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TOWARD MORE EFFICIENT NONRESIDENTIAL BUILDINGS -- A UNITED STATES PERSPECTIVE

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TOPICS COVERED

I. WHAT ARE THE BUILDING ENERGY EFFICIENCIES THAT MIGHT BE ACHIEVED BETWEEN NOW AND THE YEAR 2000?

II. WHAT ARE THE STRATEGIES AND TECHNOLOGIES THAT COULD MAKE THE POTENTIALS A REALIZATION?

III. WHAT ARE THE PRESENT EXPERIENCES IN THE FIELD WHERE ENERGY-EFFICIENCY HAS BEEN ATTEMPTED?

IV. WHAT IS KNOWN ABOUT INDOOR ENVIRONMENTS?

V. THE ECONOMICS OF IMPROVING ENERGY USE

VI. OUTLOOK FOR BUILDINGS IN SOUTHEAST ASIA

Slide 1

Types of Buildings Making Up the Commercial Building Sector

Type of Building	Percent of Floor Area
Office	15%
Retail/Wholesale	18%
Garage	2%
Warehouse	8%
Educational	23%
Public	4%
Hospital	7%
Religious	5%
Hotel/Motel	6%
Miscellaneous	12%

Slide 2

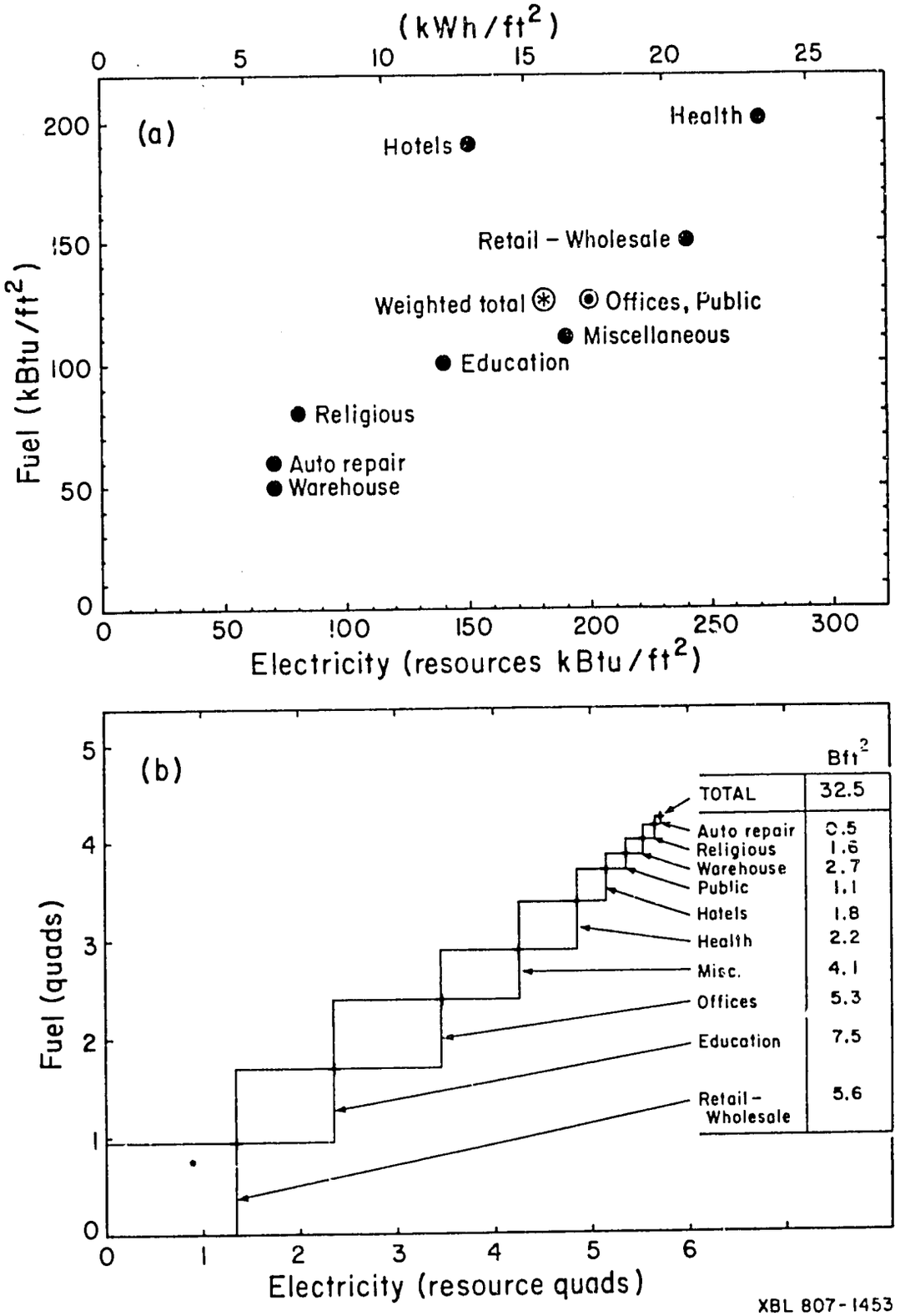
Use of Energy (10^{15} Btu's) in the Commercial Building Sector by End Use and Energy Type, 1978

End Use

Space Heat	Cooling	Water Heat	Light	Other	Total
4.46	2.26	.27	2.34	.8	10.1

Energy Type

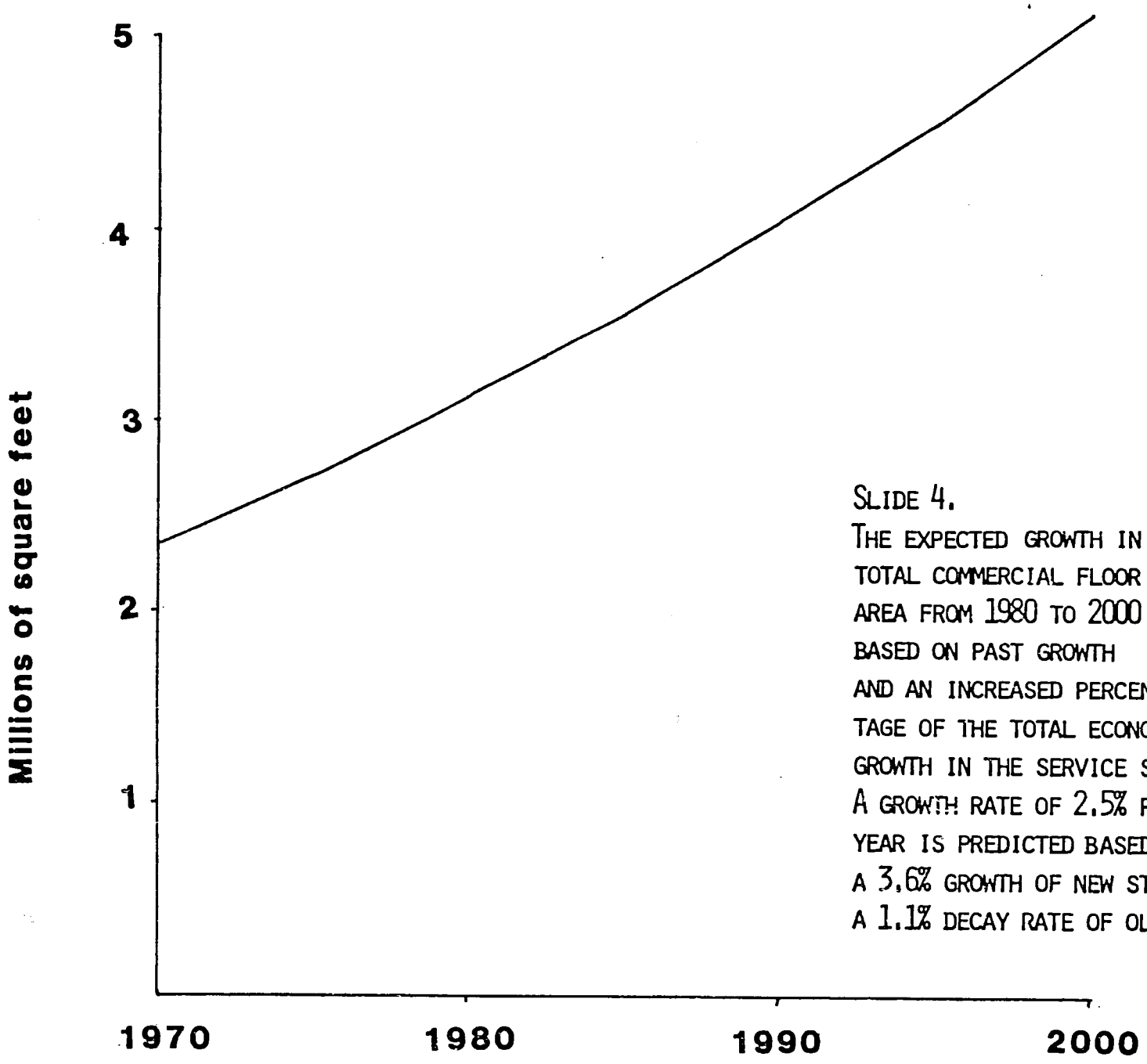
Electricity	Gas	Oil
6.73	2.12	1.17



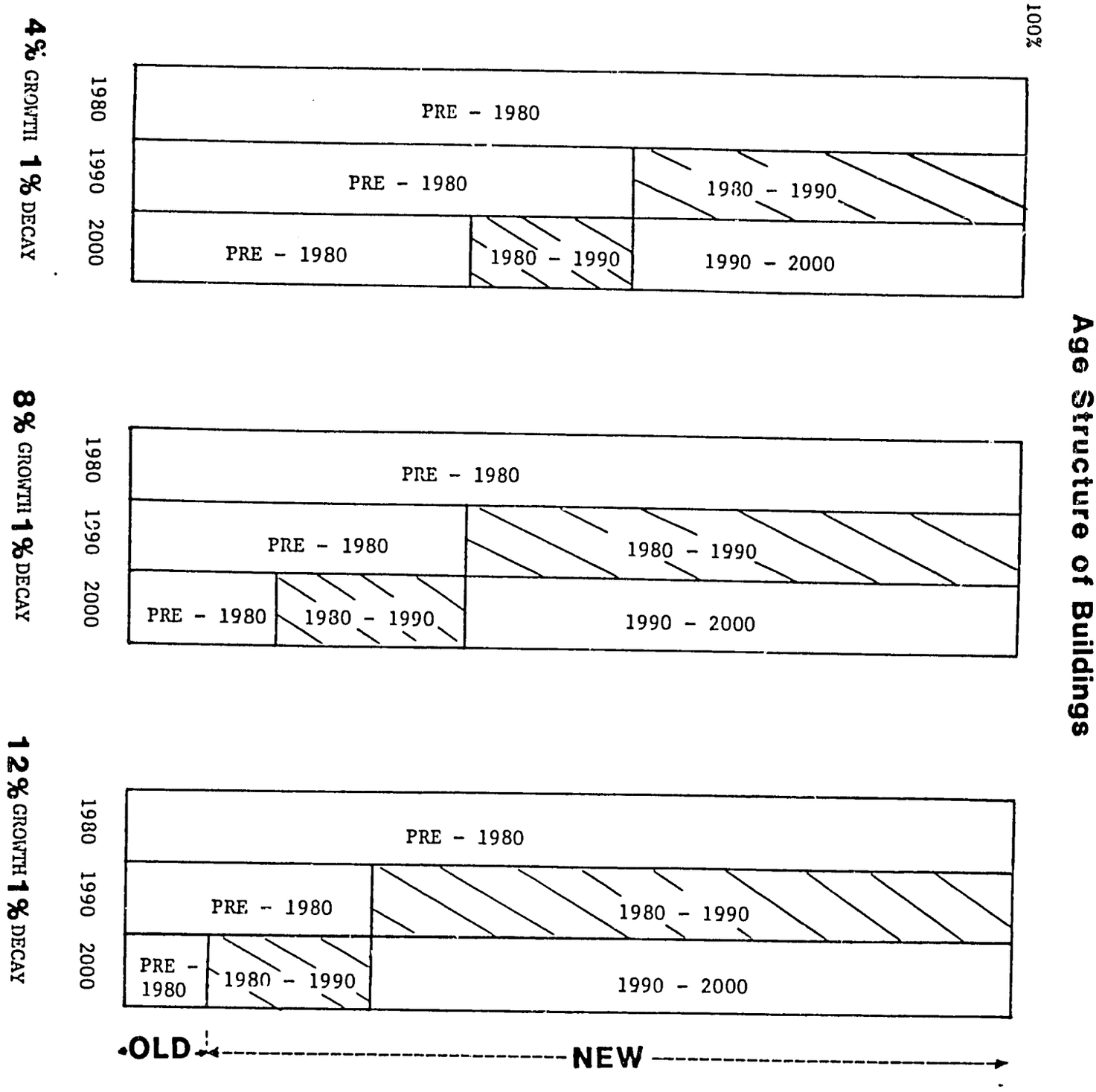
SLIDE 3

WHO ARE THE SMALL AND LARGE ENERGY USERS? SHOWN HERE IS A COMPARISON FOR THE VARIOUS BUILDING TYPES IN TERMS OF BOTH FUEL USE IN 1000S OF BTU'S/FT^2 AND ELECTRICITY USE IN KWH/FT^2.

