | Envelope Component Descriptions | 29 |
| 5 | Roof System Descriptions | 30 |
| 6 | Mechanical and Electrical System Energy Consumption Characteristics | 41 |
| 7 | Schedule of Outside Air Ventilation Rates | 42 |
| 8 | Unit Costs of Envelope Components | 52 |
| 9 | Unit Costs of Roof Systems | 53 |
| 10 | Unit Cost of Thermal Envelope System | 54 |
| 11 | Construction Cost Analysis - Mechanical Systems | 56 |
| 12 | Statewide Climate/Cost Condition Summary | 61 |
| 13 | Optimum Level of Construction | 113 |

## LIST OF FIGURES

| FIGURE NO. | TITLE | PAGE NO. |
|---|---|---|
| 1 | Prototypical Building | 22 |
| 2 | Ventilation Schedule | 25 |
| 3 | Thermal Resistance Calculation - Thermal Envelope | 28 |
| 4 | Schematic Plan - Packaged Heating | 37 |
| 5 | Schematic Plan - Central Boiler Room Arrangement | 39 |
| 6 | Systems Common To Each Mechanical System Alternate | 45 |
| 7 | Cost Estimate Calculation - Thermal Envelope | 50 |
| 8 | Climate Regions Of Alaska | 60 |
| 9 | Thermal Model Flow Chart | 63 |
| 10 | Building Thermal Model - Energy Flow Schematic | 64 |
| 11 | Calculation Procedure Capital Outlays | 69 |
| 12 | Calculation Procedure - Maintenance And Operations Costs | 71 |
| 13 | Calculation Procedure - Energy Costs | 73 |
| 14 | LCC Evaluation Flow Chart | 75 |
| 15 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 1, 8% Fuel Escalation Rate | 80 |
| 16 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 2, 8% Fuel Escalation Rate | 81 |
| 17 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 3, 8% Fuel Escalation Rate | 82 |
| 18 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 4, 8% Fuel Escalation Rate | 83 |
| 19 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 5, 8% Fuel Escalation Rate | 84 |

## LIST OF FIGURES (continued)

| FIGURE NO. | TITLE | PAGE NO. |
|---|---|---|
| 20 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 6, 8% Fuel Escalation Rate | 85 |
| 21 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 7, 8% Fuel Escalation Rate | 86 |
| 22 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 8, 8% Fuel Escalation Rate | 87 |
| 23 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 9, 8% Fuel Escalation Rate | 88 |
| 24 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 10, 8% Fuel Escalation Rate | 89 |
| 25 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 11, 8% Fuel Escalation Rate | 90 |
| 26 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 12, 8% Fuel Escalation Rate | 91 |
| 27 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 13, 8% Fuel Escalation Rate | 92 |
| 28 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 14, 8% Fuel Escalation Rate | 93 |
| 29 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 15, 8% Fuel Escalation Rate | 94 |
| 30 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 16, 8% Fuel Escalation Rate | 95 |
| 31 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 1, 12% Fuel Escalation Rate | 96 |
| 32 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 2, 12% Fuel Escalation Rate | 97 |
| 33 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 3, 12% Fuel Escalation Rate | 98 |
| 34 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 4, 12% Fuel Escalation Rate | 99 |

## LIST OF FIGURES (continued)

| FIGURE NO. | TITLE | PAGE NO. |
|---|---|---|
| 35 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 5, 12% Fuel Escalation Rate | 100 |
| 36 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 6, 12% Fuel Escalation Rate | 101 |
| 37 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 7, 12% Fuel Escalation Rate | 102 |
| 38 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 8, 12% Fuel Escalation Rate | 103 |
| 39 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 9, 12% Fuel Escalation Rate | 104 |
| 40 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 10, 12% Fuel Escalation Rate | 105 |
| 41 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 11, 12% Fuel Escalation Rate | 106 |
| 42 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 12, 12% Fuel Escalation Rate | 107 |
| 43 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 13, 12% Fuel Escalation Rate | 108 |
| 44 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 14, 12% Fuel Escalation Rate | 109 |
| 45 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 15, 12% Fuel Escalation Rate | 110 |
| 46 | Plot of Life Cycle Cost vs Thermal Construction Level, Cost Region 16, 12% Fuel Escalation Rate | 111 |

## 1.0 SUMMARY

The way that thermal systems are designed for small rural schools strongly affects first cost of construction, and long term operating costs. In the past year research has been accomplished to optimize design concepts of a prototype school of 7500 square feet. This work was accomplished for Alaska's widely varying climate and cost conditions, by categorizing the state inot 7 climate and 16 cost retions. Phase I results of the study are reported herein.

The work was accomplished at the University of Alaska Fairbanks campus by the Mechanical Engineering Department. Major organizational work was accomplished by J.S. Strandberg, Consulting Engineer, under the direction of Dr. John Zarling, P.E. Major design and cost input was provided by Maynard and Partch, Architects, HMS, Inc., Cost Estimators, and David Olson, P.E., Electrical Engineer.

The result of the research is a generalized listing of design recommendations for thermal systems of the small school, established using a computerized life cycle cost analysis technique.

## 2.0 INTRODUCTION

Energy as a major research topic under study within the state of Alaska, has the direct attentions of the state's constituent population, lawmakers, and professional community. One important component of this topic is energy consuming characteristics of Alaska's buildings. This is of particular interest to the state's Department of Transportation and Public Facilities (DOT-PF), the agency charged with facility procurement.

While there are many different parts of our state's commerce base other than buildings that require energy, certainly major consumption of energy occurs in the operation of Alaska's state owned buildings. The research reported herein has been accomplished for DOT-PF and deals with the thermal performance of a specific component of the state's building inventory, that of small rural schools.

The work has been accomplished at the University of Alaska's Fairbanks campus by U of A Mechanical Engineering Department professional staff, and subconsultants from the in-state design community.

## 2.1 PURPOSE

The research activities for this "Thermal Standards Project" are structured as a design optimization process to establish the lowest cost design solution for future small rural schools. A life cycle cost analysis is the principal tool used in the study. It is the intent that the research data realized herein will later on become a part of the basis for a statewide thermal standard for new construction.

It must be noted that the research reported herein is intended to form a basis for later thermal standard adoption, and does not in itself represent a thermal standard. What the format will be for Alaska's thermal standard is a separate subject that is to be decided by others. However, in order to aquaint the reader with the current status of thermal standards development on a nationwide level, and as it affects Alaska, Section 3 of the report deals with the different forms such a standard might take for Alaska. This section gives a backdrop with which to consider analysis results. The research work has been accomplished in response to a legislative directive expressed in Public Law A.S. 44.42.020, and paraphrased as follows: " The Department will adopt an ASHRAE thermal and lighting standard adapted to high latitude cold region environs."

## 2.2 SCOPE

The research endeavors are centered on a particular class of public building that is being constructed throughout the state, that of small rural schools of 7500 building square foot size. The study is concerned strictly with design optimization in new construction, and is not related to any renovation concepts in existing buildings for energy conservation.

It is important to note that a large percentage of buildings built by the state or used as public facilities are of the same building construction class and type as the schools described above. Therefore, the findings presented here have a considerably broader implication than it might first appear.

The reasons for beginning this work with special attention being given to rural schools are as follows:

1. Remote rural school facilities represent the highest energy costs to the state on a per square foot of facility because of the higher energy costs in most rural areas.

2. School facilities are built with greater frequency than other types of facilities.

3. The generic type of building used for rural schools cover almost the entire spectrum of light construction types and sizes.

## 3.0 A DISCUSSION OF THERMAL STANDARDS

### 3.1 Recent Federal Government Studies

The federal government is currently in the process of formulating a nationwide building standard that will regulate the energy efficiency of new construction (Reference 1). This process is a result of new laws enacted at the federal level that seek to reduce the United States dependence on foreign energy supplies.

Two major documents have been the focus for regulation of energy efficient construction, the American Society of Heating Refrigeration and Air Conditioning Engineer's (ASHRAE) Standard entitled "ASHRAE 90-75" (Reference 2), and the American Institute of Architect's (A.I.A.) more recent document "Building Energy Performance Standards (B.E.P.S.)". While the two documents each seek to regulate all non-process building energy consumptions, the approaches used are very different.

The ASHRAE 90-75 Standard uses a "component standard" approach that breaks a building down into it's energy consuming components, and impresses minimum requirements for thermal characteristics of each component. The Standard specifies the following:

* Minimum overall thermal conductances (U-factors) of wall

assemblies that consist of exterior walls, windows and doors, roof/ceiling assemblies, and floor systems. These U-factor requirements are varied with annual heating degree days.

* Minimum air leakage characteristics for building components. Maximum allowable wall, window and door leakage rates are specified.

* Specific criteria is given for design of mechanical systems. Mechanical system controls are required by the standard to incorporate a number of energy conserving design features, and duct systems are required to be designed to reduce air transport energy requirements.

* Minimum requirements for lighting design are impressed. These criteria include regulation of allowable lighting levels by occupancy, requirement for task lighting design, and requirements for mimimum "lamp efficacies", or the efficiency of lighting production in units of light output per unit power consumption rate.

This standard has been in existence now for some six years, and has been widely adopted at the local government level in city and municipal building departments. At present the document is the existing thermal standard for the State of Alaska, and Municipality of Anchorage. It has proven generally easy to enforce in the plan review building permit phase of construction.

In writing the Standard, ASHRAE involved numerous components of American Industry in the review process. Substantial input was derived from manufacturers of building components. Thus there is heavy impetus within the document on specific energy conservation design requirements for building components. These requirements are nearly always in terms of parameters that relate directly to commonly used equipment specifications and design criteria. This tends to make compliance to the Standard easily accomplished and verified.

A more recent version of the ASHRAE Standard (Reference 2) incorporates review comments from the consensus review of document 90-75R.1, a second generation standards document. While formated in much the same manner as 90-75, the document has been broken into three standards.

Within the format of component standards, the document offers expanded treatments of required envelope, mechanical and electrical component performance, but maintains the same requirements for building energy consumption analysis and annual fuel resource determination (old chapters 10 through 12).

The "concensus" approach taken by ASHRAE has yielded a document that offers ease of implementation, and a moderate level of energy conservation in the new construction sector.

In the past several years, however, with large increases in unit costs for energy, the push for nationwide energy conservation spawned new research efforts in standards development. The federal government's Department of Energy (D.O.E.) funded the American Institute of Architects (A.I.A.) in 1978 to perform additional research on building systems performance, under the "Energy Conservation Standards For New Buildings Act of 1976" (Reference 1).

The A.I.A.'s research arm in 1978 and 1979 produced, in conjunction with sub-consultants, a group of studies for D.O.E. that establishes standards of thermal performance for buildings by climate region and occupancy. This research effort subsequently was restructured by D.O.E. into a "Notice Of Proposed Rulemaking" (NOPR), which consisted of a standards document defining thermal performance requirements for buildings dubbed "BEPS", in addition to publishing this NOPR (Reference 1) and nine backup documentation reports (Reference 3 through 10). D.O.E. conducted hearings throughout the United States to gather suggestions for final standards revisions, and for input on ways to best implement the standard. The review period for the NOPR ended in early 1980; at that time the federal government postponed actual implementation of the standard pending implementation of further studies and revisions. At this time, the ASHRAE 90-75 Component Standard remains the only major nationwide standard for energy conservation regulation in general use.

The building performance document, or as it is commonly termed, the "BEPS" Standard specifies maximum levels of annual energy consumption in units of BTU's per building square foot for a one year time period, for 22 different climate regions within the contiguous United States, and for 78 different classes of building use. The performance standard approach taken seeks to regulate the overall performance of the building as a single energy consuming system, as opposed to ASHRAE component standard method of regulating the types of construction employed within each building energy system.

This approach evolved out of a well financed research project conceived to maximize energy conservation in new construction. Creation of the standard occurred under a tight time schedule with development work occurring in consultant's offices throughout the country. There was not time for a thorough consensus approach for standards such as was the case with the ASHRAE 90-75 Standard. Indeed it was the intent of the research approach that the BEPS document would be a standard for "new residential and commercial buildings which are designed to achieve the maximum practicable improvements in energy efficiency and increases in the use of non-depletable sources of energy" (Reference 1). In this light, a research approach appears to have been warranted, so that new and state of the art methods could be developed for maximum conservation. A consensus approach does not appear to match the aims of the Standards Act, since this approach tends to utilize existing uncontroversial methods of conservation, and does not favor newer more controversial methods of energy conservation, that could net major additional savings.

Under a complex project organization, the A.I.A. Research Corporation divided the nation's building inventory into occupany/use categories, and divided the nation geographically into 78 climate regions.

Each of the building categories were dealt with statistically to establish the present energy consumption profiles of structures by age, occupancy and climate region. This phase of the research work involved the following work for the A.I.A. group:

* Survey the nation's present building inventory and determine annual energy consumption levels.

* Break the building data down in several categories, the first, structures built after the first Arab oil embargo of 1973 and prior to 1976; the next those buildings designed in 1976 to the then new ASHRAE Component Standard, and finally, those buildings designed in 1978 to achieve maximum practical energy conservation.

In conjunction with this work, A.I.A. Research Corporation performed analyses of climate data, for formulation of a climate data set that could be used in computer models that simulate building thermal performance. These data sets generally consisted of classical climate variables such as heating degree days. Wind conditions were not taken as a factor.

A computerized thermal modeling technique was formulated to establish energy budgets. This technique used the standarized climate data, a set of standard building operating conditions, and a number of existing computer programs to compute annual energy consumption budgets. Programs used in the study were "DOE -2" a public domain simulator program used to compute annual energy budgets for non-solar structures, "TRNSYS", a proprietary program to simulate thermal performance of buildings with active solar heating and cooling systems and "DEROB" a thermal simulator for buildings incorporating passive solar heating and cooling systems.

These programs were used in various combinations to arrive at the various design values used in the Standard. It is well to note that each simulator is, or was at the time the B.E.P.S. work was done, a state of the art computer tool, incorporating considerable internal logic, and requiring a major computer facility and data input preparation for each simulation.

With the completion of the B.E.P.S. Standard's Document, the thermal standards criteria for a given location in the United States and a given occupancy was expressed in terms of a "Design Energy Budget". This number reflects the total allowable annual energy consumption for building heating, ventilating, cooling, and domestic hot water. Excluded here is any internal process energy consumption such as coffee pots, xerox machines, and the like. Included within the budget number is a weighting factor that varied from 1 to 3.08, designed to penalize use of certain fuels.

According to A.I.A. Research Corporation, the prime B.E.P.S. consultant, the B.E.P.S. Standard would result in considerable additional energy savings beyond that possible with the ASHRAE Standard (Reference 2). This was generally not disputed in the B.E.P.S. hearing schedule. What was disputed was the methods of proposed implementation.

Whereas the ASHRAE Component Standard can be implemented by incorporation of certain minimum levels of construction, compliance of a given building design to the B.E.P.S. Standard can only be assured by evaluating use of the building throughout the year, under certain "standard operating conditions" and computing total building energy consumption by fuel. This evaluation requirement promises extensive additional work effort for both designers and plan reviewers involved in compliance.

Critics of B.E.P.S. site the current inability of local municipal building officials to evaluate compliance to B.E.P.S., due to a lack of both technical expertise and manpower. The professional community sites the additional design requirements for determination of annual energy budgets, as well as increased costs for construction.

Proponents of B.E.P.S. site the considerable savings that are possible through B.E.P.S. implementation. B.E.P.S. will give the designer impetus to consider new and innovative energy conservation options, and will require levels of construction based on a least life cycle cost approach, rather than on the current "miminum first cost" approach. Further, the B.E. P. S. document will give a strong boost to alternative energy source concepts, something that is not accenuated in present consensus standards.

At the end of the hearing schedule for the B.E.P.S. document, in spring of 1980, the federal government had apparently acceded to B.E.P.S. opponents, by withdrawing the Standard from consideration. According to articles in several technical magazines (Reference 11). the federal government's department was planning on resubmitting a revised B.E.P.S. document for hearing review in 1981. This revised document would likely be modified from a nearly pure performance document to a part performance, part component standard, that could be implemented with present conformance standards concept.

Some of the major changes likely in a revised B.E.P.S. Document would be:

- * Drafting of an ASHRAE Standard 90 type component standards based on B.E.P.S. life cycle cost economics.
- * Drafting of a manual of recommended practice for builders to assist in B.E.P.S. compliance.
- * Provide alternate energy budget calculation methods not involving the large scale computer modeling systems originally conceived in B.E.P.S.

## 3.2 REQUIREMENTS FOR STANDARDS IN ALASKA

Under this backdrop of national standards development, the State of Alaska remains within the potential jurisdication of final standards implementation, whether the standard ends up as a component or performance standard. With Alaska's extremes of climate and widely varying economics of fuel costs, it is quite likely that the national standards as applied to the state will not respond to these extremes.

Further, the term "sanction" pervades the B.E.P.S. document wherever implementation and compliance is discussed. It is the intent of the original document that strict, timely implementation of the B.E.P.S. document be assured nationwide. Here, the B.E.P.S. document "threatens" to impose sanctions against, or to withhold certain federal assistance monies from state and local governments, unless these governments impose the B.E.P.S. Standard, or a standard of the same or greater stringency.

Thus there is a strong impetus for the State of Alaska to perform research activities that will facilitate creation of a statewide thermal standard for new construction which will be a satisfactory alternative to the national standards. The form that this standard should take is certainly not clear at this time, given the present national controversy over the B.E.P.S. document. The basis of a thermal standard, which this research report is strictly concerned with, however can be developed, regardless of what that final form may take, since such an economic justification must be accomplished. By Statute (AS 44.42.040) DOT/PF has the responsibility to adopt "an ASHRAE thermal and lighting standard adapted to high latitude cold region environs".

Since the vast majority of state buildings constructed in the past five years have conformed to ASHRAE 90-75 and since DOT/PF Division of General Design and Construction has standarized on ASHRAE 90-75, some acceptance of thermal performance standards has already been accomplished. It is important, however, to consider that it is the "adapted to high latitute climates" which is of current interest. It is clear, based on apparent lack of interest in Alaska by the national level standards makers, that such a high latitude adaption will have to be developed here.

The critical step in that development will be to arrive at an end product which serves the energy conservation needs of the state and at the same time does not conflict with any national standard mandates. Just how this might be accomplished is beyond the scope of the work to date and will become a task for future consideration.

## 4.0 LIFE CYCLE COST EVALUATION TECHNIQUE

The analysis technique employed in this study models a building from time of construction to time of replacement, with a series of equations that simulate costs of construction, and lifetime annual costs of energy and maintenance and operation.

As the study is directed toward evaluation of building thermal systems, the model deals strictly with the components within the building concerned with energy consumption. These components of the building are comprised of the building's "Thermal Envelope", and selected portions of the building's mechanical and electrical systems.

Portions of the building that do not influence thermal performance are not included in the analysis. For example, the cost of interior furniture, partitioning, artwork, and building foundation systems, are excluded from the analysis. It should be noted here that the term "model" applies to a series of equations that can simulate the operation of a building from a standpoint of total cost of ownership. Associated with these equations is a set of input parameters that describe the climate and economic environment the building exists in, as well as the physical characteristics of the envelope and energy systems that make up the building.

As the purpose of the study is to establish the "best" way to design the thermal systems of buildings, the analysis technique arrived at for this study utilizes this model life cycle cost, with the following analysis assumptions:

1. For a given size and occupancy classification there are innumerable ways that building thermal systems may be designed. Each design has its own characteristic life cycle cost. This characteristic life cycle cost is composed of three major components, first, cost of construction; second, annual cost of energy; and third, annual cost of maintaining and operating envelope and energy systems.

2. The "best" design, for a given building size and occupancy is that design which gives the lowest total life cycle cost of ownership. The "best" design may not be the design that has a very low first cost of construction. Use of more expensive building materials or equipment that represent a stringent thermal construction approach and that will result in lower long term energy and operating costs, can result in a lower total life cycle cost. On the other hand, extreme stringency in thermal system design beyond that required by climate

conditions can result in added life cycle cost beyond life cycle cost accruable with an optimum design.

3. The best design for one part of Alaska will not necessarily be the best design for another region of Alaska that has different climate and cost conditions.

4. Good design practice must involve all building systems that use, transport or convert energy . To this end, consideration of the thermal envelope, which represents the end use of heating energy, must be accompanied by careful treatment of interior mechanical and electrical systems.

To identify the least life cycle cost design for a given building configuration, a comparison technique that considers the full range of designs available to the industry is used.

The building is conceptually separated into three building component systems, the exterior thermal envelope, and energy consuming portions of mechanical and electrical systems.

The range of standard design practice is expressed for each of the systems as follows:

Thermal Envelope: Four separate conceptual designs

Mechanical Systems: Two separate conceptual designs
Electrical Systems: Two separate conceptual designs

Each design is evolved independently of other building systems, and defined in terms of first cost and operating characteristics. Four separate mechanical/electrical system combinations are established; these four interior energy systems designs are then combined with each of the four thermal envelope systems. This results in a total of sixteen different building design alternates for consideration with the life cycle cost model.

The sixteen design alternatives are then modeled to determine the total life cycle cost for each alternative. This modeling is accomplished for sixteen separate cost regions within the state. The output of the comparison procedure is a sixteen by sixteen matrix of total life cycle costs. Thus there are sixteen discrete design opportunities presented in terms of total life cycle cost for each cost region. This allows a separate least life cycle cost design solution to be selected for each climate and cost region of the state.

## 4.1 PROTOTYPE BUILDING

A rural school of 7,500 square feet size is used as the basis for the building model. This size is the upper limit for small schools allowed by the State Department of Education (Reference 12). and is felt to represent an appropriate size for a study concerned with rural facilities.

To allow a fair assessment of thermal systems available to the designer, the dimensions of the structure and the occupancy patterns within the school are held constant for all designs. Dimensions, tabulated in Table 1 are based on efficiency for layout, as well as for minimizing exterior wall area, and represents standard good design practices currently in use (see Fig. 1). Space allocations within the building are based on State of Alaska Department of Education guidelines.

Occupancy patterns as shown in Table 2 are based on expected use patterns for a large rural village school with considerable community use. Ventilation requirements for interior spaces are based solely on assumed maximum occupancy levels using the 5 CFM/person factor allowed by the DOT-PF Design Determinates and Options Report (Reference 13), with allowances made for building exhaust systems and flue losses in boilers and furnaces. Fig. 2 shows ventilation requirements by occupancy for the building.

During unoccupied times, the building is assumed to be not admitting any ventilating air via the ventilating system. Air exchange is still assumed to occur, however through natural envelope infiltration/exfiltration, as shown in Table 3. These levels of infiltration are based on assumed air change rates assignments for each of the climate regions. Actual values are set using an arbitarily assumed schedule related to mean annual wind speed.

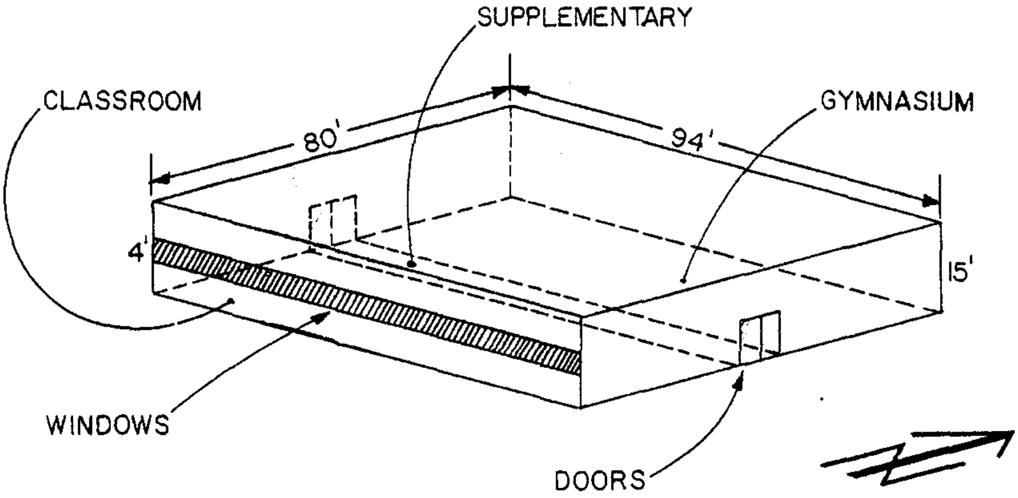


FIG. I PROTOTYPICAL BUILDING

## TABLE 1

## PROTOTYPE BUILDING CHARACTERISTICS

### I. BUILDING GEOMETRY

| | |
|---|---|
| Nominal Outside Dimensions | 80 x 94 ft. |
| Nominal Outside Building Square Footage | 7520 sq. ft. |
| Total Exterior Envelope Area | 20,260 sq. ft. |
| Total Interior Volume | 112,800 sq. ft. |

### II. ENVELOPE COMPONENT AREAS

| Component | Nominal Area (Sq. Ft.) |
|---|---|
| Floors | 7496 |
| Roof | 7496 |
| Walls | 4781 |
| Doors | 81 |
| Windows | 405 |

### III. OCCUPANCY CLASSIFICATIONS

| | Area Allocation (%) | Gross Area (Sq. Ft.) | Ceiling Height (Ft.) |
|---|---|---|---|
| Classroom | 50 | 3760 | 10 |
| Gymnasium | 40 | 3009 | 20 |
| Supplementary | 10 | 752 | 20 |

# TABLE 2

## OCCUPANCY/VENTILATION SCHEDULE

| Time Schedule Category | Time Use Breakdown | | | | Total Occupancy Head Count | Required CFM Outside Air |
|---|---|---|---|---|---|---|
| | Hrs/Day | Days/Week | Weeks/Yr | Hrs/Yr | | |
| I. Normal Class | 6 | 5 | 39 | 1170 | 228 | 1840 |
| II. Normal Class & Kitchen | 2 | 5 | 93 | 390 | 228 | 2840 |
| III. Afterhours Crowd In Gym | 4 | 1 | 39 | 156 | 430 | 2250 |
| IV. Afterhours Low Occupancy | 6 | 6 | 39 | 1404 | 120 | 700 |
| V. Night-Weekend Unoccupied | | | | 3432 | 0 | Varies see Table III |

NOTE: Minimum outside air exchange rates for any time schedule category is the computed natural ventilation rate defined in Table III. This occupancy schedule is used only for determining outside air quantities for mechanical ventilation system. Lower occupancy levels are used for determining occupant heat gain credit.

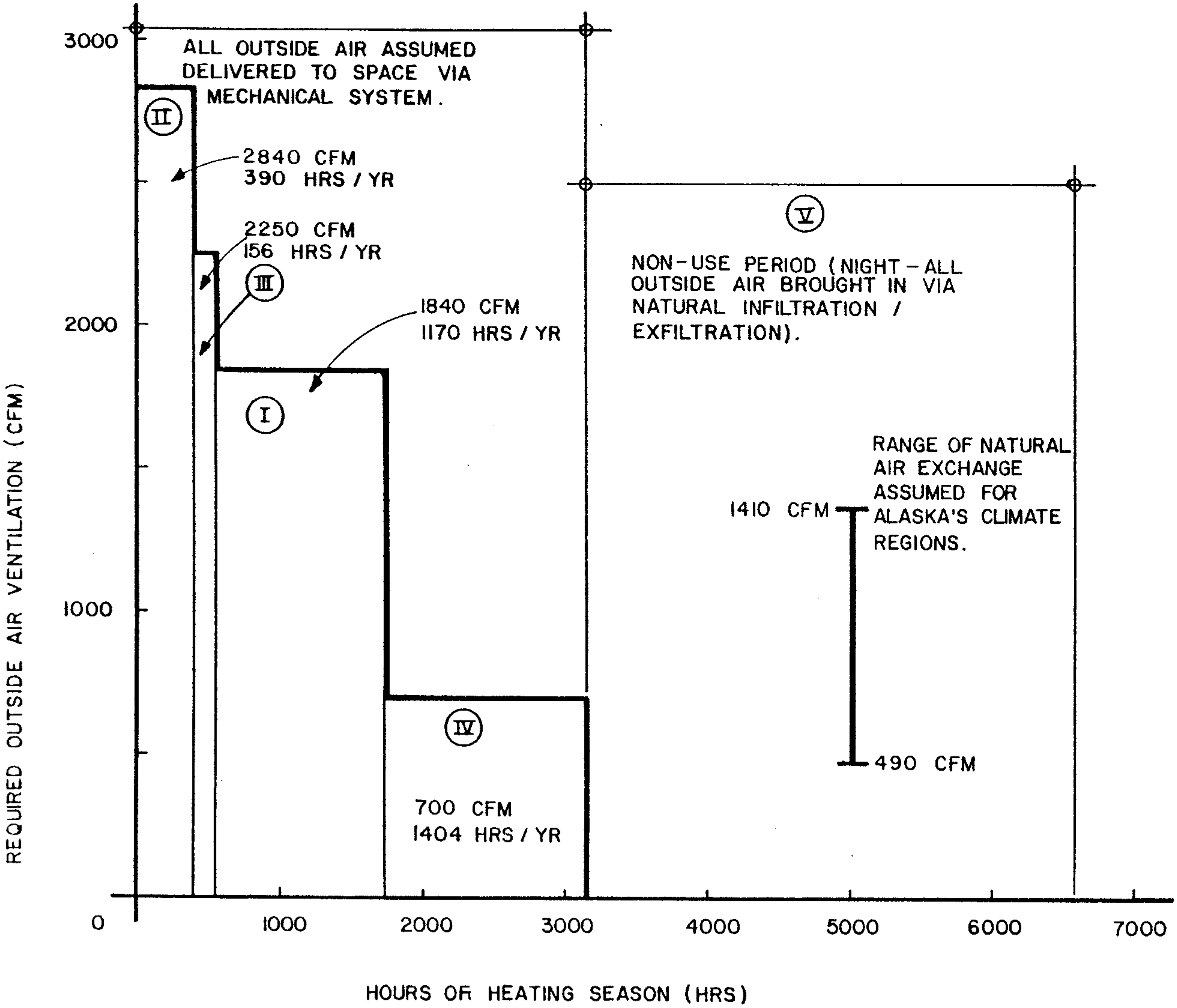


FIG. 2 VENTILATION SCHEMATIC

## TABLE 3

### VENTILATION SCHEDULE
(Due To Natural Wind/Stack Effects)

| CLIMATE REGION | REGION NAME | AIR CHANGE RATE (AC/HR) | AIR CHANGE RATE (CFM) |
|---|---|---|---|
| 1 | South Central | 1/2 | 940 |
| 2 | South Eastern | 1/2 | 940 |
| 3 | Southern Interior | 1/4 | 470 |
| 4 | Aleutian | 3/4 | 1410 |
| 5 | Western | 3/4 | 1410 |
| 6 | Northern Interior | 1/4 | 470 |
| 7 | Arctic Slope | 3/4 | 1410 |

NOTE: These ventilation rates are used only for unoccupied night-time hours. Mechanical ventilation assumed to control during day-time. However, day-time ventilation rates are not allowed to be less than night-time rates, for any given climate region.

The prototypical building is designed with a structural stud wall framework with fiberglass insulation. The structure is assumed to be elevated on a pile or post and pad type foundation, with underfloor insulation. No thermal allowance is taken for component to component connections, such as the floor-wall interfaces where thermal bridging is present.

## 4.2 ENVELOPE DESIGN ALTERNATIVES

Each of the five architectural components (walls, roof, windows, doors and floors) are dealt with separately, and four separate levels of thermal envelope construction are considered for each component, in the following categories:

| | |
|---|---|
| Lenient: | Least thermally insulative construction presently in use. |
| Moderate 1: | Middle level of thermal insulation presently in use. |
| Moderate 2: | Middle level of thermal insulation presently in use. |
| Stringent: | Most highly insulative construction presently in use. |

For each construction level, the overall thermal resistance in HR-SQ.FT. - °F/BTU,and the overall cost in dollars per square foot have been assessed. Fig. 3 shows the typical thermal calculations for each component in each level of construction.

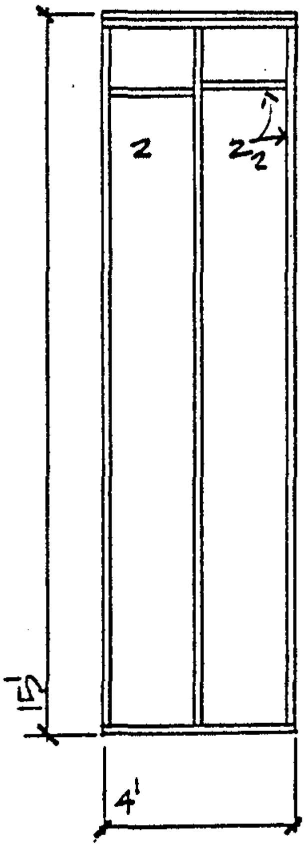
The design details and thermal characteristics of walls, floors, windows and doors for the four architectural alternates are shown in Table 4 . Roof designs vary across the state, to accomodate widely varying climate conditions. Table 5 lists the roof designs used by climate region.

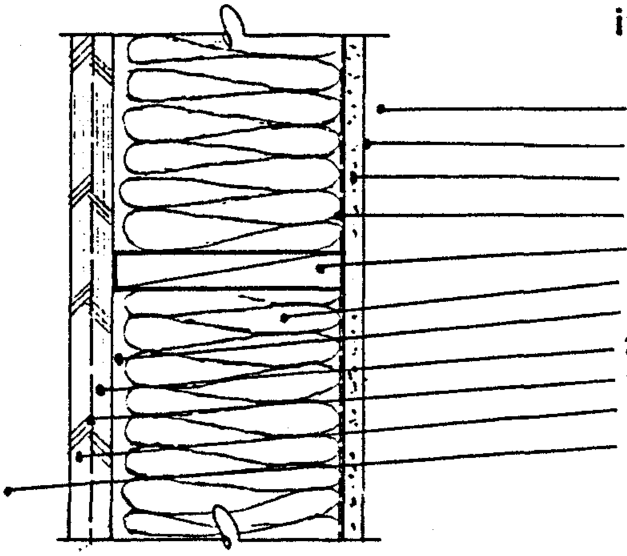
**SANDWICH TYPE:** FINISHED WALL PANEL

**ENERGY LEVEL:** MODERATE

**Dm**

**21000**





| item # | R-value |
|---|---|
| 01010 | 0.68 |
| 21810 | 0.00 |
| 21710 | 0.53 |
| 21520 | 0.00 |
| 21130 | 11.66 |
| 21620 | 28.50 |
| 01030 | 0.96 |
| 21230 | 0.46 |
| 21320 | 0.06 |
| 21420 | 0.78 |
| 01021 | 0.17 |

$$\overset{R_1}{\left(\frac{54.37}{60}\right)}(32.14) + \overset{R_2}{\left(\frac{5.6}{60}\right)}(14.34) = 30.47$$

**TOTAL THERMAL RESISTANCE:** 30.47

FIG. 3

# TABLE 4

## ENVELOPE COMPONENT DESCRIPTIONS

| | COMPONENT CATEGORY | COMPONENT U-FACTOR (BTU/HR-FT$^2$-°F) | INSULATION THICKNESS (INCHES - NOMINAL) | INSULATION TYPE | STRUCTURE |
|---|---|---|---|---|---|
| WALLS | | | | | |
| | Lenient | 0.051 | 6 | Fiberglas Batt | Wood Stud Wall |
| | Moderate 1 | 0.045 | 8 | | |
| | Moderate 2 | 0.033 | 10 | | |
| | Stringent | 0.024 | 12 | | |
| WINDOWS | | | | | |
| | Lenient | 0.490 | | | Double Pane |
| | Moderate 1 | 0.490 | | | Double Pane |
| | Moderate 2 | 0.310 | | | Triple Pane |
| | Stringent | 0.170 | | | Triple Pane* |
| DOORS | | | | | |
| | Lenient | 0.110 | 1-3/4 | Urethane Foam | Hollow Steel Door Construction |
| | Moderate 1 | 0.110 | 1-3/4 | | |
| | Moderate 2** | 0.072 | 1-3/4 | | |
| | Stringent*** | 0.045 | 1-3/4 | | |
| FLOOR | | | | | |
| | Lenient | 0.044 | 6 | Fiberglas Batt | Wood-Steel Truss Joist |
| | Moderate 1 | 0.029 | 9 | | |
| | Moderate 2 | 0.023 | 12 | | |
| | Stringent | 0.016 | 18 | | |

NOTE: ROOF COMPONENT DESCRIPTIONS INCLUDED ON TABLE V.

* With drapes

** With exterior uninsulated door to form arctic entry

*** With exterior insulated door to form arctic entry

## TABLE 5

## ROOF SYSTEM DESCRIPTIONS

| CLIMATE REGION | COMPONENT CATEGORY | U-FACTOR (BTU/HR-FT$^2$-°F) | ROOF TYPE | INSULATION TYPE | INSULATION THICKNESS (INCHES - NOMINAL) | STRUCTURE |
|---|---|---|---|---|---|---|
| 2, 3, 5, 6, 7 | Lenient | 0.0440 | Type H - Cold Roof Sloped | Fiberglas Batt | 6 | Wood-steel truss joist/Zip Rib type membrane |
| | Moderate 1 | 0.0310 | | | 9 | |
| | Moderate 2 | 0.0241 | | | 12 | |
| | Stringent | 0.0164 | | | 18 | |
| 4 | Lenient | 0.0713 | Type I - Warm Roof Sloped | Extruded Polystyrene foam | 2 | Wood-steel truss joist/Zip Rib type membrane |
| | Moderate 1 | 0.0438 | | | 4 | |
| | Moderate 2 | 0.0286 | | | 6 | |
| | Stringent | 0.0191 | | | 9 | |
| 1 | Lenient | 0.0553 | Type J - Warm Roof Flat | Extruded Polystyrene foam | 2 | Wood-steel truss joist/structural plywood deck with hot mop membrane |
| | Moderate 1 | 0.0427 | | | 4 | |
| | Moderate 2 | 0.0275 | | | 6 | |
| | Stringent | 0.0187 | | | 10 | |

Architectual envelope designs used in the study are analyzed in detail in a supplement to this report, entitled "Report Supplement - Thermal and Cost Analysis of Thermal Envelopes for a Small Rural School". This supplement presents a detailed analysis of thermal envelope designs currently in use with wood stud wall construction, throughout the state. The analysis includes an applicability study for each of the five envelope components throughout Alaska. The applicability study defines the uses of different insulation thicknesses, and roof types within the state, for small rural schools.

## 4.3 MECHANICAL SYSTEMS DESIGN ALTERNATIVES

Within the building, energy systems generate heat, condition and move ventilating air, and provide lighting and process power at the convenience of occupants and their machines. The mechanical system converts raw fossil fuels (assumed in this case to be fuel oil) to useable heating energy. The mechanical system distributes this energy throughout the interior of the architectural envelope, heating the space and providing metered amounts of ventilating air for occupant comfort.

In order to convert and move this energy for use at the envelope boundary, the mechanical system consumes "parasitic" energy. Where fuel is burned in boilers or furnaces, a portion of the energy derived from the burning process is lost through the stack as hot gases making-up the products of combustion. Electrically operated pumps and fans are used to distribute heating and ventilating mediums. The energy required to run this machinery is termed distribution energy, and while not actually a "loss", must be viewed within the context of a parasitic energy consumption.

These two components of mechanical system energy consumption have some important differences. First, the boiler/furnace stack losses are true losses out of the envelope that are to be minimized under all circumstances. The pumps and fans that consume distribution energy are a different matter. These devices are located generally within building spaces, and the distribution energy they consume is used to offset friction losses within the heating and ventilating system. The result is that a generous portion of this energy will end up as frictional heat within the envelope, and when combined with the fossil fuel heat is used to offset envelope losses. This "energy credit" serves to reduce fossil heating fuel requirements.

However, in Alaska the electrical energy used to power the pumps and fans is almost always more expensive on a dollars/BTU basis than fossil heating fuel, making this parasitic distribution energy for primary heating not desireable from a cost standpoint. Therefore, excessive levels of pump and fan energies represent a different sort of loss, that when viewed at the point where energy is brought across the building property line represents an energy cost excess.

Looking at the source of the electrical energy yields a different sort of picture. Where fossil fuel is converted to electricity using conventional engine-generator sets, as is assumed in this study, conversion efficiencies can be as low as 15% to 20%. Thus, for every equivalent BTU of electricity delivered to a pump or fan, between 5 and 7 BTU's of fossil fuel must be consumed at the source conversion point.

These source conversion losses represent real losses for the building , even though the losses occur at the power plant rather than in the building envelope proper.

Note that this criteria for minimizing electrical consumption within the building could change if an extremely cheap source of electricity is realized, as in the case of an area that has a strong hydro power base, or in certain situations where a cogeneration base is used to create heat and produce electricity. For the purposes of this study, availability of hydro or cogeneration is not considered. The source of electricity is assumed to be a conventional low efficiency conversion process using diesel generators, with a high per BTU cost of energy.