TOTAL COMMERCIAL FLOORSPACE



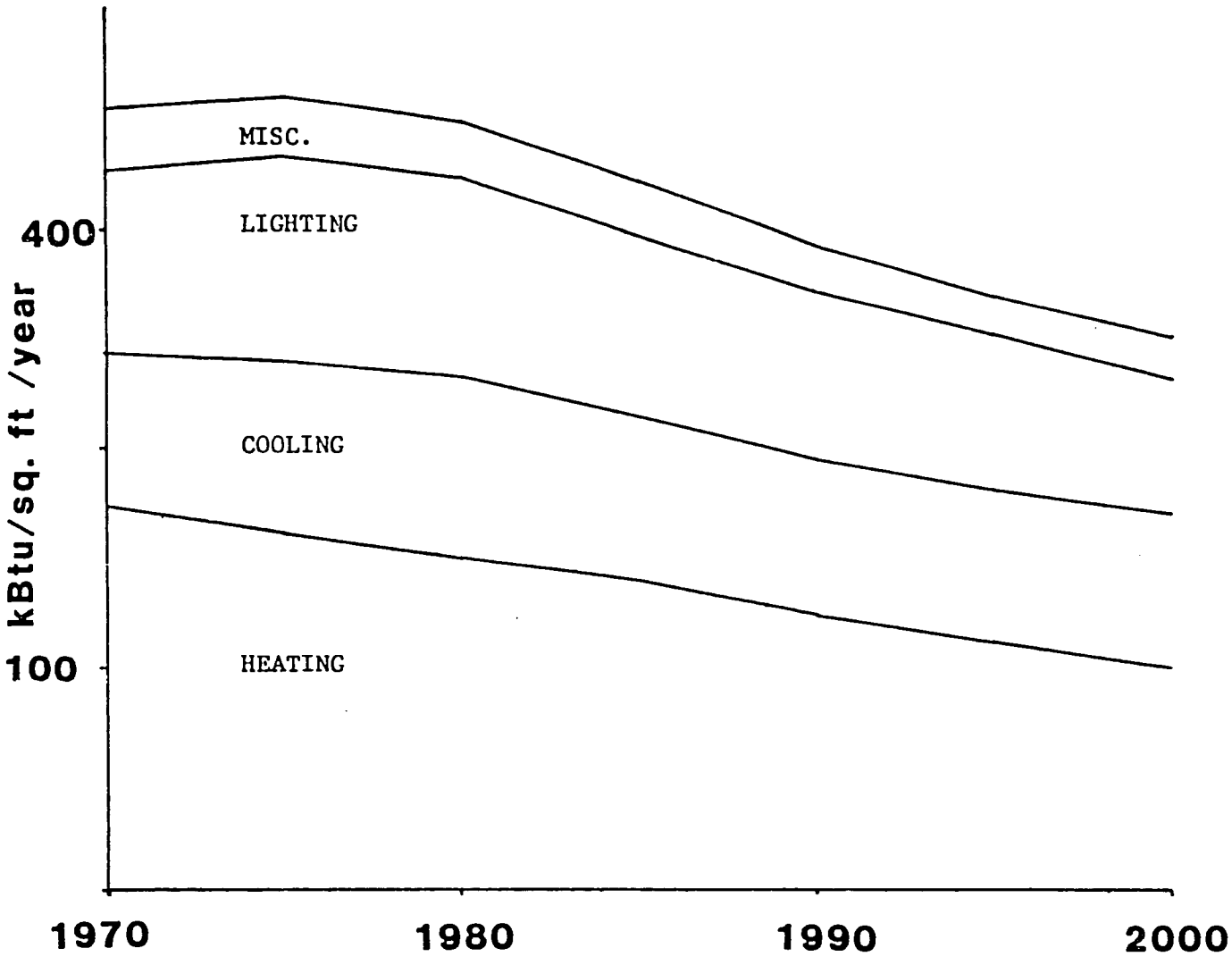
SLIDE 4.
THE EXPECTED GROWTH IN TOTAL COMMERCIAL FLOOR AREA FROM 1980 TO 2000 BASED ON PAST GROWTH AND AN INCREASED PERCENTAGE OF THE TOTAL ECONOMIC GROWTH IN THE SERVICE SECTOR. A GROWTH RATE OF 2.5% PER YEAR IS PREDICTED BASED ON A 3.6% GROWTH OF NEW STOCK AND A 1.1% DECAY RATE OF OLD STOCK.



SLIDE 5

THE AGE STRUCTURE OF BUILDINGS SHOWING HOW MUCH NEW STOCK WOULD BE PRESENT IN THE YEAR 2000 COMPARED TO THE YEAR 1980, ADDING NEW STOCK AT RATES OF 4%, 8%, AND 12%. THE OPPORTUNITY FOR DEVELOPING A CHANGE IN ENERGY USE PATTERNS BY 2000 IS SURE TO BE GREAT BECAUSE OF THE LARGE GROWTH RATE EXPECTED IN THE COMMERCIAL BUILDING SECTOR.

Office Energy Use



SLIDE 6. A PROJECTION OF ENERGY USE IN 1000S OF BTU'S/FT^2 IN THE OFFICE BUILDING SECTOR, SEPARATED ACCORDING TO END USES AND BASED UPON REACHING A 30% OVERALL IMPROVEMENT IN ENERGY-EFFICIENCY BY THE YEAR 2000.

SLIDE 7

QUESTION:

HOW CAN BUILDINGS BE MORE ENERGY-EFFICIENT WITHOUT SACRIFICING THE QUALITY OF INDOOR ENVIRONMENT, COMFORT, AESTHETICS, AND OCCUPANT PRODUCTIVITY?

ANSWER:

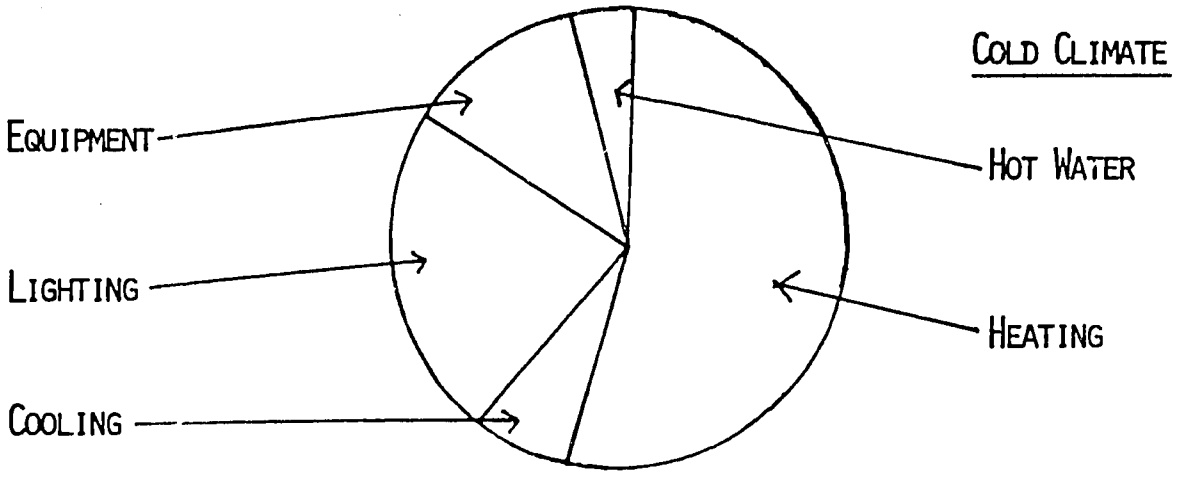
BY A COMBINATION OF INFORMATION, PRACTICE, AND INVESTMENT.

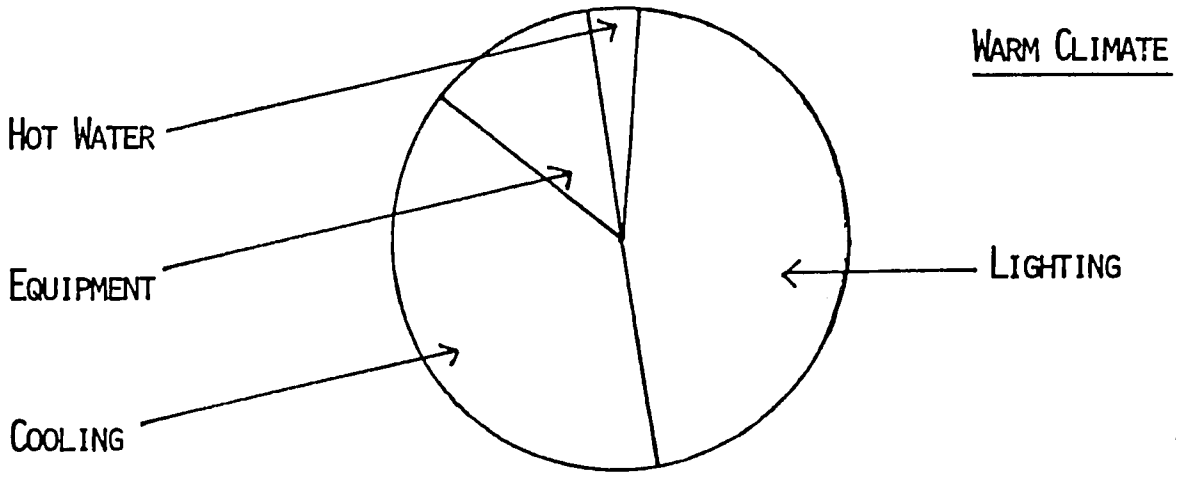
SLIDE 8
UNDERSTANDING BUILDING INTERACTING SYSTEMS

1. LOCATION — CLIMATE, RELATION TO OTHER BUILDINGS, COMMUNITY ACCESS
2. PHYSICAL ARCHITECTURAL PARAMETERS — SIZE, SHAPE, MATERIALS, LONGEVITY
3. INTERNAL SYSTEMS — LIGHTING, ELEVATORS, MACHINERY, FURNITURE, WATER, SEWERAGE
4. OCCUPANT REQUIREMENTS -- TEMPERATURE, HUMIDITY, SAFETY, AIR QUALITY, SCHEDULING, MAINTENANCE, EMERGENCIES
5. ECONOMICS — COSTS, INTEREST RATES, RENTS, TAXES, DEPRECIATION, RESALE
6. REGULATION — CODES, CONTROLS, LABOR LAWS

Slide 9

Typical Division of Energy Use in an Office Building





Slide 10

Major Opportunities for Improving the Energy Performance of Buildings

1. Operations and maintenance (O & M)
2. The Heating, ventilating, and air conditioning systems (HVAC systems)
3. Artificial and natural lighting and associated control systems
4. The air conditioning loads

Separate buildings into existing buildings with retrofit options and new buildings with different design options.

Slide 11

Examples of O & M Strategies for Improving Energy-Efficiency

No Cost

During the cooling season allow inside temperature to rise in unoccupied areas and during times of no occupation.

Low Cost

Control building ventilation.

Major Cost

Employ computer control systems for close watch on all energy systems.

Examples of HVAC System Strategies for Improving Energy-Efficiency

Low Cost

Introduce economizer cycle.

Major Cost

Introduce variable air volume (VAV) systems which regulate air flow to meet space conditioning requirements.

Slide 12

ANCO Engineers of Santa Monica, California report that modifications of air handling equipment in retrofits at 15 hospitals in southern California yield the following dollar savings:

Modification	Dollars Saved	Cost
Air Temperature	$ 377,600	$ 135,000
Air Flow	309,500	227,400
Improvement of Equipment Operation	329,600	191,900

SLIDE 13

EXAMPLES OF LIGHTING STRATEGIES FOR IMPROVING ENERGY-EFFICIENCY

LOW COST

DE-LAMP WHEN LIGHT LEVEL REQUIREMENTS PERMIT. ANCO ENGINEERS ESTIMATE THAT IN THE SAME HOSPITAL AN INVESTMENT OF $ 61,000 WILL GIVE FIRST-YEAR SAVINGS OF $ 120,000.

MAJOR COST

ADD PHOTOSENSORS FOR AVAILABLE DAYLIGHT WITH CONTROLS FOR ARTIFICIAL LIGHT.

EXAMPLES OF A/C LOAD STRATEGIES FOR IMPROVING ENERGY EFFICIENCY

LOW COST

ADD WINDOW SHADES OR BLINDS.

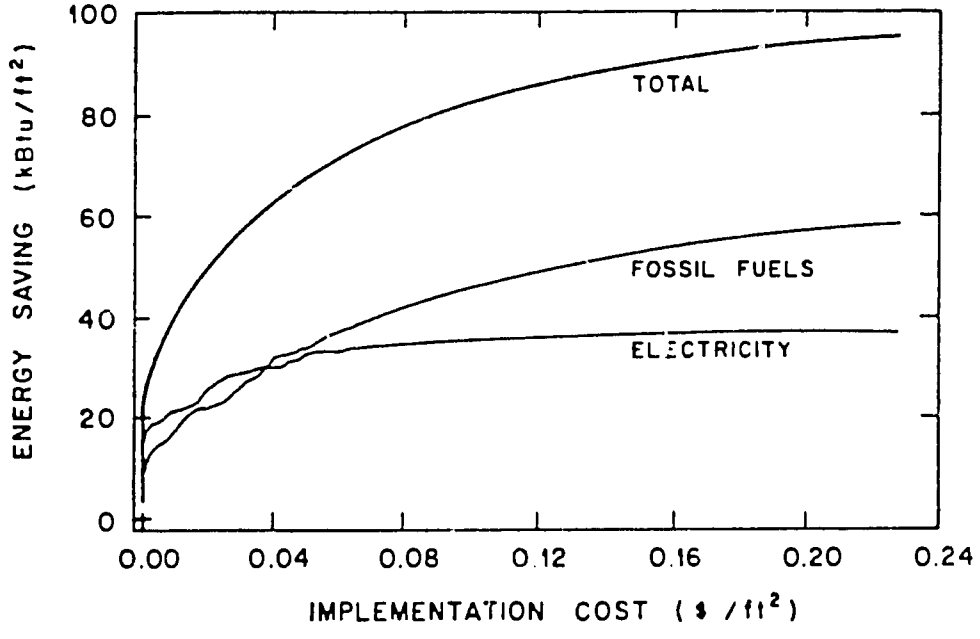
MAJOR COST

USE EXTERIOR SUN CONTROL SYSTEMS SUCH AS LOUVERED "EYELIDS".

SLIDE 14

THE CALCULATED ENERGY SAVINGS AS A FUNCTION OF COSTS BASED ON AN AUDIT OF 48 HOSPITALS. OF THE 900 SUGGESTED MEASURES, APPROXIMATELY 100 REQUIRED NO CAPITAL COST AT ALL. THE CONTINUOUS CURVES SHOWN CONNECT THE VARIOUS DISCRETE VALUES DETERMINED BY THE AUDIT-BASED CALCULATIONS. THE ELECTRICAL ENERGY SAVED (AT THE SITE) EVENTUALLY RISES AS THE COST INCREASES, BUT THESE SAVINGS ARE LESS THAN THE SAVINGS IN FOSSIL FUEL FOR THE SAME INVESTMENT.

AUDITS AT 48 HOSPITALS SHOW LARGE POTENTIAL ENERGY SAVINGS



Slide 15

Key to any investment decision is the accuracy which is associated with an energy-efficiency strategy. Since there is always the possibility that the calculations do not fully take into account the actual way a particular building behaves, the calculated savings and costs need to be compared to data compiled from actual installations and practices.

Slide 16

Compilations of actual retrofits done by Ross and Whalen, 1981

Selection of 222 Commercial Buildings

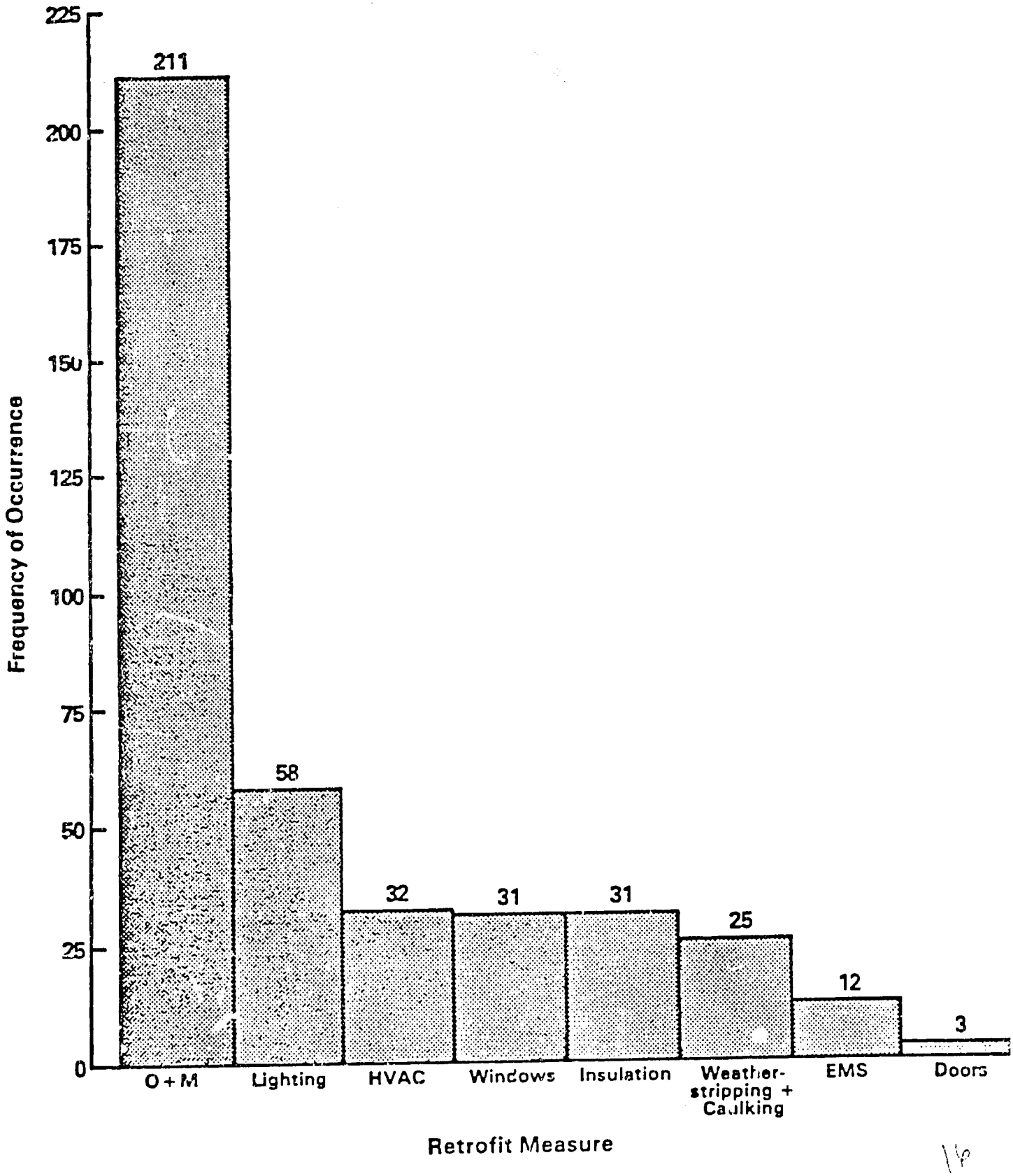
Type of Building
Large office building
Small office building
Elementary school
Secondary school
Hospital
Hotel/motel
Shopping center
Clinic

SLIDE 17

FREQUENCY DISTRIBUTION FOR THE VARIOUS RETROFIT STRATEGIES SHOWING THE STRONG PREFERENCE FOR OPERATIONS AND MAINTENANCE (O & M) AND LIGHTING.

Retrofits Attempted

N = 223



SLIDE 18

Description of Retrofit Categories

Operation + Maintenance (O)	All Actions Which Affect the Schedule of the Building Operation or the Manner in Which the HVAC Equipment Is Run; Does Not Refer to the Changing of the Design of the Primary or Secondary System Equipment
Lighting (L)	Replacement of Existing Lamps with More Energy Efficient Types, Delamping, Installing Task Lighting
HVAC (H)	Replacement of HVAC Equipment, Conversion of Equipment to a More Efficient Mode (e.g., Reheat to VAV) Rezoning of the Spaces
Windows (W)	Double or Triple Glazing of Windows, Addition of Reflecting Film Over Existing Windows, the Removal and Boarding of Windows
Weatherstripping & Caulking (C)	Self-Explanatory
Insulation (I)	Insulation of Walls, Roofs, Piping, and Ducts
Energy Management Control Systems (E)	Installation of New Central Computer Control Systems, Upgrading Present Systems
Architectural (A)	All Major Changes to the Actual Structure of the Building for the Purpose of Energy Conservation
Doors (D)	Replacement of Existing Doors with Tighter Fitting and Better Insulated Doors

SLIDE 19

Percent Savings by Building Type

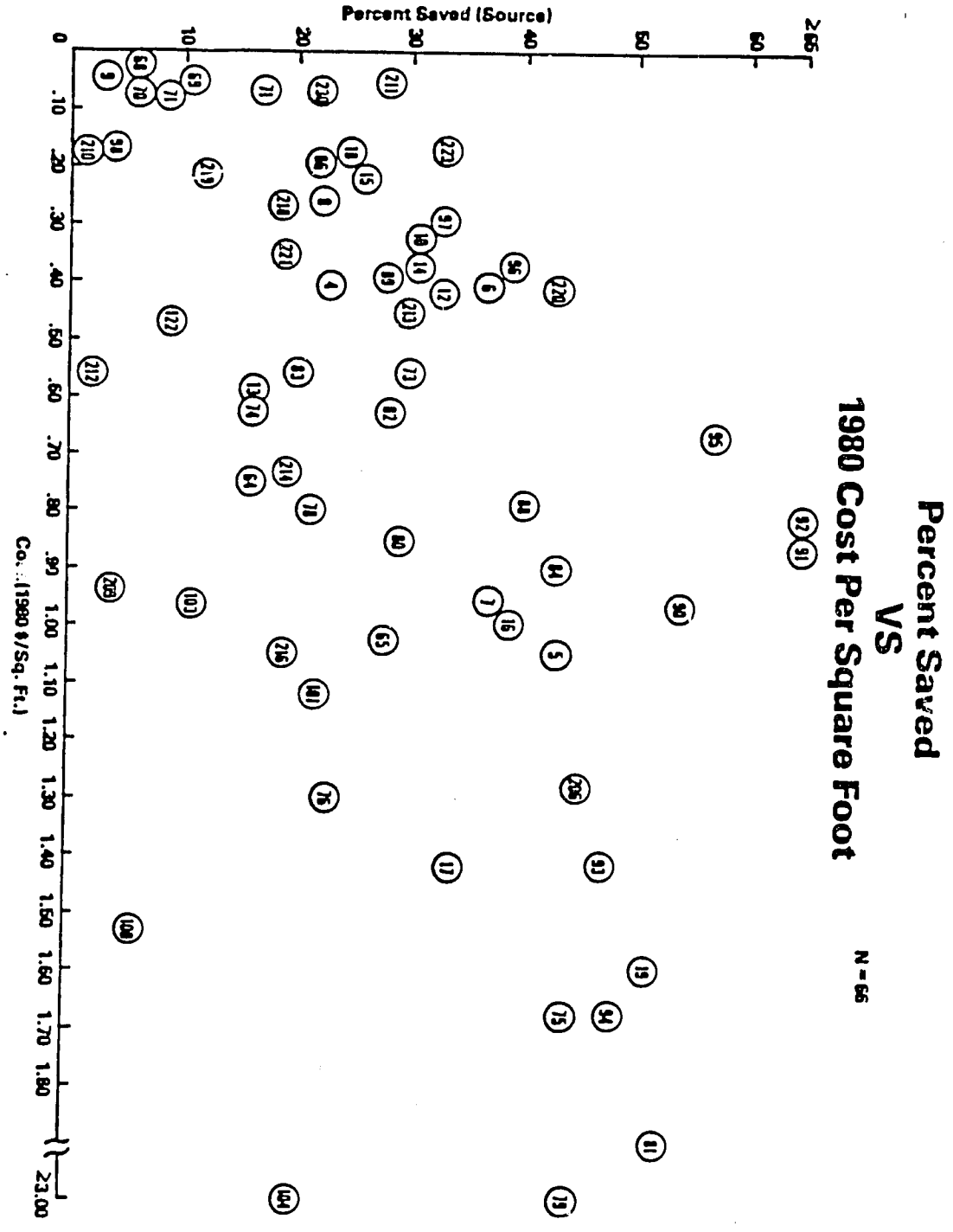
(Only Includes Buildings Which Attained Energy Savings >0.)