As in the case of the envelope system, there are innumberable ways in which mechanical and electrical systems may be designed. There is also a wide variability in the energy efficiency of interior energy systems, that is, in how much energy is consumed in stack losses and in distribution of the energy to the envelope, where it is consumed.

Each interior energy system design for a given building envelope will also exhibit a particular behavior pattern in the way interior heat gains from occupants, their activities, and energy expended in the lighting, heating and air conditioning processes interact with envelope heat losses.

Space temperature control and zone requirements as well as maintenance and operations considerations are strong determinates in how mechanical systems are designed. Where minimal control and zone requirements are impressed, system designs tend to be simple with a minimum of installed components.

However, where control and zone requirements are rigorous, mechanical system complexity tends to increase.

Unfortunately, coupled with the variability in design complexity, is a variability in energy consumption by mechanical systems. The low first cost, simple systems that offer ease of maintenance and operation, tend to use large amounts of "parasitic" conversion and distribution energy. These simpler systems, while offering low first costs, may cost much more in the long run due to high energy costs, than a more complex, yet more efficient system.

There are at present within the state, two identifiable design philosophies (out of many) for mechanical systems that address system complexity. One philosphy emphasizes low first cost and simplicity of operation, using furnace systems and ducted hot air to the envelope, with a minimum of zones and system controls. The other defined philosophy is a more complex system that uses boilers for heat generation, a glycol/water mixture for heat distribution and a separate ducted ventilation system.

This study addresses these two bounding philosophies, from the standpoint of first cost, maintenance and operations costs, and parasitic energy consumption. This study models the two interior mechanical system philosophies in terms of construction and maintenance and operations cost, and energy consumption.

The model takes into account how much energy is consumed in the process of moving energy from the site boundary to the end use location within the building. The following mechanical system operating parameters are used to describe energy consumption characteristics of each of the design alternatives:

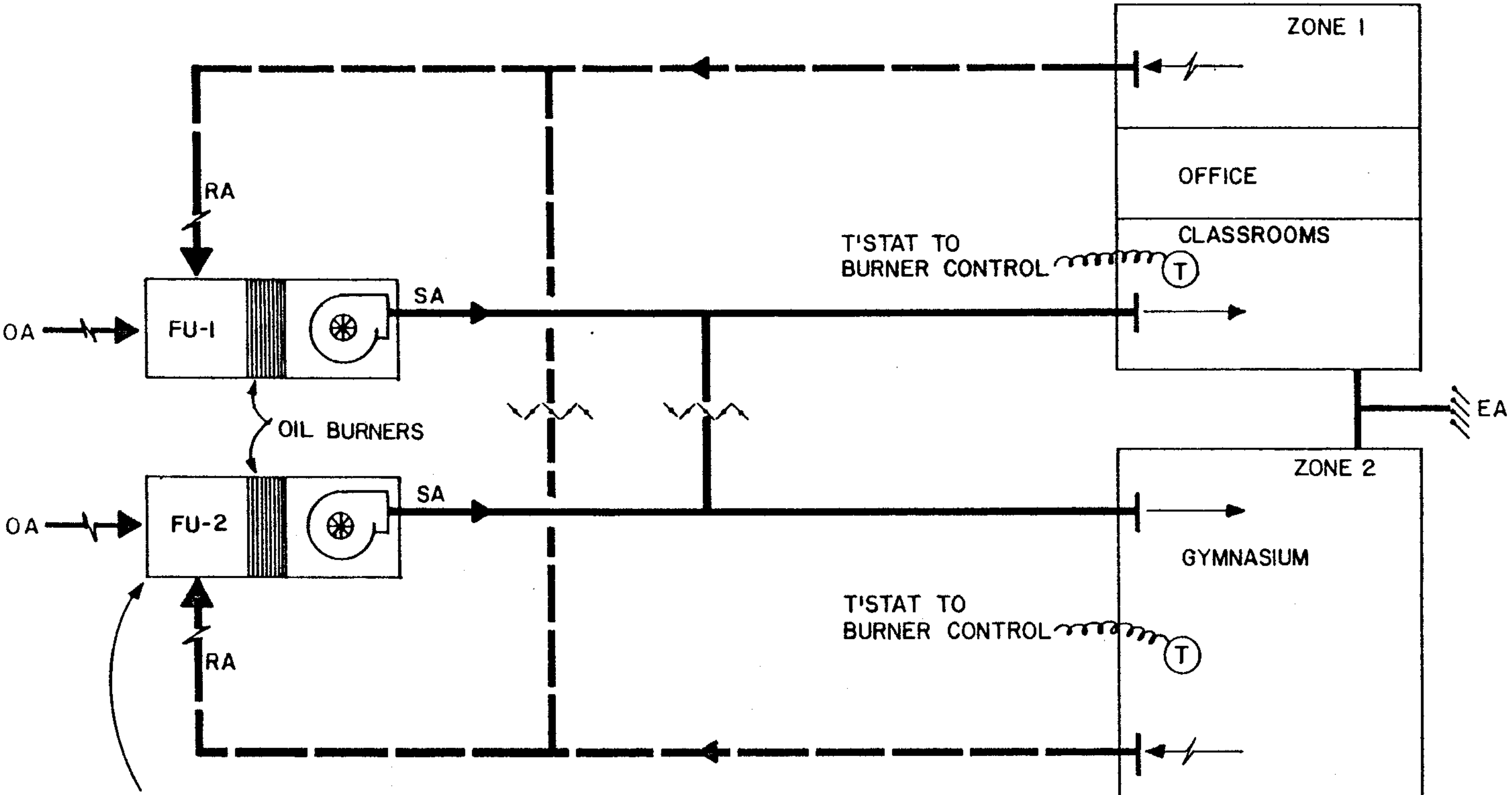
- Heat generation conversion efficiency: Defined as ratio of useable energy delivered to envelope system annually to total energy delivered to the building annually.

- Distribution energy consumption: Defined as total electrical energy consumed in the heating and ventilating process within the envelope.

- Outside air ventilation schedule: Defines outside air quantities in CFM by time schedule, for each mechanical system alternative.

The first scenario (ME 1) involves use of hot air furnace equipment that will be of low first cost but present a higher annual operating cost. This design uses the following major components (see Fig. 4):

- (2) Horizontal hot air furnaces with mixing boxes, filters, control dampers and required ductwork, diffusers and grilles,



PACKAGED OIL FIRED FURNACE UNIT
WITH MIXING BOXES, FILTERS, HI-LOW
BURNER AND CONSTANT VOLUME FAN.

FIG. 4 SCHEMATIC PLAN - PACKAGED HEATING FURNACE PLAN and package unit controls.

- System controls, consisting of room thermostats, damper motors, duct stats, time clocks, and all associated equipment.

- Kitchen exhaust system, including ductwork, fan unit, roof or wall hood and controls.

- Toilet exhaust system, including grilles, balance dampers, ductwork, fan unit, controls and roof or wall hood.

The second scenario (ME 2) models a high first cost, energy efficient mechanical system that has a heavy impact on construction budget, and additional annual maintenance and operating cost, but yields returns in increased operating efficiency and lower energy consumption. This design involves use of the following major components for the mechanical system (see Fig. 5):

- (2) Central cast iron wet base boilers with controls, breeching, stacks, and duplex circulating pumps.

- (3) Air handlers for ventilation of interior spaces, with required ductwork, diffusers and grilles, dampers and controls.

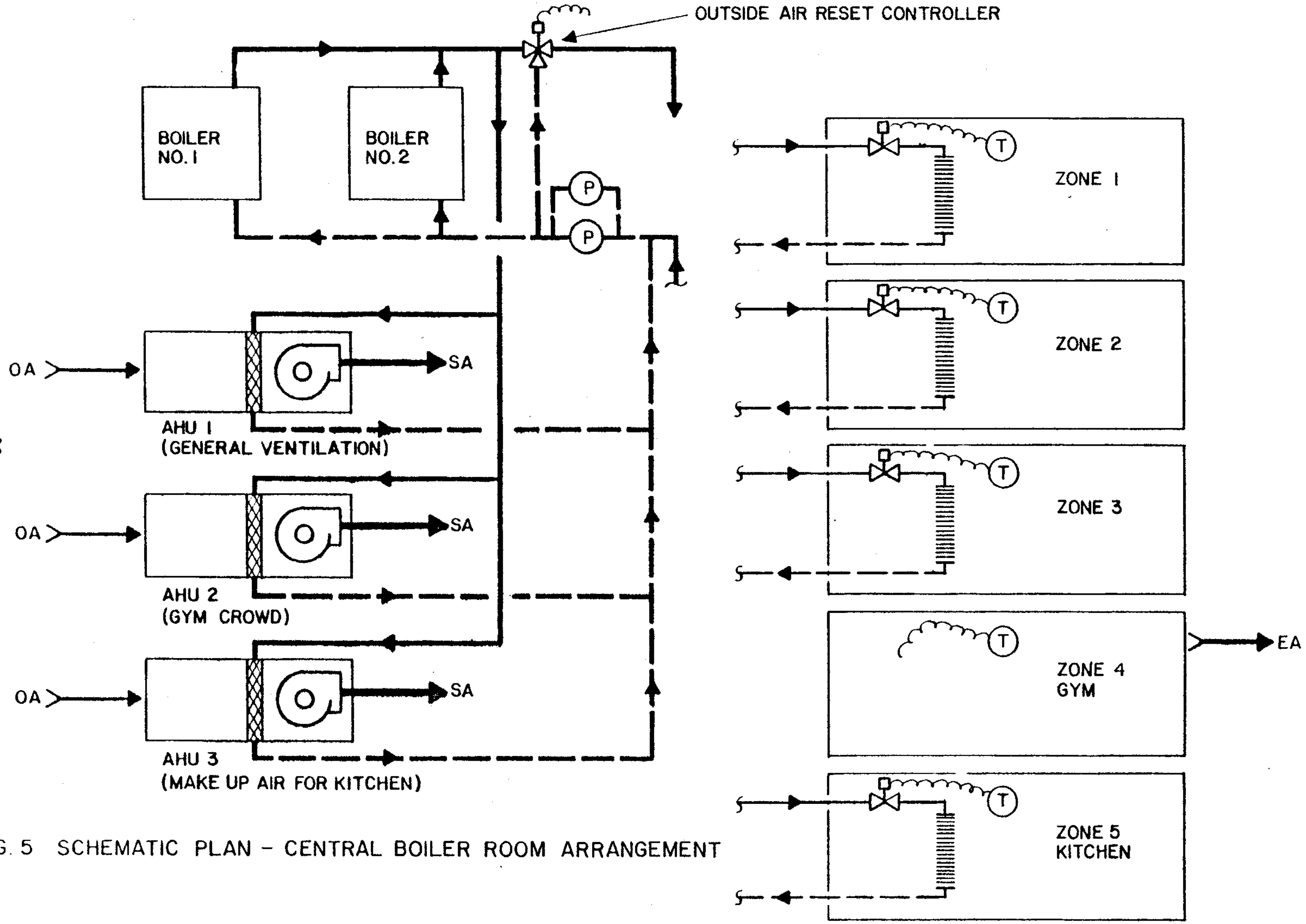


FIG. 5 SCHEMATIC PLAN – CENTRAL BOILER ROOM ARRANGEMENT

- Perimeter baseboard system for circulating glycol, including finned tube, piping, and finned tube enclosures.

- System controls, consisting of room thermostats, damper motors, control valves, and all associated control equipment.

- Kitchen exhaust system including ductwork, fan unit, roof or wall hood and controls.

- Toilet exhaust system, including grilles, balance dampers, ductwork, fan unit, controls and roof or wall hood.

The two alternative concepts for mechanical systems were arrived at through evaluation of a sampling of recently constructed small scale institutional structures throughout the states. The values used in the analysis are presented in Table 6. Values for heat generation conversion efficiency are based on results of a Brookhaven National Laboratory Study (Reference 14).

Table 7 lists the amounts of outside air that are assumed to be brought in

## TABLE 6

## MECHANICAL & ELECTRICAL SYSTEM ENERGY CONSUMPTION CHARACTERISTICS

### A. MECHANICAL SYSTEM CHARACTERISTICS

| | ME 1 Simple Mechanical System | ME 2 Complex Mechanical System |
|---|---|---|
| Seasonal Heat Generation Efficiency (%) | 70 | 70 |
| Distribution Energy Consumption (BTU/SQ.FT.-YR) | 11,130 | 3,610 |

### B. ELECTRICAL LIGHTING SYSTEM ENERGY CONSUMPTION LEVELS (Watts/Sq. Ft.)

| OCCUPANCY | EE 1 Standard Design | EE 2 Alternate Design |
|---|---|---|
| Classroom | 3.2 | 1.8 |
| Multipurpose | 1.15 | 0.85 |
| Undefined | 4.0 | 3.0 |

# TABLE 7

## SCHEDULE OF OUTSIDE AIR VENTILATION RATES (CFM)

| CLIMATE REGION | LEVEL OF CONSTRUCTION | TIME SCHEDULE (TT(I)) | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | ME 1 | 2840 | 2840 | 2840 | 2840 | 940 |
| | ME 2 | 1840 | 2840 | 2250 | 940 | 940 |
| 2 | ME 1 | 2840 | 2840 | 2840 | 2840 | 940 |
| | ME 2 | 1840 | 2840 | 2250 | 940 | 940 |
| 3 | ME 1 | 2840 | 2840 | 2840 | 2840 | 470 |
| | ME 2 | 1840 | 2840 | 2250 | 700 | 470 |
| 4 | ME 1 | 2840 | 2840 | 2840 | 2840 | 1410 |
| | ME 2 | 1840 | 2840 | 2250 | 1410 | 1410 |
| 5 | ME 1 | 2840 | 2840 | 2840 | 2840 | 1410 |
| | ME 2 | 1840 | 2840 | 2250 | 1410 | 1410 |
| 6 | ME 1 | 2840 | 2840 | 2840 | 2840 | 470 |
| | ME 2 | 1840 | 2840 | 2250 | 700 | 470 |
| 7 | ME 1 | 2840 | 2840 | 2840 | 2840 | 1410 |
| | ME 2 | 1840 | 2840 | 2250 | 1410 | 1410 |

NOTE: Time schedule intervals 1 through 4 are daytime or occupant use periods with mechanical systems bringing in metered amounts of outside air. During time schedule interval 5 outside air dampers shut, with ventilation via natural infiltration/exfiltration.

the building, listed by time schedule interval, mechanical system design alternative, and climate region. This tabulation defines the assumptions for sequence of operation of outside air damper controls.

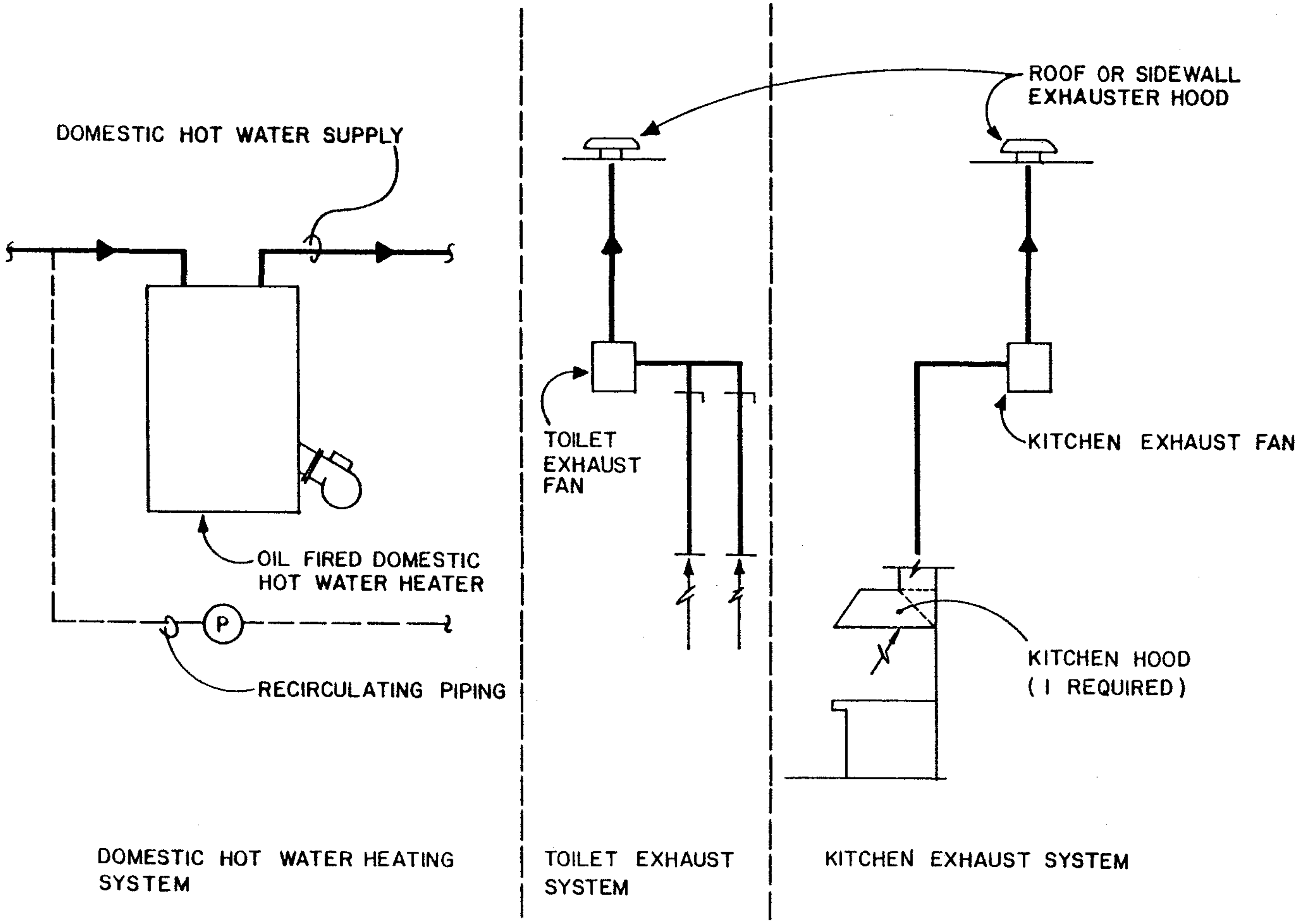
As can be seen, for the simpler ME 1 system, a relatively high level of outside air is used for all occupied time schedule intervals (1 through 4). The ME 2 design allows outside air quantities to more closely track occupancy schedules (see Table 2 and Figure 2).

The mechanical system is assumed to serve the classrooms, multipurpose room, offices, kitchen, toilet room and other undefined spaces that constitute the prototypical building. Mechanical equipment included in the design is only that equipment directly related to the energy consuming portions of the heating and ventilation systems for the building. A number of energy related systems are common to each of the mechanical system alternatives. These systems consist of domestic hot water heating equipment, assumed in the analysis to be an oil fired storage heater, and kitchen and toilet ventilation units. The systems are shown in schematic on Fig. 6.

The following building systems, while a part of the typical mechanical system, are not included in this analysis, as they do not represent major energy consumers:

- Plumbing fixtures
- Domestic hot and cold water distribution systems

- Domestic water supply and pressurization systems
- Domestic water treatment systems
- Waste water systems
- Sprinkler systems



DOMESTIC HOT WATER HEATING SYSTEM

TOILET EXHAUST SYSTEM

KITCHEN EXHAUST SYSTEM

FIG. 6 SYSTEMS COMMON TO EACH MECHANICAL SYSTEM ALTERNATE

## 4.4 Electrical System Design Alternatives

The electrical energy consumed within a building can be divided into three major uses: building lighting, motive power for mechanical system, and process power to be used by building occupants. Of these three components, mechanical system and lighting power are of major concern with envelope/energy systems studies. Process power conservation, as it is a specialized study not related to building system design, is not considered in the study.

As mechanical system electrical consumption is almost wholly dependent on selection of mechanical equipment, this subject has been discussed in Section 4.3 (Mechanical System Design Alternatives). The analysis of electrical systems thus centers on the design of interior and exterior electrical lighting.

Two basic design concepts are used in the analysis of lighting. The building is assumed to be in three area designations each with a different lighting level that results from fixture selection to match use, ceiling height, and room characteristics. The standard design (designated "EE1"), describes current practice, while the alternate design (designated "EE2"), portrays the energy conserving design using current off-the-shelf hardware.

### Standard Lighting Design

The standard design is best described as current practice. Light fixtures are reasonably energy efficient, are fluorescent, utilize an acrylic diffuser and are low first cost. The building utilizes some incandescent fixtures for esthetic qualities. Exterior fixtures are photocell controlled but operate from sundown to sunup with no timeclock override. No attempt is made to utilize waste heat from the fixtures efficiently, and the lighting layout produces a uniform light level throughout the area concerned without regard to furniture placement and, consequently, "task" lighting. The energy efficient desigh utilizes the best choice in energy efficient lamps coupled with an energy efficient luminaire. Table 6 details the watts per square foot for the areas for both the standard and the energy efficient alternate designs.

## Alternate Lighting Design

The alternate design for the classroom utilizes the same parameters as above but utilizes a more energy efficient fixture. Also, the placement of the fixtures takes into account the location of desks in the classroom and spots them where the light will be concentrated where needed. The overall average lighting level in the classroom is lower, but due to the improved design, produces equal results to the standard design above. The alternate design utilizes a slighter lower zonal cavity footcandle level but, due to an improved diffuser which allows more efficient diffusing of the light, provides equal or better results.

The design for the multi-purpose room consists of high pressure sodium luminaires, which are one of the most efficient sources of light in common use today. Mechanical rooms and undefined spaces are lighted with fluorescent fixtures.

In defining the energy consumption characteristics of the prototypical building, the interior of the structure is assumed to be divided into three separate occupancies for lighting analysis; each with a characteristic area specific energy consumption level in watts per square foot. These consumption levels are presented in Table 6.

The two alternative designs for electrical lighting systems were arrived at by an actual conceptual design process of identifying average room sizes, and architectural surfaces, and actual selection of lighting fixtures to achieve normal lighting levels for each of the three occupancies. This analysis is included as Appendix 1 of this report.

## 4.5 COST ESTIMATING

The analysis of costs for the building's energy system involves definitions of first costs of construction, and analysis of both maintenance and operations costs, and costs of energy. These component costs have been defined at a base location in Alaska, the City of Anchorage, and then related to other locations in Alaska, through use of cost indices. This index approach is discussed in Section 4.2.

### 4.5.1 CONSTRUCTION COSTS FOR THERMAL ENVELOPE

Costing for envelope components was accomplished for each of the four levels of thermal construction. This was done by selecting a unit area of construction, and estimating costs of all labor, materials, and supervision for that component. An example of a cost estimate for a typical envelope component is presented in Figure 7. This cost includes all parts of the envelope that are taken as a portion of the thermal envelope.

As can be seen in the example, which is for a 10" thick wall section, the unit area for costing is taken as 60 square feet. All parts of the envelope affecting thermal performance are costed, including paint, interior wall board, vapor barrier, structural studs and plates, exterior sheathing and stain, and thermal insulation. A strict parity is maintained between the components costed and the components included in thermal resistance calculations (Section 4.2).

| | | | | | |
|---|---|---|---|---|---|
| Project: Alaska Thermal Standards | | Element: | Finished Wall Panels (DM) | Sheet No. | 13 |
| | | Date: | November 10, 1980 . | | |

| Number | Description | Quantity/ Unit | Rate | Estimated Cost | Remarks |
|---|---|---|---|---|---|
| 01010 | Air | -0- | -0- | -0- 8" wall | Area 60 SF |
| 21810 | Paint (Latex) | 60 SF | 0.75 | 45.00 | Δ $ 1.26 |
| 21710 | 5/8" gypwall board | 60 SF | 1.02 | 61.20 | 1/2Δ + 1.32 = 195 |
| 21520 | 4 mil Polyethylene | 60 SF | 0.22 | 13.20 | |
| 21150 | 2 ~~4~~" x 10" studs | 46 LF | 2.58 1.95 | 118.68 89.70 | |
| 21670 | 9" fiberglass | 60 SF | 1.02 .78 | 61.20 46.80 | $ .78/FT² $ .11/BD FT |
| 01030 | Air | -0- | -0- | -0- | |
| 21230 | 3/8" plywood | 60 SF | 1.04 | 62.40 | |
| 21320 | Kraft paper | 60 SF | 0.32 | 19.20 | |
| 21420 | 5/8" ply T1-11 (stained) | 60 SF | 2.75 | 165.00 | |
| 01020 | Air | -0- | -0- | -0- | |

8" WALL

FIGURE 7

| | | | |
|---|---|---|---|
| Estimated Cost | $ 545.88<br>502.50 | Rate per SF<br>COMPONENT | $ 9.10<br>8" wall 8.38 |

These costs for the 60 square foot area are then converted to cost per square foot of wall component, and then to cost per square foot of building floor area, using the following relationship:

Cost(Dollars/Bldg Sq. Ft.) =
Cost (dollars/component sq. ft.)(total component area/total floor area)

These costs are presented in Tables 8 and 9, and detailed development of numbers are included in report supplement. Table 9 presents a breakdown of costs used for roof systems for the different climate regions of Alaska. These systems are based on applicability requirements for roof systems, discussed in Section 4.2. Table 10 presents a summary of costs of the total thermal envelope, by climate region. It should be noted that all costs herein are expressed as Anchorage base costs. For the analysis these costs are adjusted by suitable cost indices to different bush locations within each climate region. This is discussed in Section 4.2.

### 4.5.2 CONSTRUCTION COSTS FOR MECHANICAL AND ELECTRICAL SYSTEMS

As described in Sections 4.3 and 4.4, only those components of mechanical and electrical systems contributing to or influencing building thermal performance were analyzed. For mechanical systems, two operating schools were selected for cost analysis. The two schools are examples of a number of schools that have recently been constructed, and both are in Southwestern Alaska in small villages (References 15 and 16).

## TABLE 8

## UNIT COSTS OF ENVELOPE COMPONENTS ($/BLDG SQ FT)

| | CONSTRUCTION LEVEL | | | |
|---|---|---|---|---|
| COMPONENT | LENIENT | MODERATE 1 | MODERATE 2 | STRINGENT |
| Walls | $ 5.26 | $ 5.58 | $ 5.89 | $ 7.75 |
| Roof | Roof costs are variable by climate region - See Table 9 | | | |
| Windows | 1.21 | 1.21 | 2.07 | 2.79 |
| Door | 0.323 | 0.323 | 0.630 | 0.645 |
| Floor | 9.62 | 9.96 | 10.30 | 10.98 |
| Total Unit Cost (excluding roof) | $ 16.41 | $ 17.07 | $ 18.89 | $ 22.17 |

## TABLE 9

## UNIT COSTS OF ROOF SYSTEMS ($/BLDG SQ FT)

| | | THERMAL CONSTRUCTION LEVEL | | | |
|---|---|---|---|---|---|
| CLIMATE REGION | ROOF TYPE | LENIENT | MODERATE 1 | MODERATE 2 | STRINGENT |
| 1 South Central | J | $ 13.10 | $ 14.74 | $ 17.63 | $ 22.11 |
| 2 South Eastern | H* | 12.42 | 12.80 | 13.20 | 14.67 |
| 3 Southern Interior | H* | 12.42 | 12.80 | 13.20 | 14.67 |
| 4 Aleutian | I* | 15.08 | 16.95 | 20,29 | 25.45 |
| 5 Western | H* | 12.42 | 12.80 | 13.20 | 14.67 |
| 6 Northern Interior | H* | 12.42 | 12.80 | 13.20 | 14.67 |
| 7 Arctic Slope | H* | 12.42 | 12.80 | 13.20 | 14.67 |

*Sloped roof factor of 1.054 applied

NOTE: See Table 5 for description of roof types.

## TABLE 10

## UNIT COST OF THERMAL ENVELOPE SYSTEM ($/BLDG SQ FT)

| | THERMAL CONSTRUCTION LEVEL | | | |
|---|---|---|---|---|
| CLIMATE REGION | LIENENT | MODERATE 1 | MODERATE 2 | STRINGENT |
| 1 | $29.51 | $31.81 | $36.52 | $44.28 |
| 2 | 28.83 | 29.87 | 32.09 | 36.84 |
| 3 | 28.83 | 29.87 | 32.09 | 36.84 |
| 4 | 31.49 | 34.02 | 39.18 | 47.62 |
| 5 | 28.83 | 29.87 | 32.09 | 36.84 |
| 6 | 28.83 | 29.87 | 32.09 | 36.84 |
| 7 | 28.83 | 29.87 | 32.09 | 36.84 |

This analysis yielded an Anchorage based cost of $10.96/bldg. sq.ft. for the simple system (MI 1) and $21.92/bldg. sq.ft. for the complex system (ME 2). These numbers are based on a cost takeoff from project plans and specifications. A breakdown of costs are included in Table 11.

Electrical systems are defined by a cost analysis of the two different design concepts discussed in Section 4.4. Costs are assessed on the basis of assumed layouts for fixtures and approximate wiring requirements. The costs of major service components and associate switching hardware, were not included in the estimate as it is felt that these costs do not influence thermal performance. The costs used in the analysis for the two electrical design alternatives are $2.28/bldg. sq.ft. for a standard design and $2.55/bldg. sq.ft. for an alternate energy conserving design. These costs are Anchorage base costs and are adjusted upward using cost indices to various cost regions in the state within modeling equations.

## TABLE 11

## CONSTRUCTION COST ANALYSIS-MECHANICAL SYSTEMS

| | ME 1<br>SIMPLE | ME 2<br>COMPLEX |
|---|---|---|
| Heat Generation and Oil Supply | $ 8,265 | $ 24,900 |
| Hydronics | ----- | 48,260 |
| Hot Air Generation | 46,855 | 33,020 |
| Air Supply | 31,815 | 43,770 |
| Exhaust System | 11,505 | 35,420 |
| Hot Water Generation | 4,025 | 9,830 |
| TOTAL | $102,465 | $195,200 |
| Gross Floor Area | 9,348 SF | 8,904 SF |
| Unit Cost ($/bldg. sq. ft.) | $10.96/SF | $21.92/SF |

NOTE: These costs are Anchorage based costs for a portion of the mechanical system that influences thermal performance.

### 4.5.3 Analysis Of Maintenance

The cost of maintaining energy systems within a rural school is rather nebulous and is difficult to quantify. There are a number of cost components associated with the rural system operation, as listed below:

- Onsite direct labor costs for scheduled preventative maintenance.
- Onsite direct labor costs for unscheduled repair and maintenance.
- Home office adminstration.
- Travel costs.
- Travel time.
- Maintenance materials.
- Overhead burden for labor force.

Each of these components is difficult to separate from maintenance and operations costs for other non-energy consuming systems. Further hard data on thermal systems maintenance costs are generally not available from school districts currently.

For these reasons, maintenance costs for systems are assessed using the following parameters:

1. Costing was accomplished assuming only preventative maintenance activities once per year by contractor.

2. All costs of the contractor administration, home office, travel and onsite labor are included.

It has been assumed that differences in cost between architectural and electrical systems will be minimal regardless of level of thermal construction assumed. For this reason, costs for envelope and architectural systems are assumed as zero.

Mechanical system costs are assumed to be as follows for the Anchorage base case:

| | | |
|---|---|---|
| ME 1 | Simple System | $0.072/Sq.Ft. - Yr |
| ME 2 | Complex System | $0.144/Sq.Ft. - Yr |

These costs are adjusted upward in the analysis by application of construction cost indices by cost region.

## 4.6 STATEWIDE CLIMATE & COST CONDITIONS

Total life cycle costs of a typical building are sensitive to climate and cost conditions throughout the state. In recognition of this, the State of Alaska was divided into seven separate climate regions and sixteen separate cost regions. Climate regions within the state were chosen by a subjective analysis of available long term weather information, and review of existing climate literature (References 17 and 18). The seven regions are listed in Table 12, and shown in Figure 8. Climate conditions for each region are expressed in terms of mean annual temperature, mean annual wind speed, and a value of indident solar energy as a credit. Climate data used is shown as Appendix 2.

Cost regions within the state were chosen by an evaluation of available cost analyses by in-state cost consultants (Reference 19). A total of sixteen different regions are identified to categorize rural Alaska; these regions are identified in Table 12. Within each of the regions first costs of construction, as well as costs of fuel oil and electricity are addressed. These data are expressed as indices with base values for the City of Anchorage. Table 12 shows the breakdowns of cost indices by cost region. Boundaries of climate regions were made to be coincident with cost region boundaries. Thus each cost region is wholly within a climate region, to simplify analysis logic. The basis of development of these cost regions is included in the report supplement.

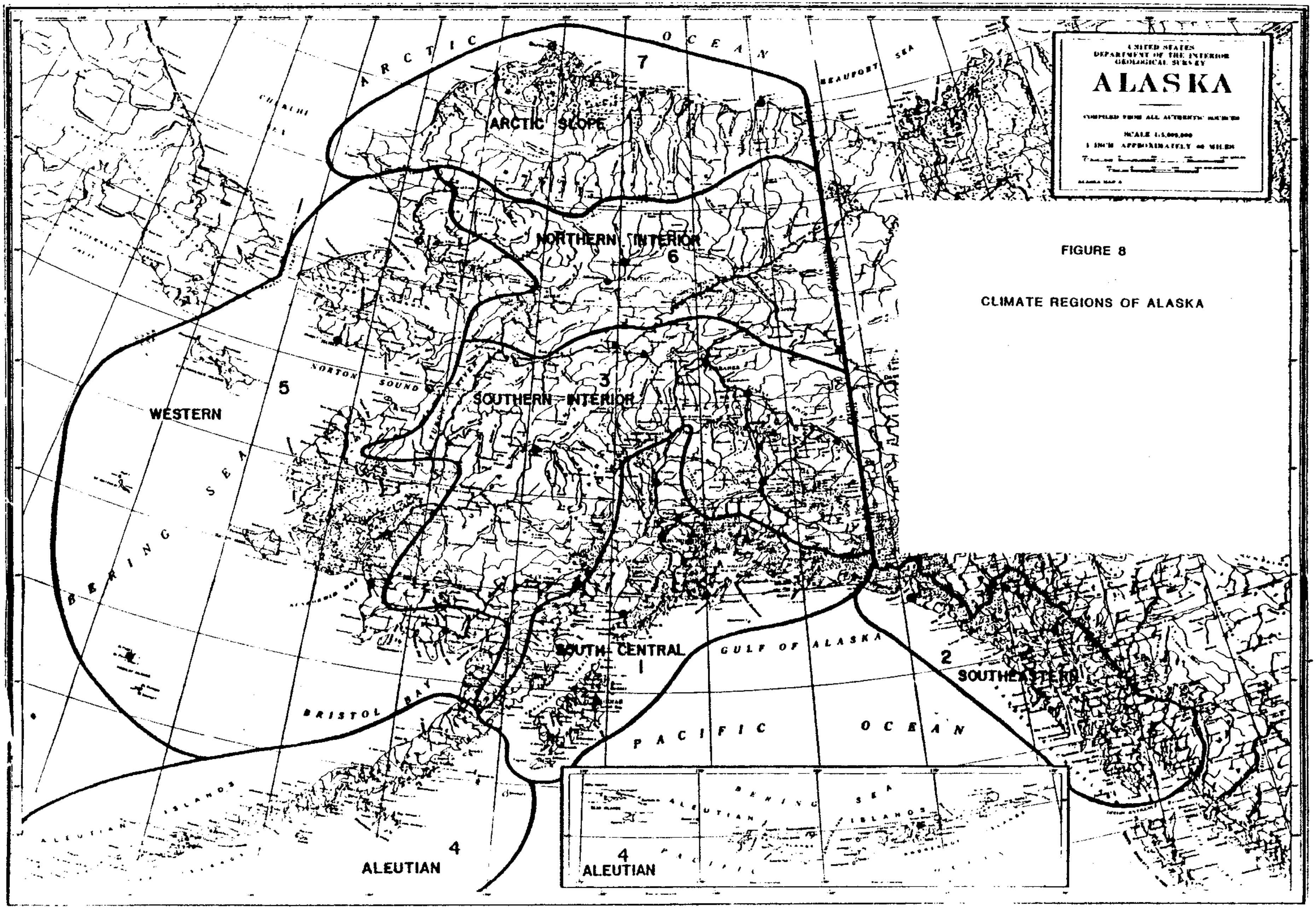


FIGURE 8

CLIMATE REGIONS OF ALASKA

TABLE 12

STATEWIDE CLIMATE/COST CONDITION SUMMARY

| COST REGION NUMBER | COST REGION NAME | CLIMATE REGION NUMBER | CLIMATE REGION NAME | CONSTRUCTION COST INDEX* | ENERGY COST INDEX |  | MEAN ANNUAL HEATING SEASON TEMPERATURE (°F) | MEAN ANNUAL WIND SPEED (MPH) |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | HEATING FUEL OIL** | ELECTRICITY*** |  |  |
| 1 | Anchorage Zone | 1 | South Central | 1.22 | 1.04 | 2.11 | 31.2 | 6.9 |
| 2 | Village |  |  | 1.32 | 1.04 | 6.32 |  |  |
| 3 | Kodiak Island |  |  | 1.34 | 1.04 | 3.48 |  |  |
| 4 | Juneau Zone | 2 | South Eastern | 1.13 |  | 2.54 | 38.8 | 8.9 |
| 5 | Main Center |  |  | 1.29 | 1.00 | 1.84 |  |  |
| 6 | Village |  |  | 1.81 | 1.06 | 2.73 |  |  |
| 7 | Sitka Island |  |  | 1.34 | 1.04 | 1.57 |  |  |
| 8 | Fairbanks Zone | 3 | Southern Interior | 1.30 | 1.0 | 2.43 | 15.9 | 6.3 |
| 9 | Village |  |  | 2.13 | 1.36 | 5.75 |  |  |
| 10 | Village | 4 | Aleutian | 2.25 | 1.08 | 3.36 | 36.4 | 13.6 |
| 11 | Bethel | 5 | Western | 1.50 | 1.09 | 4.00 | 20.9 | 13.1 |
| 12 | Large Village |  |  | 1.53 | 1.16 | 4.63 |  |  |
| 13 | Coastal Village |  |  | 2.44 | 1.40 | 9.09 |  |  |
| 14 | Village | 6 | Northern Interior | 2.67 | 2.86 | 9.09 | 11.5 | 6.7 |
| 15 | Barrow | 7 | Arctic Slope | 1.92 | 1.36 | 3.06 | 0.6 | 12.5 |
| 16 | Coastal Village |  |  | 2.94 | 1.09 | 5.68 |  |  |

BASIS FOR INDICES:
* Base Construction Cost $100.00/Sq. Ft. Building Space
** Base Heating Fuel Oil Cost $0.957/Gal ($6.91/Million BTU's)
***Base Electricity Cost $0.044/KWH ($12.89/Million BTU's)

## 4.7 THERMAL MODELING TECHNIQUES

The program incorporates a steady state thermal model that evaluates the amounts of heating and electrical energy that will be consumed annually within the building. The model uses mean annual heating season temperatures and an assumed year round air infiltration rate as a basis for the heat loss calculations. Interior temperatures are assumed to be 70°F except during unoccupied hours when temperatures are set back to 65°F. Internal building gains are evaluated and used as credits to establish a corrected annual heating budget. Two energies are assumed to be supplied to the building. No.2 fuel oil with a heating value of 138,500 BTU/gallon is the prime heating energy. Electrical energy for lighting and heating/ventilating system power is the second energy. The calculation procedures used are presented in Fig. 9, and the energy flows the model considers within the building are presented in Fig. 10.

Conversion losses in heat generation equipment are included in the analysis, so that heating requirements computed are total amounts of energy that must be delivered to the building. Electrical energies required are also "site boundary" energy quantities that are fed to the main building service for internal comsumption. However, the electrical energy budget does not include energies required for process loads such as coffee pots, film projectors, headbolt heaters, or exterior lighting.