Building Category	Site		Source	
	Ave % Savings	Sample Size	Ave % Savings	Sample Size
Elementary	24%	72	21%	72
Secondary	30%	38	28%	37
Large Office	23%	37	21%	24
Hospital	21%	13	17%	10
Community Center	56%	3	23%	18
Hotel	25%	4	24%	4
Corrections	7%	4	5%	4
Small Office	33%	1	30%	1
Shopping Center	11%	1	11%	1
Multi Family Apartment	44%	1	43%	1

SLIDE 20

THE PERCENTAGE OF ENERGY SAVED IS SHOWN AS A FUNCTION OF COST IN DOLLARS PER SQUARE FOOT. THE AVERAGE COST WAS $ 0.65 ± $ 0.52 PER SQUARE FOOT. THE AVERAGE SAVINGS WAS 22% ± 15% WHEN BUILDINGS WITH FAILED RETROFITS WERE SUBTRACTED. THE AVERAGE COST IS APPROXIMATELY THE ANNUAL COST OF LIGHTING AT 3 WATTS PER SQUARE FOOT OF INSTALLED LIGHTING CAPACITY.

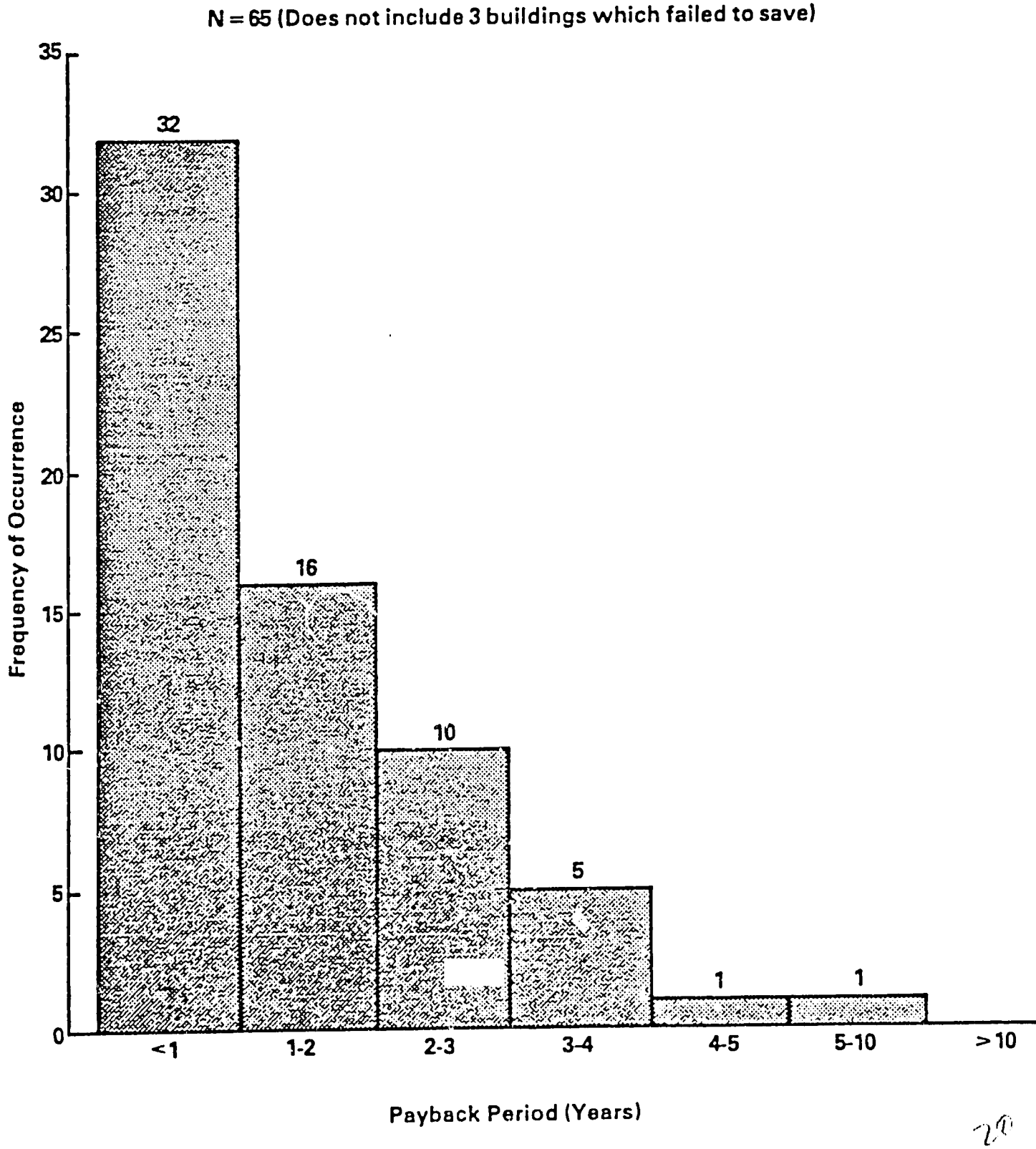
SLIDE 20

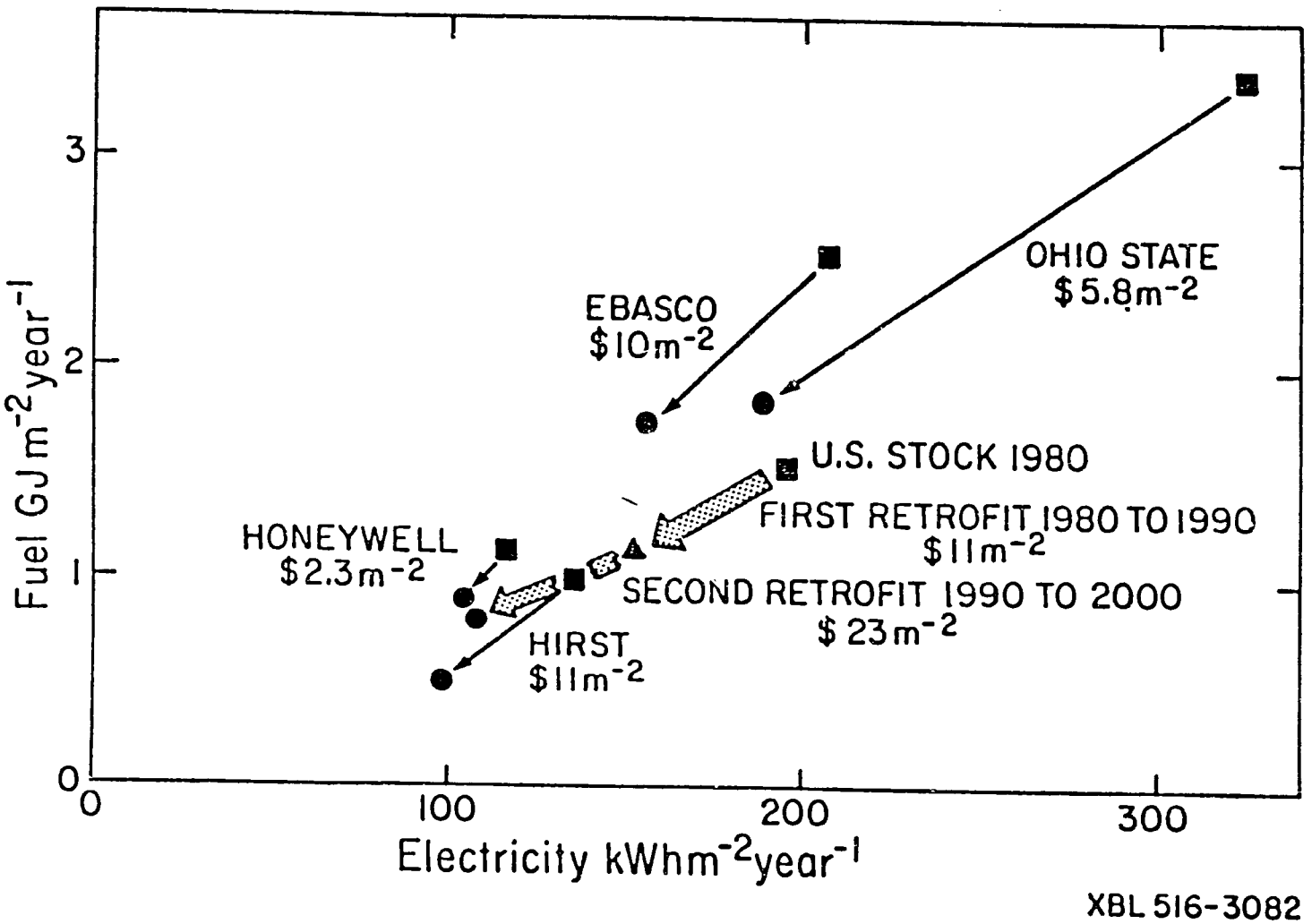


SLIDE 21

THE SIMPLE PAYBACK PERIOD, I.E. THE RATIO OF RETROFIT COST TO FUEL SAVINGS PER YEAR, IS SHOWN. THE VERY LOW COST OF AVERAGE RETROFIT AND THE SHORT PAYBACK PERIOD INDICATE A VERY FAVORABLE AMOUNT OF ENERGY SAVINGS CAN BE OBTAINED WITH SMALL INVESTMENTS.

Simple Payback Period





SLIDE 22. SUMMARY OF SOME OF THE CASES IN THE ROSS AND WHALEN STUDY IN TERMS OF FUEL SAVED AND COSTS PER SQUARE METER. ALSO PROVIDED IS A PROJECTION OF THE POTENTIAL FOR U.S. STOCK AND AN ESTIMATE OF THE INVESTMENT REQUIRED TO ACHIEVE THE POTENTIAL.

SLIDE 23

HUMAN RESPONSES TO CONCENTRATION LEVELS OF FORMALDEHYDE IN AIR

RESPONSE	CONCENTRATION
PUNGENT ODOR	LESS THAN 100 $\mu G/M^3$ (MICROGRAMS PER CUBIC METER)
SWELLING OF MUCOUS MEMBRANES	100 $\mu G/M^3$ TO 200 $\mu G/M^3$
BURNING AND TEARING OF EYES, IRRITATION TO UPPER RESPIRATORY PASSAGES	200 $\mu G/M^3$ TO 1000 $\mu G/M^3$
COUGHING, CONSTRICTIONS IN CHEST, SENSE OF PRESSURE IN HEAD	GREATER THAN 1000 $\mu G/M^3$

PROPOSED INDOOR STANDARDS RANGE FROM 120 $\mu G/M^3$ TO 600 $\mu G/^3$.

SLIDE 24

MEASUREMENTS CARRIED OUT BY LBL IN AN ENERGY-EFFICIENT RESIDENTIAL BUILDING WHERE THE AIR EXCHANGE RATE WAS 0.2 AIR EXCHANGES PER HOUR. MUCH OF THE FORMALDEHYDE IS PRESUMED TO BE ASSOCIATED WITH THE VARNISHES AND GLUES (RESINS) USED IN THE FURNITURE.

Indoor Formaldehyde Concentrations

in a New

Residential Building

Condition	Formaldyhyde ($\mu g/m^3$)
Unoccupied, without furniture[a]	80 ± 9%
Unoccupied, with furniture[a]	223 ± 7%
Occupied, day[a]	261 ± 10%
Occupied, night[b]	140 ± 31%
Outdoor Air	<20

[a]Air exchange rate ≈ 0.4

[b]Windows open part of time; air exchange rate significantly greater than 0.4 and variable.

SLIDE 25

SOURCES OF FORMALDEHYDE	SOURCES OF HYDROCARBONS
PARTICLE BOARD	ADHESIVES
INSULATION	PAINT
COMBUSTION APPLIANCES	COPY MACHINES
RESINS AND GLUES	HUMAN METABOLIC ACTIVITY
	CLEANING AND COOKING PRODUCTS

SLIDE 26

Organic Compounds in Indoor Environments

Compounds	Health Effects	Sources and/or Uses
Formaldehyde and other Aldehydes	Eye and respiratory irritation; may have more serious long term health effects	Out-gassing from building materials -- particle board, plywood and urea-formaldehyde insulation foam; also generated by cooking and smoking
C_n Alkanes N = 5 ∿ 16	Narcotic at high concentrations; moderately irritating	Gasoline, mineral spirits, solvents, etc.
C_n Alkenes N = 5 ∿ 16	Similar to that of alkanes	Similar to that of alkanes
Benzene	Respiratory irritation; recognized carcinogen	Plastic and rubber solvents; from cigarette smoking; used in paints and varnishes, including putty, filler, stains and finishes
Xylene	Narcotic; irritating; high concentrations may cause injury to heart, liver, kidney, and nervous system	Used as solvent for resins, enamels, etc.; also used in non-lead automobile fuels and in manufacture of pesticides, dyes, pharmaceuticals
Toluene	Narcotic; may cause anemia	Solvents; by-product of organic compounds used in several household products
Styrene	Narcotic; can cause headache, fatigue, stupor, depression, incoordination and possible eye injury	Widely used in manufacture of plastics, synthetic rubber and resins
1,1,1-Trichloroethane	Subject of OSHA carcinogenesis inquiry	Aerosol propellant, pesticide, cleaning solvents
Trichloroethylene	Animal carcinogen; subject of OSHA carcinogenesis inquiry	Oil and wax solvents, cleaning compounds, vapour degreasing products, dry cleaning operations; also used as an anaesthetic
Ethyl Benzene	Highly irritating to eyes, etc.	Solvents; used in Styrene related products
Chloro Benzenes	Strong narcotic; possible lung, liver, and kidney damage	Used in production of paint, varnish, pesticides, and various organic solvents
Polychlorinated Biphenyls (PCB's)	Sustected carcinogens	Used in various electrical components; may appear in waste oil supplies and in plastic and paper products in which PCB's are used as plasticizers
Pesticides	Suspected carcinogens	Used for insect control

SLIDE 27

Summary of Average Indoor Air Quality Measurements in an Office Building and Air Quality Standards

	Office Building Air Quality		Air Quality Standards	
Contaminant	Concentration	Averaging Time	Concentration	Averaging Time
Carbon monoxide	4.6 mg/m^3 (4 ppm)	1 hr	40 mg/m^3 (35 ppm)[a]	1 hr
Carbon dioxide	1800 mg/m^3 (1000 ppm)	8-10 hrs	9,000 mg/m^3[b] (5,000)	8 hrs
Nitrogen dioxide	60 $\mu g/m^3$ (30 ppb)	1 week	100 $\mu g/m^3$ (50 ppb)[a]	1 yr
Hydrocarbons (non-methane)	1627 $\mu g/m^3$ (2.5 ppm)	30 minutes	160 $\mu g/m^3$[a] (0.24 ppm)	3 hours (6-9 am)
Formaldehyde	49 $\mu g/m^3$ (41 ppb)	6 hours	120-840 $\mu g/m^3$[c] (100-700 ppb)	maximum
Aliphatic aldehydes	108 $\mu g/m^3$ (90 ppb)	6 hours	No standard	
Particulates	31 $\mu g/m^3$	12 hours	75 $\mu g/m^3$[a] 260 $\mu g/m^3$[a]	1 yr 24 hrs
Lead	0.2 $\mu g/m^3$	12 hours	1.5 $\mu g/m^3$[d]	3 months
Sulfur (as SO_4)	2.5 $\mu g/m^3$	12 hours	25 $\mu g/m^3$[d]	24 hrs
Ariborne Microbes	179 CFP/m^3	20 minutes	No standard	

[a] U.S. EPA Ambient Air Quality Standard for outdoor air.

[b] State of California Air Quality Standard.

[c] range of recommended standards

[d] U.S. Occupational Safety and Health Administration (OSHA).

SLIDE 28

THE CENTRAL ANALYTIC TOOL FOR ANALYZING BUILDING ENERGY CONSUMPTION IS THE DOE-2 COMPUTER PROGRAM.

THIS PROGRAM CONSISTS OF FOUR PRINCIPAL, SEPARATE BUT LINKED SUBPROGRAMS REFERRED TO AS LOADS, SYSTEMS, PLANT, AND ECONOMICS AS WELL AS A WEATHER DATA PROCESSOR AND SUBPROGRAMS FOR GENERATING RESPONSE AND WEIGHTING FACTORS THAT MODEL THE BUILDING'S TRANSIENT THERMAL CHARACTERISTICS.

SLIDE 29

THE LOADS PROGRAM CALCULATES THE HEAT ENTERING AND LEAVING A BUILDING FOR EACH HOUR OF A YEAR (8760 H). HEAT GAINS AND LOSSES THROUGH WALLS, ROOFS, WINDOWS, AND DOORS ARE CALCULATED SEPARATELY. HEAT TRANSFER BY CONDUCTION AND RADIATION THROUGH THE BUILDING ENVELOPE IS COMPUTED CONSIDERING THE EFFECTS OF THE THERMAL MASS; PLACEMENT OF INSULATION; SUN ANGLE; CLOUD COVER; AND BUILDING LOCATION, ORIENTATION, AND ARCHITECTURAL FEATURES. INFILTRATION LOADS ARE CALCULATED BASED ON THE DIFFERENCE BETWEEN THE INSIDE AND OUTSIDE CONDITIONS AND ON AN ASSUMED LEAK RATE (CRACK METHOD) OR USE OF THE AIR-CHANGE METHOD.

SLIDE 30

THE SYSTEMS PROGRAM IS COMPOSED OF ALGORITHMS FOR SIMULATING THE PERFORMANCE OF THE HVAC SECONDARY EQUIPMENT USED BY THE ENERGY AND MOISTURE DISTRIBUTION SYSTEM TO CONTROL THE TEMPERATURE AND HUMIDITY WITHIN THE BUILDING. THESE ALGORITHMS HAVE BEEN ORGANIZED AND CODED TO ALLOW A USER TO SELECT 1 OF THE 17 PREPROGRAMMED SPACE-CONDITIONING SYSTEMS. TO USE THE SYSTEMS PROGRAM, THE USER CHOOSES ONE OF THESE PREPROGRAMMED HVAC SYSTEMS AND PROVIDES THE NECESSARY INPUT DATA FOR THE SIMULATION CALCULATIONS. IF A USER WISHES TO ANALYZE A SYSTEM THAT HAS NOT BEEN PREPROGRAMMED, HE MAY ADD HIS OWN SUBROUTINES TO MODEL A PARTICULAR SYSTEM.

SLIDE 31

THE PLANT PROGRAM CONTAINS ALGORITHMS THAT SIMULATE THE PERFORMANCE OF THE PRIMARY ENERGY CONVERSION EQUIPMENT. THE OPERATION OF EACH PLANT COMPONENT (FOR EXAMPLE, BOILER, ABSORPTION CHILLER, COMPRESSION CHILLER, OR COOLING TOWER) IS MODELED AS A FUNCTION OF OPERATING CONDITIONS AND PART-LOAD PERFORMANCE CHARACTERISTICS. A USER SELECTS THE TYPE OF PLANT EQUIPMENT TO BE MODELED, THE SIZE OF EACH UNIT, THE NUMBER OF UNITS, AND THE NUMBER OF UNITS SIMULTANEOUSLY AVAILABLE. VALUES FOR EQUIPMENT LIFETIME AND MAINTENANCE FREQUENCY MAY ALSO BE ENTERED BY A USER IF HE WISHES NOT TO USE THE DEFAULT (PREPROGRAMMED) VALUES GIVEN FOR THESE VARIABLES.

SLIDE 32

THE ECONOMICS PROGRAM COMPUTES THE LIFE-CYCLE COST OF OPERATING A BUILDING. THE USUAL IMPUTS REQUIRED ARE THE INTEREST RATE, LABOR INFLATION RATE, MATERIALS INFLATION RATE, ENERGY INFLATION RATE, PROJECT LIFE, COST OF LABOR, AND SITE COST FACTORS. EQUIPMENT COSTS ARE ASSIGNED IN PLANT BY GENERIC CLASS OR BY SPECIFIC SIZE. THE COST OF ELECTRICITY, NATURAL GAS, OIL, AND COAL, AS WELL AS COST ESCALATION FACTORS, MAY ALSO BE ENTERED BY A USER. THESE USER-SPECIFIED INPUT DATA ARE COMBINED WITH THE RESULTS OF THE LOADS, SYSTEMS, AND PLANT PROGRAMS TO RUN THE ECONOMICS ANALYSIS PROGRAM.

SLIDE 33

TEST BUILDINGS WHERE UTILITY DATA HAVE BEEN COMPARED TO DOE-2 RUNS AS A VERIFICATION OF PROGRAM ACCURACY AND ABILITY TO HANDLE FULL STRUCTURES.

SHOWN BELOW ARE COMPARISONS FOR:

1) MULTIFLOOR OFFICE BUILDING, DAYTON, OHIO - 70,000 FT^2

2) RETAIL STORE, ALBUQUERQUE, NEW MEXICO - ONE STORY, 33,000 FT^2

3) RESTAURANT, CHICAGO, ILLINOIS - ONE STORY AND BASEMENT, 21,000 FT^2

4) HOSPITAL, CHATANOOGA, TENNESSEE - 500,000 FT^2

5) ELEMENTARY SCHOOL, KENNEWICK, WASHINGTON - SINGLE STORY, 40,000 FT^2

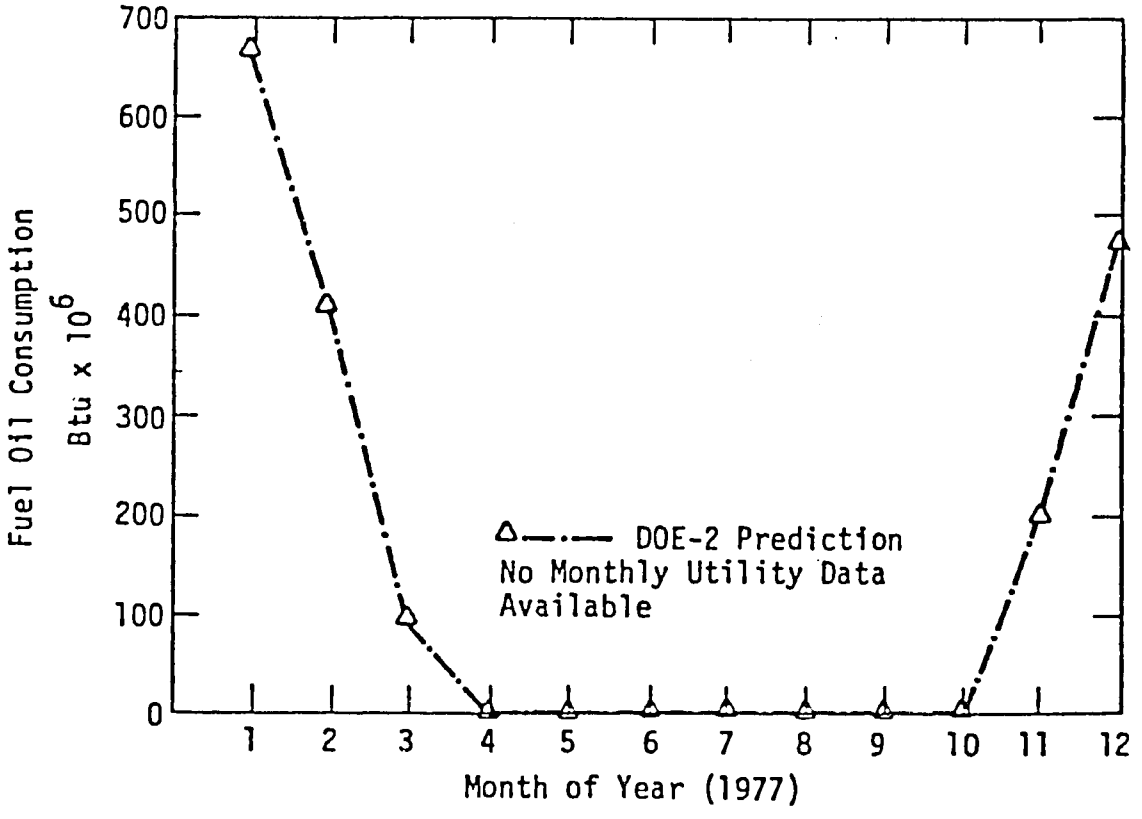


Fig. 28. Reference run - DOE-2 predicted fuel oil consumption for multifloor office building.