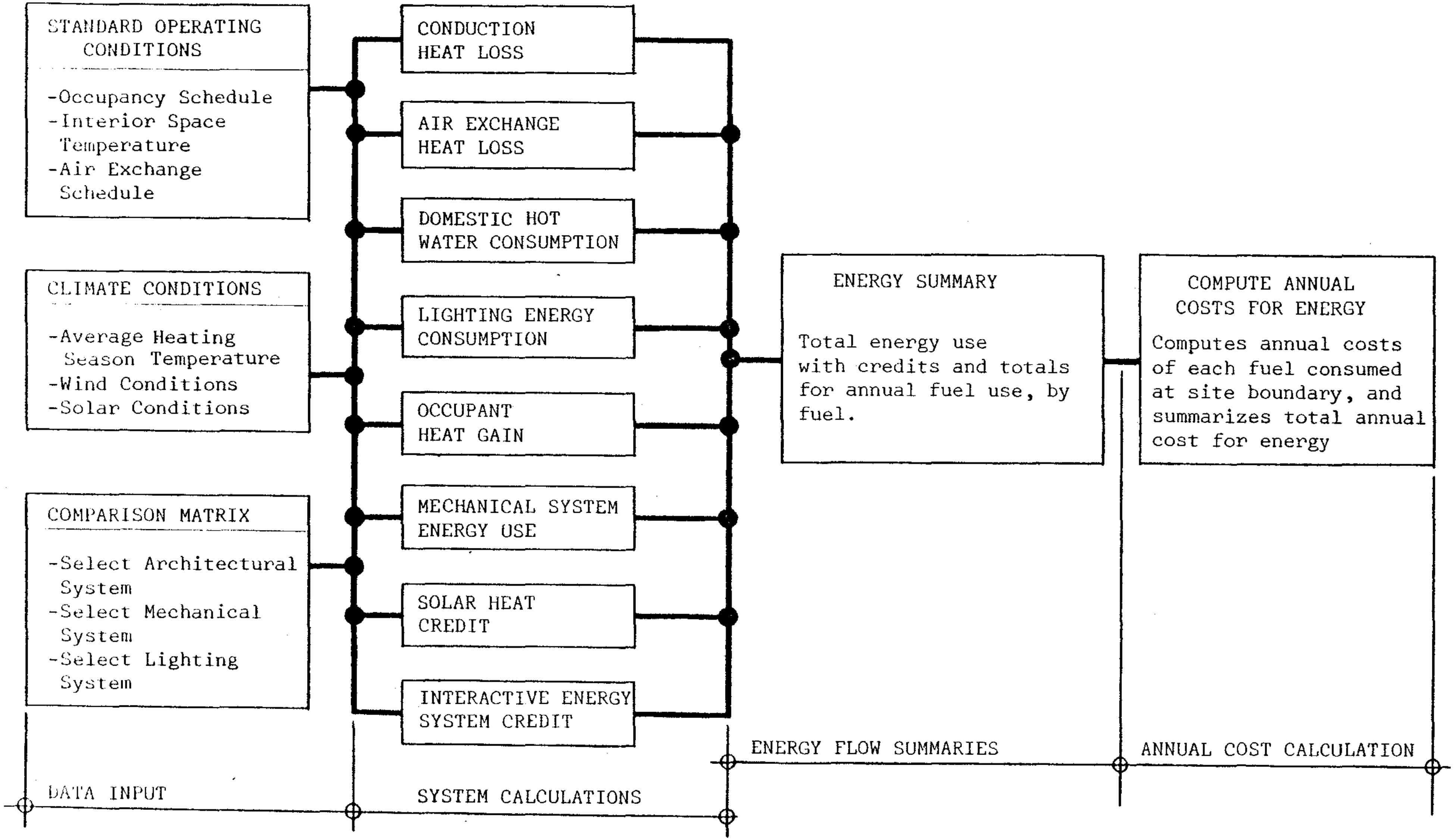


FIG. 9 THERMAL MODEL FLOW CHART

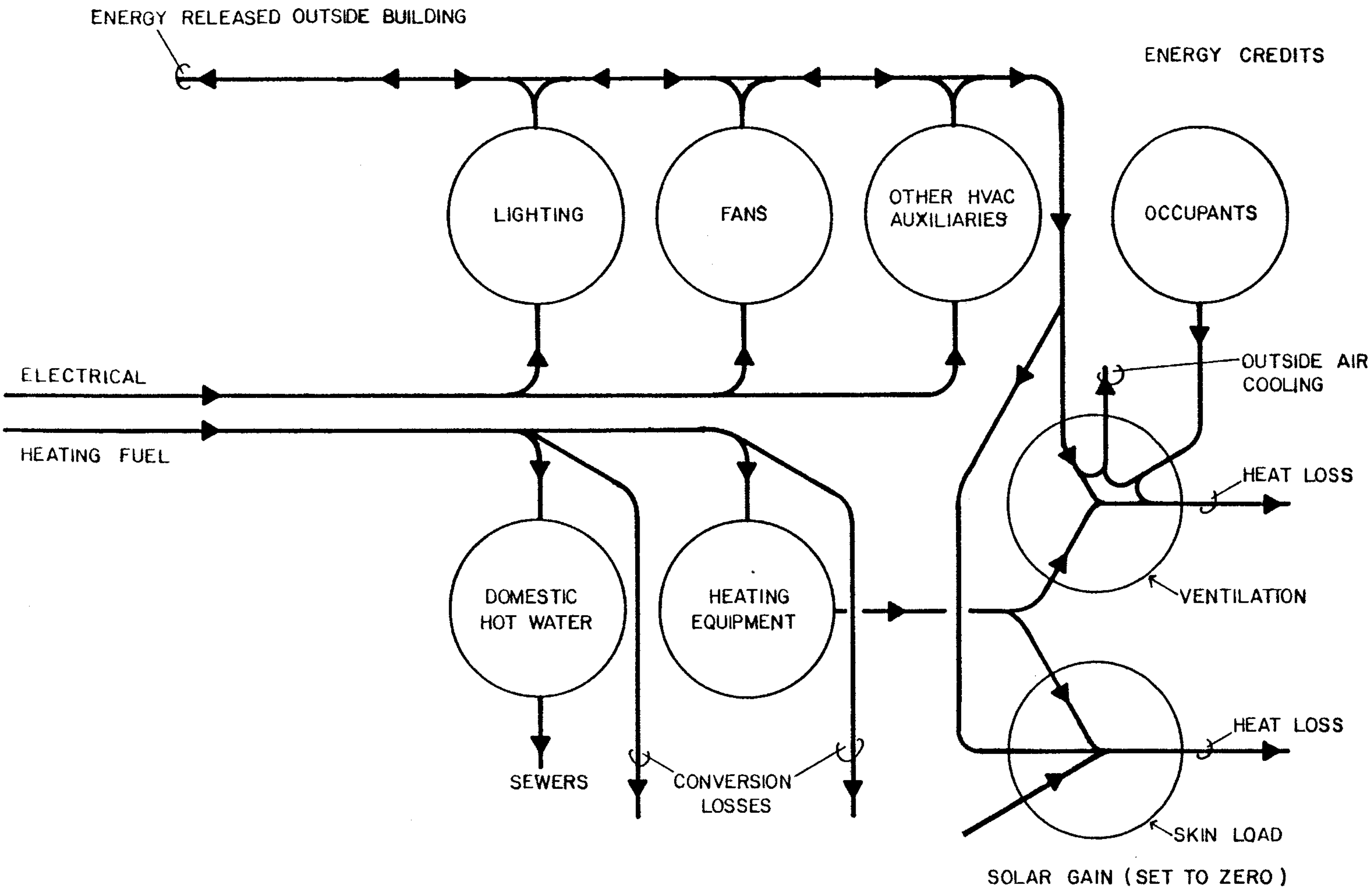


FIG. 10
BUILDING THERMAL MODEL

Amounts of energy for domestic hot water are computed based on a daily level of consumption using an average occupancy input parameter, and a 100 degree F temperature rise. No credits for interior building heat gain are allowed for losses from the hot water system.

The output from the thermal model is annual consumption amounts for heating oil and for electrical energy. Both energy quantities are in terms of BTU/Year. Annual energy consumptions of all design cases considered are presented in Appendix 5.

The model has been validated on several small institutional sized buildings with interior mechanical systems that match the complexity of the prototype building used in this study, with generally good correlation. Further a partial simulation check was accomplished with a program that considers daily transients in interior building energy flows (Reference 20). Good correlation results were obtained with the calculations, indicating that the steady state approach for thermal calculations yielded appropriate estimates of energy consumption.

## 4.8 METHODS OF ECONOMIC ANALYSIS

All costs associated with the ownership of the rural school, are modeled in the analysis and expressed in a bottom line cost parameter termed "uniform annual cost of operation". This parameter is a derived number that represents all ownership costs spread equally throughout the building life time in a single annual dollar "payment", or uniform annual amount. The various calculation procedures used for the study account for the time value of money. The equations used are standard textbook equations in common use with feasibility analyses (References 21 and 22). A building life time of thirty (30) years is assumed throughout the analysis. This parameter selection is highly subjective, and can be expected to be highly variable with location and circumstance. Life times of 50 to 70 years are certainly possible, however, the 30 year value has been selected as a conservative middle ground value.

A cost of money of 10.5% annual compounded rate is selected for this study, based on conversations with state of Alaska life cycle cost personnel (Reference 23). This amount relates to the bonding cost the state of Alaska faces, should it choose to obtain construction monies via a bond sale approach.

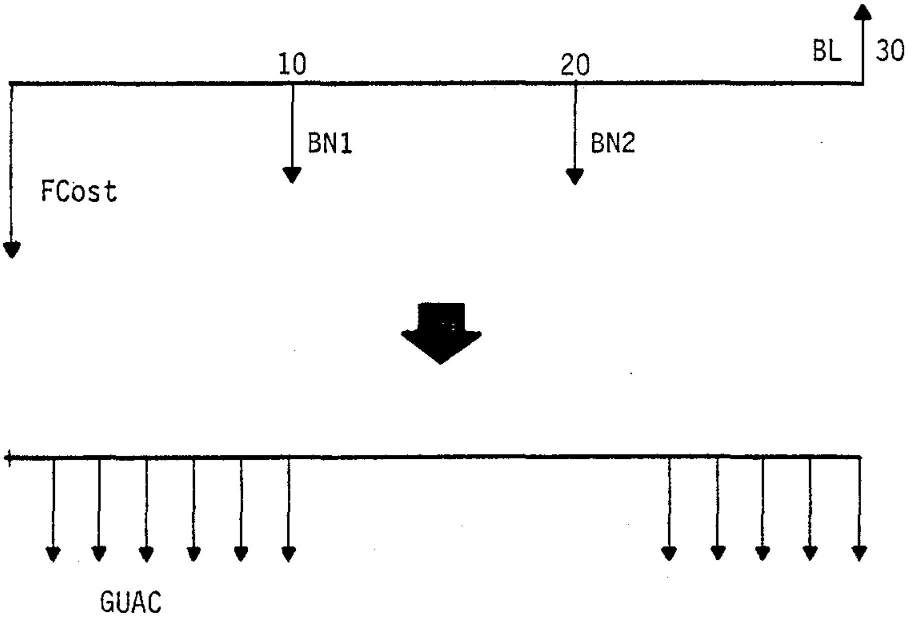
To facilitate an equitable comparison of the 256 design alternatives created in the comparison matrix, all costs were computed in the same manner throughout the analysis. Life cycle cost methodology parallels that in use in the government sector (References 24 through 25).

It should be noted that, even though the state does not need to sell bonds for financing this year, what is known as an opportunity investment rate does still exist. This rate of investment interest for the state is that rate of return the state could receive on its wealth should it choose to conservatively invest in bonds, instead of building buildings. Here the opportunity rate is taken as 10.5%, a conservative time value of money.

### 4.8.1 ANALYSIS OF FIRST COST AND RENOVATION COSTS

The first cost of construction, a single dollar value of cost burden assumed to accrue in the first year, is converted to a uniform annual cost. This work is accomplished for each of the three building energy systems. Similarly, renovation costs assumed to occur at years 10 and 20 and a end of life time salvage value are converted to uniform annual costs. As presented in Fig. 11 these costs are summed, and represent the capital expenditure portion of the life cycle cost analysis.

Note that for this phase of the study, the mid-life renovations, and end of life salvage values are set to zero, since inadequate data were available during the analysis phase.



MODEL EQUATION:

$$GUAC = PVC \left[ \frac{BIE/100 \, (1 + BIE/100)^{30}}{(1 + BIE/100)^{30} - 1} \right]$$

WHERE $PVC = (RENV\ 1 + RENV\ 2 + SALV + 1)\ F\ COST$

$$RENV\ 1 = \frac{BN1/100}{(1 + BIE)^{10}}$$

$$RENV\ 2 = \frac{BN2/100}{(1 + BIE)^{20}}$$

$$SALV = -\frac{BL/100}{(1 + BIE)^{30}}$$

Note: BN 1, BN 2, BL set at zero for this report phase.

BN 1 = % OF FCOST, RENOVATION 1 @ YR. 10
BN 2 = % OF FCOST, RENOVATION 2 @ YR. 20
BL = % OF FCOST, SALVAGE @ YR. 30

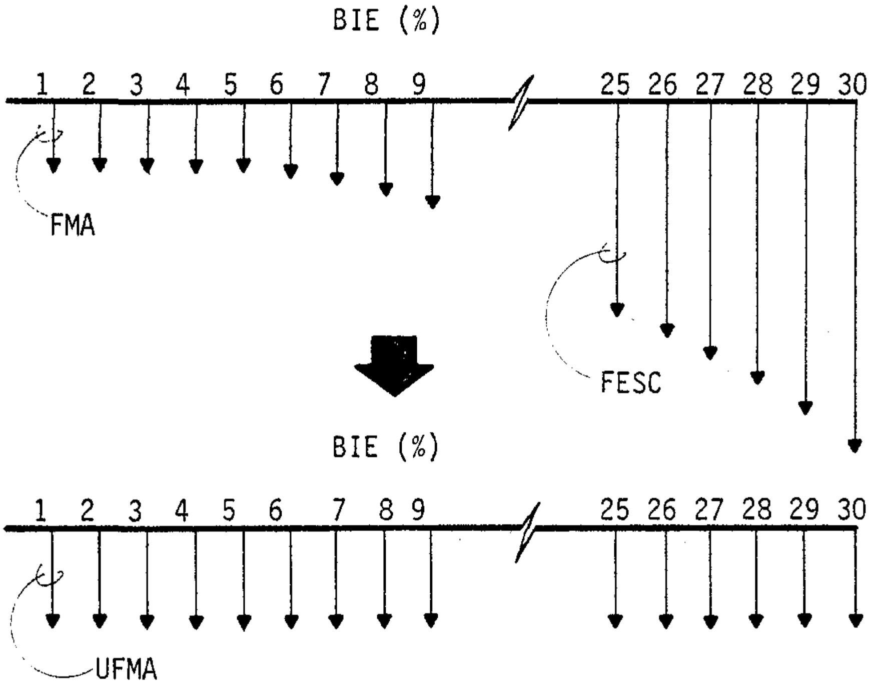
FIG. 11

CALCULATION PROCEDURE CAPITAL OUTLAYS

GUAC = EQUIVALENT UNIFORM ANNUAL COST OF CAPITALIZATION

### 4.8.2 ANALYSIS OF MAINTENANCE AND OPERATIONS COSTS

An assessment of maintenance and operations costs for the prototype building is made using yearly costs of maintenance for each of the three energy systems. These costs are assumed to accrue at a set annual amount for the first five years, and then at a compounded escalating rate thereafter. Fig. 12 presents the calculation procedure used in the analysis. As presented in Fig. 12, all life time costs are expressed as a uniform annual dollar amount.



MODEL EQUATION:

$$UFMA = \frac{(BIE/100)(1+BIE/100)^{30}}{(1+(BIE/100))^{30}-1}\left[(FMA)\frac{(1+(BIE/100))^{5}-1}{(BIE/100)(1+(BIE/100))^{5}}+\frac{FMA\,(PST)}{(1+(BIE/100))^{5}}\right]$$

WHERE $PST = \frac{(1+DSE)^{25}-1}{DSE\,(1+DSE)^{25}}$

$$DSE = \frac{1+(BIE/100)}{1+(FESC/100)} - 1$$

UFMA = Equivalent Uniform Annual M & O Cost
FMA = First year M & O cost ($/yr)
BIE = State of Alaska minimum acceptable rate of return (%)

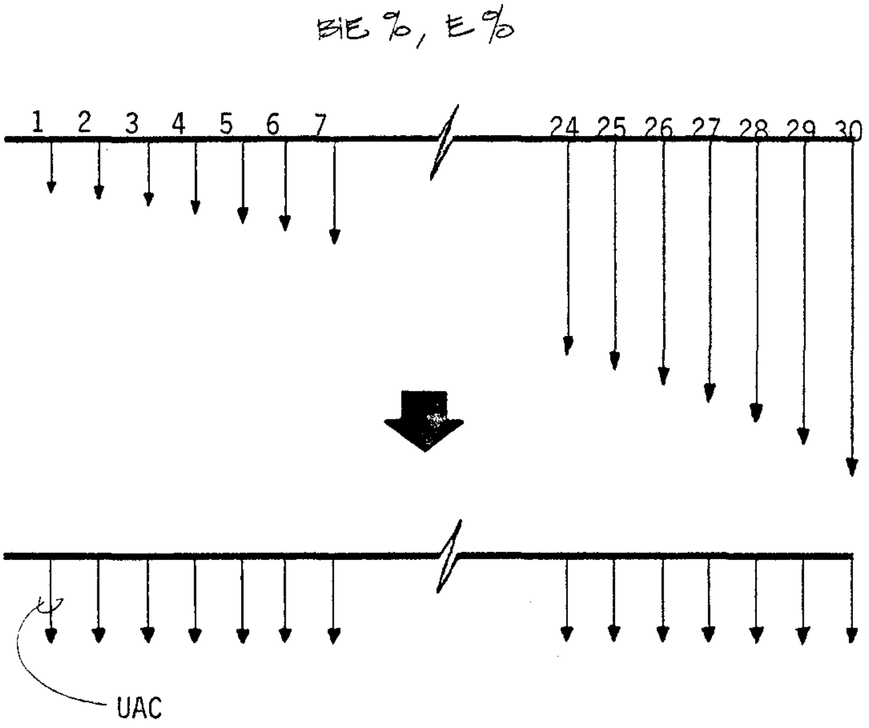
NOTE: FESC set at zero for this report phase

FIG. 12
CALCULATION PROCEDURE
MAINTENANCE AND OPERATIONS COSTS

### 4.8.3 ANALYSIS OF ANNUAL ENERGY CONSUMPTION

Energy expenses associated with the prototype building are treated as follows. Annual energy consumption for each of two fuels calculated by the thermal model are combined with fuel costs by region, using fuel cost indices discussed in Section 2, to arrive at present year fuel costs in dollars per year.

These values for each fuel are then assumed to escalate at a compounded yearly escalation rate to the building's end of life time. As presented in Fig. 13, these assumed life costs are reduced to a single uniform annual amount that expresses life cycle cost.



MODEL EQUATIONS :

$$UAC = (P)(EA)(APT)$$

WHERE $P = \dfrac{(1+DIA)^{30} - 1}{DIA(1+DIA)^{30}}$ $\qquad DIA = \dfrac{1+BIE/100}{1+E/100} - 1$

$$EA = \frac{(BIE/100)(1+BIE/100)^{30}}{(1+BIE/100)^{30} - 1}$$

$$APT = (TFUEL)(AP)(ECIDX)$$

UAC = UNIFORM ANNUAL COSTS FOR FUEL
BIE = STATE OF ALASKA'S MINIMUM ACCEPTABLE RATE OF RETURN (%)
E = COMPOUNDED ANNUAL FUEL ESCALATION RATE (%)
TFUEL = ANNUAL PRESENT YEAR CONSUMPTION OF FUEL (BTU/YR)
AP = BASELINE COST OF FUEL IN ANCHORAGE
ECIDX = FUEL COST INDEX FOR COST REGION (NO UNITS)

FIG. 13
CALCULATION PROCEDURE ENERGY COSTS

## 4.9 LCC COMPUTER MODEL "MAINDEV"

The 256 case LCC simulation was accomplished using an inhouse developed program, written in Fortran IV, and run on the University of Alaska's Honeywell Computer.

This program consists of a simplified annual energy analysis, and an engineering economy analysis to calculate costs associated with operation of the building. The thermal model assumes that each prototype building is heated with fuel oil, and powered by electrical energy obtained from a local utility. Total life cycle costs of each building case are expressed in terms of a uniform annual cost in present value dollars.

Fig. 14 gives a simplified flow chart for the program. A program listing is included in Appendix 3 . The output from the program is six sixteen by sixteen matrices. An input data set that compiles all building systems data is used for the program. This set consists of an integrated system of environmental, economic, and building system data necessary to run the program. Appendix 4 presents a listing of all input variables and their descriptions.

The life cycle cost program models costs associated with the building, breaking costs into three components, as defined in discussion of the

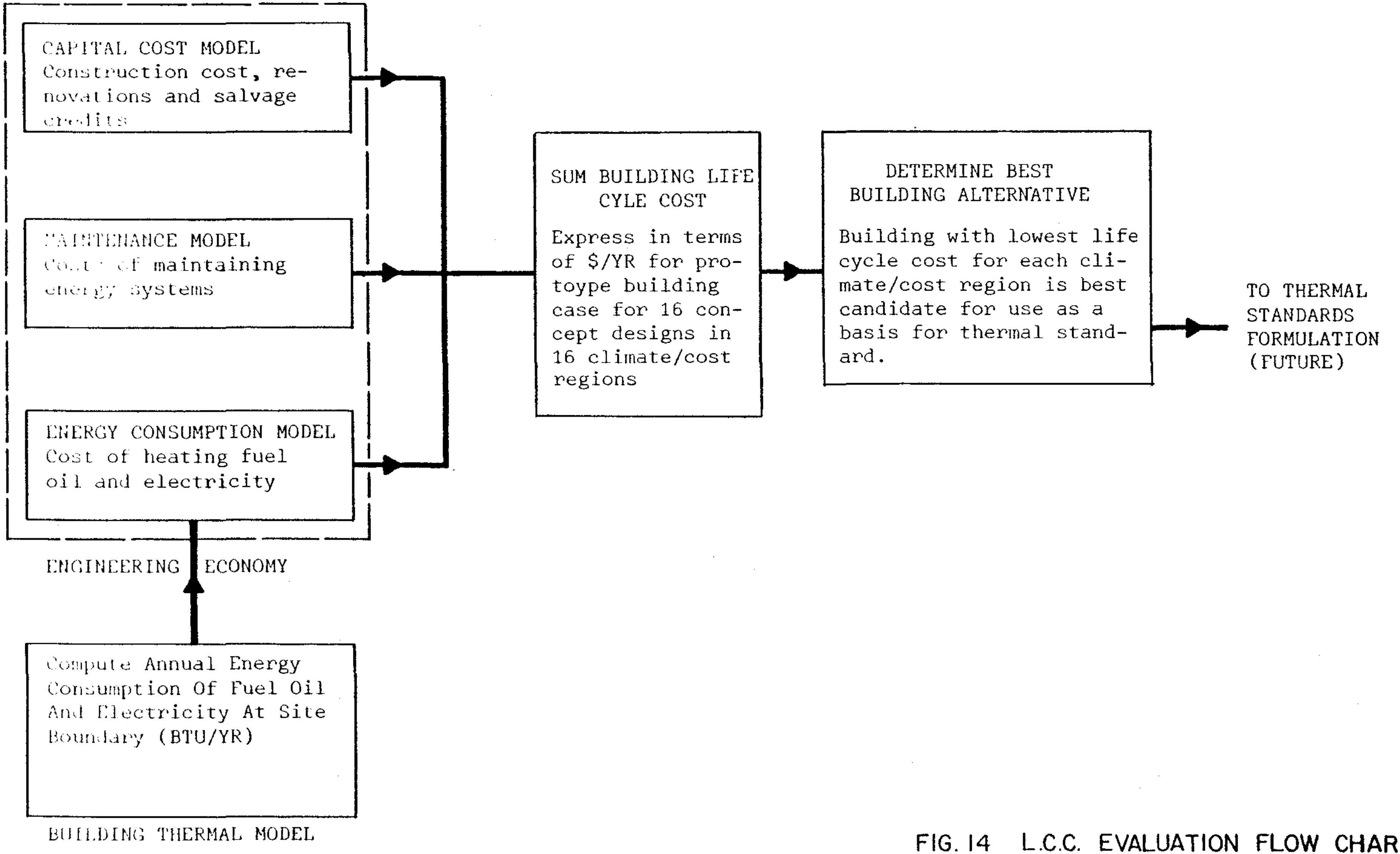


FIG. 14 L.C.C. EVALUATION FLOW CHART

analysis method and as presented in Fig. 14. Costs are expressed in terms of uniform annual amounts (dollars) for each component of life cycle cost. Calculation equations for the mathematic manipulations required to convert the various costs that occur throughout a building's life time to uniform annual amounts are included in Section 4.8. The output from the program is expressed in terms of dollars per square foot of building space, and is presented in Appendix 6 in four separate formats, as follows:

| | |
|---|---|
| Annual Heating Fuel Use | Million BTU/YR |
| Annual Electrical Use | Million BTU/YR |
| Annual Energy Cost | Dollars/SQ.FT. - YR |
| Annual Cost Of Capitalization | Dollars/SQ.FT. - YR |
| Annual Cost Of Maintenance | Dollars/SQ.FT. - YR |
| Total Building Life Cycle Cost | Dollars/SQ.FT. - YR |

## 5.0 ANALYSIS OF RESULTS

The thermal modeling process used in the analysis has created some 256 different design alternatives, and a detailed breakdown of annual energy consumptions and life cycle costs for each of the design alternatives. The task addressed in this section is the presentation of analysis results to allow optimum design alternatives to be selected.

Output data produced by the computer model are presented in raw computer program output in Appendices 5 and 6 , Figures 15 through 46, and further summarized on Table 13.

### 5.1 Description of Life Cycle Cost Model Results

Three separate computer runs are used as a basis for analysis results. The three life cycle cost matrices have been generated by running the analysis program "MAIN" with three sets of fuel escalation rates as indicated below.

Thirty two plots (Fiures 15 through 46), have been formulated to show the relationship between three major analysis variables as follows:

- Level of envelope thermal construction
- Interior energy system design
- Total annual life cycle cost

Each graph presents life cycle costs for all building concept designs within a given cost region. The horizontal axis of each graph expresses envelope stringency in terms of the total summed UA product (overall thermal conductance factor x component area) for the prototype building. Since areas of each envelope component are held constant in the analysis, this parameter reflects the aggregate thermal conductivity for the prototype building, in units of BTU/Hr-°F, and thus directly reflects thermal construction level.

The vertical axis expresses total life cycle cost in units of uniform annual cost per year. This parameter is the sum of all life cycle costs associated with the building, including costs of construction, maintenance, operations, and energy. Each cost component is expressed in terms of a uniform annual payment each year the building is in existance.

On each graph are a family of curves representing four design configurations for interior mechanical and electrical systems. The four design configurations represent all possible combinations of two levels of construction for mechanical systems, and two levels of construction for electrical systems.

By presenting the analysis results in this graphical format it is possible to easily select the architectural, mechanical and electrical construction that results in least life cycle cost, i.e. the optimum design solution.

Figures 14 through 30 are design optimization graphs for an optimistic profile of future energy cost escalations, while Figures 31 through 46 are the same graphs for a pessimistic profile of fuel escalation. These graphs are based on two of the three computer runs that form the basis of the study.

| | Annually Compounded Fuel Escalation Rate | | |
|---|---|---|---|
| Economic Assumption | Heating Fuel (%) | Electricity (%) | Appendix |
| Optimistic | 8 | 8 | 6A |
| Pessimistic | 12 | 12 | 6B |
| Present Year | 0 | 0 | 6C |

These different runs serve to offer the range of optimum design solutions for two bounding economic scenarios, with the zero fuel escalation rate run presenting component life cycle costs in terms of present year dollars.

The optimistic scenario represents a future path for price hikes that would approximate the long term inflation rate, while the pessimistic scenario is based on a long term escalation rate that considerably exceeds annual dollar inflation.

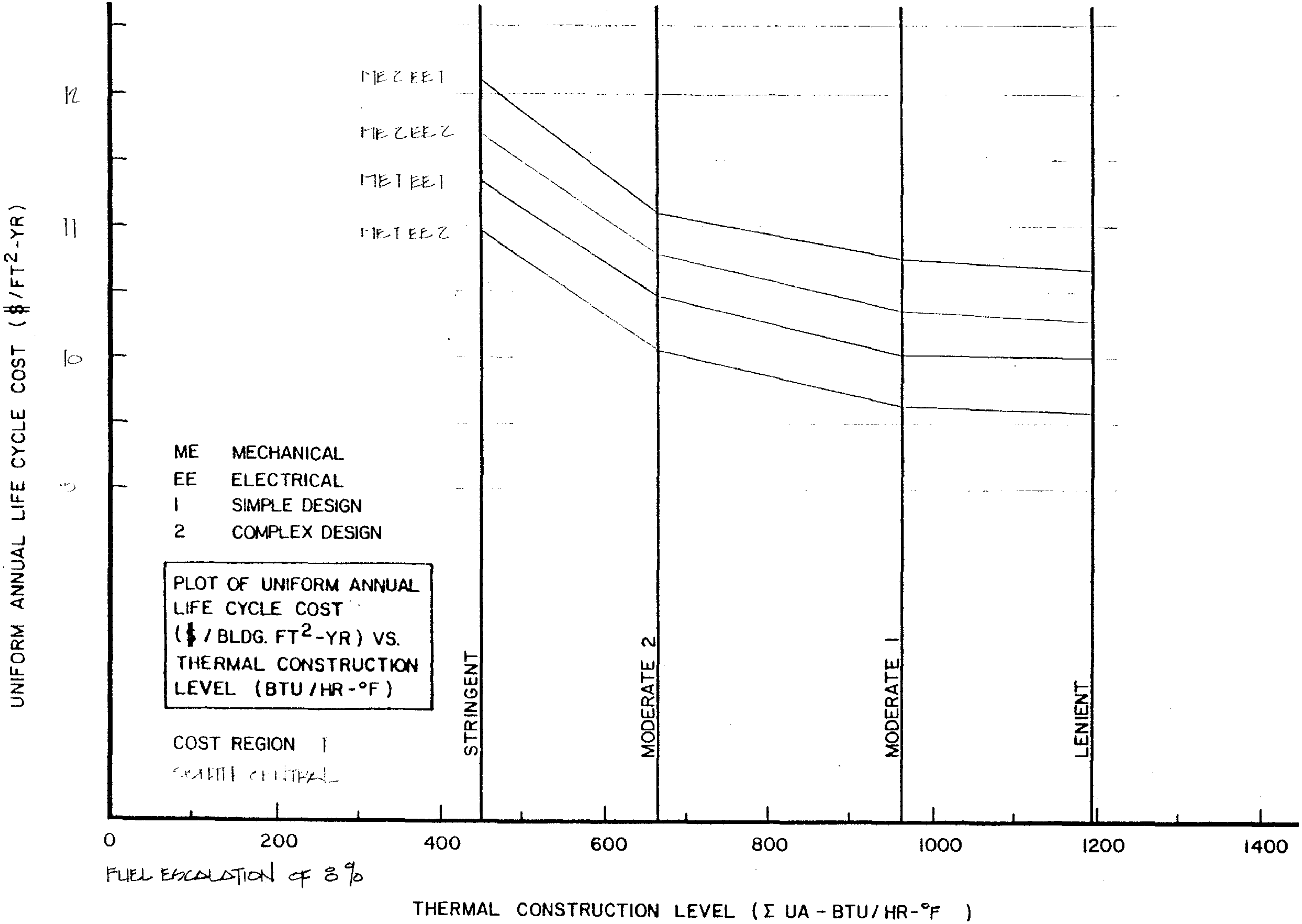

ME 2 EE 1
ME 2 EE 2
ME 1 EE 1
ME 1 EE 2
12
11
10
9
UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 1
SOUTH CENTRAL
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F )

FIG. 15

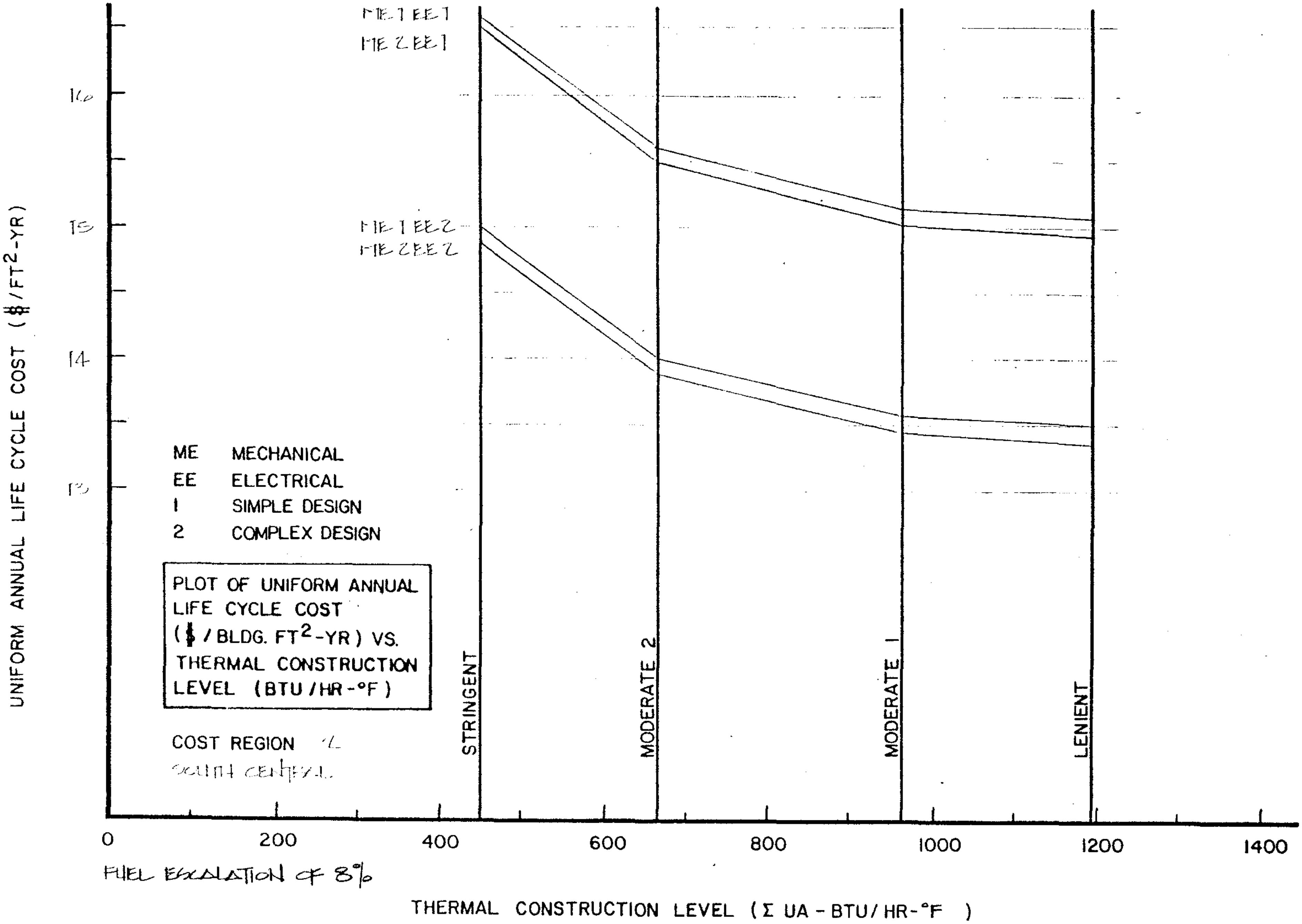
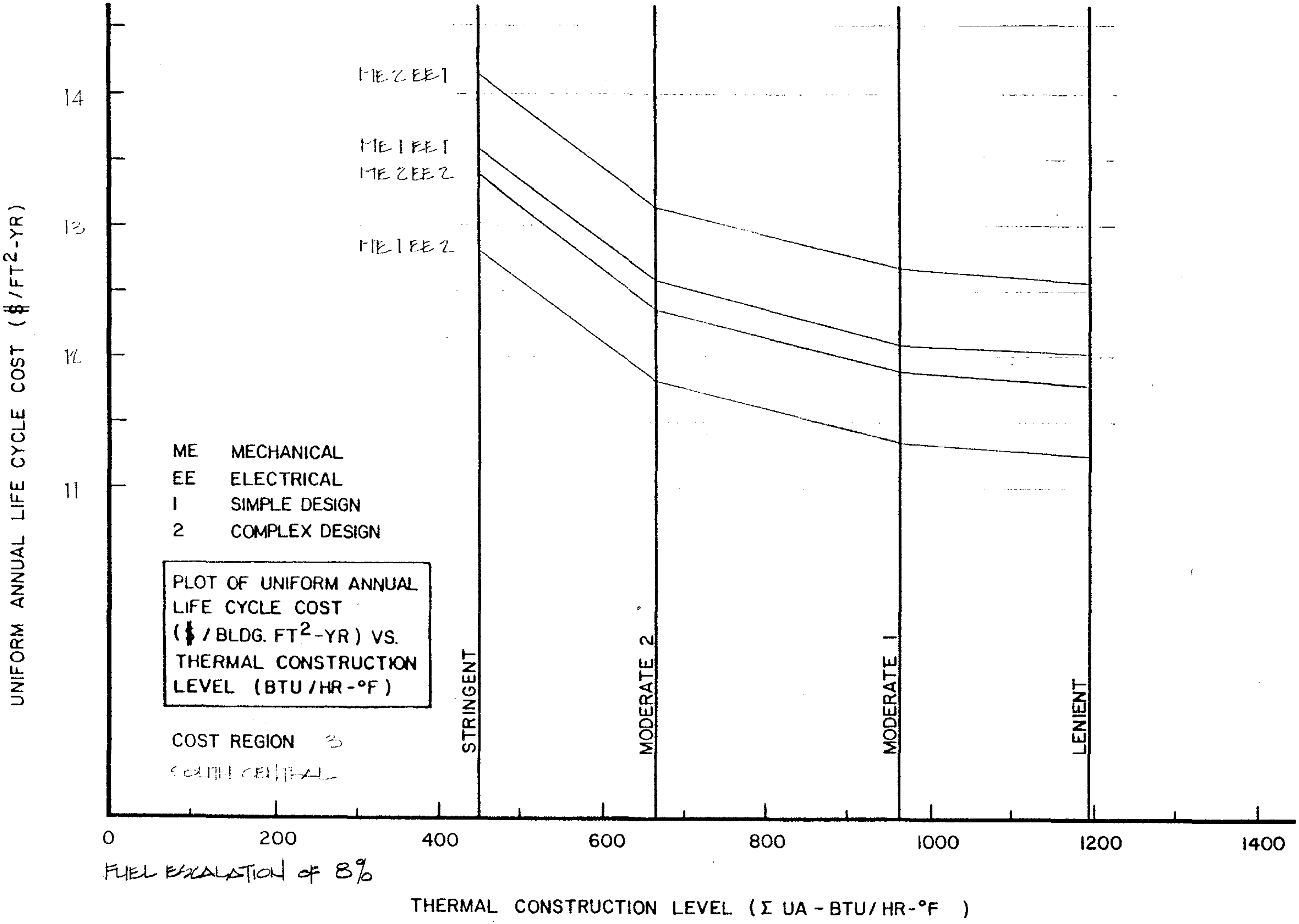

ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
16
15
14
13
UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($/BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)
COST REGION 4
SOUTH CENTRAL
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F)

FIG. 16



FUEL ESCALATION OF 8%

Fig. 17

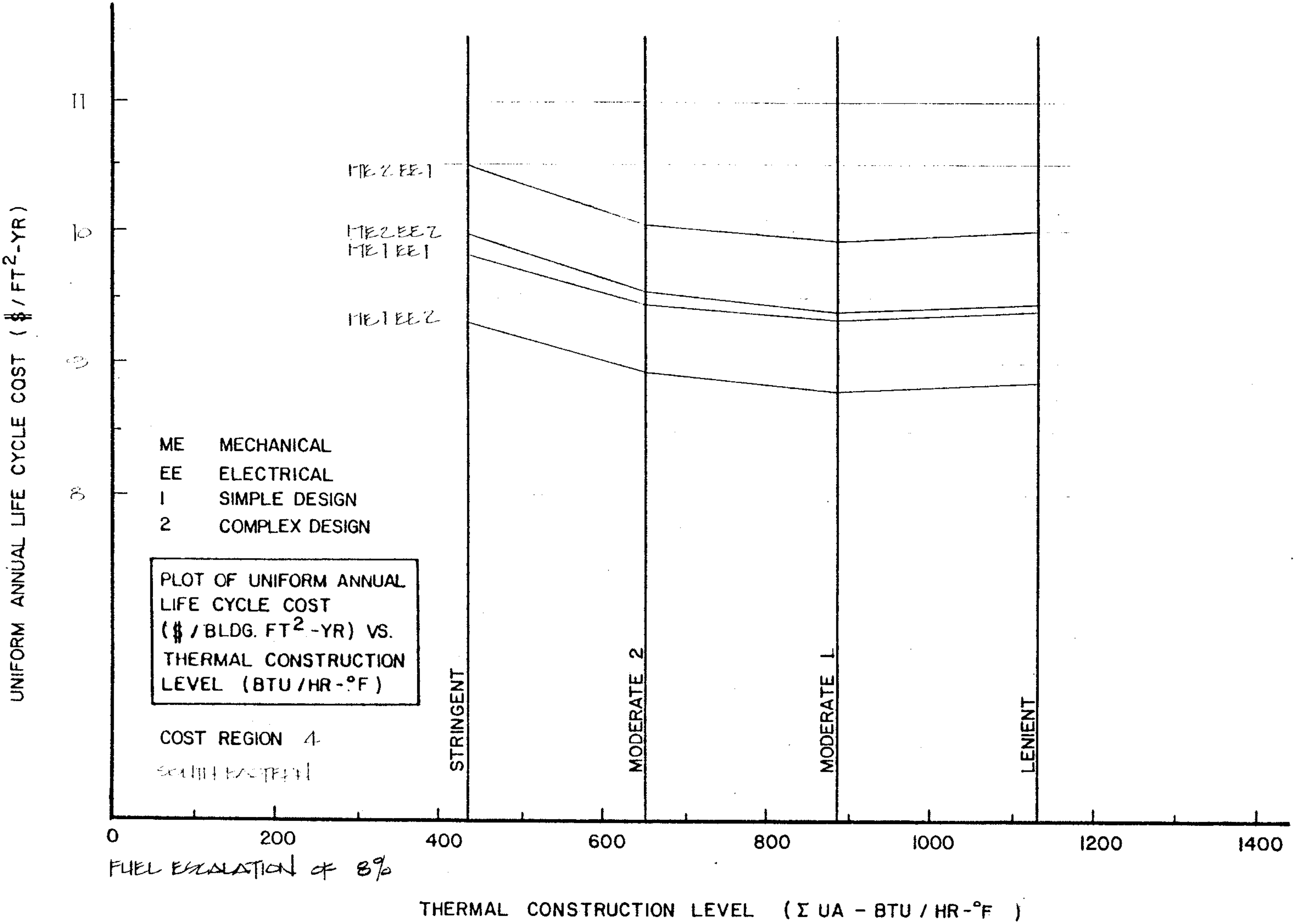

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
11
10
9
8
ME2EE1
ME2EE2
ME1EE1
ME1EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 4
SOUTH EASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR-°F)

FIG. 18

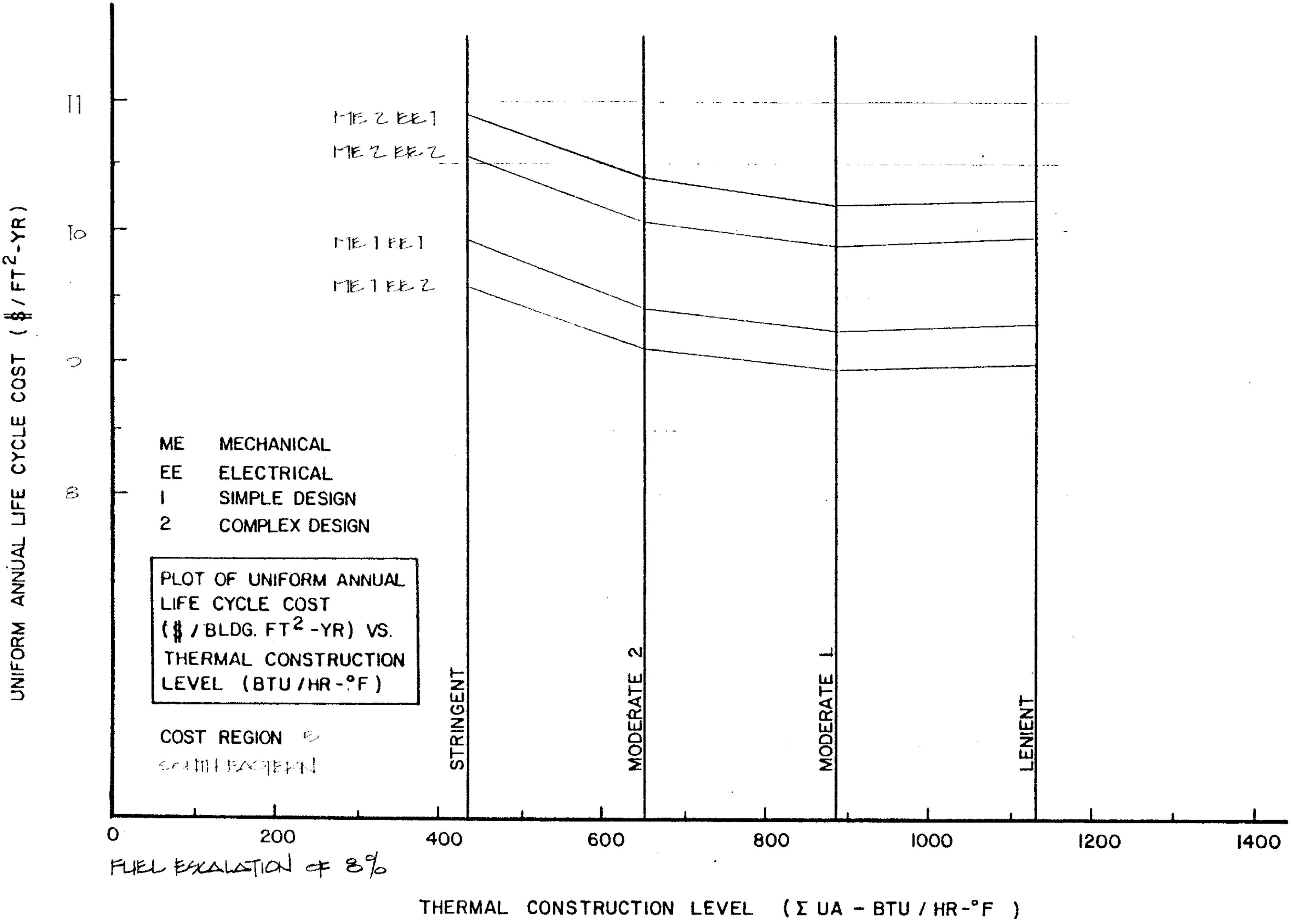

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
11
10
9
8
ME 2 EE 1
ME 2 EE 2
ME 1 EE 1
ME 1 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 5
SOUTHEASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 19

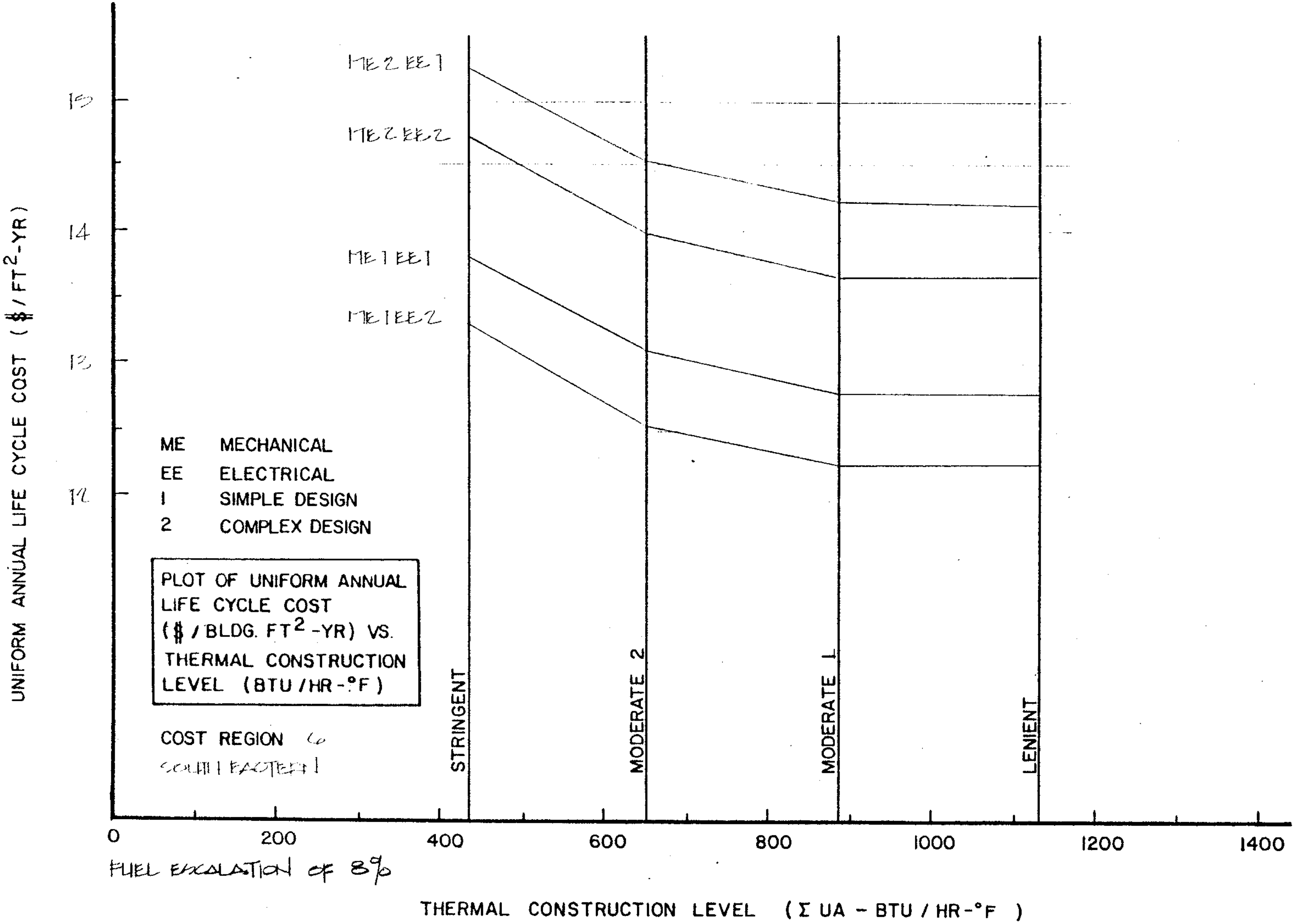

ME2 EE1
ME2 EE2
ME1 EE1
ME1 EE2
15
14
13
12
UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($/BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)
COST REGION 6
SOUTH EASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F)

FIG. 20

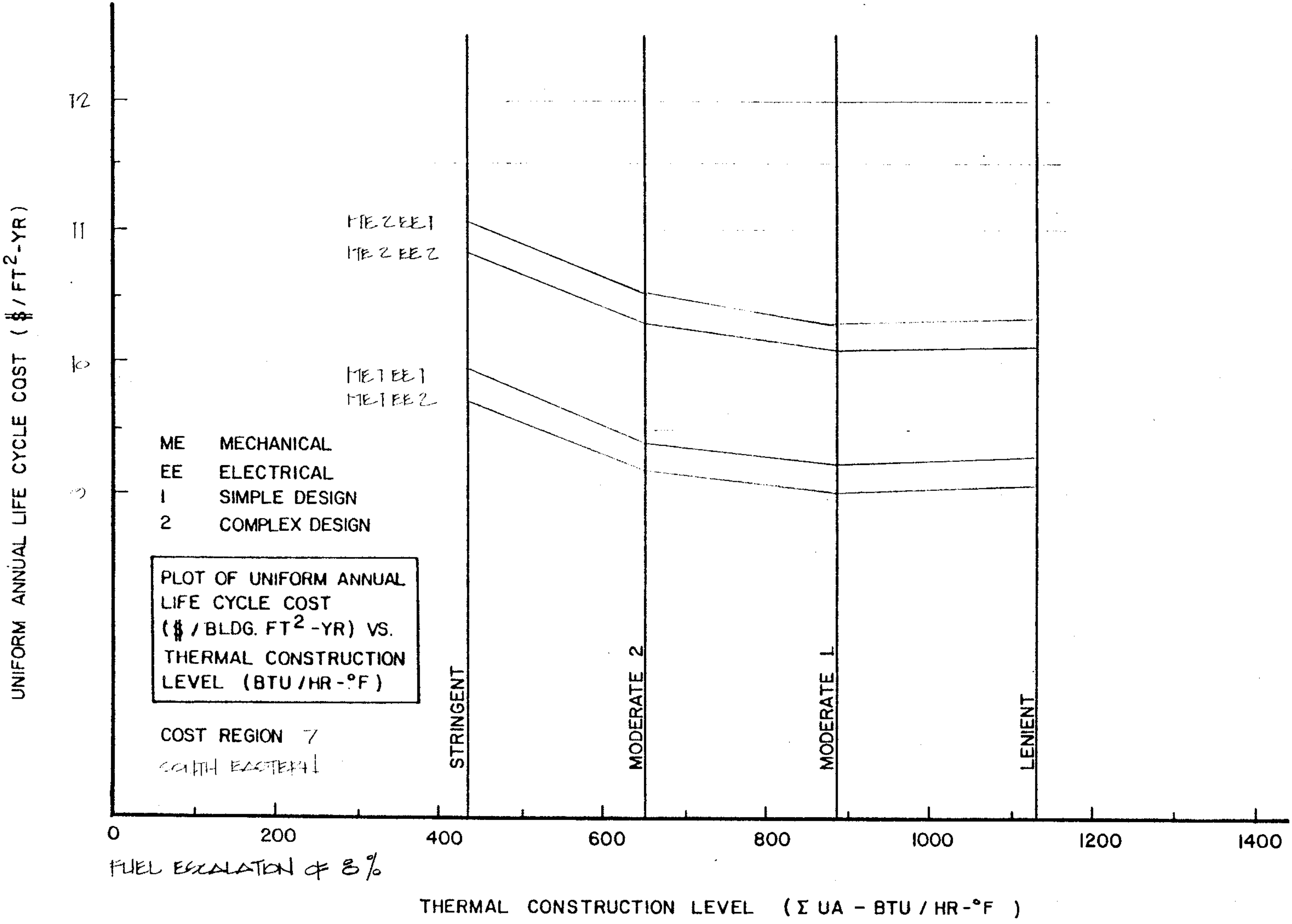

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT² - YR)
12
11
10
9
ME 2 EE 1
ME 2 EE 2
ME 1 EE 1
ME 1 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT² - YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 7
SOUTH EASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION @ 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 21

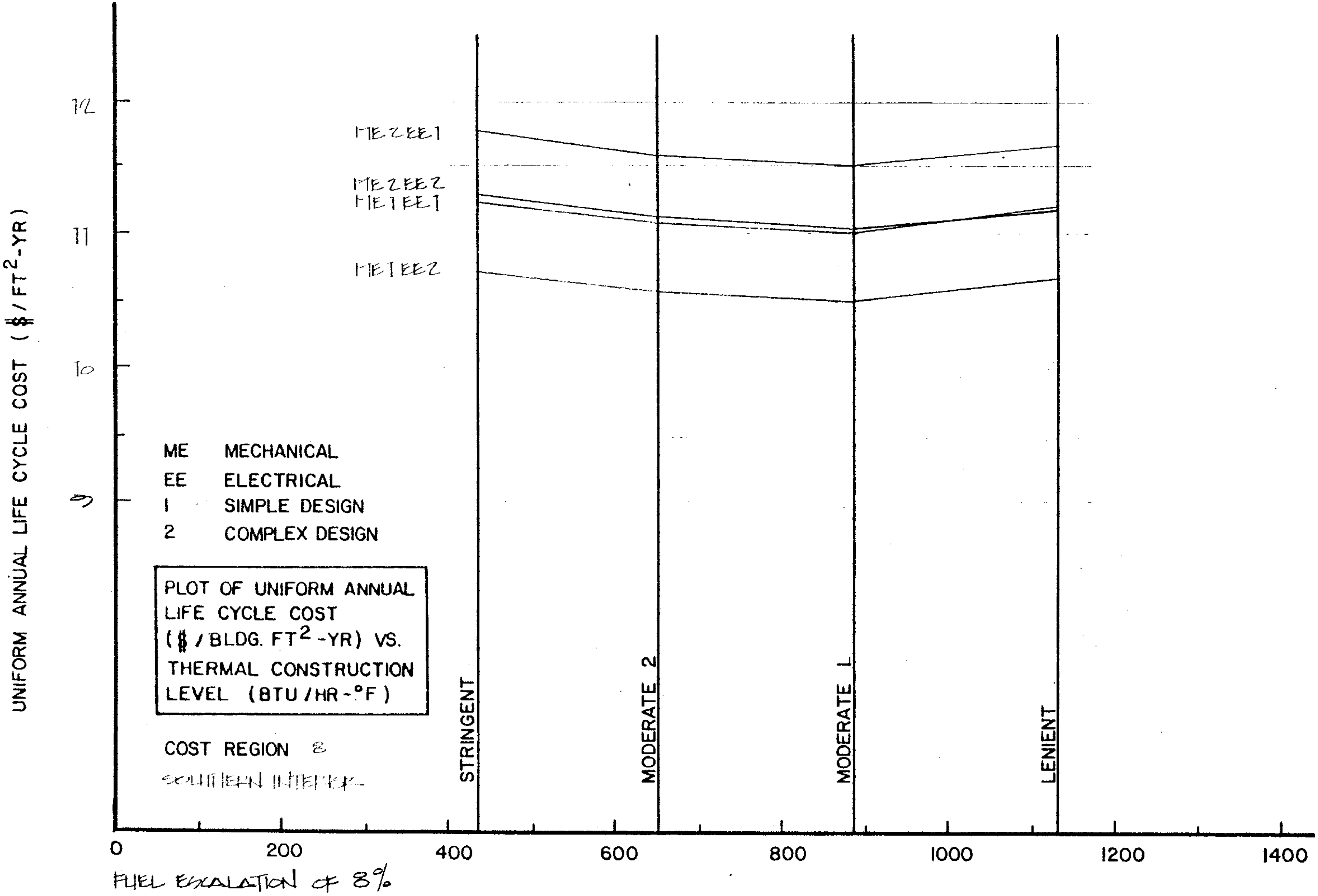
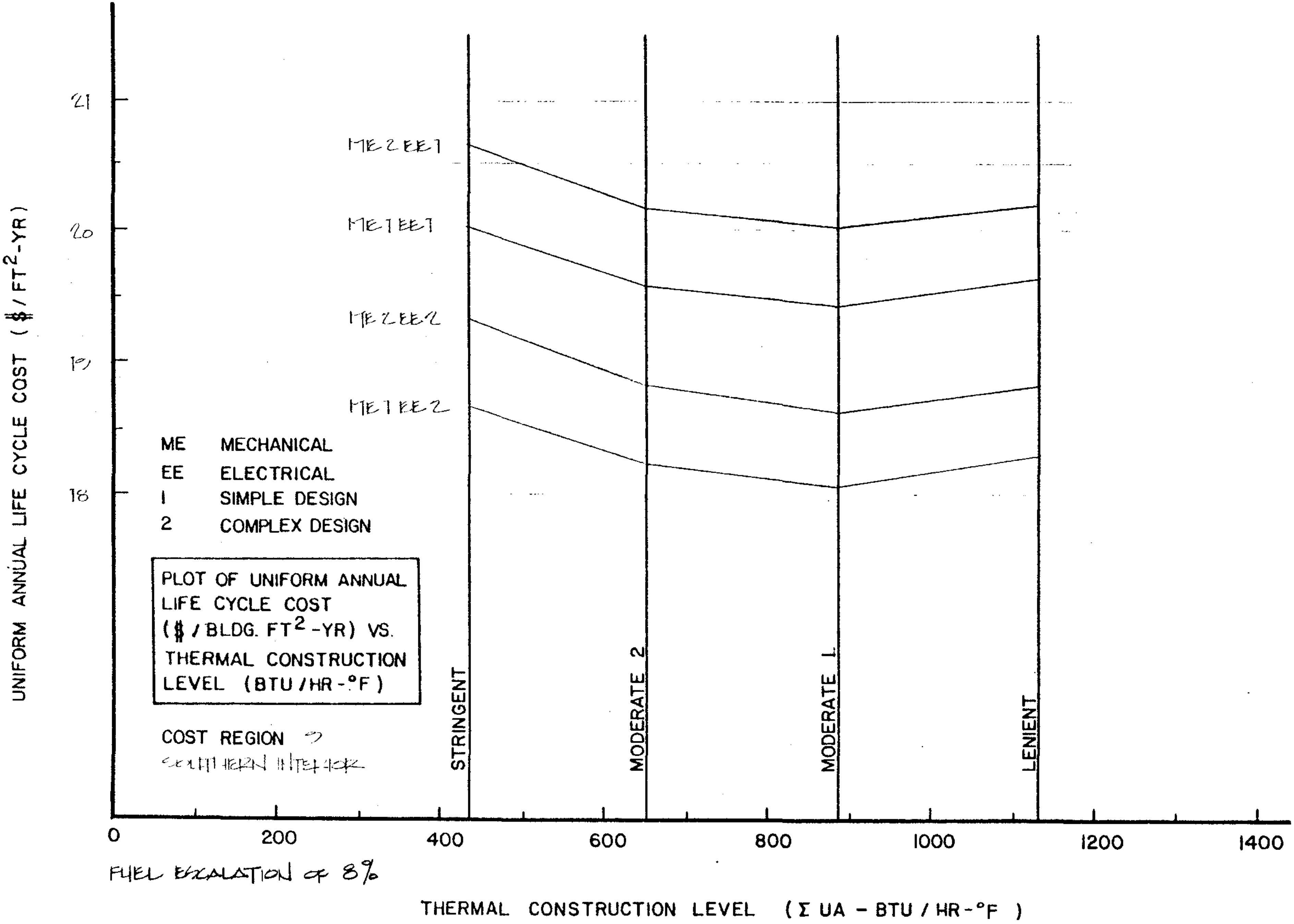

12
11
10
9
MEZEE1
MEZEE2
MEIEE1
MEIEE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 8
SOUTHERN INTERIOR
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 22



PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F )

COST REGION 7
SOUTHERN INTERIOR

FUEL ESCALATION OF 8%

FIG. 23

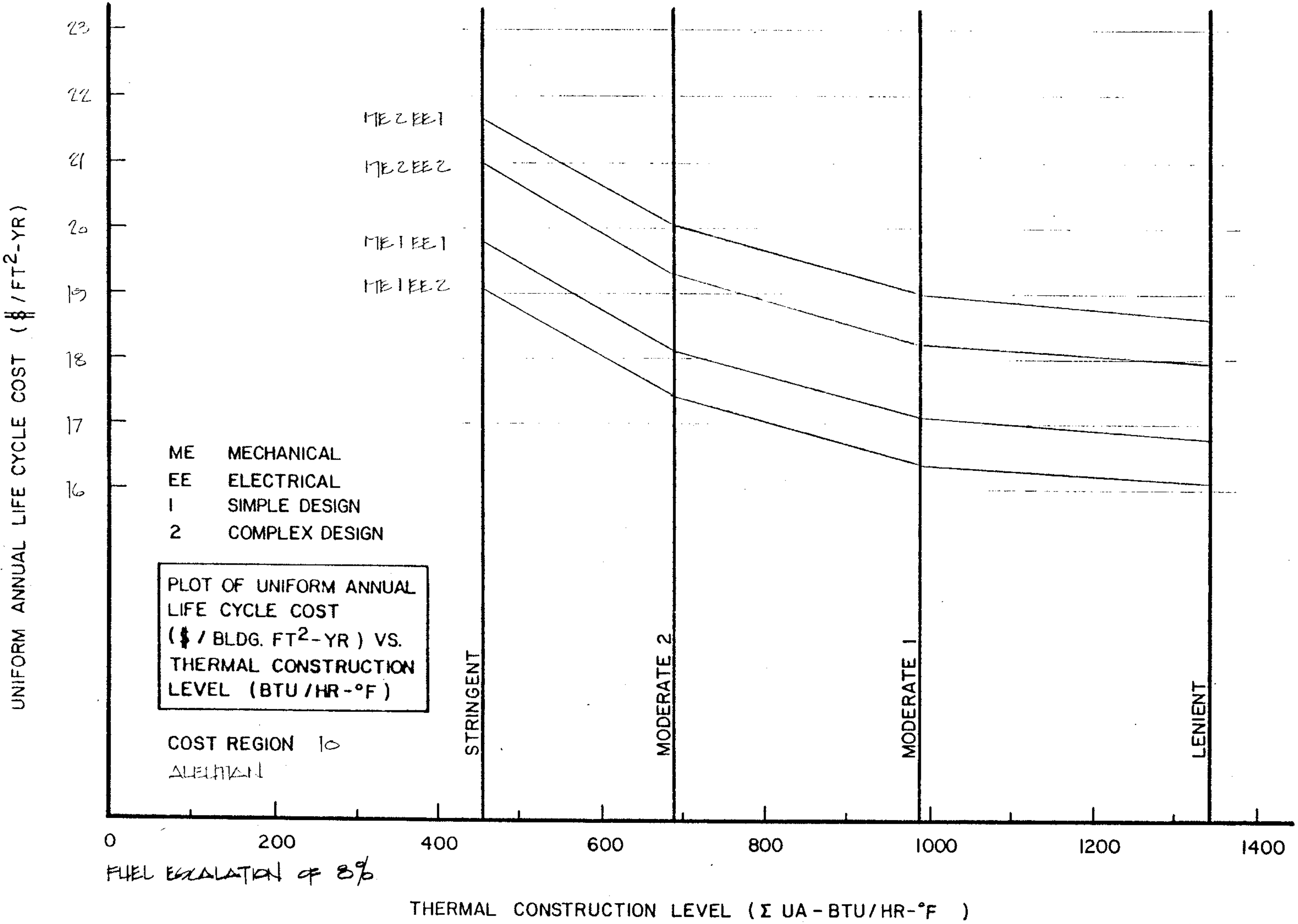
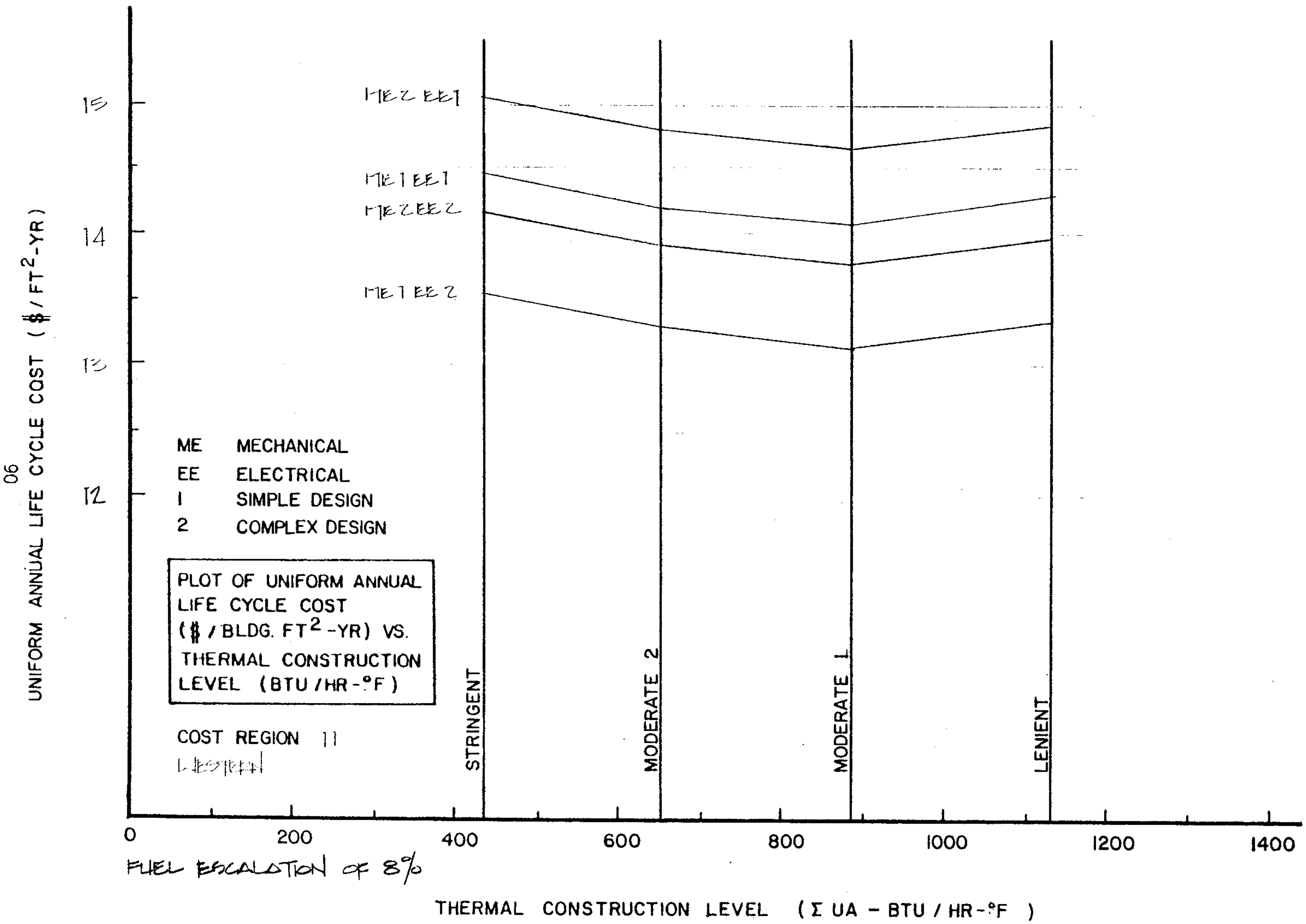

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT² - YR)
23
22
21
20
19
18
17
16
ME2EE1
ME2EE2
ME1EE1
ME1EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT²-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 10
ALEUTIAN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F )

FIG. 24



FUEL ESCALATION OF 8%

FIG. 25

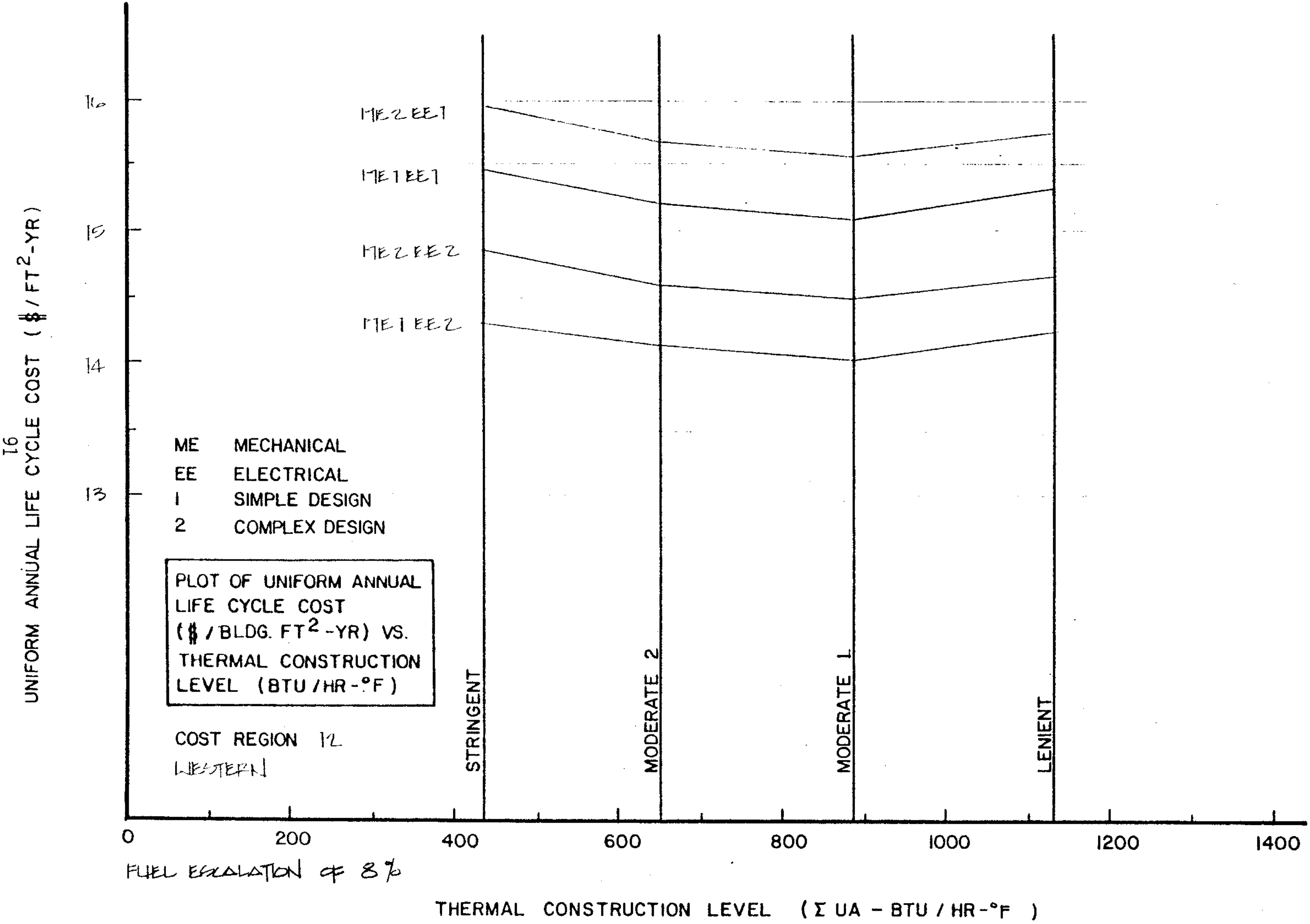

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
16
16
15
14
13
ME2EE1
ME1EE1
ME2EE2
ME1EE2
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 12
WESTERN
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR-°F )

FIG. 26

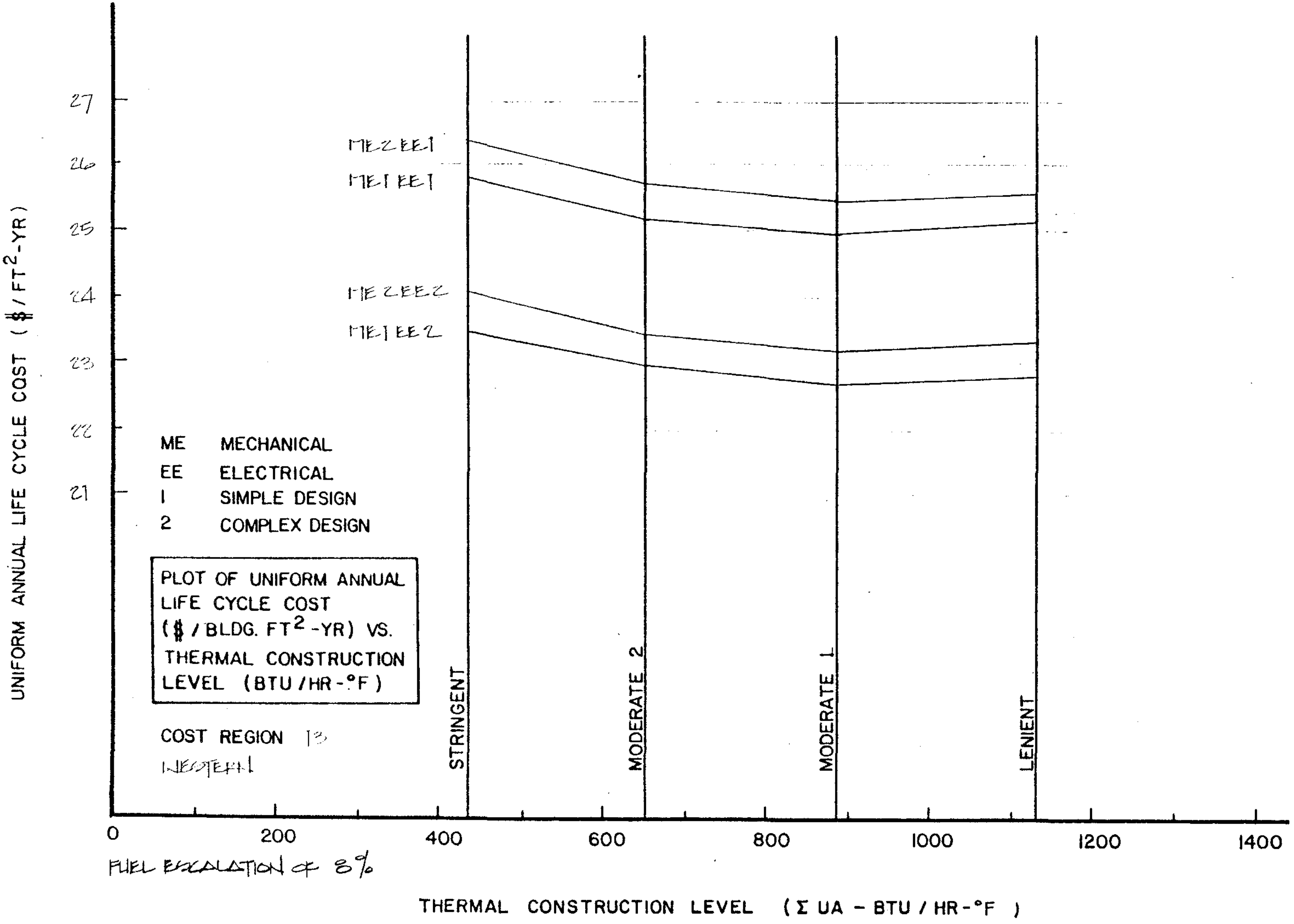

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
27
26
25
24
23
22
21
ME2EE1
ME1EE1
ME2EE2
ME1EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 13
WESTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR-°F)

FIG. 27

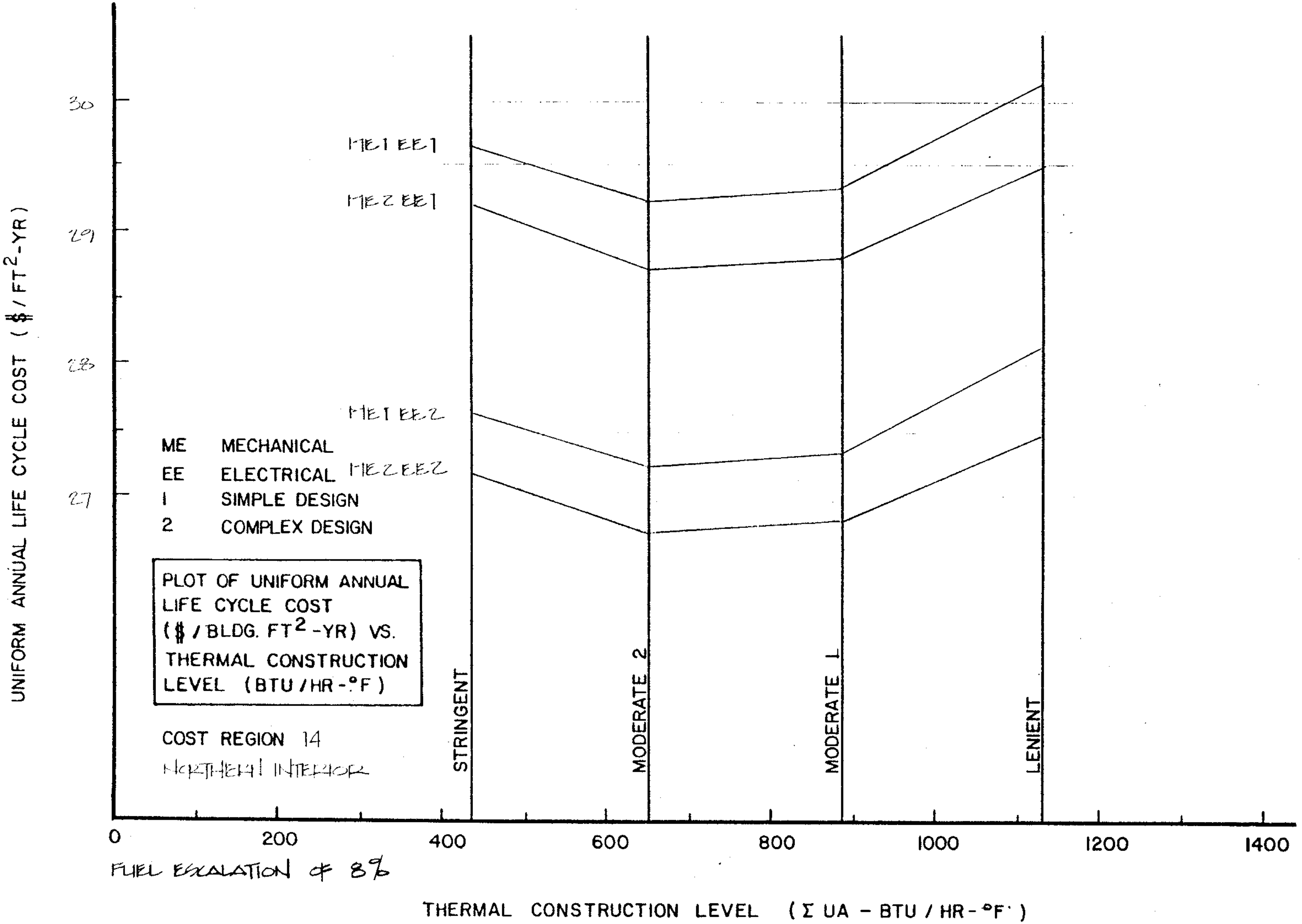

UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
30
29
28
27
ME1 EE1
ME2 EE1
ME1 EE2
ME2 EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($/BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)
COST REGION 14
NORTHERN INTERIOR
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F)