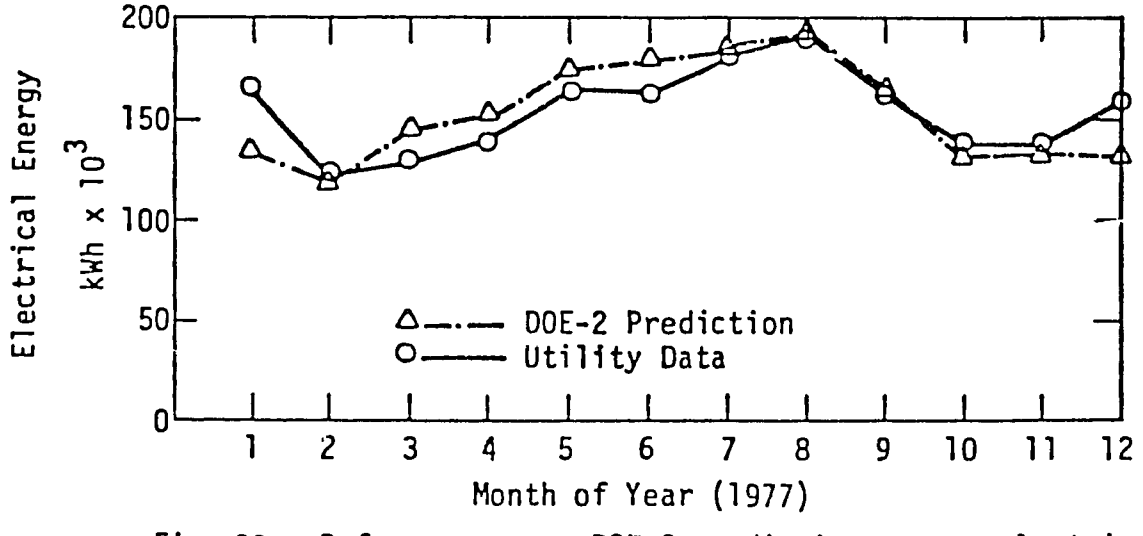


Fig. 29. Reference run - DOE-2 prediction versus electric utility data for multifloor office building.

SLIDE 34

SLIDE 35

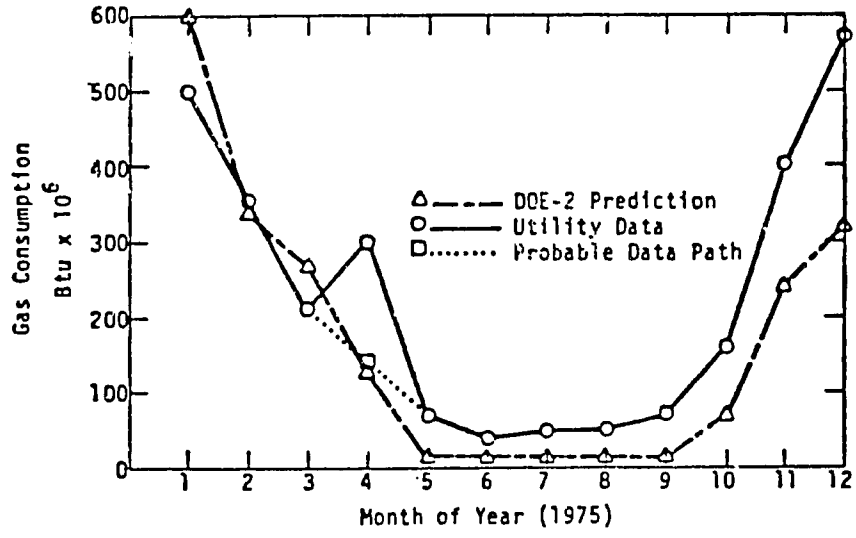


Fig. 30. Reference run - DOE-2 prediction versus gas utility data for retail store

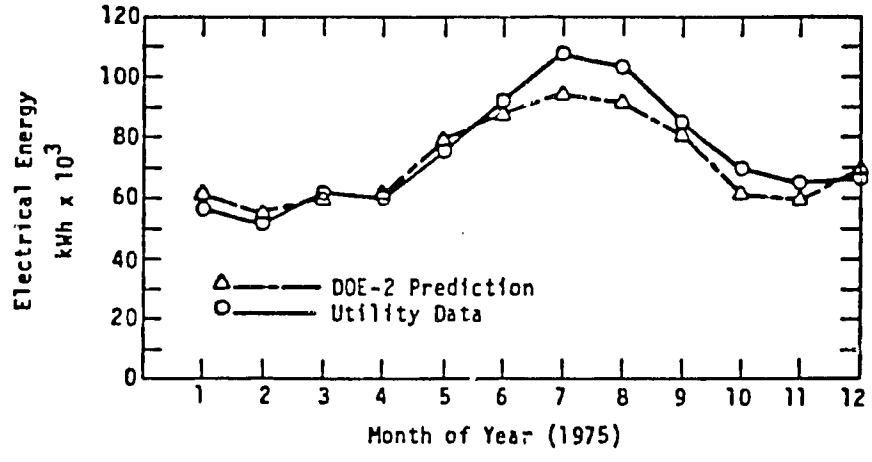


Fig. 31. Reference run - DOE-2 prediction versus electric utility data for retail store.

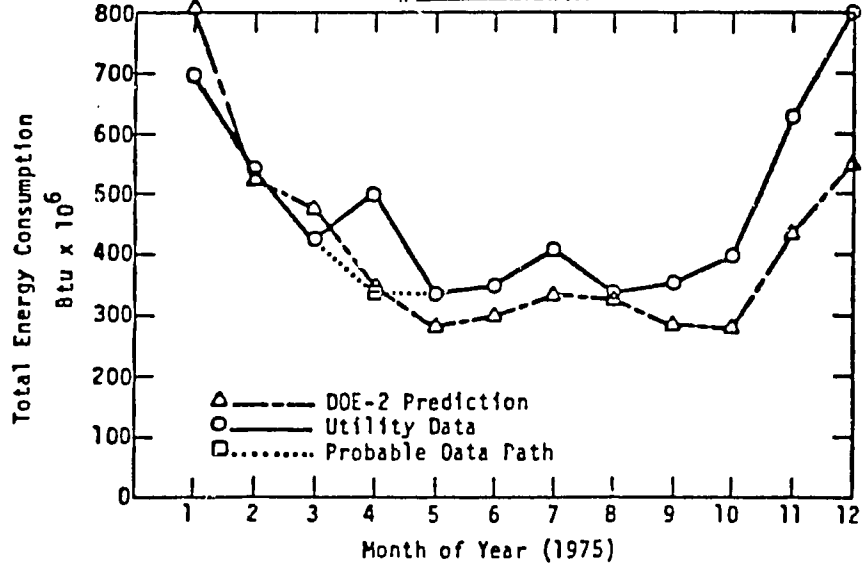


Fig. 32. Reference run - DOE-2 prediction versus total energy utility data for retail store.

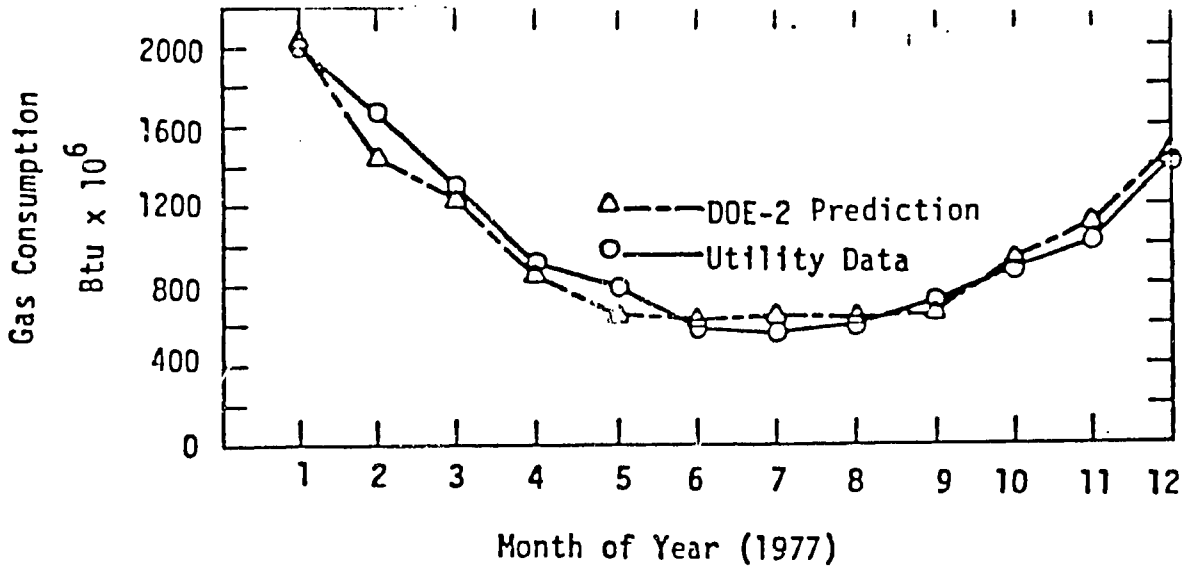


Fig. 33. Reference run - DOE-2 prediction versus gas utility data for restaurant.

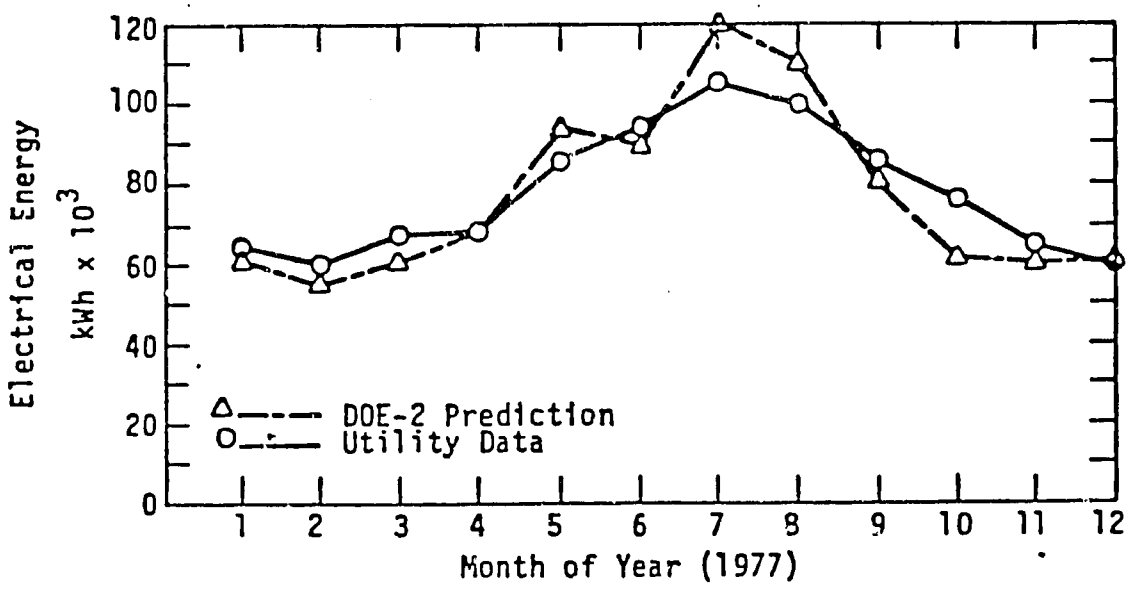


Fig. 34. Reference run - DOE-2 prediction versus electric utility data for restaurant.

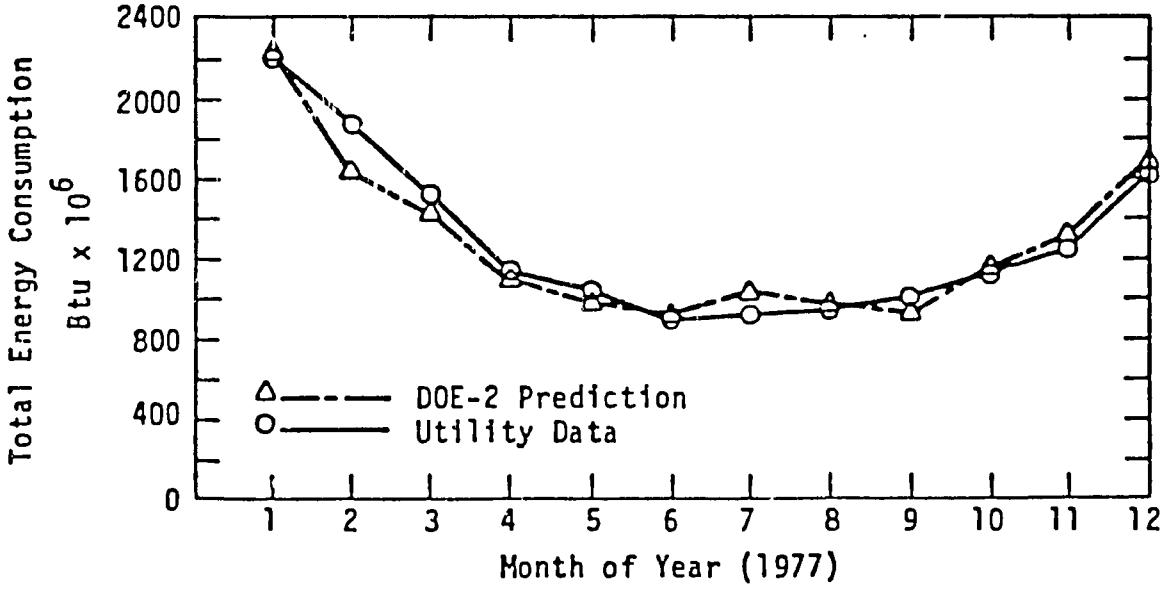


Fig. 35. Reference run - DOE-2 prediction versus total energy utility data for restaurant.