FIG. 28

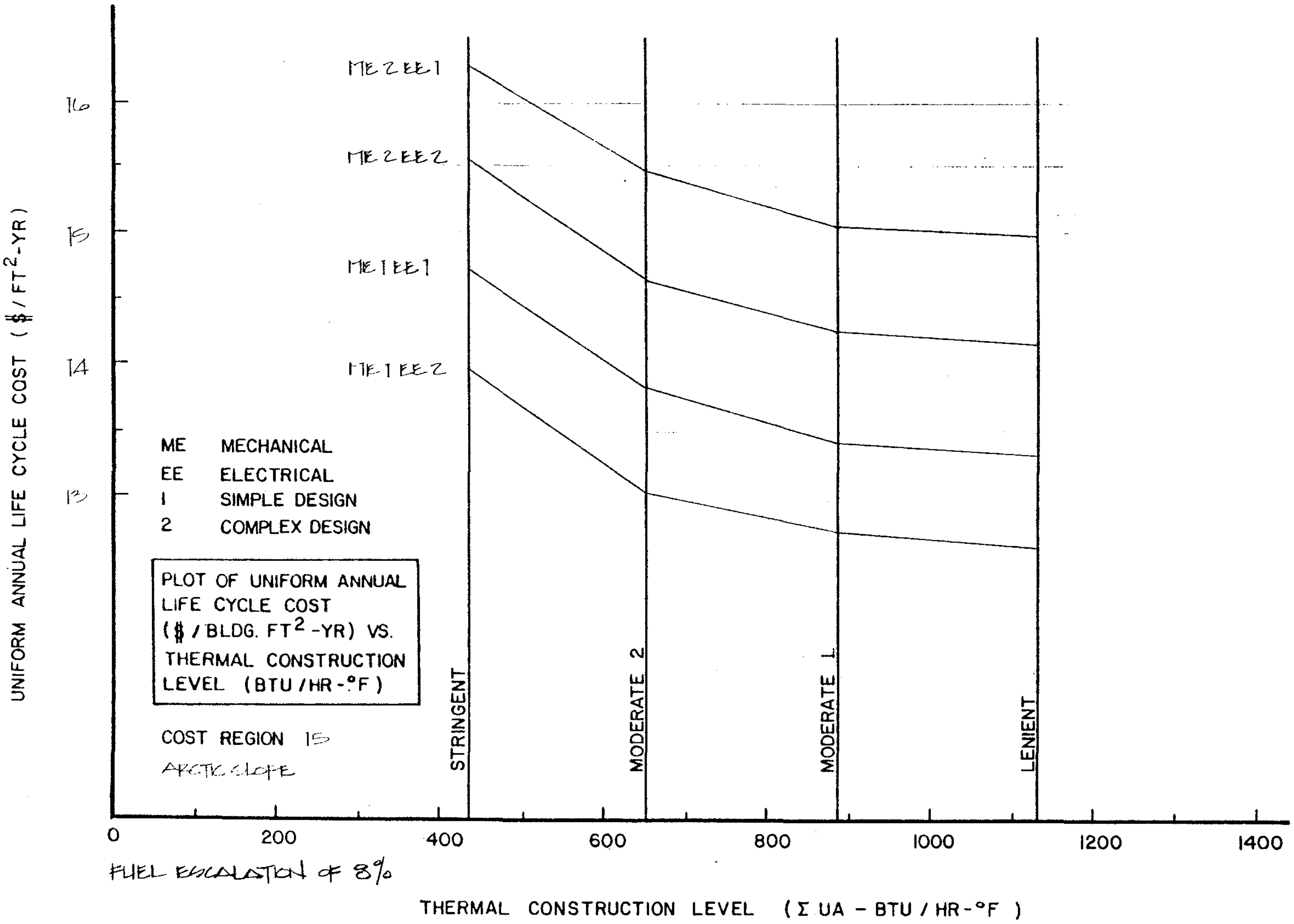
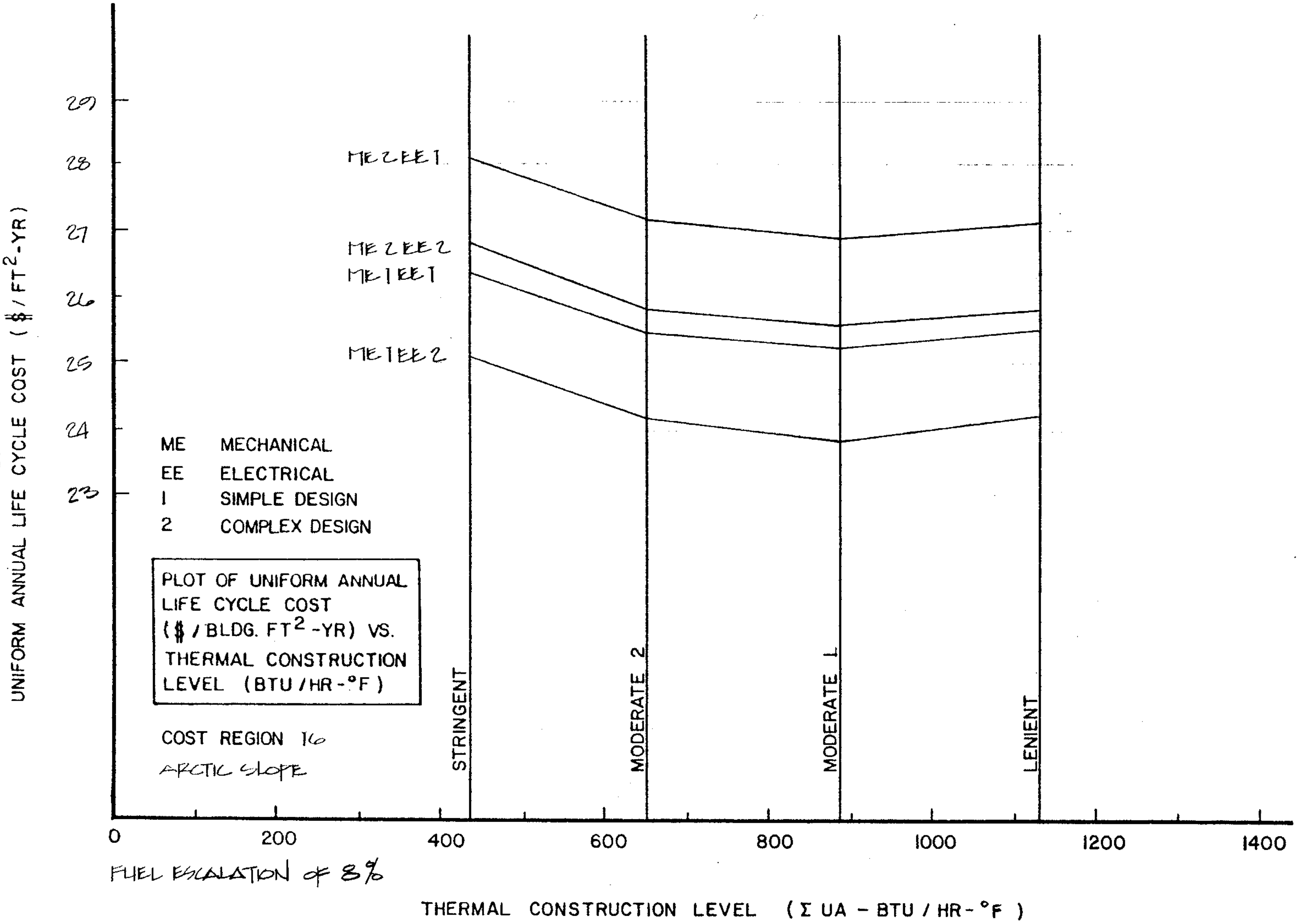

ME2EE1
ME2EE2
ME1EE1
ME1EE2
16
15
14
13
UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 15
ARCTIC SLOPE
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR-°F)

FIG. 29



29
28
27
26
25
24
23
UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$ -YR)
ME2EE1
ME2EE2
ME1EE1
ME1EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 16
ARCTIC SLOPE
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 8%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 30

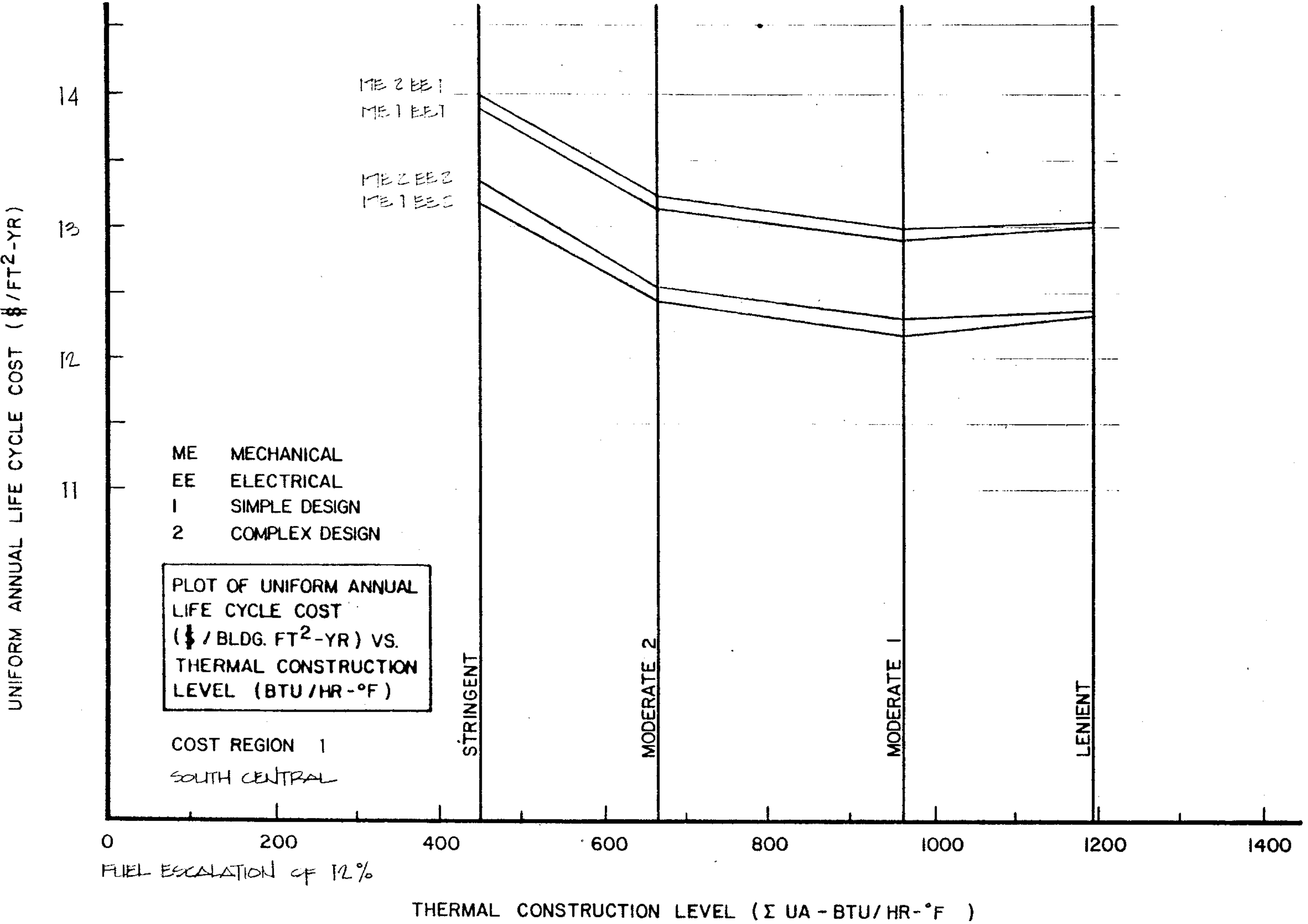

UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
14
13
12
11
ME 2 EE 1
ME 1 EE 1
ME 2 EE 2
ME 1 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 1
SOUTH CENTRAL
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 31

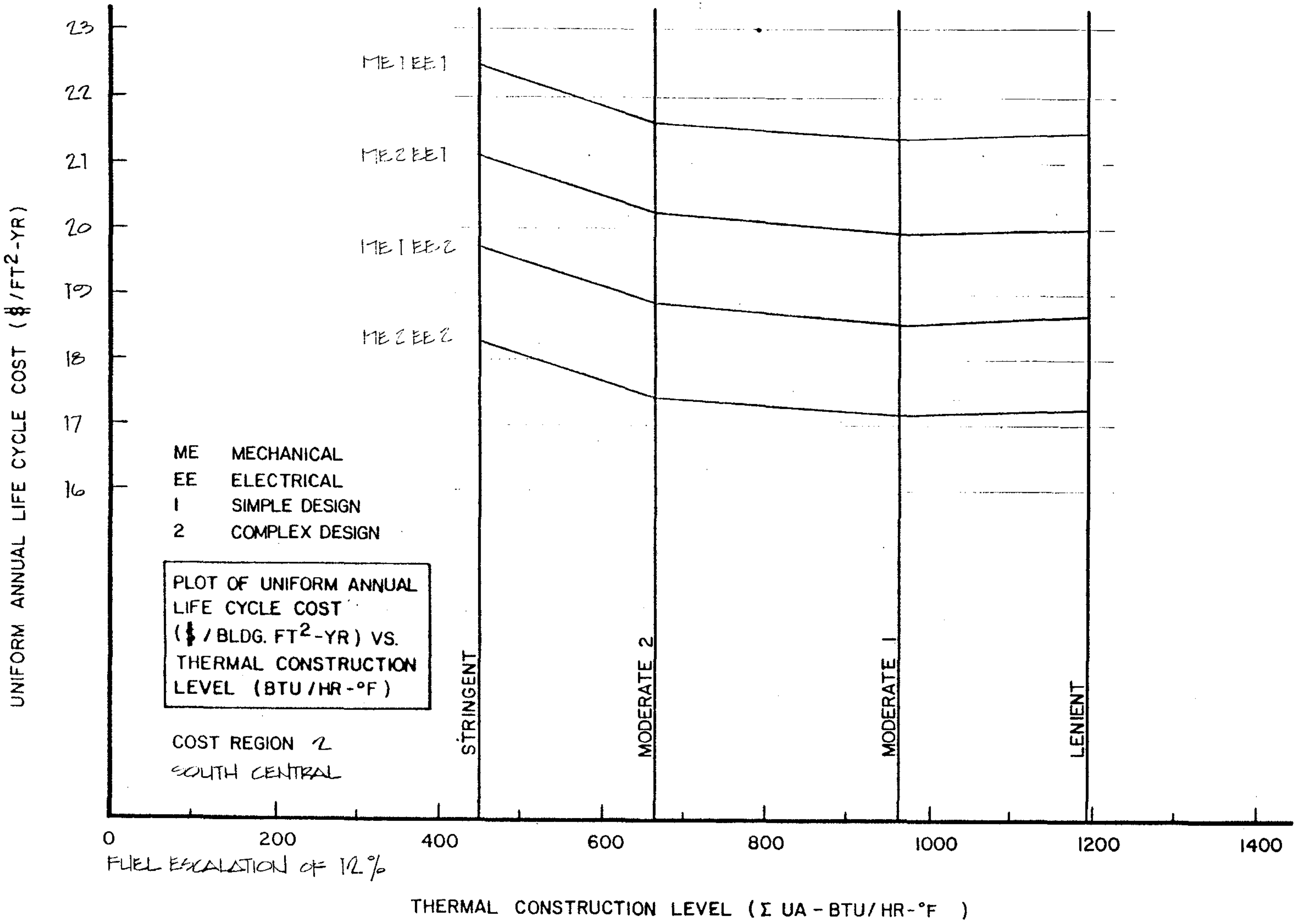

UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
23
22
21
20
19
18
17
16
ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 2
SOUTH CENTRAL
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/ HR - °F )

FIG. 32

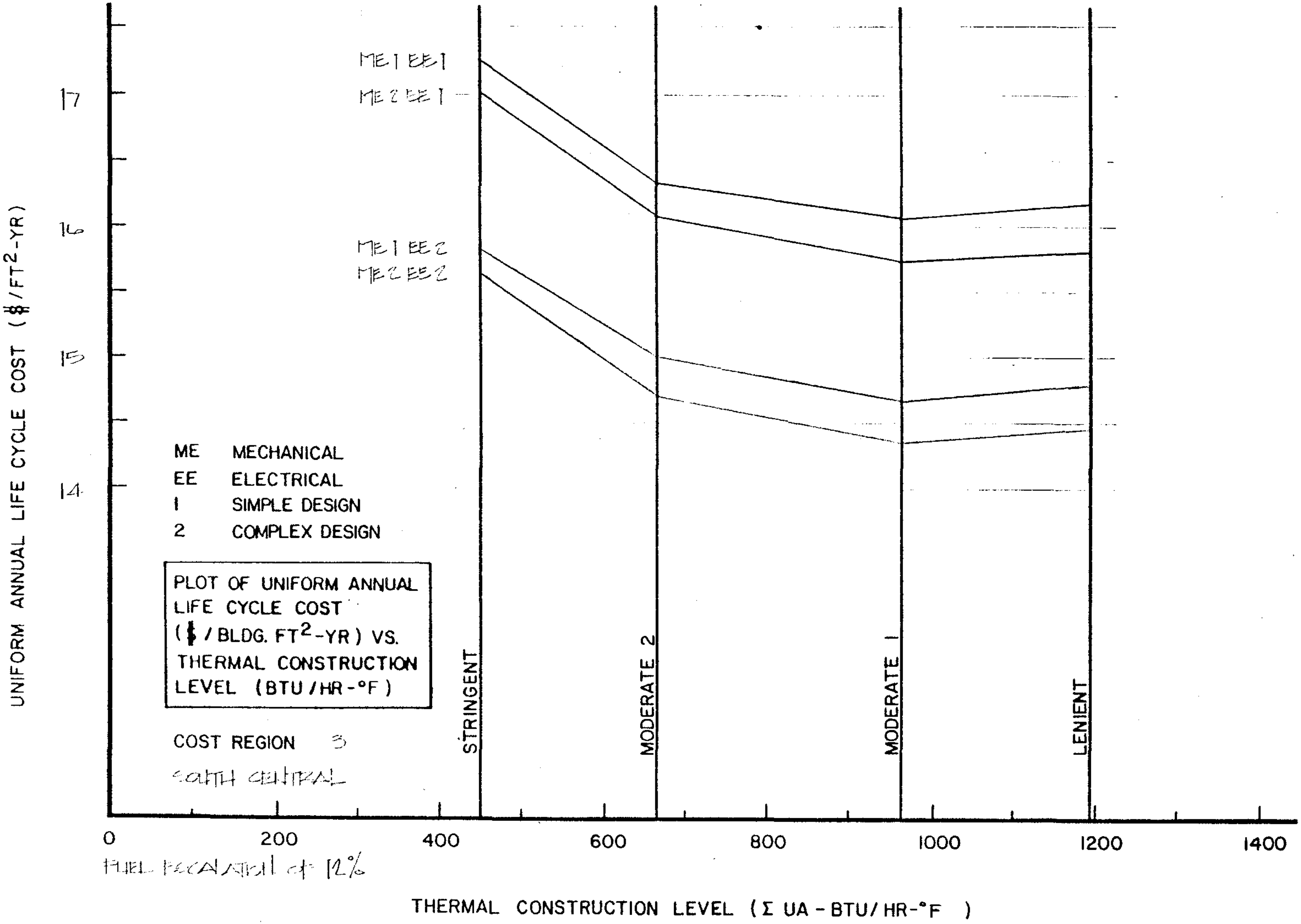

UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
17
16
15
14
ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($/BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)
COST REGION 3
SOUTH CENTRAL
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F )

Fig. 33

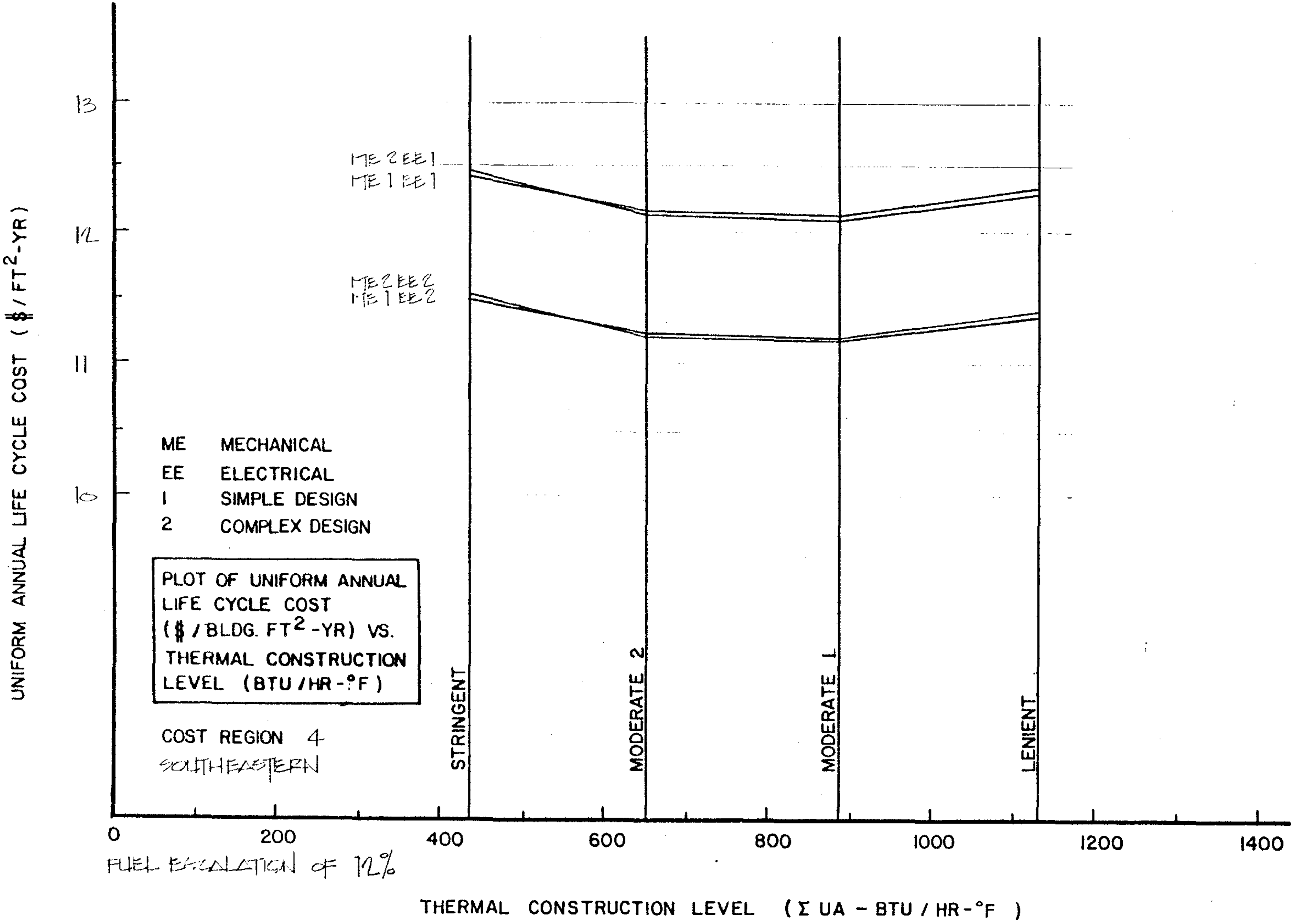

13
12
11
10
ME 2 EE 1
ME 1 EE 1
ME 2 EE 2
ME 1 EE 2
UNIFORM ANNUAL LIFE CYCLE COST ($ / FT² - YR)
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT² - YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 4
SOUTHEASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 34

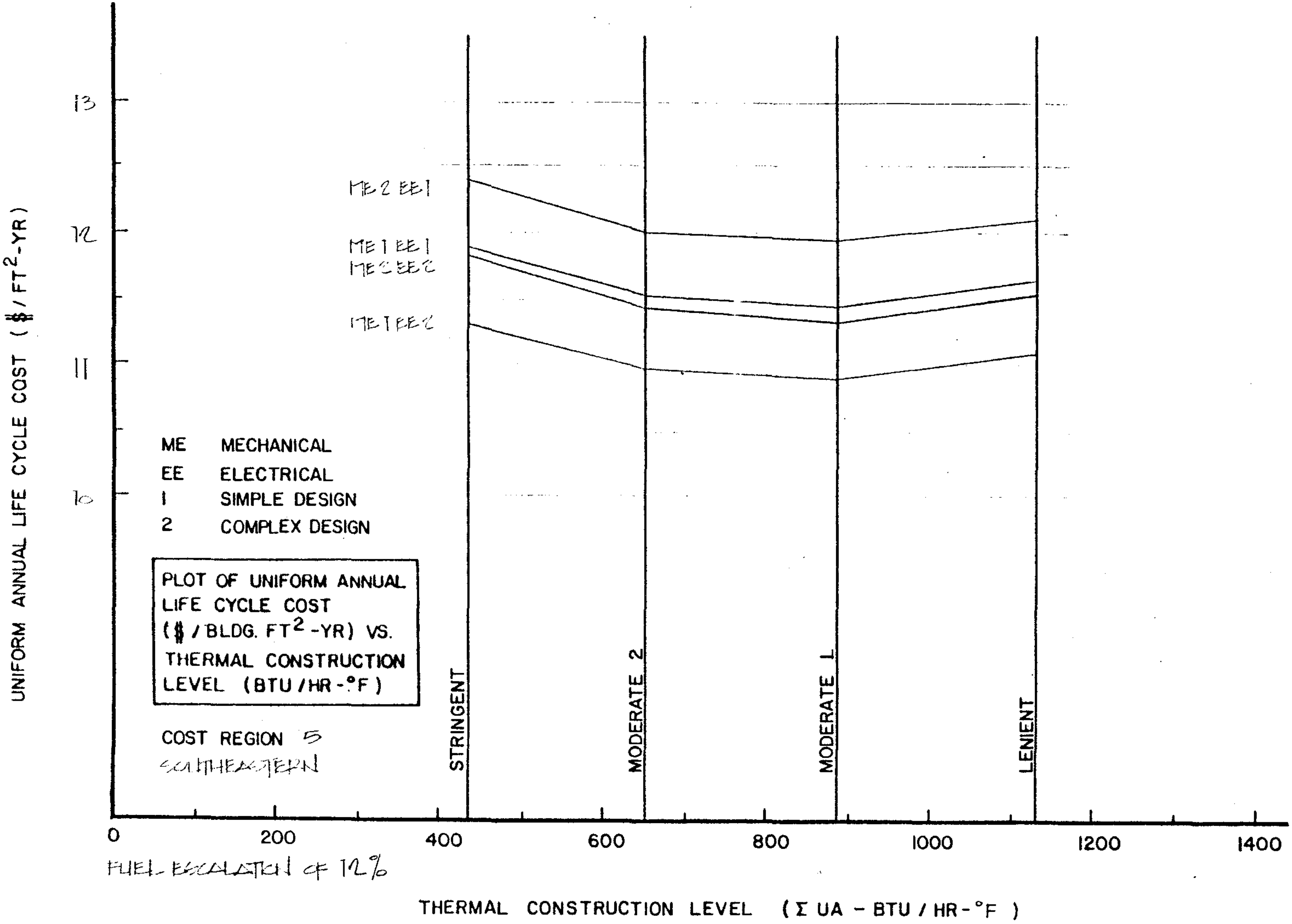

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
13
12
11
10
ME 2 EE 1
ME 1 EE 1
ME 2 EE 2
ME 1 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 5
SOUTHEASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 35

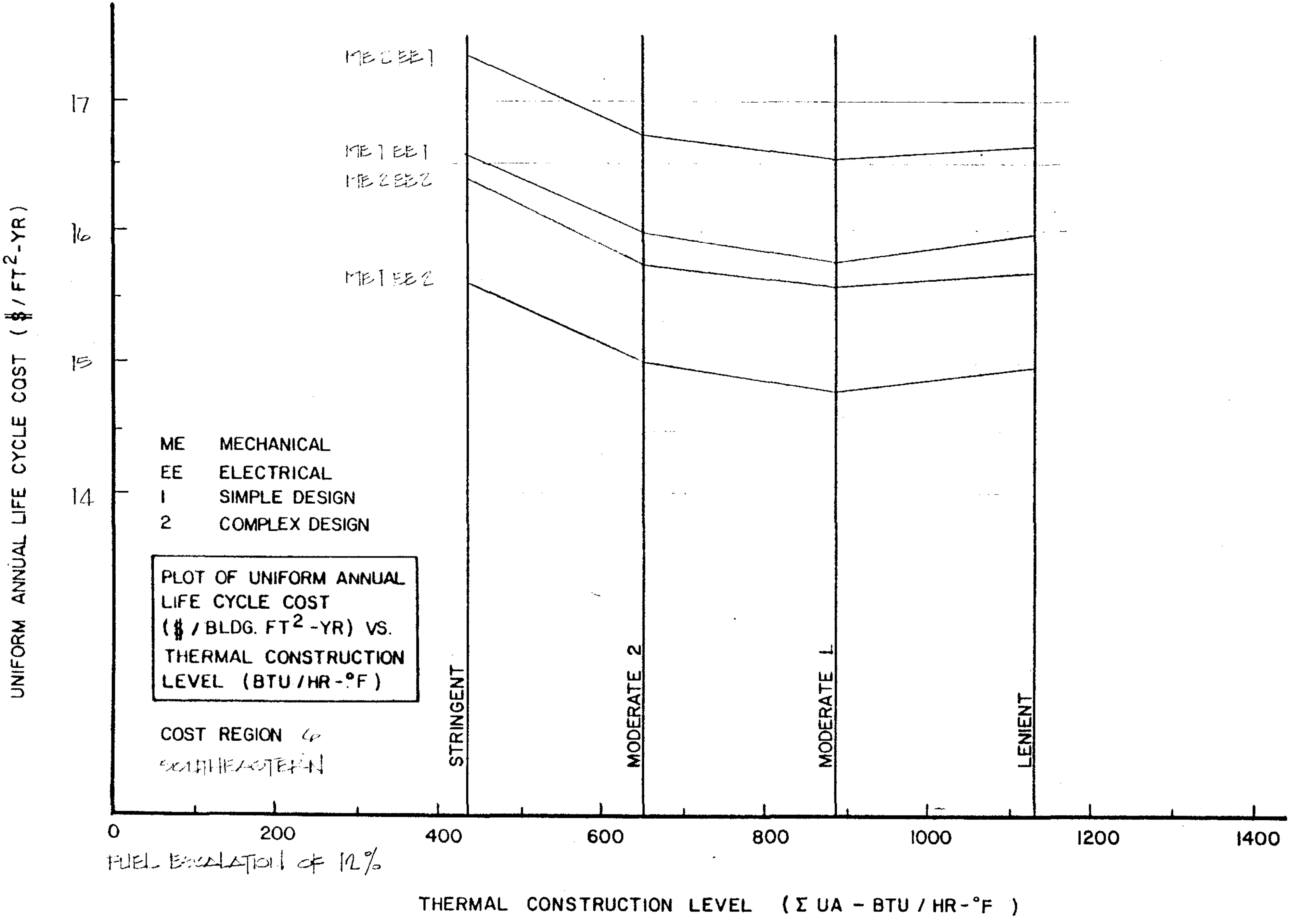

ME 2 EE 1
ME 1 EE 1
ME 2 EE 2
ME 1 EE 2
17
16
15
14
UNIFORM ANNUAL LIFE CYCLE COST ($/FT$^2$-YR)
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($/BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)
COST REGION 6
SOUTHEASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F)

FIG. 36

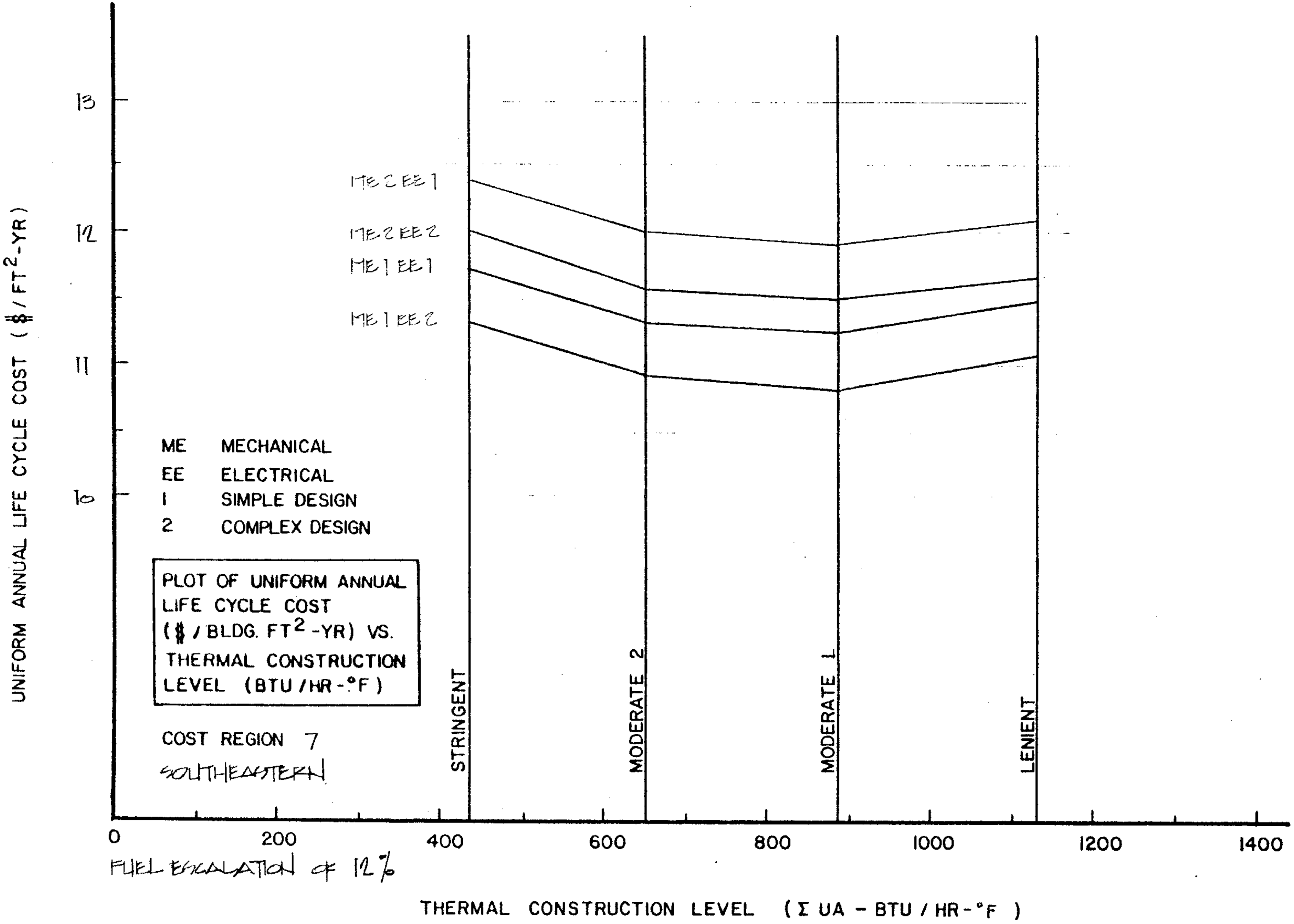

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
13
12
11
10
ME 2 EE 1
ME 2 EE 2
ME 1 EE 1
ME 1 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 7
SOUTHEASTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 3T

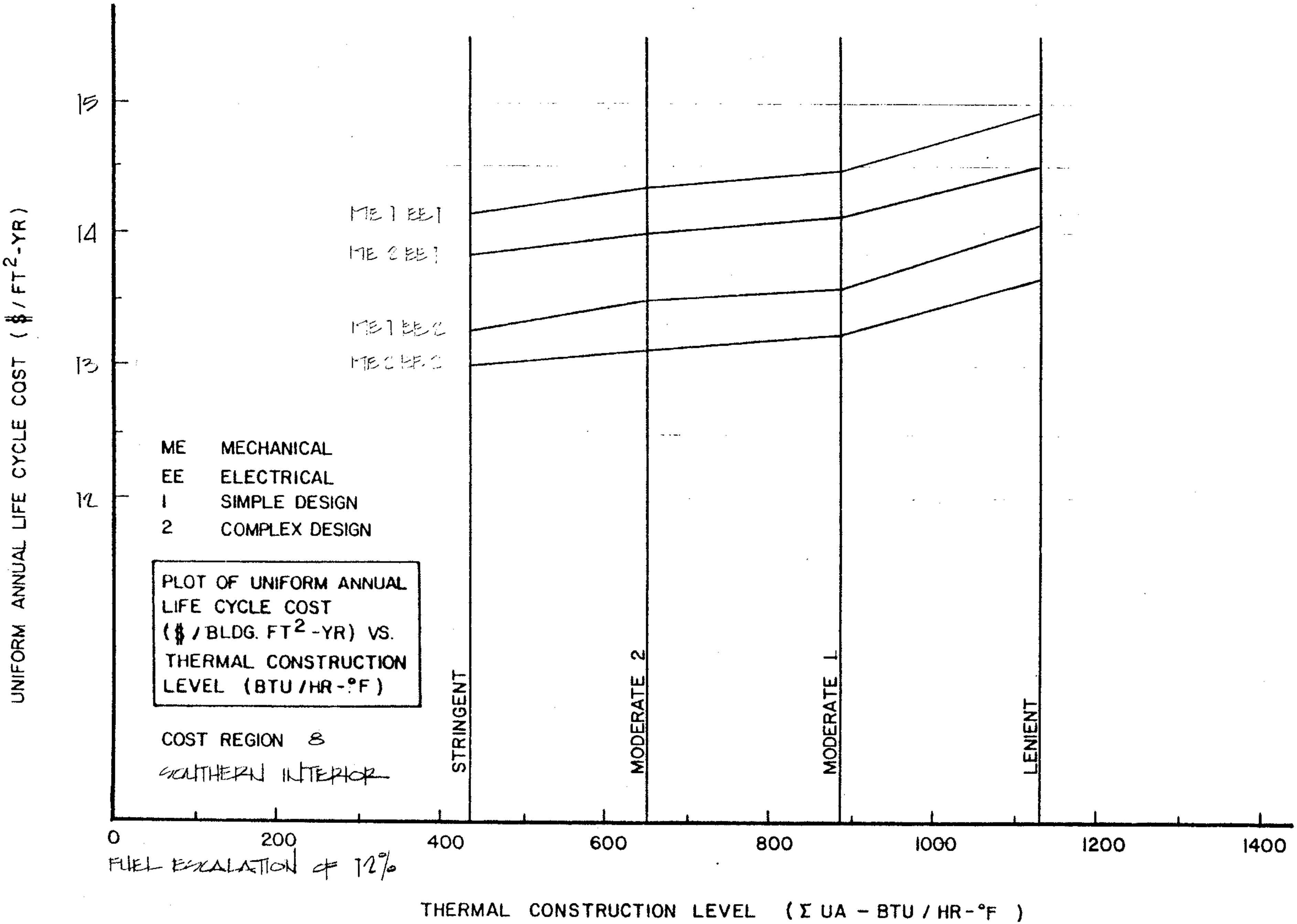

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
15
14
13
12
ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 8
SOUTHERN INTERIOR
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR-°F)

FIG. 38

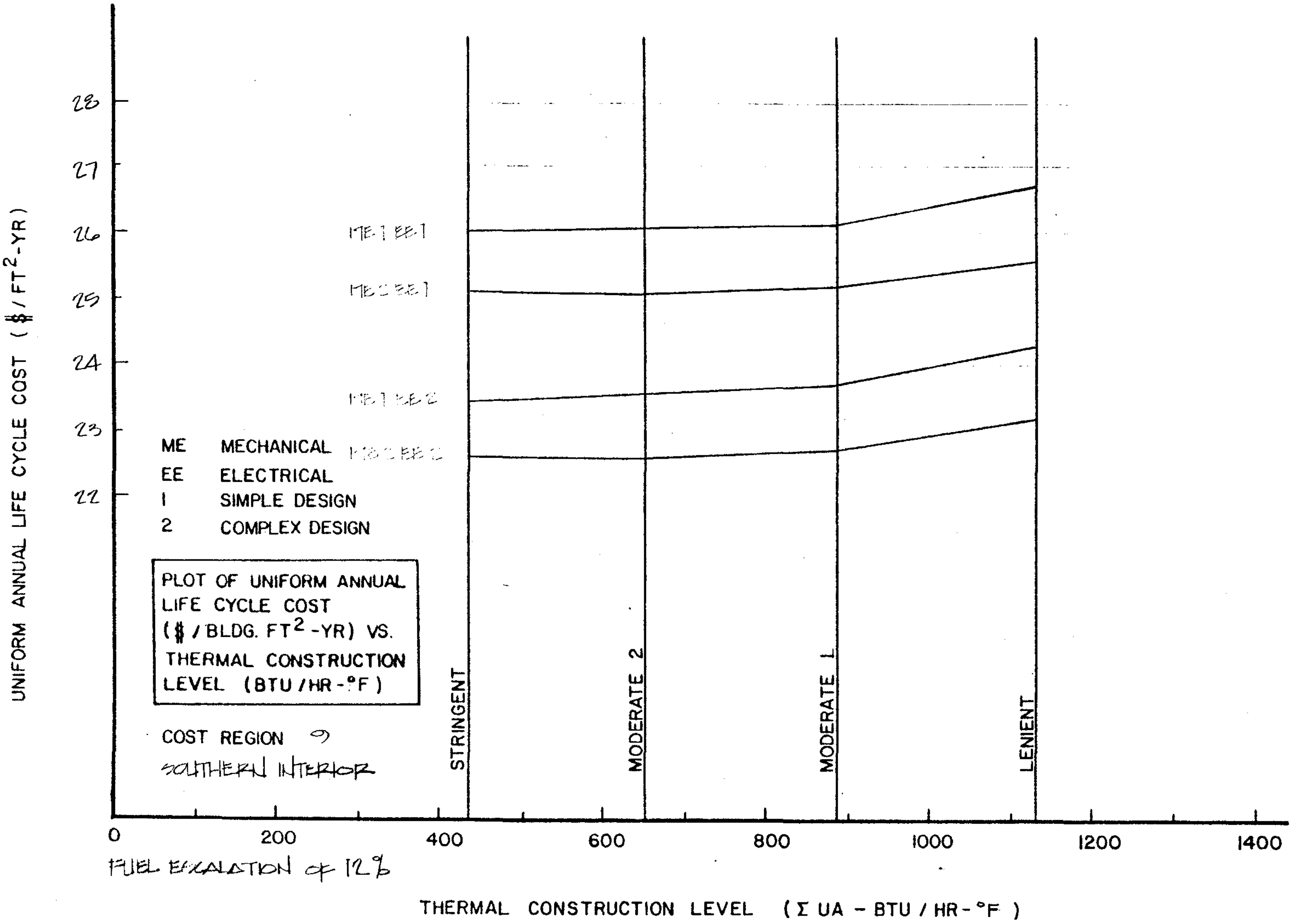
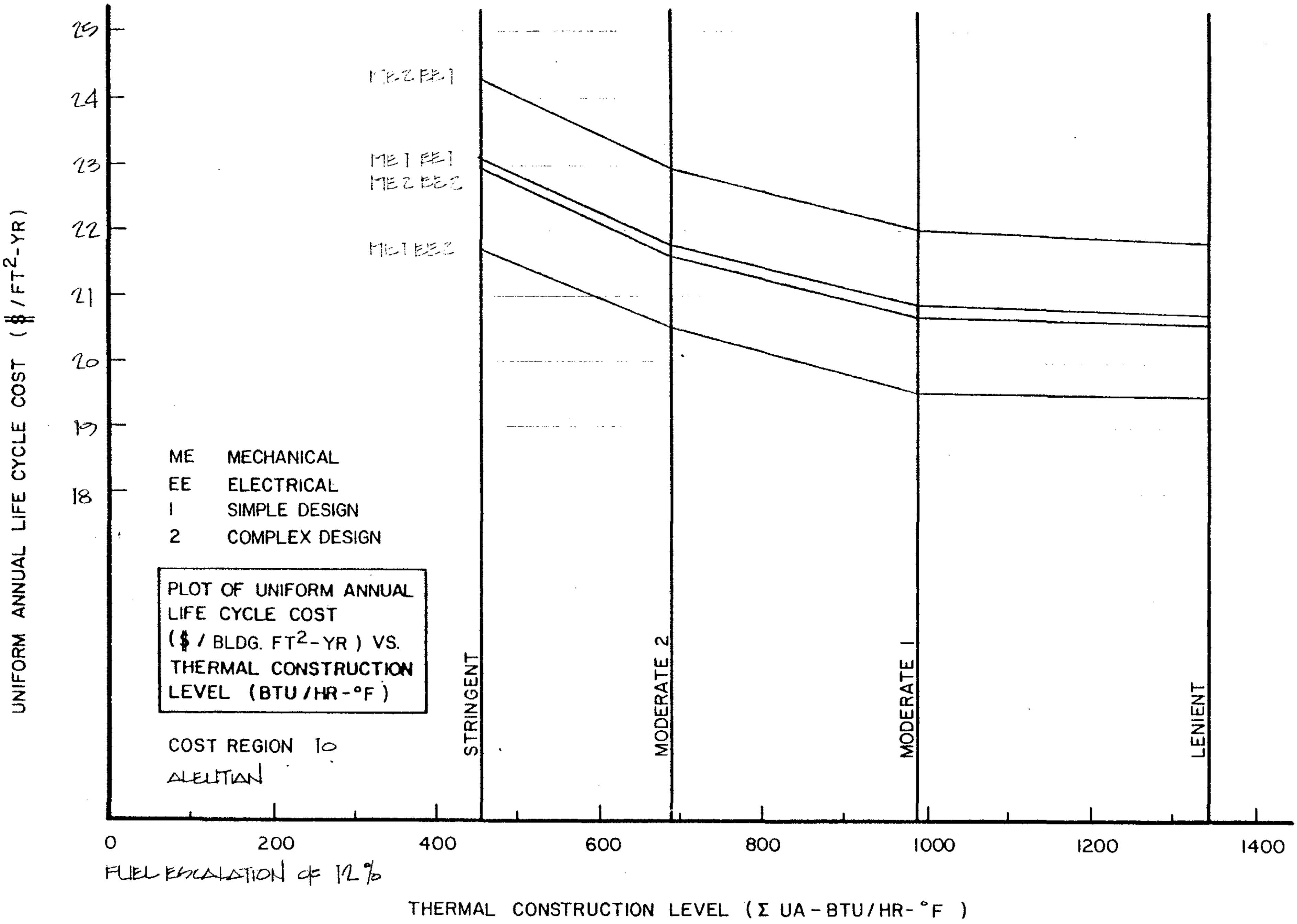

28
27
26
25
24
23
22
UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F)
COST REGION 9
SOUTHERN INTERIOR
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F)

FIG. 39



PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)

COST REGION 10
ALEUTIAN

FUEL ESCALATION OF 12%

FIG. 40

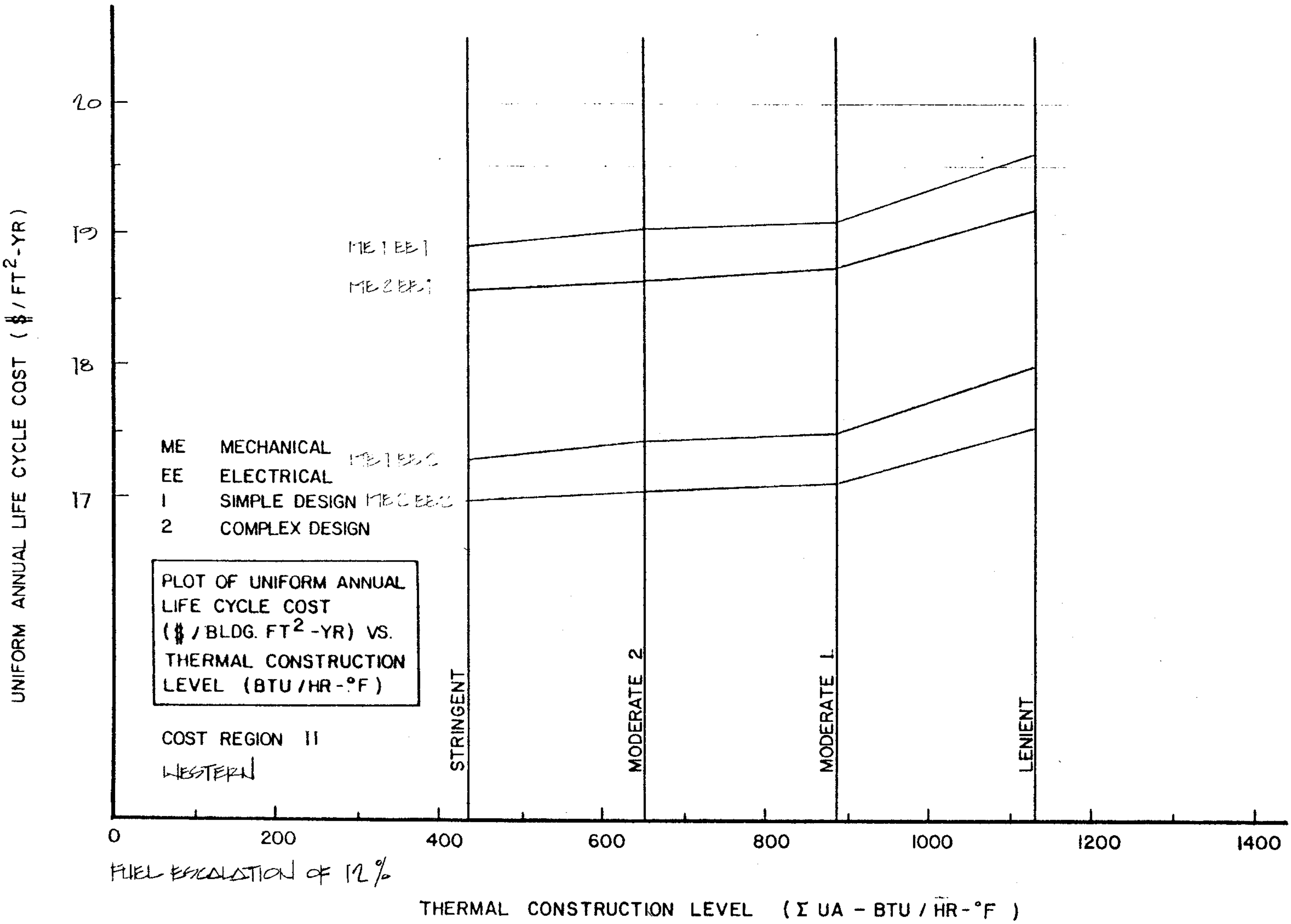

UNIFORM ANNUAL LIFE CYCLE COST ($/FT²-YR)
20
19
18
17
ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($/BLDG. FT²-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU/HR-°F)
COST REGION II
WESTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU/HR-°F)

FIG. 41

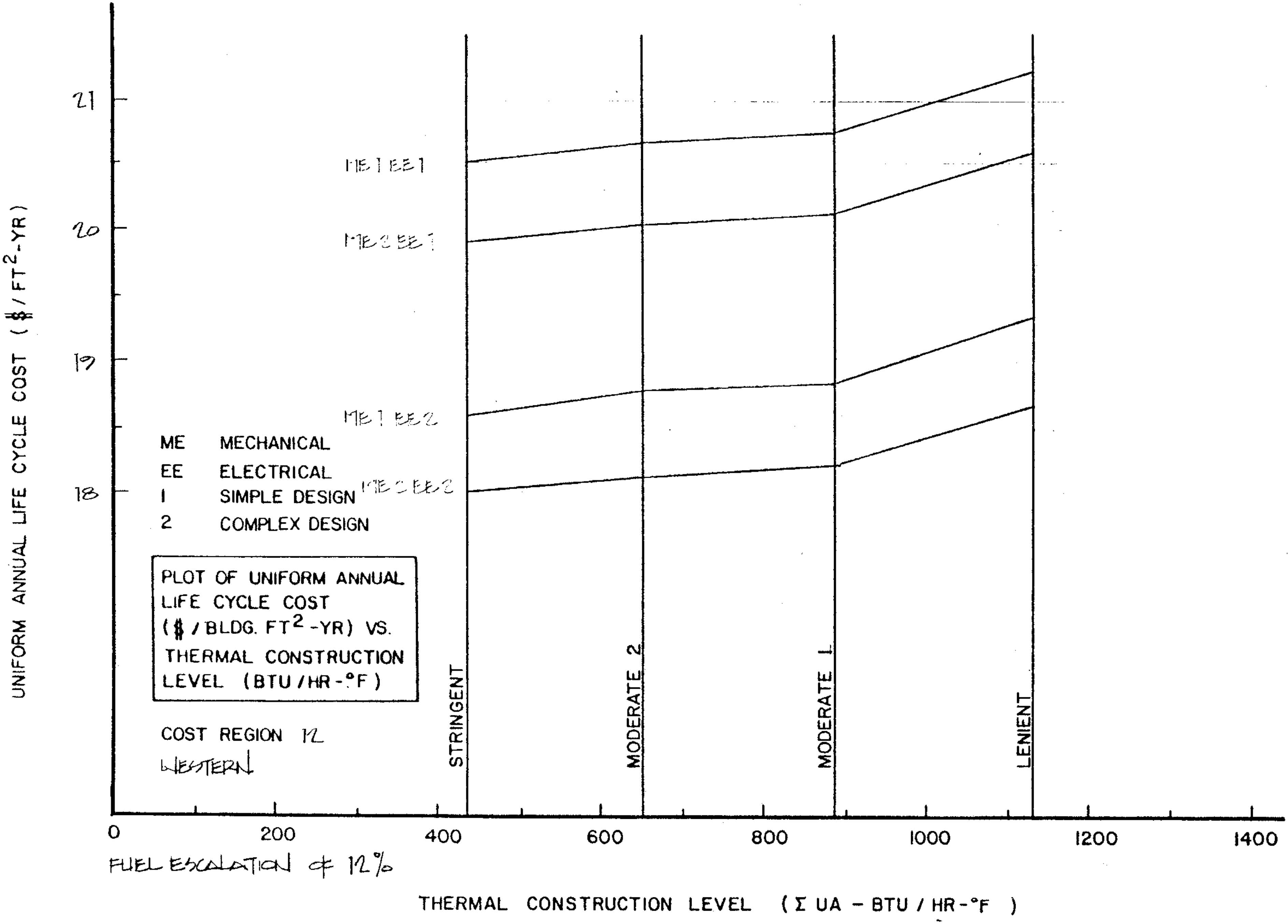

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
21
20
19
18
ME1 EE1
ME2 EE1
ME1 EE2
ME2 EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$-YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR-°F)
COST REGION 12
WESTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION @ 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR-°F)

FIG. 42

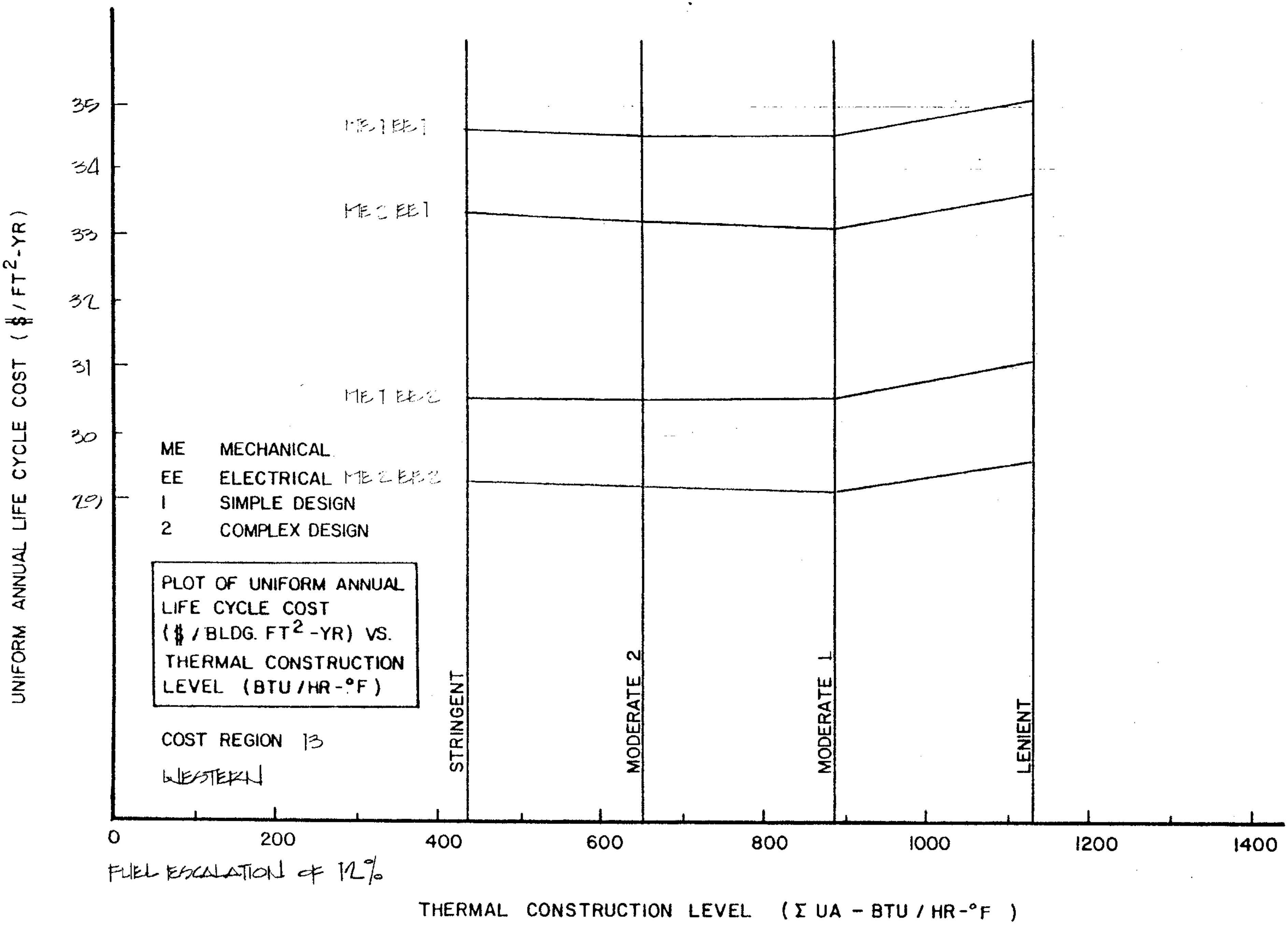
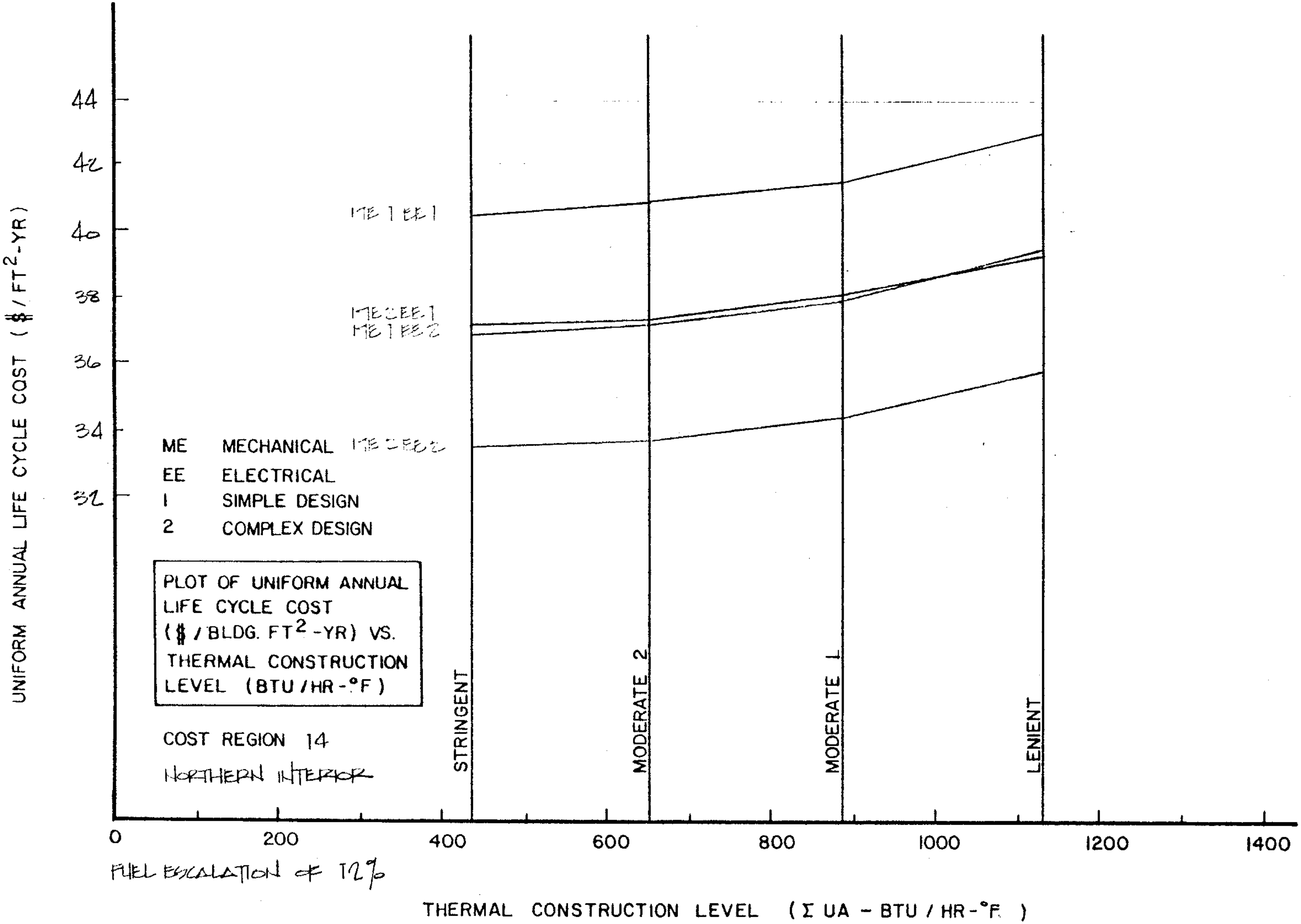

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
35
34
33
32
31
30
29
ME 1 EE 1
ME 2 EE 1
ME 1 EE 2
ME 2 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F )
COST REGION 13
WESTERN
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR - °F )

FIG. 43



FUEL ESCALATION OF 12%

FIG. 44

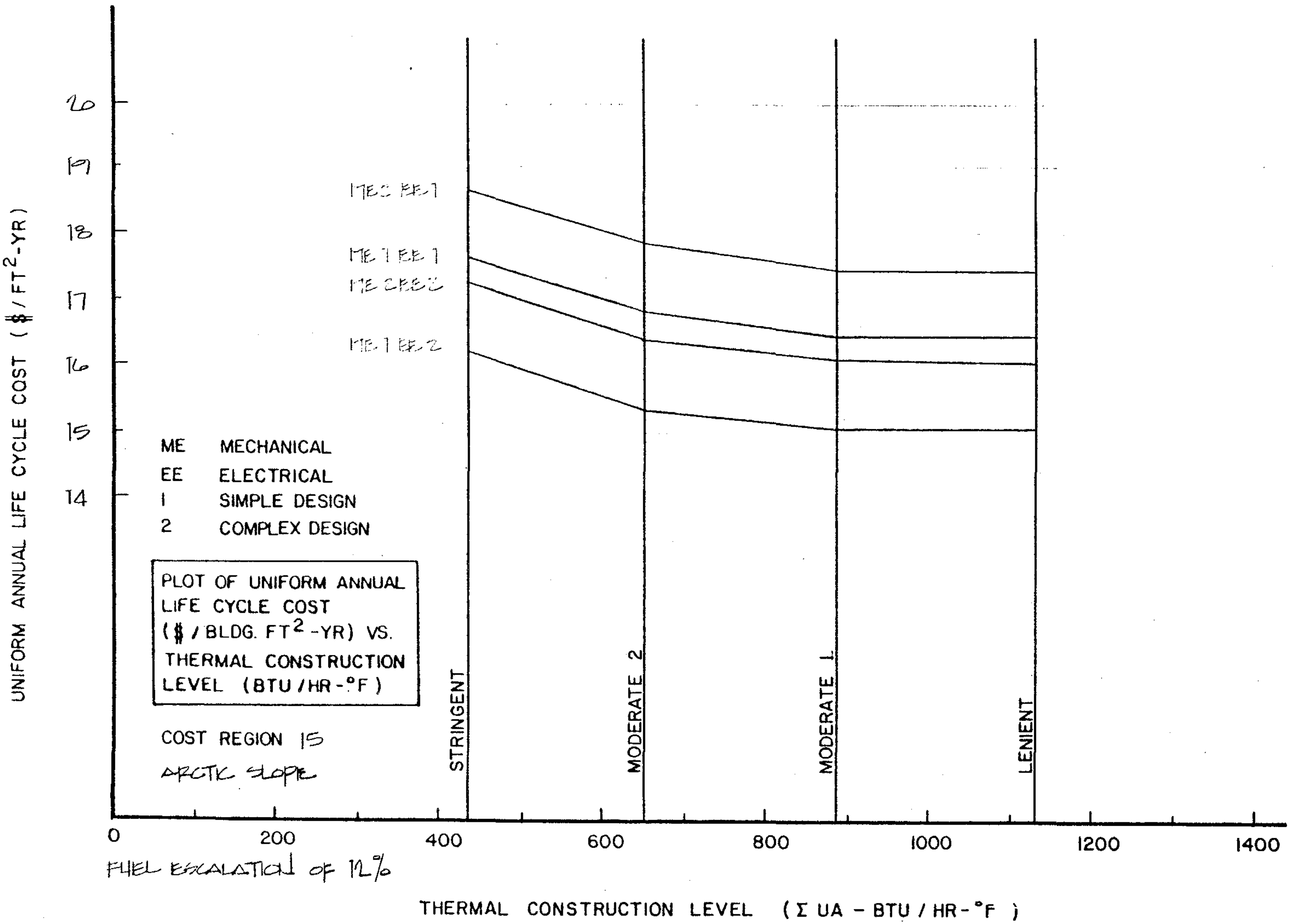

UNIFORM ANNUAL LIFE CYCLE COST ($ / FT$^2$-YR)
20
19
18
17
16
15
14
ME2 EE1
ME1 EE1
ME2 EE2
ME1 EE2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST ($ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR - °F )
COST REGION 15
ARCTIC SLOPE
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL ( Σ UA - BTU / HR - °F )

FIG 45

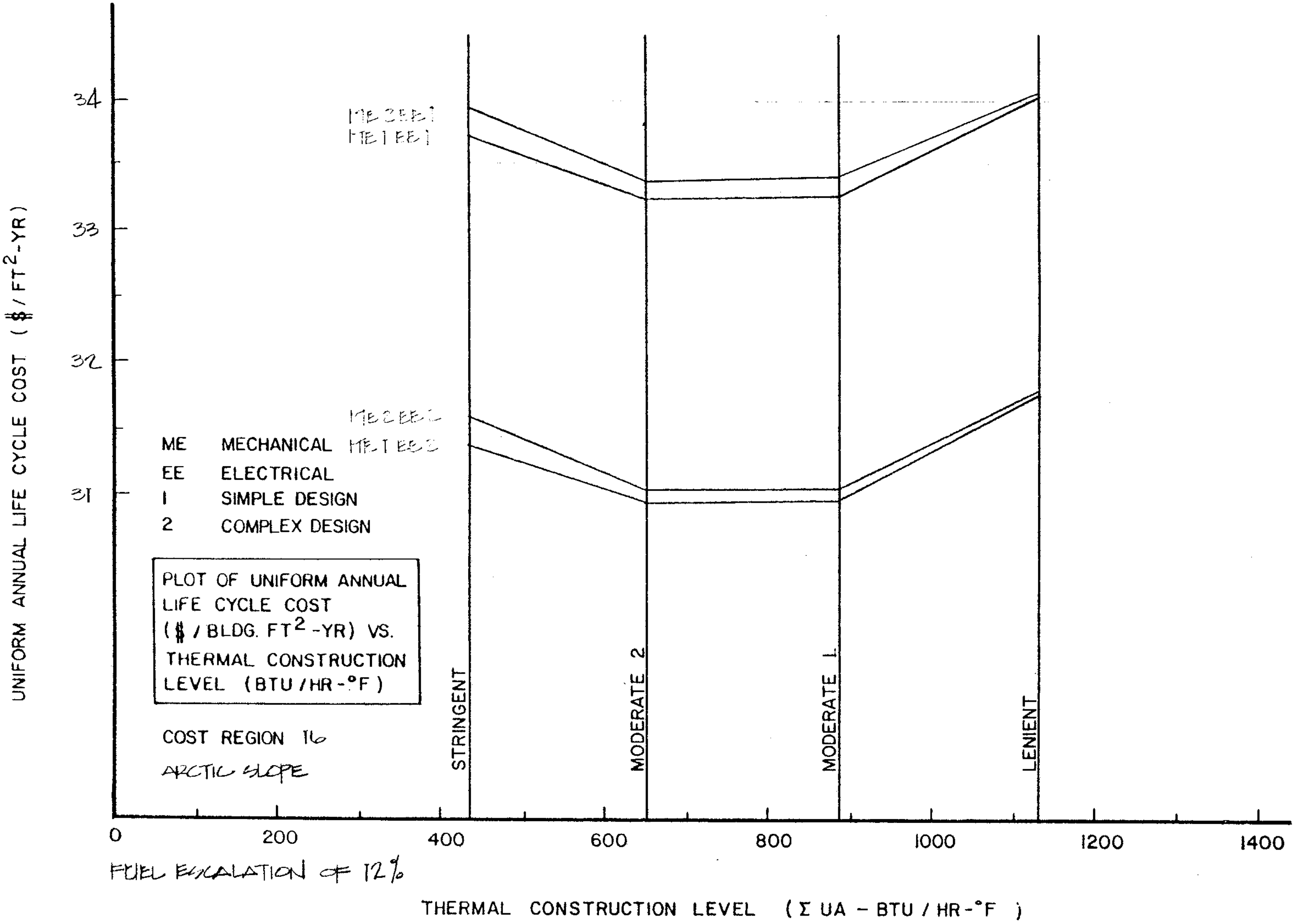

UNIFORM ANNUAL LIFE CYCLE COST (\$ / FT$^2$-YR)
34
33
32
31
ME 2 EE 1
ME 1 EE 1
ME 2 EE 2
ME 1 EE 2
ME MECHANICAL
EE ELECTRICAL
1 SIMPLE DESIGN
2 COMPLEX DESIGN
PLOT OF UNIFORM ANNUAL LIFE CYCLE COST (\$ / BLDG. FT$^2$ -YR) VS. THERMAL CONSTRUCTION LEVEL (BTU / HR -°F)
COST REGION 16
ARCTIC SLOPE
STRINGENT
MODERATE 2
MODERATE 1
LENIENT
0
200
400
600
800
1000
1200
1400
FUEL ESCALATION OF 12%
THERMAL CONSTRUCTION LEVEL (Σ UA - BTU / HR -°F )

FIG. 46

## 5.2 Selection of Least Life Cycle Cost Design Alternatives

Optimum design solutions for the two bounding economic scenarios are expressed in Table 13. This table is a summary of life cycle cost curves discussed in Section 5.1. For example, for Cost Region 8, with an optimistic economic outlook for fuel prices, the optimum design incorporates the following optimum design thermal construction levels.

Architectural Systems: Moderate 1 (8" walls)
Mechanical Systems: ME1 (simple system)
Electrical Systems: EE2 (complex system)
Least Life Cycle Cost: $10.51/Sq. Ft.-Yr.

For the pessimistic economic outlook for fuel prices, the following thermal construction levels yield minimum life cycle cost:

Architectural Systems: Stringent (12" walls)
Mechanical Systems: ME2 (complex system)
Electrical Systems: EE2 (complex system)
Least Life Cycle Cost: $13.65/Sq. Ft. - Yr.

The Table indicates that, for Cost Region 8 (Southern Interior) the actual fuel price economic conditions assumed to occur throughout the building's lifetime, optimum construction levels will range from a moderate level of thermal construction to a stringent level.

# TABLE 13

## OPTIMUM LEVEL OF CONSTRUCTION

| COST REGION | COST REGION TITLE | LOWER BOUND (OPTIMISTIC) FUEL ESCALATION RATE= 8% | | | UPPER BOUND (PESSIMISTIC) FUEL ESCALTION RATE= 12% | | |
|---|---|---|---|---|---|---|---|
| | | ARCHITECTURAL | MECH | ELEC | ARCHITECTURAL | MECH | ELEC |
| 1 | Anchorage Zone | Lenient | ME1 | EE2 | Moderate 1 | ME1 | EE2 |
| 2 | Village | Lenient | ME2 | EE2 | Moderate 1 | ME2 | EE2 |
| 3 | Kodiak Island | Lenient | ME1 | EE2 | Moderate 1 | ME2 | EE2 |
| 4 | Juneau Zone | Moderate 1 | ME1 | EE2 | Moderate 1 | ME2 | EE2 |
| 5 | Main Center | Moderate 1 | ME1 | EE2 | Moderate 1 | ME1 | EE2 |
| 6 | Village | Len/Mod 1 | ME1 | EE2 | Moderate 1 | ME1 | EE2 |
| 7 | Sitka Island | Moderate 1 | ME1 | EE2 | Moderate 1 | ME1 | EE2 |
| 8 | Fairbanks Zone | Moderate 1 | ME1 | EE2 | Stringent | ME2 | EE2 |
| 9 | Village | Moderate 1 | ME1 | EE2 | Moderate 2 | ME2 | EE2 |
| 10 | Village | Lenient | ME1 | EE2 | Lenient | ME1 | EE2 |
| 11 | Bethel | Moderate 1 | ME1 | EE2 | Stringent | ME2 | EE2 |
| 12 | Large Village | Moderate 1 | ME1 | EE2 | Stringent | ME2 | EE2 |
| 13 | Coastal Village | Moderate 1 | ME1 | EE2 | Moderate 1 | ME2 | EE2 |
| 14 | Village | Moderate 2 | ME2 | EE2 | Stringent | ME2 | EE2 |
| 15 | Barrow | Lenient | ME1 | EE2 | Lenient | ME1 | EE2 |
| 16 | Coastal Village | Moderate 1 | ME1 | EE2 | Moderate 2 | ME1 | EE2 |

Architectural levels of construction described on Tables 4 & 5. ME and EE designates respectively mechanical and electrical systems, with "1" meaning simple design and "2" meaning complex design.

With this rather wide range of suggested construction levels, the analysis indicates a rather extreme sensitivity to future fuel price economics. This effect is prevalent throughout all cost regions. Other effects are observable in analysis results. The effects of climate conditions, and cost components strongly effect design optimization. The climate conditions strongly effect the amounts of heating fuel energy consumption. Appendix 5 lists annual energy use for each of the 256 design solutions. It can be seen that annual heating fuel requirements will vary from a low of 27,000 BTU/Sq.Ft.-Yr. in Southeastern Alaska with most stringent thermal construction, to a high of 253,000 BTU/Sq. Ft.-Yr. on Alaska's North Slope, with most lenient construction.

Predicted present year costs of energy also vary significantly. Minimum levels of energy cost are indicated for Cost Region 7 (Sitka Island) at $0.66/Sq.Ft.-Yr. and maximum levels in Cost Region 14 (Northern Interior Village) at $7.40/Sq.Ft.-Yr.

Appendix 6C presents the life cycle cost analysis using present year fuel costs throughout the building's lifetime (zero fuel escalation). This analysis generally indicates the lenient levels of architectural constructions and simple mechanical system designs as optimum designs. The data is presented to allow comparison of this model's results with other analyses that do not incorporate fuel escalation.

The sensitivity of minor variations in input variables is at present still a major unknown with the life cycle cost technique. In performing the analysis, variations were made in fuel escalation rates. No other variables have been examined for sensitivity, although further sensitivity analyses are a major topic for future studies.

The following points regarding sensitivity may be stated:

- Major sensitivity is expected in compounding variables that strongly affect future costs of operation, that is, costs that are incurred in the future, with a volatile escalation profile.

- Major sensitivity is expected with the cost of capitalization the state must bear. However, this is a present year cost, and thus is fairly well defined. In this light then, this cost of capitalization may be secondary to volatile future costs, as a sensitive parameter.

- Thermal modeling techniques employed assess outside air quantities brought into structures using an assumed air change rate for night and ventilation schedules for day. This parameter displays strong sensitivity to predicted annual energy costs. Changes in these amounts will strongly affect results.

Analysis of future costs of maintenance and operations, as well as potential mid-life renovations or replacements have not been dealt with in this analysis. While the analysis program has the capability of modeling two mid-life renovations and an escalating maintenace and operations cost, the modeling process has not incorporated these study aspects. The prime reason for this is a nearly total lack of reasonable input data for the actual expenses that are incurred for rural school operation.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

The thermal analysis has developed for some sixteen cost regions, ranges of recommendation for thermal construction. These recommendations are seen to vary extensively under the influence of climate severity, the local costs of construction, and expected long term cost profiles for energy.

The results presented in this report are a first phase assessment of thermal stringency requirements for the state. The range of thermal construction levels for each cost region presents an envelope of design solutions the state may choose from in assessing construction requirements. Further narrowing of this range of solutions will require further directions in analysis of economic parameters.

### 6.1 Conclusions

The study results are shown to be highly sensitive to the economic assumptions regarding long term fuel escalation rates. The optimum level of thermal stringency that the state should build into new construction thus varies significantly within each cost region. Selection of actual levels of construction within the envelope of bounding least life cycle cost solutions will strongly affect capital costs of future construction. Due care will be required to avoid over stringency.

Selection of an integrated building thermal system is shown to be necessary.

By properly selecting an interior energy system, and using an improper mechanical or electrical system, life cycle costs for a design can be raised significantly. This effect is prevalent in extremely remote areas with extremely expensive energy. In certain situations, selection of mechanical and electrical systems designs are of greater importance than architectural systems, within the bounds of normally accepted envelope design practice.

The results of the study are general, with input data for climate conditions collected for relatively few sites within each climate region. Cost data is similarly generalized. The results can thus be best applied for planning and programming functions, as opposed to individual circumstances. However, the modeling process employed can certainly be made to pertain to a certain building case merely by remodeling input data to fit that case.

Further, these studies model a building assumed to be served by a local public utility, without benefit of any alternative energy sources. This rather simplistic approach serves to put all evaluation on a fair equitable basis. Such concepts would certainly alter results.

## 6.2 Recommendations

For the class of state building studied, these results represent a simplistic analysis of a buildings thermal systems. Given the rather major future capital expenditures that will be made in future building construction, the recommendations made herein bear close scrutiny from the design community.

Specific additional studies are needed to further support the life cycle cost research. Sensitivity analysis on the data input is one of the first major tasks to be performed. This information can then be used to direct further modeling studies, and to evaluate the need for better modeling data. Of special need is a clearer definition of maintenance and operations costs of the two classes of mechanical and electrical systems used in the study.

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# TABLE OF APPENDICES

Appendix 1: Electrical Systems Design

Appendix 2: Climate Data

Appendix 3: Listing of Analysis Program

Appendix 4: Listing of Program Variables

Appendix 5: Energy Use Summary

Appendix 6: Life Cycle Cost Summary

# APPENDIX 1

# ELECTRICAL SYSTEM DESIGN

## ELECTRICAL SYSTEM DESIGN ($EE_1$ and $EE_2$)

### Scope

The scope of the electrical design is to produce input for the computer program which will evaluate the overall efficiency and savings of various designs. The electrical evaluation includes 2 basic designs for 3 area designations. These areas are a typical classroom, a multipurpose room and undefined spaces such as utility rooms and corridor. Each of these areas will be evaluated on the basis of watts/square foot.

### Description

The standard design is best described as current practice. Light fixtures are reasonably energy efficient, are fluorescent, utilize an acrylic diffuser and are low first cost. The building utilizes some incandescent fixtures for esthetic qualities. Exterior fixtures are photocell controlled but operate from sundown to sunup with no timeclock override. No attempt is made to utilize waste heat from the fixtures efficiently, and the lighting layout produces a uniform light level throughout the area concerned without regard to furniture placement and, consequently, "task" lighting. The energy efficient design utilizes the best choice in energy efficient lamps coupled with an energy efficient luminaire. The table below details the watts/sq.ft. for the areas for both the standard and the energy efficient designs.

## Standard Design ($EE_1$)

The standard design utilizes for the classroom areas a 4-lamp wrap-around fluorescent fixture such as the Lithonia LB440A. This fixture will provide the IES recommended 70 footcandles when installed in a 1500 square foot classroom. The number of fixtures required is 18. This assumes that the Room Cavity Ratio is 1.6, the floor reflectance is 30%, the ceiling reflectance is 80%, and the wall reflectance is 50%. It is assumed that the fixtures would be installed in 3 rows of 6 fixtures evenly spaced. The total watts/square-foot with this design is 2.4. The final footcandle level is approximately 80. It should be noted that frequently the designs will show lighting levels of 100 footcandles is insufficient for close work such as accounting or drawing. The design will frequently show, therefore, 24 fixtures which would produce the 100 footcandle level. This calculates to be 3.2 watts/square-foot.

The multipurpose room typically is 2500 square feet of space with a higher ceiling height. The room has a half-court basketball court and is also used for meetings. The lighting levels are usally 50 footcandles from surface-mounted, industrial fluorescent fixtures. The lighting layout is usually accomplished with standard 4 foot lamps to facilitate shipping to the remote areas. The layouts vary but would typically consist of tandem fixtures (2 4-foot fixtures connected end to end to form an 8 foot fixture). There would be approximately 14 tandem fixtures producing the 50 footcandles desired at a power loading of 1.15 watts/square foot.