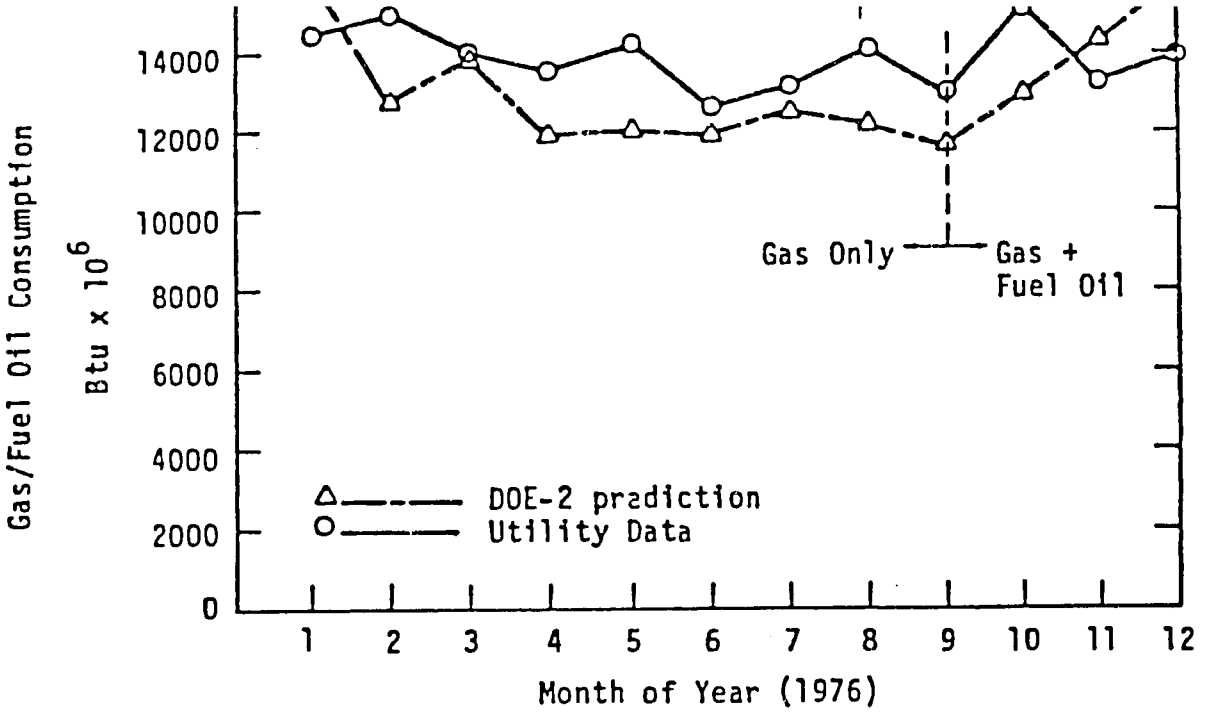


Fig. 36. Reference run - DOE-2 prediction versus gas/fuel oil utility data for hospital.

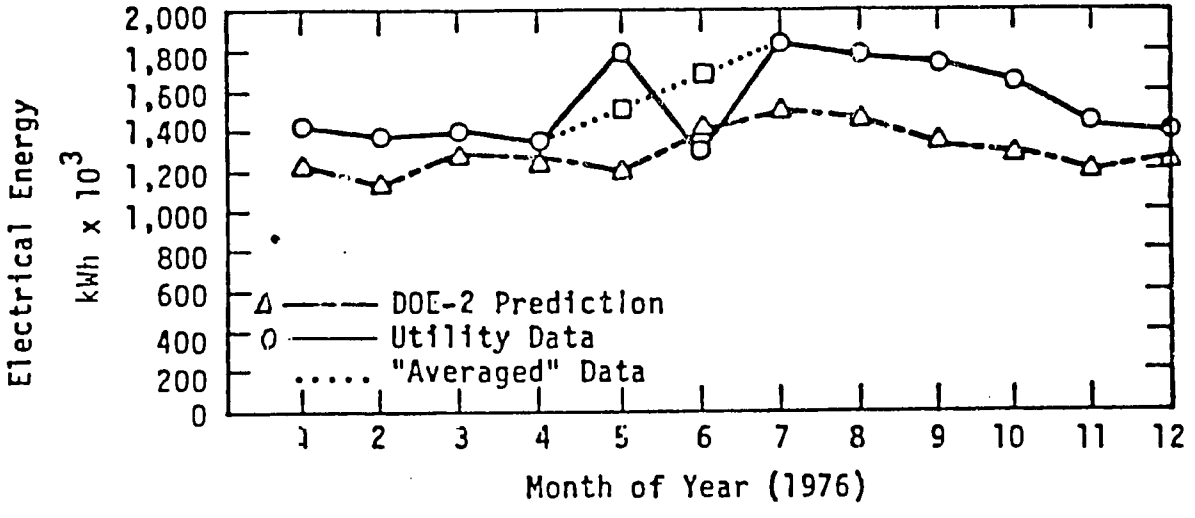
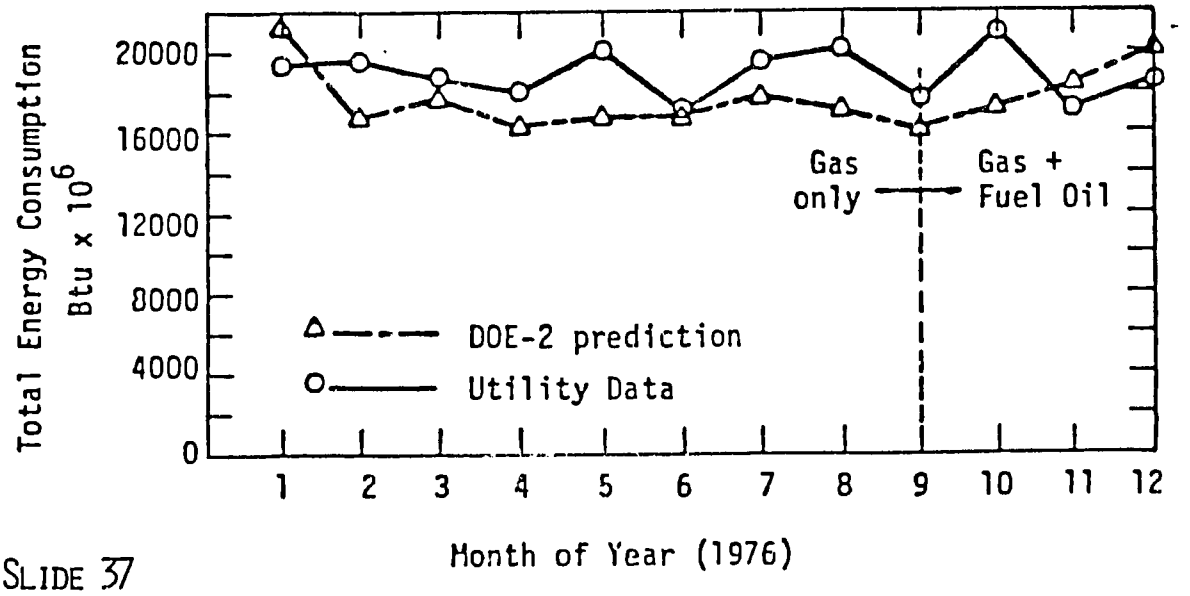


Fig. 37. Reference run - DOE-2 prediction versus electric utility data for hospital.



SLIDE 37

Fig. 38. Reference run - DOE-2 prediction versus total energy utility data for hospital.

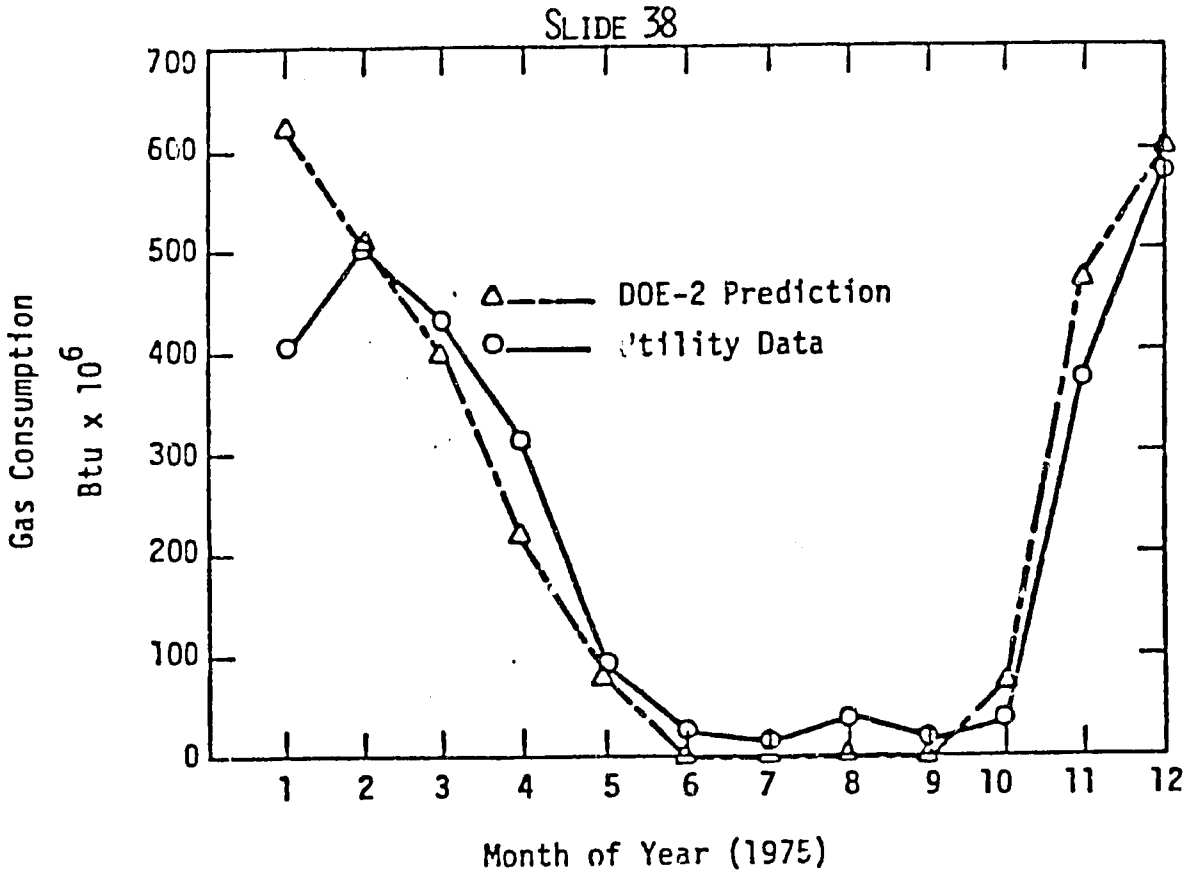


Fig. 39. Reference run - DOE-2 prediction versus gas utility data for school building.