Alternate Designs ($EE_2$)

The alternate design for the classroom utilizes the same parameters as above but utilizes a more energy efficient fixture. Also, the placement of the fixtures takes into account the location of desks in the classroom and spots them where the light will be concentrated where needed. The overall average lighting level in the classroom calculates as lower but, due to the improved design, produces equal results to the standard design above. The alternate design utilizes a slighter lower zonal cavity footcandle level but, due to an improved diffuser which allows more efficient diffusing of the light, provides equal or better results. The fixture chosen is a Columbia #4643-43-243. This is a surface mounted "Parabolume" fixture. This fixture uses 3 lamps instead of the 4 for the standard design. The total number of fixtures to give equivalent lighting is 18. This is the same as for the standard design. Energy savings are inherent in the reduction of 1 lamp per fixture (25% reduction). The watts per square foot for this design is 1.8. This represents a savings of 1.4 watts/square foot over the "standard" design.

A highly efficient design for the multipurpose room would consist of high pressure sodium luminaires which are one of the most efficient sources of light in common use today. The same multipurpose room could be illuminated to 50 footcandles with 12 150 watt fixtures such as the General Electric "minimount". The total wattage is approximately 2100 watts or .85 watts/square foot.

Mechanical rooms and undefined spaces could be lighted with fluorescent fixtures, and a tremendous improvement in the watts/square-foot indicator could be achieved. The first cost may not be justified, however, when the low number of hours of operation are considered. It would require a specific application to determine the most cost effective choice in any given application. As a first approximation to the power loading from these undefined spaces in a typical building, we can assume an average lighting level of approximately 50 foot-candles. The lighting would be provided by a combination of incandescent and fluorescent. The load is estimated at 4 watts/square-foot. The hours of use, however, could be very minimal if care is taken to control the use of these fixtures.

The watts/square-foot can be reduced by utilizing strip fluorescent fixtures in mechanical rooms and storage rooms, eliminating the use of recessed incandescent lights, utilizing fluorescent fixtures in lavatories and providing local switching for each room to allow lights to be turned off when not in use. A combination photocell/timeclock arrangement connected to exterior floodlights would shut-down floodlights after hours and keep them from operating all night when they are really not required. Although these considerations are not all likely to reduce the power loading, they will greatly reduce the KWH's consumed by eliminating waste. The strict use of fluorescent fixtures would probably reduce the 4 watt/square-foot power loading to 2.5 watts/square foot.

## Conclusions

The following is a recap of the above watt/square-foot loading:

| | STANDARD DESIGN ($EE_1$) | ALTERNATE DESIGN ($EE_2$) |
|---|---|---|
| Classroom | 3.2 | 1.8 |
| Multipurpose | 1.15 | 0.85 |
| Undefined | 4.0 | 3.0 |

These numbers should be considered approximate as the mounting heights, manufacturer of the fixture, mounting configuration, room finishes, line voltage, lamp type and other similar factors encountered in any specific application may cause considerable variation.

# APPENDIX 2

# STATEWIDE CLIMATE ANALYSIS

## CLIMATE ANALYSIS

| CLIMATE REGION | COMMUNITY | MEAN ANNUAL HEATING SEASON TEMP. (°F) | REGION AVERAGE (°F) |
|---|---|---|---|
| Southcentral | Anchorage | 28.0 | 31.2 |
| | Homer | 31.7 | |
| | Talkeetna | 25.2 | |
| | Valdez | 30.7 | |
| | Seward | 34.5 | |
| | Cordova | 34.1 | |
| | Matanuska | 28.7 | |
| | Kodiak | 36.6 | |
| Southeastern | Juneau | 38.2 | 38.8 |
| | Yakutat | 34.4 | |
| | Annette | 41.9 | |
| | Ketchikan | 42.5 | |
| | Sitka | 39.8 | |
| | Wrangell | 39.5 | |
| | Skagway | 35.5 | |
| South Interior | Fairbanks | 14.8 | 15.9 |
| | McGrath | 15.0 | |
| | Gulkana | 17.3 | |
| | Big Delta | 17.6 | |
| | McKinley Park | 19.2 | |
| | Tanana | 13.2 | |
| | Northway | 11.2 | |
| | Manley Hot Springs | | |
| | Paxson | 15.9 | |
| | Glenallen | 18.7 | |
| Western | Kotzebue | 11.5 | 20.9 |
| | Bethel | 20.7 | |
| | St. Paul | 31.1 | |
| | Nome | 18.1 | |
| | Unalakleet | 18.1 | |
| | King Salmon | 26.6 | |
| | Holy Cross | 20.4 | |
| Aleutian | Cold Bay | 34.2 | 36.4 |
| | Adak | 38.5 | |
| Northern Interior | Bettles | 9.9 | 11.5 |
| | Eagle | 13.0 | |
| Arctic Slope | Barrow | 0.3 | 0.6 |
| | Barter Island | 0.8 | |

# APPENDIX 3

# LISTING OF ANALYSIS PROGRAM

```
C**********************************************************************
C
C         *****   MAIN   *****
C
C     PROGRAM FOR ANALYZING LIFE CYCLE COSTS OF BUILDING THERMAL SYSTEMS.
C     CREATED FOR THE STATE OF ALASKA, DIV. OF BUILDING RESEARCH, DOTPF.
C     BY THE UNIVERSITY OF ALASKA MECHANICAL ENGINEERING DEPARTMENT
C
C     MAY 5, 1981
C
C**********************************************************************
      CHARACTER IPR*3,IPRI*3,PTR*8
      DIMENSION A(5),   AP(2), APT(2)
      DIMENSION BTT(2)
      DIMENSION BL(3,4,2,2), BN1(3,4,2,2), BN2(3,4,2,2), CFM(7,2,5)
      DIMENSION CIDX(16), DIA(2)
      DIMENSION DEN(2),  E(2), EA(2), ECIDX(16,2)
      DIMENSION ECON(2),  EET(3)
      DIMENSION FCOST (7,3,4,2,2), FESC(3,4,2,2), FMA(3,4,2,2)
      DIMENSION NL(2)
      DIMENSION GUAC(3), ICC(5)
      REAL KWH(5,5)
      DIMENSION OCR(5), P(4), Q(5), QCT(7,3), QIET(7,2), ST(3)
      DIMENSION QIE(5), RMTT(2)
      DIMENSION SUN(7), STT(7), TMTT(2)
      DIMENSION TFUEL(2), TLCR(2), TBLDG(16,4,2,2), TFCOST(16,4,2,2)
      DIMENSION TMCR(2), TOUT(7), TSQFT(16,4,2,2),TT(5)
      DIMENSION U(7,4,5), UA(7,4), UAC(4), UFMA(3)
      DIMENSION WFT(3,2)
      DIMENSION TFU1(16,4,2,2),TFU2(16,4,2,2)
      DIMENSION TGUU(16,4,2,2),TUFF(16,4,2,2)
      DIMENSION TBSQ(16,4,2,2)
C
      CALL FPARAM (1,132)
C
C     DATA INPUT
C
C   ***    ARCHITECTUAL PARAMETERS
C
```

```
0400      DATA (((U(I,J,K),K=1,5),J=1,4),I=1,7)/
0410 &     .051,.055,.490,.110,.044,
0420 &     .045,.043,.490,.110,.029,
0430 &     .033,.027,.310,.072,.023,
0440 &     .024,.019,.170,.045,.016,
0450 &     .051,.044,.490,.110,.044,
0460 &     .045,.031,.490,.110,.029,
0470 &     .033,.024,.310,.072,.023,
0480 &     .024,.016,.170,.045,.016,
0490 &     .051,.044,.490,.110,.044,
0500 &     .045,.031,.490,.110,.029,
0510 &     .033,.024,.310,.072,.023,
0520 &     .024,.016,.170,.045,.016,
0530 &     .051,.071,.490,.110,.044,
0540 &     .045,.044,.490,.110,.029,
0550 &     .033,.029,.310,.072,.023,
0560 &     .024,.019,.170,.045,.016,
0570 &     .051,.044,.490,.110,.044,
0580 &     .045,.031,.490,.110,.029,
0590 &     .033,.024,.310,.072,.023,
0600 &     .024,.016,.170,.045,.016,
0610 &     .051,.044,.490,.110,.044,
0620 &     .045,.031,.490,.110,.029,
0630 &     .033,.024,.310,.072,.023,
0640 &     .024,.016,.170,.045,.016,
0650 &     .051,.044,.490,.110,.044,
0660 &     .045,.031,.490,.110,.029,
0670 &     .033,.024,.310,.072,.023,
0680 &     .024,.016,.170,.045,.016/
0690C
0700C   ***  BUILDING COST  ***
0710C
0720     DATA ((((BN1(I,J,K,L),L=1,2),K=1,2),J=1,4),I=1,3)/48*0.0/
0730     DATA ((((BN2(I,J,K,L),L=1,2),K=1,2),J=1,4),I=1,3)/48*0.0/
0740     DATA ((((BL(I,J,K,L),L=1,2),K=1,2),J=1,4),I=1,3)/48*0.0/
0750C
0760     DATA (((((FCOST(I,J,K,L,M),M=1,2),L=1,2),K=1,4),J=1,3),I=1,7)/
0770 &     4*29.51,4*31.81,4*36.52,4*44.28,
0780 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
```

```
0790 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0800 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0810 &     4*28.83,4*29.87,4*32.09,4*36.84,
0820 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
0830 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0840 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0850 &     4*28.83,4*29.87,4*32.09,4*36.84,
0860 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
0870 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0880 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0890 &     4*31.49,4*34.02,4*39.18,4*47.62,
0900 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
0910 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0920 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0930 &     4*28.83,4*29.87,4*32.09,4*36.84,
0940 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
0950 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0960 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
0970 &     4*28.83,4*29.87,4*32.09,4*36.84,
0980 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
0990 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
1000 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
1010 &     4*28.83,4*29.87,4*32.09,4*36.84,
1020 &     2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,2*10.96,2*21.92,
1030 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55,
1040 &     2.28,2.55,2.28,2.55,2.28,2.55,2.28,2.55/
1050C
1060      DATA ((((FMA(I,J,K,L),L=1,2),K=1,2),J=1,4),I=1,3)/
1070 & 16*0.,2*.072,2*.144,2*.072,2*.144,2*.072,2*.144,2*.072,2*.144,16*0./
1080      DATA ((((FESC(I,J,K,L),L=1,2),K=1,2),J=1,4),I=1,3)/48*0.0/
1090C
1100C  ***    CLIMATE CONDITIONS  ***
1110C
1120      DATA SUN/7*0.0/
1130      DATA TOUT/31.2,38.8,15.9,36.4,20.9,11.5,0.6/
1140C
1150C  ***  COST INDEX  ***
1160C
1170      DATA CIDX/
```

```
1180 &            1.2243,1.3203,1.3395,1.1340,
1190 &            1.2869,1.8085,1.3410,1.2969,
1200 &            2.1327,2.2536,1.4991,1.5335,
1210 &            2.4449,2.6656,1.9153,2.9418/
1220C
1230C  ***   ECONOMIC DATA  ***
1240C
1250       DATA BIE /10.5/
1260       DATA RN/30./
1270C
1280C  ***   ELECTRICAL SYSTEM PARAMETERS  ***
1290C
1300      DATA NL/3,3/
1310      DATA ST/48.7,29.9,21.4/
1320      DATA TLCR/.8,.8/
1330      DATA ((WFT(I,J),J=1,2),I=1,3)/3.2,1.8,1.15,.85,2.0,1.5/
1340C
1350C  ***  ENERGY COST DATA  ***
1360C
1370      DATA AP/6.91E-06,12.89E-06/
1380      DATA E/12.,12./
1390      DATA JT/2/
1400C
1410C   ***   ENERGY COST INDEX  ***
1420C
1430      DATA ((ECIDX(I,J),J=1,2),I=1,16)/1.041,2.114,
1440 &     1.041,6.318,
1450 &     1.038,3.477,
1460 &     1.032,2.546,
1470 &     1.000,1.841,
1480 &     1.060,2.727,
1490 &     1.042,1.568,
1500 &     1.004,2.432,
1510 &     1.364,5.750,
1520 &     1.082,3.364,
1530 &     1.093,4.000,
1540 &     1.161,4.636,
1550 &     1.396,9.091,
1560 &     2.859,9.091,
```

```
1570 &    0.228,3.068,
1580 &    1.356,5.682/
1590C
1600C   ***  ENVELOPE COMPONENT AREAS  ***
1610C
1620      DATA A/4781.,7496.,405.,81.,7496./
1630      DATA BSQ/7520./
1640C
1650C  ***  MECHANICAL SYSTEMS  ***
1660C
1670      DATA (((CFM(I,J,K),K=1,5),J=1,2),I=1,7)/4*2840.,940.,
1680 &    1840.,2840.,2250.,2*940.,
1690 &    4*2840.,940.,
1700 &    1840.,2840.,2250.,940.,940.,
1710 &    4*2840.,470.,
1720 &    1840.,2840.,2250.,700.,470.,
1730 &    4*2840.,1410.,
1740 &    1840.,2840.,2250.,1410.,1410.,
1750 &    4*2840.,1410.,
1760 &    1840.,2840.,2250.,1410.,1410.,
1770 &    4*2840.,470.,
1780 &    1840.,2840.,2250.,700.,470.,
1790 &    4*2840.,1410.,
1800 &    1840.,2840.,2250.,1410.,1410./
1810C
1820      DATA DEN/11132.,3610./
1830      DATA ECON/.70,.70/
1840      DATA TMCR/.8,.8/
1850C
1860C  ***  STANDARD OPERATING CONDITIONS  ***
1870C
1880      DATA ICC/94,94,430,26,0/
1890      DATA TT/17.9,6.0,2.4,21.4,52.4/
1900C
1910C  ***  TEMPERATURE & CONSUMPTION CONSTANTS
1920C
1930      DATA DHW/3./
1940      DATA IOC/94/
1950      DATA IR/4/
```

```
1960     DATA IT/5/
1970     DATA TL/6552./
1980     DATA TRD/70./
1990     DATA TRN/65./
2000C
2010C   *********     VALIDATION OF INPUT DATA   ************
2020C
2025     PTR="TTY43"
2030C
2040C  ***   OPTION FOR EQUATION VALIDATION PRINTOUT  ***
2050C
2060      IPR="N"
2070C
2080C
2090C  ***   OPTION FOR PRINTING INPUT DATA  ***
2100C
2110      IPRI="N"
2120C
2130     IF (IPRI.NE."Y".OR.IPRI.NE."YES") GO TO 122
2140C
2150     DO 5 I = 1,7
2160C
2170       WRITE (6,11) ((U(I,J,K),K=1,5),J=1,4)
2180 11    FORMAT (5F10.3)
2190     PRINT ," "
2200C
2210 5   CONTINUE
2220C
2230     DO 10 I = 1,7
2240C
2250       PRINT , " "
2260       WRITE (6,12) ((((FCOST(I,J,K,L,M),M=1,2),L=1,2),K=1,4),J=1,3)
2270 12    FORMAT (16F6.1)
2280C
2290 10  CONTINUE
2300C
2310     DO 15 I = 1,3
2320C
2330       WRITE (6,13) (WFT(I,J),J=1,2)
```

```
 13    FORMAT (2F10.1)
C
 15   CONTINUE
C
     DO 20 I = 1,16
C
       WRITE (6,14) (ECIDX(I,J),J=1,2)
 14    FORMAT (2F10.3)
C
 20  CONTINUE
C
     DO 25 I =1,7
C
       WRITE (6,16) ((CFM(I,J,K),K=1,5),J=1,2)
 16    FORMAT (5F10.0)
C
 25  CONTINUE
C
C  ***********      BEGINNING OF CALCULATION LOOPS   **********
C
 122     CONTINUE
C
C  ***  INITIALIZE DO LOOP INDEX FOR CASES DESIRED  ***
C
     IBEGREG=1
     IENDREG=16
     IBEGARCH=1
     IENDARCH=4
     IBEGEE=1
     IENDEE=2
     IBEGME=1
     IENDME=2
C
     DO 1 IC = IBEGREG,IENDREG
C
       IF (IC.EQ.1.OR.IC.EQ.2.OR.IC.EQ.3) IREG=1
       IF (IC.EQ.4.OR.IC.EQ.5.OR.IC.EQ.6.OR.IC.EQ.7) IREG=2
       IF (IC.EQ.8.OR.IC.EQ.9) IREG=3
       IF (IC.EQ.10) IREG=4
```

```
       IF (IC.EQ.11.OR.IC.EQ.12.OR.IC.EQ.13) IREG=5
       IF (IC.EQ.14) IREG=6
       IF (IC.EQ.15.OR.IC.EQ.16) IREG=7
C
      DO 2 IARCH=IBEGARCH,IENDARCH
C
         DO 3 IME=IBEGME,IENDME
C
            DO 4 IEE=IBEGEE,IENDEE
C
C *** THIS PORTION OF THE PROGRAM COMPUTES SYSTEM ENERGY FLOWS, AND
C *** INVOLVES CONDUCTION, AND AIR EXCHANGE LOSSES AS WELL AS
C *** MECHANICAL AND ELECTRICAL SYSTEM ENERGY CONSUMPTIONS
C *** CONDUCTION HEAT LOSSES
C
C
      QCT(IREG,IARCH)=0.0
      TRA=(TT(5)/100.)*TRN+(1.-TT(5)/100.)*TRD
C
C
     DO 160 K=1,5
C
C  ***  IF ROOF IS SLOPED, THEN INCREASE AREA  ***
C
     ROOFM=1.000
     IF (IREG.NE.1.AND.K.EQ.2) ROOFM=1.054
     Q(K)=A(K)*U(IREG,IARCH,K)*(TRA-TOUT(IREG))*TL*ROOFM
     QCT(IREG,IARCH)=QCT(IREG,IARCH)+Q(K)
     IF (IPR.EQ."Y") PRINT ,"QCT(IREG,IARCH)",QCT(IREG,IARCH)
C
 160 CONTINUE
C
C *** COMPUTATION OF VENTILATION/AIR EXCHANGE HEAT ***
C *** LOSSES
C
     IF (IARCH.EQ.1) RDX=1.0
     IF (IARCH.EQ.2) RDX=0.95
     IF (IARCH.EQ.3) RDX=0.95
     IF (IARCH.EQ.4) RDX=0.90
```

```
3120C
3130      QIET(IREG,IME)=0.0
3140C
3150      TEMP=TRD
3160C
3170      DO 170 I=1,IT
3180C
3190      IF (I.EQ.IT) TEMP=TRN
3200      QIE(I)=CFM(IREG,IME,I)*1.08*(TEMP-TOUT(IREG))*(TT(I)/100.)*TL*RDX
3210      QIET(IREG,IME)=QIET(IREG,IME)+QIE(I)
3220C
3230 170 CONTINUE
3240C
3250      IF (IPR.EQ."Y") PRINT,"QIET",QIET(IREG,IME)
3260C
3270C *** COMPUTATION OF ENERGY CONSUMPTION FOR HEATING DOMESTIC ***
3280C *** HOT WATER ***
3290C
3300       QDHW=DHW*IOC*216630.
3310C
3320      IF (IPR.EQ."Y") PRINT,"QDHW",QDHW
3330C
3340C
3350C *** LIGHTING SYSTEM ENERGY CONSUMPTION
3360C
3370      ETT=0
3380C
3390      DO 180 J=1,NL(IEE)
3400C
3410      EET(J)=0.
3420C
3430      IR = IT-1
3440C
3450      DO 175 I=1,IR
3460C
3470      KWH(I,J)=(ST(J)/100.)*BSQ*WFT(J,IEE)*(TT(I)/100.)*(TL/1000.)
3480      EET(J)=EET(J)+KWH(I,J)
3490C
3500 175 CONTINUE
```

```
3510C
3520      ETT=ETT+EET(J)
3530C
3540 180 CONTINUE
3550C
3560      BTT(IEE)=ETT*3412.
3570      IF (IPR.EQ."Y") PRINT,"BTT",BTT(IEE)
3580C
3590C     MECHANICAL SYSTEM DISTRIBUTION ENERGY
3600C
3610      TMTT(IME)=BSQ*DEN(IME)
3620C
3630      IF (IPR.EQ."Y") PRINT,"TMTT",TMTT(IME)
3640C *** TOTAL ENERGY CONSUMPTION WILL BE THE SUM OF CONDUCTION
3650C *** VENTILATION/AIR EXCHANGE, AND ELECTRICAL/MECHANICAL
3660C *** SYSTEMS CONSUMPTION
3670C
3680      QT=QCT(IREG,IARCH)+QIET(IREG,IME)+QDHW+BTT(IEE)+TMTT(IME)
3690C
3700      IF (IPR.EQ."Y") PRINT,"QT",QT
3710C
3720C *** COMPUTE ENERGY CREDITS ***
3730C
3740C     HEAT GAIN FROM OCCUPANTS
3750C
3760      OCS=0.
3770C
3780      DO 250 I=1,IT
3790C
3800      OCR(I)=TT(I)*TL*ICC(I)/100.
3810      OCS=OCS+OCR(I)
3820C
3830 250 CONTINUE
3840C
3850      EOCS=OCS*250.
3860      IF (IPR.EQ."Y") PRINT,"EOCS",EOCS
3870C
3880C *** HEAT GAIN FROM LIGHTING SYSTEM
3890C
```

```
3900      RTT=TLCR(IEE)*BTT(IEE)
3910C
3920      IF (IPR.EQ."Y") PRINT,"RTT",RTT
3930C     HEAT GAIN FROM MECHANICAL SYSTEM
3940C
3950      RMTT(IME)=TMCR(IME)*TMTT(IME)
3960      IF (IPR.EQ."Y") PRINT,"RMTT",RMTT(IME)
3970C
3980C *** SOLAR HEAT GAIN THROUGH WINDOWS
3990C
4000      STT(IREG)=SUN(IREG)*BSQ
4010C
4020      IF (IPR.EQ."Y") PRINT ,"STT",STT(IREG)
4030C *** COMPUTE TOTAL SYSTEM ENERGY CONSUMPTION WITH HEAT GAIN
4040C *** CREDITS APPLIED ***
4050C
4060      RTV=EOCS+RTT+RMTT(IME)+STT(IREG)
4070      RTU=QT-RTV
4080C
4090C  *** DIVIDE ENERGYS BY FUEL FOR COMPUTATION OF CONVERSION LOSSES
4100C
4110      FUEL1=((1.-ECON(IME))*((QCT(IREG,IARCH)+QIET(IREG,IME)+QDHW)-RTV))/ECON(IME)
4120      TFUEL(1)=FUEL1+(QCT(IREG,IARCH)+QIET(IREG,IME)+QDHW-RTV)
4130      TFU1(IC,IARCH,IME,IEE)=TFUEL(1)/BSQ
4140      TFUEL(2)=BTT(IEE)+TMTT(IME)
4150      TFU2(IC,IARCH,IME,IEE)=TFUEL(2)/BSQ
4160      IF (IPR.EQ."Y") PRINT,"FUEL1",FUEL1,"TFUEL(1)",TFUEL(1),"TFUEL(2)",TFUEL(2)
4170C
4180C  *** COMPUTE UNIFORM ANNUAL M & O COSTS
4190C
4200      TUFMA=0.0
4210C
4220      DO 60 L=1,3
4230C
4240      R1=FMA(L,IARCH,IME,IEE)*(((1+(BIE/100.))**5)-1)/((BIE/100.)*((1+(BIE/100.))**5))
4250      DSE=((1+(BIE/100.))/(1+(FESC(L,IARCH,IME,IEE)/100.)))-1
4260      PST= (((1+DSE)**(RN-5))-1)/(DSE*((1+DSE)**(RN-5)))
4270      R2=FMA(L,IARCH,IME,IEE)*PST
4280      R3=R2/((1+(BIE/100.))**5)
```

```
4290      RT=R1+R3
4300      UFMA(L)=RT*(BIE/100.)*((1+(BIE/100.))**RN)/(((1+(BIE/100.))**RN)-1)
4310      TUFMA=UFMA(L)+TUFMA
4320C
4330 60   CONTINUE
4340C
4350    TUFMA=TUFMA*CIDX(IC)
4360      IF (IPR.EQ."Y") PRINT,"TUFMA",TUFMA
4370C *** COMPUTE UNIFORM ANNUAL COST EQUIVALENT FOR CAPITAL OUTLAYS TO INCLUDE
4380C *** FIRST COST MID TERM RENOVATIONS, AND SALVAGE
4390C
4400      TUAC=0.0
4410      TGUAC=0.0
4420      TTUAC=0.0
4430      DO 70 L=1,3
4440C
4450      RENV1=((BN1(L,IARCH,IME,IEE))/100.)/((1+(BIE/100.))**10)
4460      RENV2=((BN2(L,IARCH,IME,IEE))/100.)/((1+(BIE/100.))**20)
4470      SALV=((-BL(L,IARCH,IME,IEE))/100.)/((1+(BIE/100.))**30)
4480      PVC=((RENV1+RENV2+SALV+1)*FCOST(IREG,L,IARCH,IME,IEE))
4490      GUAC(L)=(((PVC*(BIE/100.))*(1+BIE/100.)**RN))/((1+BIE/100.)**RN-1)
4500      TGUAC=TGUAC+GUAC(L)
4510      IF (IPR.EQ."Y") PRINT ,"GUAC(L) ",GUAC(L),"  PVC  ",PVC
4520      IF (IPR.EQ."Y") PRINT ,"TGUAC",TGUAC
4530C
4540 70   CONTINUE
4550      TGUAC=TGUAC*CIDX(IC)
4560C
4570      TTUAC=TGUAC*BSQ
4580C
4590      IF (IPR.EQ."Y") PRINT,"TTUAC",TTUAC
4600C
4610C
4620       DO 72 L=1,JT
4630C
4640       APT(L)=TFUEL(L)*AP(L)*ECIDX(IC,L)
4650       DIA(L)=((1+(BIE/100))/(1+(E(L)/100)))-1
4660       P(L)=(((1+DIA(L))**RN)-1)/(DIA(L)*((1+DIA(L))**RN))
4670       EA(L)=(BIE/100)*((1+BIE/100)**RN)/(((1+BIE/100)**RN)-1)
```

```
4680       UAC(L)=P(L)*EA(L)*APT(L)
4690       TUAC=TUAC+UAC(L)
4700C
4710 72    CONTINUE
4720C
4730      IF (IPR.EQ."Y") PRINT ,"TUAC",TUAC
4740C *** COMPUTE TOTAL LIFE CYCLE COST
4750C
4760      TUFF(IC,IARCH,IME,IEE)=TUFMA
4770      TGUU(IC,IARCH,IME,IEE)=TGUAC
4780      TBSQ(IC,IARCH,IME,IEE)=TUAC/BSQ
4790C
4800      TSQFT(IC,IARCH,IME,IEE)=TUFMA+TGUAC+TUAC/BSQ
4810      TBLDG(IC,IARCH,IME,IEE)=TSQFT(IC,IARCH,IME,IEE)*BSQ
4820C
4830      IF (IPR.EQ."Y") PRINT,"TBLDG",TBLDG(IC,IARCH,IME,IEE)
4840      IF (IPR.EQ."Y") PRINT,"TSQFT",TSQFT(IC,IARCH,IME,IEE)
4850C
4860 4          CONTINUE
4870   3      CONTINUE
4880       2 CONTINUE
4890        1 CONTINUE
4900C
4910      WRITE (6,106)
4920 106 FORMAT ("1",45X,"ANNUAL HEATING FUEL USE (BTU/SQFT-YR)")
4930      WRITE (6,107)
4940 107 FORMAT ("0",14X,"LENIENT",26X,"MODERATE 1",23X,"MODERATE 2",
4950 &            23X,"STRINGENT")
4960      WRITE (6,102)
4970      DO 8 I = 1,IENDREG
4980      WRITE (6,104) I,(((TFU1(I,J,K,L),L=1,2),K=1,2),J=1,4)
4990 8    CONTINUE
4995      IF (PTR.EQ."TTY43") PRINT 123,
4996 123 FORMAT (1X,14(/))
5000      WRITE (6,108)
5010 108 FORMAT ("1",45X,"ANNUAL ELECTRICAL USE (BTU/SQFT-YR)")
5020      WRITE (6,107)
5030      WRITE (6,102)
5040      DO 9 I = 1,IENDREG
```

```
5050      WRITE (6,104) I,(((TFU2(I,J,K,L),L=1,2),K=1,2),J=1,4)
5060 104 FORMAT ("0",I2,16(1X,F7.0))
5070 9    CONTINUE
5075      IF (PTR.EQ."TTY43") PRINT 123,
5080      WRITE (6,109)
5090 109 FORMAT ("1",45X,"ANNUAL ENERGY COST ($/SQFT-YR)")
5100      WRITE (6,107)
5110      WRITE (6,102)
5120      DO 110 I =1,IENDREG
5130      WRITE (6,105) I,(((TBSQ(I,J,K,L),L=1,2),K=1,2),J=1,4)
5140 105 FORMAT ("0",I2,16(1X,F7.2))
5150  110 CONTINUE
5155      IF (PTR.EQ."TTY43") PRINT 123,
5160      WRITE (6,111)
5170 111 FORMAT ("1",45X,"ANNUAL COST OF CAPITALIZATION ($/SQFT-YR)")
5180      WRITE (6,107)
5190      WRITE (6,102)
5200      DO 120 I=1,IENDREG
5210      WRITE (6,105) I,(((TGUU(I,J,K,L),L=1,2),K=1,2),J=1,4)
5220  120 CONTINUE
5225      IF (PTR.EQ."TTY43") PRINT 123,
5230      WRITE (6,112)
5240 112 FORMAT ("1",45X,"ANNUAL COST OF MAINTENANCE ($/SQFT-YR)")
5250      WRITE (6,107)
5260      WRITE (6,102)
5270      DO 130 I = 1,IENDREG
5280      WRITE (6,105) I,(((TUFF(I,J,K,L),L=1,2),K=1,2),J=1,4)
5290  130 CONTINUE
5295      IF (PTR.EQ."TTY43") PRINT 123,
5300      WRITE (6,101)
5310 101 FORMAT ("1",45X,"TOTAL BUILDING LIFE CYCLE COST ($/SQFT-YR)")
5320      WRITE (6,107)
5330C
5340      WRITE (6,102)
5350 102   FORMAT ("0","CR",4(1X,"*","ME1EE1",2X,"ME1EE2",2X,"ME2EE1",2X,"ME2EE2"))
5360C
5370      DO 7 I = 1,IENDREG
5380C
5390        WRITE (6,105) I, (((TSQFT(I,J,K,L),L=1,2),K=1,2),J=1,4)
```

```
5400C FORMAT FOR TOTAL BLDG SQFT LCC   FORMAT ("0",I2,16(1X,F7.0))
5410C
5420      7 CONTINUE
5430C
5440    STOP;END
```

# APPENDIX 4

# LISTING OF PROGRAM VARIABLES

# LISTING OF PROGRAM VARIABLES

| | TYPE VARIABLE | | | |
|---|---|---|---|---|
| VARIABLE | INPUT | CALCULATION | UNITS | DESCRIPTION |
| A | x | | Sq. Ft. | Area of envelope component |
| AP | x | | $/Million BTU | 1980 Annual fuel cost |
| APT | | x | $/Yr | Present year annual energy cost |
| BET | | x | BTU/Yr | Consumption level section season |
| BIE | x | | % | State minimum required rate of return |
| BL | x | | % | Salvage value bldg. system expressed as % of first cost |
| BN1 | x | | % | 1st renovation of systems @ year 10 expressed as % of first cost |
| BN2 | x | | % | 2nd renovation of systems @ year 20 expressed as % of first cost |
| BSQ | x | | | Total building square feet |
| BTT | | x | BTU/Yr | Total building lighting consumption |
| CFM | x | | CFM | CFM of outside air brought in throughout the time interval I |
| CIDX | x | | | Construction cost index |
| DEN | x | | BTU/Yr/Sq.Ft. | Electrical distribution energy consumption |
| DHW | x | | Gal/Person/Day | Daily hot water consumption |
| DIA | | x | % | Adjusted discount rate -fuels |
| DSE | | x | % | Discounted escalation rate |
| E | x | | % | Compounded escalation rate for each fuel |

## LISTING OF PROGRAM VARIABLES

| | TYPE VARIABLE | | | |
|---|---|---|---|---|
| VARIABLE | INPUT | CALCULATION | UNITS | DESCRIPTION |
| EA | | x | | Capital recovery factor determined from uniform annual cost for fuel |
| ECIDX | x | | | Energy cost index |
| ECON | x | | % | Conversion efficiency for primary fuel |
| EET | | x | KWH/Yr | Total annual electrical energy for lighting |
| EOCS | | x | BTU/Yr | Heat gain from human occupants |
| ETT | | x | KWH/Yr | Total building lighting consumption |
| FCOST | x | | $/Sq.Ft. | First cost of construction for building thermal system |
| FESC | x | | % | Escalation rate for M & O costs for time period year 5 to end year |
| FMA | x | | $/Yr | Initial maintenance costs for 1st 5 years |
| FUEL1 | | x | BTU/Yr | Total conversion losses for heating fuel |
| GUAC | | x | $/Sq.Ft. | Uniform annual cost for all capital outlays, by system |
| ICC | x | | | Occupancy level per occupancy schedule interval |
| IEE | | x | | Electrical construction level number |
| IME | | x | | Mechanical construction level number |
| IOC | x | | | Average daily occupancy level (interger for DHW computation) |
| IPR | | x | | Printout option variable |
| IPRI | | x | | Printout option variable |

# LISTING OF PROGRAM VARIABLES

| | TYPE VARIABLE | | | |
|---|---|---|---|---|
| VARIABLE | INPUT | CALCULATION | UNITS | DESCRIPTION |
| IR | x | | | # of occupancy schedule intervals with lighting on |
| IREG | | x | | Climate region number |
| KWH | | x | KWH/Yr | Energy consumption level for bldg. section and occupancy interval |
| NL | x | | | # of areas building divided into for lighting calculations |
| OCR | | x | HR-persons/Yr | # of HR-persons/occ. schedule interval-Yr |
| OCS | | x | | # of HR-persons/Yr of occupancy |
| P | | x | | Present worth factor for annual fuel costs escalating at annual rate E(L) |
| PST | | x | #/Yr Sq.Ft. | Present worth of escalated M & O, by system |
| PTR | | x | | Printout option variable |
| PVC | | x | | Total present worth of all capital outlays |
| Q | | x | BTU/Yr | Component conduction heat loss |
| QCT | | x | BTU/Yr | Total conduction heat loss |
| QOHW | | x | BTU/Yr | Energy to heat domestic water |
| QIE | | x | BTU/Yr | Ventilation schedule component heat loss |
| QIET | | x | BTU/Yr | Total yearly ventilation system losses |
| QT | | x | BTU/Yr | Total systems energy consumption |
| RDX | | x | | Infiltration credit for stringent thermal construction |

# LISTING OF PROGRAM VARIABLES

| | TYPE VARIABLE | | | |
|---|---|---|---|---|
| VARIABLE | INPUT | CALCULATION | UNITS | DESCRIPTION |
| RENV1 | | x | $/Sq.Ft. | By system, present worth of renovation cost at RN=10 |
| RENV2 | | x | $/Sq.Ft. | By system, present worth of renovation cost at RN=20 |
| RMTT | | x | BTU/Yr | Mechanical systems energy recovered as credit |
| RN | x | | Yrs | Expected lifetime of building in yrs |
| ROOFM | | x | | Correction factor for sloped roof |
| RTT | | x | BTU/Yr | Total energy credits |
| RTU | | x | BTU/Yr | Total energy consumed w/credits considered w/o conversion losses |
| RTV | | x | BTU/Yr | Total energy credits w/o conversion losses |
| SALV | | x | | Salvage value, present worth by system |
| ST | x | | % | % of building space w/lighting level (fraction) |
| STT | x | | BTU/Yr | Solar energys recovered as credit |
| SUN | x | | BTU/Yr Sq. Ft. | Amount of recoverable solar energy credit for structure |
| TBLDG | | x | $/Yr | Total lifecycle cost |
| TBSQ | | x | $/Sq.Ft.-Yr | Annualized costs of energy |
| TFCOST | | | | Not used this run |
| TFU1 | | x | BTU/Sq.Ft.-Yr | Annual heating fuel energy consumption |
| TFU2 | | x | BTU/Sq.Ft.-Yr | Annual electrical energy consumption annualized |

## LISTING OF PROGRAM VARIABLES

| | TYPE VARIABLE | | | |
|---|---|---|---|---|
| VARIABLE | INPUT | CALCULATION | UNITS | DESCRIPTION |
| TFUEL1 | | x | BTU/Yr | Total consumption of heating fuel at site boundary |
| TFUEL2 | | x | BTU/Yr | Total consumption of electrical at site boundary |
| TGUAC | | x | $/Sq.Ft.-Yr | Total annualized cost of construction renovation and salvage, for all systems |
| TGUU | | x | $/Sq.Ft.-Yr | Annualized cost of construction |
| TL | x | | Hrs | Length of the heating season |
| TLCR | x | | | Fraction of lighting energy to space |
| TMCR | x | | | Fraction of mechanical system distribution energies to space |
| TMTT | | x | BTU/Yr | Distribution energy for building |
| TOUT | x | | °F | Mean annual heating season temperature |
| TRA | x | | °F | Average heating season interior space temperature |
| TRD | x | | °F | Interior space termperature (day) |
| TRN | x | | °F | Interior space temperature (night) |
| TSQFT | | x | $/Sq.Ft.-Yr | Total life cycle cost |
| TT | x | | | Time interval (% of heating season) |
| TTUAC | | x | $/Yr | Total uniform annual cost for building for all systems, for first cost, renovation and salvage |

## LISTING OF PROGRAM VARIABLES

|  | TYPE VARIABLE |  |  |  |
|---|---|---|---|---|
| VARIABLE | INPUT | CALCULATION | UNITS | DESCRIPTION |
| TUFF |  | x | $/Sq.Ft.-Yr | Annualized cost of maintenance and operation |
| TUFMA |  | x | $/Sq.Ft.-Yr | Total annualized cost of maintenance and operation, all systems |
| U | x |  | BTU/Yr-Sq.Ft./°F | Overall value of thermal conductance |
| UA |  |  |  | Not used this run |
| UAC |  | x | $/Yr | Equivalent uniform annual cost of energy over lifetime of building for fuel |
| UFMA |  | x | $/Yr-Sq.Ft. | Uniform annual costs for maintenance and operation by system |
| WFT | x |  | Watts/Sq.Ft. | Energy consumption level |

# APPENDIX 5

# ANNUAL ENERGY USE SUMMARIES

```
*RUN *
                                          ANNUAL HEATING FUEL USE (BTU/SQFT-YR)

               LENIENT                                   MODERATE 1                               MODERATE 2                               STRINGENT

CR *ME1EE1  ME1EE2  ME2EE1  ME2EE2 *ME1EE1  ME1EE2  ME2EE1  ME2EE2 *ME1EE1  ME1EE2  ME2EE1  ME2EE2 *ME1EE1  ME1EE2  ME2EE1  ME2EE2

 1 105324. 116030.  82639.  93345.  90266. 100973.  69145.  79851.  76835.  87541.  55714.  66420.  67697.  78403.  48140.  58846.

 2 105324. 116030.  82639.  93345.  90266. 100973.  69145.  79851.  76835.  87541.  55714.  66420.  67697.  78403.  48140.  58846.

 3 105324. 116030.  82639.  93345.  90266. 100973.  69145.  79851.  76835.  87541.  55714.  66420.  67697.  78403.  48140.  58846.

 4  72864.  83571.  56307.  67013.  60482.  71188.  45182.  55888.  52171.  62877.  36871.  47577.  41138.  51844.  27095.  37802.

 5  72864.  83571.  56307.  67013.  60482.  71188.  45182.  55888.  52171.  62877.  36871.  47577.  41138.  51844.  27095.  37802.

 6  72864.  83571.  56307.  67013.  60482.  71188.  45182.  55888.  52171.  62877.  36871.  47577.  41138.  51844.  27095.  37802.

 7  72864.  83571.  56307.  67013.  60482.  71188.  45182.  55888.  52171.  62877.  36871.  47577.  41138.  51844.  27095.  37802.

 8 145644. 156350. 106888. 117594. 124281. 134987.  87893.  98599. 109311. 120017.  72923.  83629.  78589.  89295.  44568.  55275.

 9 145644. 156350. 106888. 117594. 124281. 134987.  87893.  98599. 109311. 120017.  72923.  83629.  78589.  89295.  44568.  55275.

10  99890. 110596.  85940.  96646.  81743.  92449.  68920.  79626.  70296.  81003.  57474.  68180.  44090.  54796.  32394.  43101.

11 157059. 167765. 132708. 143414. 136292. 146998. 113588. 124295. 122776. 133482. 100072. 110778.  92320. 103026.  71263.  81970.

12 157059. 167765. 132708. 143414. 136292. 146998. 113588. 124295. 122776. 133482. 100072. 110778.  92320. 103026.  71263.  81970.

13 157059. 167765. 132708. 143414. 136292. 146998. 113588. 124295. 122776. 133482. 100072. 110778.  92320. 103026.  71263.  81970.

14 161294. 172000. 118687. 129394. 138123. 148829.  98076. 108782. 121873. 132579.  81826.  92532. 100526. 111233.  63040.  73746.

15 242705. 253412. 204733. 215439. 212921. 223627. 177277. 187983. 193501. 204208. 157857. 168563. 165898. 176604. 132582. 143288.

16 242705. 253412. 204733. 215439. 212921. 223627. 177277. 187983. 193501. 204208. 157857. 168563. 165898. 176604. 132582. 143288.
```

# ANNUAL ELECTRICAL USE (BTU/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 2 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 3 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 4 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 5 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 6 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 7 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 8 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 9 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 10 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 11 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 12 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 13 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 14 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 15 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |
| 16 | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. | 35981. | 26613. | 28459. | 19091. |

## APPENDIX 6

## LIFE CYCLE COST SUMMARY

# APPENDIX 6A

## SUMMARY FOR LOWER BOUND ENERGY ESCALATIONS

## (8% FOR HEATING FUEL AND ELECTRICITY)

ANNUAL ENERGY COST ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 4.12 | 3.70 | 3.25 | 2.83 | 3.87 | 3.44 | 3.02 | 2.60 | 3.64 | 3.21 | 2.79 | 2.37 | 3.48 | 3.06 | 2.66 | 2.24 |
| 2 | 8.75 | 7.12 | 6.91 | 5.28 | 8.49 | 6.86 | 6.68 | 5.05 | 8.26 | 6.63 | 6.45 | 4.82 | 8.10 | 6.48 | 6.32 | 4.69 |
| 3 | 5.62 | 4.80 | 4.43 | 3.62 | 5.36 | 4.55 | 4.20 | 3.39 | 5.13 | 4.32 | 3.97 | 3.16 | 4.98 | 4.16 | 3.84 | 3.03 |
| 4 | 4.03 | 3.48 | 3.17 | 2.62 | 3.82 | 3.28 | 2.98 | 2.43 | 3.68 | 3.13 | 2.84 | 2.29 | 3.50 | 2.95 | 2.67 | 2.13 |
| 5 | 3.22 | 2.87 | 2.52 | 2.17 | 3.02 | 2.66 | 2.34 | 1.99 | 2.88 | 2.53 | 2.21 | 1.85 | 2.70 | 2.35 | 2.05 | 1.69 |
| 6 | 4.27 | 3.67 | 3.35 | 2.76 | 4.05 | 3.46 | 3.16 | 2.56 | 3.91 | 3.31 | 3.01 | 2.42 | 3.71 | 3.12 | 2.84 | 2.25 |
| 7 | 2.97 | 2.70 | 2.33 | 2.06 | 2.76 | 2.49 | 2.14 | 1.87 | 2.62 | 2.35 | 1.99 | 1.73 | 2.43 | 2.16 | 1.83 | 1.56 |
| 8 | 5.07 | 4.55 | 3.87 | 3.35 | 4.72 | 4.20 | 3.56 | 3.04 | 4.47 | 3.95 | 3.32 | 2.80 | 3.97 | 3.45 | 2.85 | 2.33 |
| 9 | 9.58 | 8.17 | 7.39 | 5.98 | 9.10 | 7.70 | 6.97 | 5.56 | 8.77 | 7.36 | 6.63 | 5.22 | 8.08 | 6.67 | 6.00 | 4.59 |
| 10 | 5.47 | 4.70 | 4.45 | 3.68 | 5.15 | 4.38 | 4.15 | 3.38 | 4.95 | 4.17 | 3.95 | 3.17 | 4.48 | 3.71 | 3.50 | 2.73 |
| 11 | 7.21 | 6.26 | 5.86 | 4.90 | 6.84 | 5.89 | 5.51 | 4.56 | 6.60 | 5.65 | 5.27 | 4.32 | 6.05 | 5.10 | 4.76 | 3.80 |
| 12 | 8.09 | 6.96 | 6.56 | 5.43 | 7.69 | 6.57 | 6.19 | 5.07 | 7.44 | 6.31 | 5.94 | 4.81 | 6.86 | 5.73 | 5.39 | 4.27 |
| 13 | 13.59 | 11.23 | 10.94 | 8.59 | 13.12 | 10.76 | 10.51 | 8.15 | 12.81 | 10.45 | 10.20 | 7.84 | 12.11 | 9.75 | 9.54 | 7.18 |
| 14 | 17.56 | 15.45 | 13.47 | 11.37 | 16.47 | 14.37 | 12.50 | 10.40 | 15.71 | 13.61 | 11.74 | 9.64 | 14.71 | 12.61 | 10.86 | 8.76 |
| 15 | 4.28 | 3.44 | 3.43 | 2.60 | 4.17 | 3.33 | 3.33 | 2.49 | 4.10 | 3.26 | 3.26 | 2.42 | 3.99 | 3.16 | 3.16 | 2.33 |
| 16 | 11.64 | 10.25 | 9.49 | 8.10 | 10.98 | 9.59 | 8.88 | 7.49 | 10.55 | 9.16 | 8.45 | 7.06 | 9.94 | 8.55 | 7.89 | 6.50 |

## ANNUAL COST OF CAPITALIZATION ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 5.78 | 5.82 | 7.27 | 7.30 | 6.10 | 6.13 | 7.58 | 7.62 | 6.73 | 6.77 | 8.22 | 8.25 | 7.78 | 7.82 | 9.27 | 9.30 |
| 2 | 6.24 | 6.28 | 7.84 | 7.88 | 6.57 | 6.61 | 8.17 | 8.21 | 7.26 | 7.30 | 8.86 | 8.90 | 8.39 | 8.43 | 9.99 | 10.03 |
| 3 | 6.33 | 6.37 | 7.95 | 7.99 | 6.67 | 6.71 | 8.29 | 8.33 | 7.37 | 7.41 | 8.99 | 9.03 | 8.52 | 8.56 | 10.14 | 10.18 |
| 4 | 5.27 | 5.31 | 6.65 | 6.68 | 5.40 | 5.44 | 6.78 | 6.81 | 5.68 | 5.72 | 7.06 | 7.09 | 6.28 | 6.31 | 7.65 | 7.68 |
| 5 | 5.98 | 6.02 | 7.54 | 7.58 | 6.13 | 6.17 | 7.69 | 7.73 | 6.45 | 6.49 | 8.01 | 8.05 | 7.12 | 7.16 | 8.68 | 8.72 |
| 6 | 8.41 | 8.46 | 10.60 | 10.65 | 8.62 | 8.67 | 10.81 | 10.86 | 9.06 | 9.12 | 11.25 | 11.31 | 10.01 | 10.06 | 12.20 | 12.26 |
| 7 | 6.24 | 6.28 | 7.86 | 7.90 | 6.39 | 6.43 | 8.01 | 8.05 | 6.72 | 6.76 | 8.34 | 8.38 | 7.42 | 7.46 | 9.05 | 9.09 |
| 8 | 6.03 | 6.07 | 7.60 | 7.64 | 6.18 | 6.22 | 7.75 | 7.79 | 6.50 | 6.54 | 8.07 | 8.11 | 7.18 | 7.22 | 8.75 | 8.79 |
| 9 | 9.92 | 9.98 | 12.50 | 12.56 | 10.16 | 10.23 | 12.75 | 12.81 | 10.69 | 10.75 | 13.27 | 13.33 | 11.81 | 11.87 | 14.39 | 14.45 |
| 10 | 11.14 | 11.21 | 13.87 | 13.94 | 11.77 | 11.84 | 14.50 | 14.57 | 13.06 | 13.12 | 15.79 | 15.85 | 15.16 | 15.23 | 17.89 | 17.96 |
| 11 | 6.97 | 7.02 | 8.79 | 8.83 | 7.14 | 7.19 | 8.96 | 9.00 | 7.51 | 7.56 | 9.33 | 9.37 | 8.30 | 8.34 | 10.11 | 10.16 |
| 12 | 7.13 | 7.18 | 8.99 | 9.03 | 7.31 | 7.35 | 9.16 | 9.21 | 7.68 | 7.73 | 9.54 | 9.59 | 8.49 | 8.53 | 10.35 | 10.39 |
| 13 | 11.37 | 11.44 | 14.33 | 14.40 | 11.65 | 11.72 | 14.61 | 14.68 | 12.25 | 12.32 | 15.21 | 15.28 | 13.53 | 13.61 | 16.49 | 16.57 |
| 14 | 12.39 | 12.47 | 15.62 | 15.70 | 12.70 | 12.78 | 15.93 | 16.01 | 13.36 | 13.43 | 16.58 | 16.66 | 14.75 | 14.83 | 17.98 | 18.06 |
| 15 | 8.91 | 8.96 | 11.23 | 11.28 | 9.13 | 9.18 | 11.45 | 11.50 | 9.60 | 9.65 | 11.92 | 11.97 | 10.60 | 10.66 | 12.92 | 12.98 |
| 16 | 13.68 | 13.77 | 17.24 | 17.33 | 14.02 | 14.11 | 17.58 | 17.67 | 14.74 | 14.83 | 18.30 | 18.39 | 16.28 | 16.37 | 19.85 | 19.94 |

# ANNUAL COST OF MAINTENANCE ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 0.09 | 0.09 | 0.18 | 0.18 | 0.09 | 0.09 | 0.18 | 0.18 | 0.09 | 0.09 | 0.18 | 0.18 | 0.09 | 0.09 | 0.18 | 0.18 |
| 2 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 |
| 3 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 |
| 4 | 0.08 | 0.08 | 0.16 | 0.16 | 0.08 | 0.08 | 0.16 | 0.16 | 0.08 | 0.08 | 0.16 | 0.16 | 0.08 | 0.08 | 0.16 | 0.16 |
| 5 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 |
| 6 | 0.13 | 0.13 | 0.26 | 0.26 | 0.13 | 0.13 | 0.26 | 0.26 | 0.13 | 0.13 | 0.26 | 0.26 | 0.13 | 0.13 | 0.26 | 0.26 |
| 7 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 |
| 8 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 |
| 9 | 0.15 | 0.15 | 0.31 | 0.31 | 0.15 | 0.15 | 0.31 | 0.31 | 0.15 | 0.15 | 0.31 | 0.31 | 0.15 | 0.15 | 0.31 | 0.31 |
| 10 | 0.16 | 0.16 | 0.32 | 0.32 | 0.16 | 0.16 | 0.32 | 0.32 | 0.16 | 0.16 | 0.32 | 0.32 | 0.16 | 0.16 | 0.32 | 0.32 |
| 11 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 |
| 12 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 |
| 13 | 0.18 | 0.18 | 0.35 | 0.35 | 0.18 | 0.18 | 0.35 | 0.35 | 0.18 | 0.18 | 0.35 | 0.35 | 0.18 | 0.18 | 0.35 | 0.35 |
| 14 | 0.19 | 0.19 | 0.38 | 0.38 | 0.19 | 0.19 | 0.38 | 0.38 | 0.19 | 0.19 | 0.38 | 0.38 | 0.19 | 0.19 | 0.38 | 0.38 |
| 15 | 0.14 | 0.14 | 0.28 | 0.28 | 0.14 | 0.14 | 0.28 | 0.28 | 0.14 | 0.14 | 0.28 | 0.28 | 0.14 | 0.14 | 0.28 | 0.28 |
| 16 | 0.21 | 0.21 | 0.42 | 0.42 | 0.21 | 0.21 | 0.42 | 0.42 | 0.21 | 0.21 | 0.42 | 0.42 | 0.21 | 0.21 | 0.42 | 0.42 |

## TOTAL BUILDING LIFE CYCLE COST ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 10.00 | 9.61 | 10.69 | 10.31 | 10.05 | 9.66 | 10.77 | 10.39 | 10.46 | 10.07 | 11.18 | 10.80 | 11.35 | 10.97 | 12.10 | 11.72 |
| 2 | 15.08 | 13.49 | 14.93 | 13.35 | 15.16 | 13.57 | 15.04 | 13.45 | 15.62 | 14.03 | 15.50 | 13.91 | 16.59 | 15.01 | 16.50 | 14.91 |
| 3 | 12.04 | 11.27 | 12.58 | 11.80 | 12.13 | 11.35 | 12.69 | 11.91 | 12.59 | 11.82 | 13.16 | 12.38 | 13.59 | 12.81 | 14.18 | 13.40 |
| 4 | 9.39 | 8.87 | 9.98 | 9.46 | 9.31 | 8.79 | 9.92 | 9.41 | 9.45 | 8.93 | 10.06 | 9.54 | 9.85 | 9.34 | 10.49 | 9.97 |
| 5 | 9.30 | 8.98 | 10.25 | 9.94 | 9.24 | 8.93 | 10.22 | 9.90 | 9.42 | 9.11 | 10.40 | 10.08 | 9.92 | 9.60 | 10.91 | 10.60 |
| 6 | 12.80 | 12.26 | 14.21 | 13.67 | 12.80 | 12.26 | 14.23 | 13.68 | 13.10 | 12.56 | 14.53 | 13.98 | 13.85 | 13.31 | 15.30 | 14.76 |
| 7 | 9.30 | 9.07 | 10.38 | 10.15 | 9.24 | 9.02 | 10.34 | 10.12 | 9.43 | 9.20 | 10.53 | 10.30 | 9.95 | 9.72 | 11.07 | 10.84 |
| 8 | 11.20 | 10.71 | 11.66 | 11.18 | 10.99 | 10.51 | 11.50 | 11.02 | 11.06 | 10.58 | 11.57 | 11.09 | 11.24 | 10.76 | 11.79 | 11.30 |
| 9 | 19.65 | 18.31 | 20.20 | 18.86 | 19.42 | 18.07 | 20.02 | 18.68 | 19.61 | 18.26 | 20.21 | 18.86 | 20.04 | 18.70 | 20.69 | 19.35 |
| 10 | 16.78 | 16.07 | 18.65 | 17.94 | 17.08 | 16.38 | 18.97 | 18.27 | 18.17 | 17.46 | 20.06 | 19.35 | 19.80 | 19.10 | 21.71 | 21.01 |
| 11 | 14.29 | 13.38 | 14.86 | 13.95 | 14.09 | 13.18 | 14.69 | 13.78 | 14.22 | 13.31 | 14.82 | 13.91 | 14.46 | 13.55 | 15.09 | 14.18 |
| 12 | 15.33 | 14.25 | 15.77 | 14.69 | 15.11 | 14.03 | 15.58 | 14.50 | 15.23 | 14.15 | 15.70 | 14.62 | 15.45 | 14.38 | 15.96 | 14.88 |
| 13 | 25.14 | 22.85 | 25.63 | 23.34 | 24.94 | 22.66 | 25.47 | 23.19 | 25.23 | 22.95 | 25.76 | 23.48 | 25.82 | 23.53 | 26.39 | 24.10 |
| 14 | 30.14 | 28.12 | 29.48 | 27.46 | 29.36 | 27.34 | 28.82 | 26.80 | 29.26 | 27.23 | 28.71 | 26.69 | 29.66 | 27.63 | 29.23 | 27.21 |
| 15 | 13.33 | 12.54 | 14.94 | 14.15 | 13.43 | 12.65 | 15.05 | 14.27 | 13.83 | 13.05 | 15.45 | 14.67 | 14.73 | 13.95 | 16.36 | 15.58 |
| 16 | 25.53 | 24.23 | 27.16 | 25.86 | 25.21 | 23.91 | 26.89 | 25.59 | 25.50 | 24.20 | 27.18 | 25.88 | 26.43 | 25.13 | 28.16 | 26.86 |

*

# APPENDIX 6B

## SUMMARY FOR UPPER BOUND ENERGY ESCALATIONS

## (12% FOR HEATING FUEL AND ELECTRICTY)

## ANNUAL ENERGY COST ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 7.15 | 6.42 | 5.64 | 4.90 | 6.71 | 5.97 | 5.24 | 4.50 | 6.31 | 5.57 | 4.84 | 4.11 | 6.04 | 5.30 | 4.62 | 3.88 |
| 2 | 15.17 | 12.35 | 11.98 | 9.16 | 14.73 | 11.91 | 11.58 | 8.76 | 14.33 | 11.51 | 11.18 | 8.36 | 14.06 | 11.24 | 10.96 | 8.14 |
| 3 | 9.74 | 8.33 | 7.69 | 6.28 | 9.30 | 7.89 | 7.29 | 5.88 | 8.90 | 7.49 | 6.89 | 5.48 | 8.63 | 7.22 | 6.67 | 5.26 |
| 4 | 7.00 | 6.05 | 5.49 | 4.54 | 6.63 | 5.68 | 5.17 | 4.22 | 6.39 | 5.44 | 4.92 | 3.97 | 6.07 | 5.11 | 4.64 | 3.69 |
| 5 | 5.58 | 4.97 | 4.38 | 3.77 | 5.23 | 4.62 | 4.06 | 3.45 | 5.00 | 4.39 | 3.83 | 3.22 | 4.68 | 4.07 | 3.55 | 2.94 |
| 6 | 7.40 | 6.37 | 5.81 | 4.78 | 7.03 | 5.99 | 5.48 | 4.45 | 6.78 | 5.74 | 5.23 | 4.19 | 6.44 | 5.41 | 4.93 | 3.90 |
| 7 | 5.15 | 4.69 | 4.03 | 3.57 | 4.78 | 4.32 | 3.71 | 3.24 | 4.54 | 4.08 | 3.46 | 3.00 | 4.21 | 3.75 | 3.17 | 2.71 |
| 8 | 8.80 | 7.90 | 6.72 | 5.82 | 8.19 | 7.29 | 6.18 | 5.28 | 7.76 | 6.86 | 5.75 | 4.85 | 6.88 | 5.98 | 4.94 | 4.04 |
| 9 | 16.62 | 14.18 | 12.82 | 10.38 | 15.79 | 13.35 | 12.09 | 9.65 | 15.21 | 12.77 | 11.51 | 9.06 | 14.02 | 11.58 | 10.41 | 7.97 |
| 10 | 9.49 | 8.15 | 7.72 | 6.38 | 8.93 | 7.59 | 7.20 | 5.86 | 8.58 | 7.24 | 6.85 | 5.50 | 7.78 | 6.43 | 6.07 | 4.73 |
| 11 | 12.51 | 10.86 | 10.16 | 8.51 | 11.87 | 10.21 | 9.57 | 7.91 | 11.45 | 9.79 | 9.15 | 7.49 | 10.50 | 8.85 | 8.25 | 6.60 |
| 12 | 14.03 | 12.08 | 11.38 | 9.43 | 13.35 | 11.40 | 10.75 | 8.80 | 12.90 | 10.95 | 10.30 | 8.35 | 11.89 | 9.94 | 9.35 | 7.40 |
| 13 | 23.58 | 19.49 | 18.99 | 14.90 | 22.76 | 18.67 | 18.23 | 14.14 | 22.22 | 18.13 | 17.69 | 13.60 | 21.01 | 16.92 | 16.55 | 12.46 |
| 14 | 30.46 | 26.81 | 23.37 | 19.72 | 28.58 | 24.93 | 21.69 | 18.05 | 27.25 | 23.61 | 20.37 | 16.73 | 25.52 | 21.87 | 18.85 | 15.20 |
| 15 | 7.43 | 5.97 | 5.96 | 4.50 | 7.23 | 5.78 | 5.78 | 4.32 | 7.11 | 5.65 | 5.65 | 4.20 | 6.93 | 5.48 | 5.49 | 4.04 |
| 16 | 20.20 | 17.79 | 16.47 | 14.06 | 19.05 | 16.64 | 15.41 | 13.00 | 18.30 | 15.89 | 14.66 | 12.25 | 17.24 | 14.83 | 13.69 | 11.28 |

## ANNUAL COST OF CAPITALIZATION ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 5.78 | 5.82 | 7.27 | 7.30 | 6.10 | 6.13 | 7.58 | 7.62 | 6.73 | 6.77 | 8.22 | 8.25 | 7.78 | 7.82 | 9.27 | 9.30 |
| 2 | 6.24 | 6.28 | 7.84 | 7.88 | 6.57 | 6.61 | 8.17 | 8.21 | 7.26 | 7.30 | 8.86 | 8.90 | 8.39 | 8.43 | 9.99 | 10.03 |
| 3 | 6.33 | 6.37 | 7.95 | 7.99 | 6.67 | 6.71 | 8.29 | 8.33 | 7.37 | 7.41 | 8.99 | 9.03 | 8.52 | 8.56 | 10.14 | 10.18 |
| 4 | 5.27 | 5.31 | 6.65 | 6.68 | 5.40 | 5.44 | 6.78 | 6.81 | 5.68 | 5.72 | 7.06 | 7.09 | 6.28 | 6.31 | 7.65 | 7.68 |
| 5 | 5.98 | 6.02 | 7.54 | 7.58 | 6.13 | 6.17 | 7.69 | 7.73 | 6.45 | 6.49 | 8.01 | 8.05 | 7.12 | 7.16 | 8.68 | 8.72 |
| 6 | 8.41 | 8.46 | 10.60 | 10.65 | 8.62 | 8.67 | 10.81 | 10.86 | 9.06 | 9.12 | 11.25 | 11.31 | 10.01 | 10.06 | 12.20 | 12.26 |
| 7 | 6.24 | 6.28 | 7.86 | 7.90 | 6.39 | 6.43 | 8.01 | 8.05 | 6.72 | 6.76 | 8.34 | 8.38 | 7.42 | 7.46 | 9.05 | 9.09 |
| 8 | 6.03 | 6.07 | 7.60 | 7.64 | 6.18 | 6.22 | 7.75 | 7.79 | 6.50 | 6.54 | 8.07 | 8.11 | 7.18 | 7.22 | 8.75 | 8.79 |
| 9 | 9.92 | 9.98 | 12.50 | 12.56 | 10.16 | 10.23 | 12.75 | 12.81 | 10.69 | 10.75 | 13.27 | 13.33 | 11.81 | 11.87 | 14.39 | 14.45 |
| 10 | 11.14 | 11.21 | 13.87 | 13.94 | 11.77 | 11.84 | 14.50 | 14.57 | 13.06 | 13.12 | 15.79 | 15.85 | 15.16 | 15.23 | 17.89 | 17.96 |
| 11 | 6.97 | 7.02 | 8.79 | 8.83 | 7.14 | 7.19 | 8.96 | 9.00 | 7.51 | 7.56 | 9.33 | 9.37 | 8.30 | 8.34 | 10.11 | 10.16 |
| 12 | 7.13 | 7.18 | 8.99 | 9.03 | 7.31 | 7.35 | 9.16 | 9.21 | 7.68 | 7.73 | 9.54 | 9.59 | 8.49 | 8.53 | 10.35 | 10.39 |
| 13 | 11.37 | 11.44 | 14.33 | 14.40 | 11.65 | 11.72 | 14.61 | 14.68 | 12.25 | 12.32 | 15.21 | 15.28 | 13.53 | 13.61 | 16.49 | 16.57 |
| 14 | 12.39 | 12.47 | 15.62 | 15.70 | 12.70 | 12.78 | 15.93 | 16.01 | 13.36 | 13.43 | 16.58 | 16.66 | 14.75 | 14.83 | 17.98 | 18.06 |
| 15 | 8.91 | 8.96 | 11.23 | 11.28 | 9.13 | 9.18 | 11.45 | 11.50 | 9.60 | 9.65 | 11.92 | 11.97 | 10.60 | 10.66 | 12.92 | 12.98 |
| 16 | 13.68 | 13.77 | 17.24 | 17.33 | 14.02 | 14.11 | 17.58 | 17.67 | 14.74 | 14.83 | 18.30 | 18.39 | 16.28 | 16.37 | 19.85 | 19.94 |

## ANNUAL COST OF MAINTENANCE ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 0.09 | 0.09 | 0.18 | 0.18 | 0.09 | 0.09 | 0.18 | 0.18 | 0.09 | 0.09 | 0.18 | 0.18 | 0.09 | 0.09 | 0.18 | 0.18 |
| 2 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 |
| 3 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 |
| 4 | 0.08 | 0.08 | 0.16 | 0.16 | 0.08 | 0.08 | 0.16 | 0.16 | 0.08 | 0.08 | 0.16 | 0.16 | 0.08 | 0.08 | 0.16 | 0.16 |
| 5 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 |
| 6 | 0.13 | 0.13 | 0.26 | 0.26 | 0.13 | 0.13 | 0.26 | 0.26 | 0.13 | 0.13 | 0.26 | 0.26 | 0.13 | 0.13 | 0.26 | 0.26 |
| 7 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 | 0.10 | 0.10 | 0.19 | 0.19 |
| 8 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 | 0.09 | 0.09 | 0.19 | 0.19 |
| 9 | 0.15 | 0.15 | 0.31 | 0.31 | 0.15 | 0.15 | 0.31 | 0.31 | 0.15 | 0.15 | 0.31 | 0.31 | 0.15 | 0.15 | 0.31 | 0.31 |
| 10 | 0.16 | 0.16 | 0.32 | 0.32 | 0.16 | 0.16 | 0.32 | 0.32 | 0.16 | 0.16 | 0.32 | 0.32 | 0.16 | 0.16 | 0.32 | 0.32 |
| 11 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 |
| 12 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 | 0.11 | 0.11 | 0.22 | 0.22 |
| 13 | 0.18 | 0.18 | 0.35 | 0.35 | 0.18 | 0.18 | 0.35 | 0.35 | 0.18 | 0.18 | 0.35 | 0.35 | 0.18 | 0.18 | 0.35 | 0.35 |
| 14 | 0.19 | 0.19 | 0.38 | 0.38 | 0.19 | 0.19 | 0.38 | 0.38 | 0.19 | 0.19 | 0.38 | 0.38 | 0.19 | 0.19 | 0.38 | 0.38 |
| 15 | 0.14 | 0.14 | 0.28 | 0.28 | 0.14 | 0.14 | 0.28 | 0.28 | 0.14 | 0.14 | 0.28 | 0.28 | 0.14 | 0.14 | 0.28 | 0.28 |
| 16 | 0.21 | 0.21 | 0.42 | 0.42 | 0.21 | 0.21 | 0.42 | 0.42 | 0.21 | 0.21 | 0.42 | 0.42 | 0.21 | 0.21 | 0.42 | 0.42 |

TOTAL BUILDING LIFE CYCLE COST ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 13.02 | 12.33 | 13.08 | 12.38 | 12.89 | 12.19 | 12.99 | 12.30 | 13.13 | 12.43 | 13.23 | 12.54 | 13.91 | 13.21 | 14.06 | 13.36 |
| 2 | 21.51 | 18.72 | 20.01 | 17.23 | 21.40 | 18.61 | 19.95 | 17.16 | 21.69 | 18.90 | 20.24 | 17.45 | 22.55 | 19.77 | 21.14 | 18.36 |
| 3 | 16.17 | 14.80 | 15.83 | 14.46 | 16.07 | 14.69 | 15.77 | 14.40 | 16.37 | 14.99 | 16.07 | 14.70 | 17.25 | 15.87 | 17.00 | 15.63 |
| 4 | 12.35 | 11.43 | 12.30 | 11.39 | 12.12 | 11.20 | 12.11 | 11.19 | 12.15 | 11.24 | 12.14 | 11.23 | 12.42 | 11.51 | 12.45 | 11.53 |
| 5 | 11.66 | 11.09 | 12.11 | 11.54 | 11.46 | 10.89 | 11.94 | 11.37 | 11.54 | 10.96 | 12.02 | 11.45 | 11.90 | 11.33 | 12.42 | 11.84 |
| 6 | 15.94 | 14.96 | 16.67 | 15.70 | 15.77 | 14.80 | 16.55 | 15.57 | 15.97 | 14.99 | 16.74 | 15.76 | 16.58 | 15.61 | 17.39 | 16.42 |
| 7 | 11.48 | 11.06 | 12.09 | 11.67 | 11.27 | 10.85 | 11.91 | 11.49 | 11.35 | 10.93 | 12.00 | 11.57 | 11.73 | 11.31 | 12.41 | 11.99 |
| 8 | 14.92 | 14.06 | 14.51 | 13.65 | 14.46 | 13.60 | 14.12 | 13.25 | 14.35 | 13.49 | 14.01 | 13.14 | 14.16 | 13.29 | 13.88 | 13.02 |
| 9 | 26.69 | 24.31 | 25.63 | 23.25 | 26.11 | 23.73 | 25.14 | 22.76 | 26.05 | 23.67 | 25.08 | 22.70 | 25.98 | 23.60 | 25.10 | 22.72 |
| 10 | 20.80 | 19.52 | 21.92 | 20.64 | 20.87 | 19.59 | 22.02 | 20.75 | 21.80 | 20.53 | 22.96 | 21.68 | 23.10 | 21.82 | 24.29 | 23.01 |
| 11 | 19.59 | 17.98 | 19.16 | 17.55 | 19.12 | 17.51 | 18.74 | 17.13 | 19.07 | 17.46 | 18.69 | 17.08 | 18.91 | 17.30 | 18.58 | 16.97 |
| 12 | 21.27 | 19.37 | 20.59 | 18.68 | 20.76 | 18.86 | 20.13 | 18.23 | 20.69 | 18.79 | 20.06 | 18.16 | 20.49 | 18.59 | 19.92 | 18.01 |
| 13 | 35.13 | 31.11 | 33.67 | 29.65 | 34.58 | 30.56 | 33.19 | 29.17 | 34.65 | 30.63 | 33.26 | 29.24 | 34.72 | 30.70 | 33.40 | 29.38 |
| 14 | 43.05 | 39.48 | 39.38 | 35.81 | 41.47 | 37.90 | 38.01 | 34.44 | 40.80 | 37.23 | 37.34 | 33.77 | 40.47 | 36.90 | 37.21 | 33.65 |
| 15 | 16.47 | 15.07 | 17.46 | 16.06 | 16.50 | 15.10 | 17.50 | 16.10 | 16.84 | 15.45 | 17.85 | 16.45 | 17.67 | 16.27 | 18.69 | 17.29 |
| 16 | 34.09 | 31.77 | 34.14 | 31.81 | 33.28 | 30.96 | 33.41 | 31.09 | 33.25 | 30.93 | 33.39 | 31.07 | 33.73 | 31.41 | 33.96 | 31.64 |

*

# APPENDIX 6C

# SUMMARY FOR 0% FUEL ESCALATION LCC CALCULATIONS

ANNUAL ENERGY COST ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 1.74 | 1.56 | 1.37 | 1.19 | 1.63 | 1.45 | 1.27 | 1.09 | 1.53 | 1.35 | 1.18 | 1.00 | 1.47 | 1.29 | 1.12 | 0.94 |
| 2 | 3.69 | 3.00 | 2.91 | 2.23 | 3.58 | 2.89 | 2.82 | 2.13 | 3.48 | 2.80 | 2.72 | 2.03 | 3.42 | 2.73 | 2.66 | 1.98 |
| 3 | 2.37 | 2.02 | 1.87 | 1.53 | 2.26 | 1.92 | 1.77 | 1.43 | 2.16 | 1.82 | 1.68 | 1.33 | 2.10 | 1.76 | 1.62 | 1.28 |
| 4 | 1.70 | 1.47 | 1.34 | 1.10 | 1.61 | 1.38 | 1.26 | 1.03 | 1.55 | 1.32 | 1.20 | 0.97 | 1.47 | 1.24 | 1.13 | 0.90 |
| 5 | 1.36 | 1.21 | 1.06 | 0.92 | 1.27 | 1.12 | 0.99 | 0.84 | 1.21 | 1.07 | 0.93 | 0.78 | 1.14 | 0.99 | 0.86 | 0.71 |
| 6 | 1.80 | 1.55 | 1.41 | 1.16 | 1.71 | 1.46 | 1.33 | 1.08 | 1.65 | 1.40 | 1.27 | 1.02 | 1.57 | 1.32 | 1.20 | 0.95 |
| 7 | 1.25 | 1.14 | 0.98 | 0.87 | 1.16 | 1.05 | 0.90 | 0.79 | 1.10 | 0.99 | 0.84 | 0.73 | 1.02 | 0.91 | 0.77 | 0.66 |
| 8 | 2.14 | 1.92 | 1.63 | 1.41 | 1.99 | 1.77 | 1.50 | 1.28 | 1.89 | 1.67 | 1.40 | 1.18 | 1.67 | 1.45 | 1.20 | 0.98 |
| 9 | 4.04 | 3.45 | 3.12 | 2.52 | 3.84 | 3.24 | 2.94 | 2.34 | 3.70 | 3.10 | 2.80 | 2.20 | 3.41 | 2.81 | 2.53 | 1.94 |
| 10 | 2.31 | 1.98 | 1.88 | 1.55 | 2.17 | 1.85 | 1.75 | 1.42 | 2.09 | 1.76 | 1.66 | 1.34 | 1.89 | 1.56 | 1.48 | 1.15 |
| 11 | 3.04 | 2.64 | 2.47 | 2.07 | 2.88 | 2.48 | 2.33 | 1.92 | 2.78 | 2.38 | 2.22 | 1.82 | 2.55 | 2.15 | 2.01 | 1.60 |
| 12 | 3.41 | 2.94 | 2.77 | 2.29 | 3.24 | 2.77 | 2.61 | 2.14 | 3.14 | 2.66 | 2.50 | 2.03 | 2.89 | 2.42 | 2.27 | 1.80 |
| 13 | 5.73 | 4.74 | 4.62 | 3.62 | 5.53 | 4.54 | 4.43 | 3.44 | 5.40 | 4.41 | 4.30 | 3.31 | 5.11 | 4.11 | 4.02 | 3.03 |
| 14 | 7.40 | 6.52 | 5.68 | 4.79 | 6.95 | 6.06 | 5.27 | 4.39 | 6.62 | 5.74 | 4.95 | 4.07 | 6.20 | 5.32 | 4.58 | 3.69 |
| 15 | 1.81 | 1.45 | 1.45 | 1.09 | 1.76 | 1.40 | 1.40 | 1.05 | 1.73 | 1.37 | 1.37 | 1.02 | 1.68 | 1.33 | 1.33 | 0.98 |
| 16 | 4.91 | 4.32 | 4.00 | 3.42 | 4.63 | 4.04 | 3.75 | 3.16 | 4.45 | 3.86 | 3.56 | 2.98 | 4.19 | 3.60 | 3.33 | 2.74 |

E/0,0.1

## TOTAL BUILDING LIFE CYCLE COST ($/SQFT-YR)

| | LENIENT | | | | MODERATE 1 | | | | MODERATE 2 | | | | STRINGENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 | *ME1EE1 | ME1EE2 | ME2EE1 | ME2EE2 |
| 1 | 7.61 | 7.47 | 8.81 | 8.67 | 7.81 | 7.67 | 9.03 | 8.89 | 8.35 | 8.21 | 9.57 | 9.43 | 9.34 | 9.20 | 10.56 | 10.42 |
| 2 | 10.02 | 9.37 | 10.94 | 10.29 | 10.25 | 9.60 | 11.18 | 10.53 | 10.84 | 10.19 | 11.77 | 11.12 | 11.91 | 11.26 | 12.85 | 12.20 |
| 3 | 8.79 | 8.49 | 10.01 | 9.71 | 9.03 | 8.72 | 10.26 | 9.95 | 9.63 | 9.32 | 10.86 | 10.55 | 10.71 | 10.41 | 11.95 | 11.65 |
| 4 | 7.06 | 6.86 | 8.15 | 7.95 | 7.10 | 6.90 | 8.20 | 8.00 | 7.32 | 7.12 | 8.42 | 8.22 | 7.83 | 7.64 | 8.94 | 8.74 |
| 5 | 7.43 | 7.32 | 8.79 | 8.68 | 7.50 | 7.39 | 8.86 | 8.75 | 7.75 | 7.64 | 9.12 | 9.01 | 8.35 | 8.24 | 9.73 | 9.62 |
| 6 | 10.34 | 10.14 | 12.27 | 12.08 | 10.46 | 10.26 | 12.40 | 12.20 | 10.84 | 10.64 | 12.78 | 12.59 | 11.71 | 11.51 | 13.66 | 13.46 |
| 7 | 7.58 | 7.51 | 9.03 | 8.96 | 7.65 | 7.58 | 9.11 | 9.04 | 7.92 | 7.85 | 9.38 | 9.30 | 8.54 | 8.47 | 10.01 | 9.94 |
| 8 | 8.26 | 8.08 | 9.42 | 9.24 | 8.26 | 8.08 | 9.44 | 9.26 | 8.48 | 8.30 | 9.65 | 9.47 | 8.95 | 8.76 | 10.14 | 9.96 |
| 9 | 14.11 | 13.58 | 15.92 | 15.39 | 14.15 | 13.62 | 15.99 | 15.46 | 14.54 | 14.01 | 16.37 | 15.84 | 15.37 | 14.84 | 17.23 | 16.70 |
| 10 | 13.61 | 13.35 | 16.07 | 15.81 | 14.11 | 13.85 | 16.58 | 16.32 | 15.31 | 15.05 | 17.78 | 17.52 | 17.21 | 16.95 | 19.69 | 19.43 |
| 11 | 10.12 | 9.76 | 11.47 | 11.11 | 10.14 | 9.78 | 11.50 | 11.14 | 10.40 | 10.04 | 11.77 | 11.41 | 10.96 | 10.60 | 12.34 | 11.98 |
| 12 | 10.65 | 10.22 | 11.97 | 11.55 | 10.66 | 10.23 | 12.00 | 11.57 | 10.93 | 10.50 | 12.27 | 11.84 | 11.49 | 11.06 | 12.84 | 12.41 |
| 13 | 17.28 | 16.35 | 19.30 | 18.38 | 17.36 | 16.44 | 19.39 | 18.47 | 17.83 | 16.90 | 19.86 | 18.94 | 18.82 | 17.89 | 20.87 | 19.95 |
| 14 | 19.99 | 19.18 | 21.69 | 20.88 | 19.84 | 19.03 | 21.59 | 20.78 | 20.17 | 19.36 | 21.92 | 21.11 | 21.15 | 20.34 | 22.95 | 22.14 |
| 15 | 10.85 | 10.55 | 12.95 | 12.65 | 11.02 | 10.73 | 13.13 | 12.83 | 11.46 | 11.17 | 13.57 | 13.27 | 12.42 | 12.13 | 14.53 | 14.24 |
| 16 | 18.80 | 18.30 | 21.67 | 21.17 | 18.86 | 18.36 | 21.75 | 21.25 | 19.40 | 18.90 | 22.29 | 21.79 | 20.69 | 20.19 | 23.60 | 23.10 |

TABLE 12

STATEWIDE CLIMATE/COST CONDITION SUMMARY

| COST REGION NUMBER | COST REGION NAME | CLIMATE REGION NUMBER | CLIMATE REGION NAME | CONSTRUCTION COST INDEX* | ENERGY COST INDEX | | MEAN ANNUAL HEATING SEASON TEMPERATURE (°F) | MEAN ANNUAL WIND SPEED (MPH) |
|---|---|---|---|---|---|---|---|---|
| | | | | | HEATING FUEL OIL** | ELECTRICITY*** | | |
| 1 | Anchorage Zone | 1 | South Central | 1.22 | 1.04 | 2.11 | 31.2 | 6.9 |
| 2 | Village | | | 1.32 | 1.04 | 6.32 | | |
| 3 | Kodiak Island | | | 1.34 | 1.04 | 3.48 | | |
| 4 | Juneau Zone | 2 | South Eastern | 1.13 | | 2.54 | 38.8 | 8.9 |
| 5 | Main Center | | | 1.29 | 1.00 | 1.84 | | |
| 6 | Village | | | 1.81 | 1.06 | 2.73 | | |
| 7 | Sitka Island | | | 1.34 | 1.04 | 1.57 | | |
| 8 | Fairbanks Zone | 3 | Southern Interior | 1.30 | 1.0 | 2.43 | 15.9 | 6.3 |
| 9 | Village | | | 2.13 | 1.36 | 5.75 | | |
| 10 | Village | 4 | Aleutian | 2.25 | 1.08 | 3.36 | 36.4 | 13.6 |
| 11 | Bethel | 5 | Western | 1.50 | 1.09 | 4.00 | 20.9 | 13.1 |
| 12 | Large Village | | | 1.53 | 1.16 | 4.63 | | |
| 13 | Coastal Village | | | 2.44 | 1.40 | 9.09 | | |
| 14 | Village | 6 | Northern Interior | 2.67 | 2.86 | 9.09 | 11.5 | 6.7 |
| 15 | Barrow | 7 | Arctic Slope | 1.92 | 1.36 | 3.06 | 0.6 | 12.5 |
| 16 | Coastal Village | | | 2.94 | 1.09 | 5.68 | | |

BASIS FOR INDICES:
* Base Construction Cost $100.00/Sq. Ft. Building Space
** Base Heating Fuel Oil Cost $0.957/Gal ($6.91/Million BTU's)
***Base Electricity Cost $0.044/KWH ($12.89/Million BTU's)