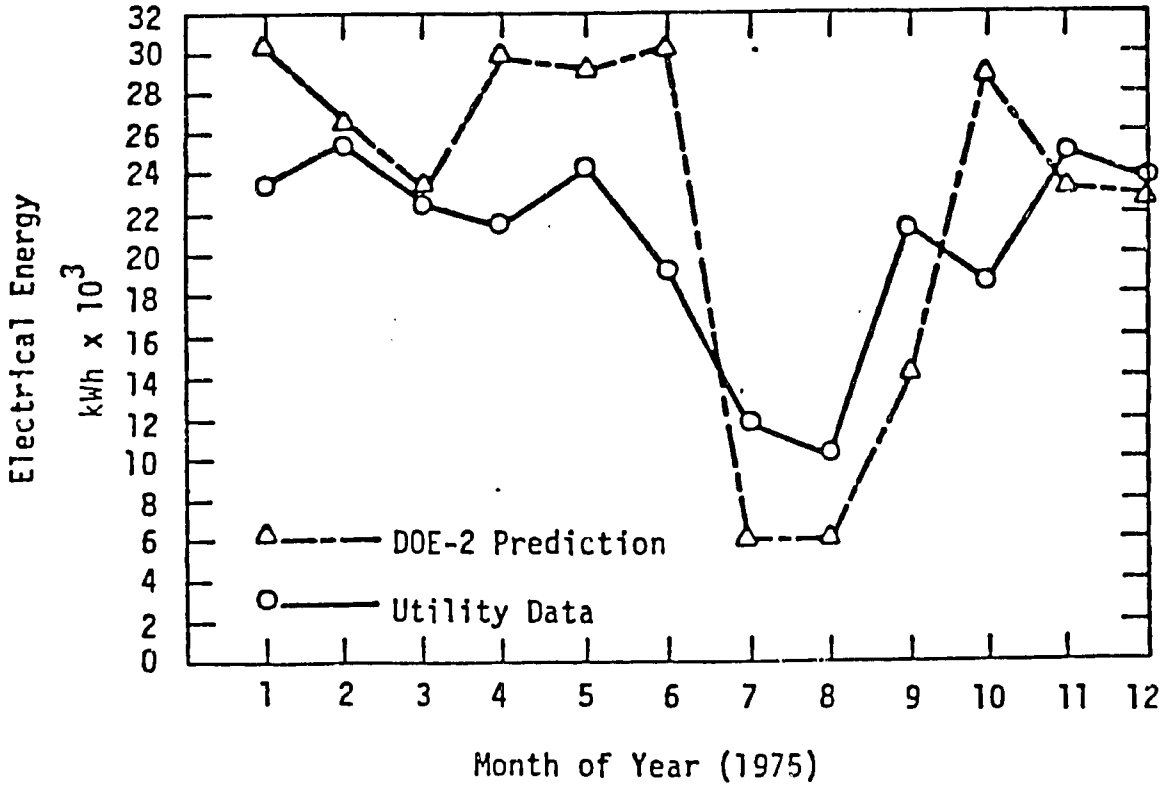


Fig. 40. Reference run - DOE-2 prediction versus electric utility data for school.

SLIDE 39

SUMMARY OF REFERENCE-RUN RESULTS (ANNUAL)

DOE-2 PREDICTIONS VERSUS MEASURED DATA

BUILDING	GAS/FUEL OIL (96%)	ELECTRICAL ENERGY (96%)	TOTAL ENERGY (96%)	PREDICTED ENERGY BUDGET (BTU/FT^2-YR)	MEASURED ENERGY BUDGET (BTU/FT^2-YR)
SINGLE-FLOOR OFFICE	-15	+6	-6	136,695	146,214
MULTIFLOOR OFFICE	-14	-1	-4	117,000	121,258
RETAIL STORE	-19	-4	-12	150,642	171,739
RESTAURANT	-1	-2	-1	701,313	708,203
HOSPITAL	-4	-14	-7	424,051	455,657
SCHOOL	+5	-1	+4	94,731	90,980
NSRSC (SOLAR)	N/A	-15	-12	43,380	49,528

SLIDE 40

AIA/RC COMPARISONS OF ANNUAL ENERGY CONSUMPTION FOR HEATING AND COOLING, PREDICTED BY 23 DIFFERENT COMPUTER BUILDING-ENERGY CODES FOR A THEORETICAL BUILDING. THIS BUILDING HAS 12 STORIES, LIGHT FRAME CONSTRUCTION, AND AN AREA OF 18,700 FT^2 WITH 53% GLASS AND IS LOCATED IN WEATHERFIELD, U.K. VARIATIONS AS LARGE AS A FACTOR OF TWO CAN BE SEEN IN BOTH ANNUAL HEATING ENERGY AND COOLING ENERGY.

AIA/RC PROGRAM COMPARISON
WAREHOUSE

Parameter (Btu/ft^2-yr)	Program DOE-1.4	AXCESS	BLAST	TC 4.7
Total energy	29,877	39,626	47,537	27,083
Heating energy	21,460	31,807	40,451	18,311
Cooling energy	37	720	344	592
Supply fans	945	239	542	478
Lights	6,370	5,606	5,237	5,429
DHW	412	426	415	427
Exhaust fans	475	501	479	482

TABLE XII

AIA/RC PROGRAM COMPARISON
OFFICE BUILDING

Parameter (Btu/ft^2-yr)	Program DOE-1.4	AXCESS	BLAST	TC 4.7
Total energy	28,866	30,989	32,824	30,248
Heating energy	7,525	1,657	8,028	4,454
Cooling energy	4,377	5,912	——	5,194
Supply fans	6,837	6,544	8,922	4,578
Lights	13,910	14,408	13,997	14,604
DHW	2,005	746	——	——
Vertical transport	748	735	716	753
Exhaust fans	643	634	618	665

SLIDE 41

INVESTMENTS IN ENERGY-EFFICIENCY SHOULD BE COMPARED ON A LIFE CYCLE BASIS, SINCE THESE INVESTMENTS ARE TO BE RETURNED IN PART BY THE SAVINGS ON ENERGY COSTS. LIFE CYCLE COSTS COMBINE INITIAL COSTS WITH OTHER COSTS OCCURRING OVER THE TIME SPAN UNDER CONSIDERATION (POSSIBLY USEFUL LIFE SPAN). THESE TOTAL COSTS ARE THEN COMPARED WITH THE TOTAL BENEFITS ARISING FROM THE ENERGY SAVED, TAX BENEFITS RESULTING FROM DEPRECIATION AND INTEREST, AND SALVAGE VALUE.

SLIDE 42

ONE METHOD WHICH HELPS IN MAKING DECISIONS ON INVESTMENTS IN ENERGY-EFFICIENCY IS USING RETURN-ON-INVESTMENT COMPARISONS.

AN INITIAL INVESTMENT OF P DOLLARS IN AN ENERGY-EFFICIENCY STRATEGY WILL PRODUCE A CERTAIN SAVINGS S AFTER A PERIOD OF N YEARS. AVERAGE RETURN ON INVESTMENT IS DETERMINED BY FINDING THE STEADY INTEREST RATE WHEN APPLIED TO THE INITIAL INVESTMENT P WHICH PRODUCES THE SAVINGS S AT THE END OF THE N-YEAR PERIOD. INCOME AND CORPORATE TAXES ARE CRUCIAL TO MAKING ANY DECISION AND MUST BE INCLUDED IN THE DETERMINATION OF RETURN ON INVESTMENT.

SLIDE 43

FOR A BUILDING OWNER, HAVING REDUCED ENERGY COSTS MEANS MORE PROFITS. THUS, AN ANNUAL SAVINGS S RESULTING FROM AN ENERGY-EFFICIENCY STRATEGY MUST BE REDUCED BY A FACTOR $(1 - R_T)$ WHERE R_T IS THE TAX RATE. THE REAL OR AFTER-TAX ANNUAL SAVINGS IS THEN $\bar{s} = s(1 - R_T)$. SIMILAR TAX CONSIDERATIONS FOLLOW FOR O & M COSTS. ANNUAL SAVINGS FOR DEPRECIATION AND INTEREST CHARGES ARE PROPORTIONAL TO R_T. THUS, THE NET SAVINGS AFTER N YEARS IS GIVEN BY THE SUM OF FIVE TERMS.

SLIDE 44

A. THE APPRECIATED SUM OVER N YEARS OF ANNUAL AFTER-TAX ENERGY SAVINGS AUGMENTED BY ANY INFLATION RATE FOR FUEL COSTS.

B. THE APPRECIATED SUM OF ANNUAL DEPRECIATION ALLOWANCE.

C. THE APPRECIATED SUM OF ANNUAL TAX BENEFITS COMING FROM INTEREST PAYMENTS MADE ON LOAN TO PURCHASE ENERGY-EFFICIENCY STRATEGY. THIS FACTOR DEPENDS ON BOTH THE AFTER-TAX INTEREST RATE AND THE BORROWING INTEREST RATE APPLICABLE TO THE PURCHASE.

D. THE SALVAGE VALUE APPROPRIATE AFTER N YEARS.

E. THE APPRECIATED SUM OF ANNUAL AFTER-TAX O & M COSTS AUGMENTED BY ANY INFLATION RATE FOR SUCH COSTS.

SLIDE 45

THE NET SAVINGS S AFTER N YEARS, NOT INCLUDING INTEREST BENEFITS, IS THEN

$$S = A + B + D - E.$$

TO DETERMINE THE (AFTER TAX) RATE OF RETURN ON INVESTMENT $\bar{R}$, THE SAVINGS DUE TO INTEREST CHARGES SHOULD NOT BE INCLUDED, SINCE THIS VALUE IS PREDICATED ON NOT BORROWING OR CONSIDERING LOAN EXPENSES. (INTEREST <u>IS</u> INCLUDED IN DETERMINING THE REAL PAYBACK PERIOD.) THEN

$$\bar{R} = (S/P)^{1/N} - 1.$$

SLIDE 46

THE QUANTITIES A, B, C, AND E CAN BE COMPUTED IN TERMS OF:

$\bar{s} = s(1 - R_T)$ (THE NET ANNUAL SAVINGS AT THE END OF THE FIRST YEAR)

I = THE ANNUAL INTEREST RATE BEFORE TAXES WHICH CAN BE EARNED ON AN INVESTMENT BY THE OWNER (BANK, MONEY MARKET)

$\bar{I} = I(1 - R_T)$ (R_T IS THE INCOME TAX RATE)

M = THE ANNUAL O & M COSTS AT THE END OF THE FIRST YEAR

I_B = THE INTEREST RATE WHICH APPLIES TO THE LOAN USED TO PURCHASE THE ENERGY-EFFICIENCY STRATEGY

F_1 = THE UNIFORM INFLATION RATE FOR FUEL COSTS

F_2 = THE UNIFORM INFLATION RATE FOR O & M COSTS.

SLIDE 47

$$A = [\bar{s}/(\bar{I} - F_1)][(1 + \bar{I})^N - (1 + F_1)^N]$$

$$B = \frac{PR_T}{N\bar{I}}[(1 + \bar{I})^N - 1] \qquad \text{(STRAIGHT LINE)}$$

$$= P\,R\,R_T\,[(1 + \bar{I})^N - 1][1 - (1 - R)^N]/\bar{I}\,R \qquad \text{(DECLINING BALANCE)}$$

(WHERE $N\,R$ = ACCELERATION FACTOR OVER STRAIGHT LINE)

$$= \frac{2\,P\,R_T}{N(N + 1)(\bar{I})^2}[(1 + \bar{I})\{(1 + \bar{I})^N - 1\} - \bar{I}\,N] \qquad \text{(SUM-OF-THE-YEARS DIGITS)}$$

SLIDE 48

$$C = P R_T \left\{ \frac{G(I_B)}{H(\bar{I})} - H(I_B) \left[\frac{(1 + \bar{I})^N - (1 + I_B)^N}{\bar{I} - I_B} \right] \right\}$$

WHERE $G(I) = \dfrac{I(1 + I)^N}{[(1 + I)^N - 1]}$ AND $H(I) = \dfrac{I}{[(1 + I)^N - 1]}$

D = SALVAGE VALUE

$$E = [\bar{M}/(\bar{I} - F_2)][(1 + \bar{I})^N - (1 + F_2)^N]$$

SLIDE 49

WHEN MONEY IS BORROWED TO INCLUDE AN ENERGY-EFFICIENCY STRATEGY, A USEFUL CRITERION FOR EVALUATING THE QUALITY OF THE INVESTMENT IS THE PAYBACK PERIOD. THIS IS THE PERIOD OF TIME OVER WHICH THE ENERGY SAVINGS ARE ACCUMULATED (LESS ANY O & M COSTS) TO PAY FOR THE ACCUMULATED TOTAL COSTS — PRINCIPAL PLUS INTEREST. THE SIMPLE PAYBACK PERIOD, WHICH DOES NOT TAKE INTO ACCOUNT FUEL COST INFLATION, INTEREST, TAXES, DEPRECIATION AND OTHER ITEMS, IS CALCULATED BY

$$\text{SIMPLE PAYBACK} = \frac{\text{PRINCIPAL COST}}{\text{ANNUAL ENERGY SAVINGS (IN DOLLARS)}}$$

SLIDE 50

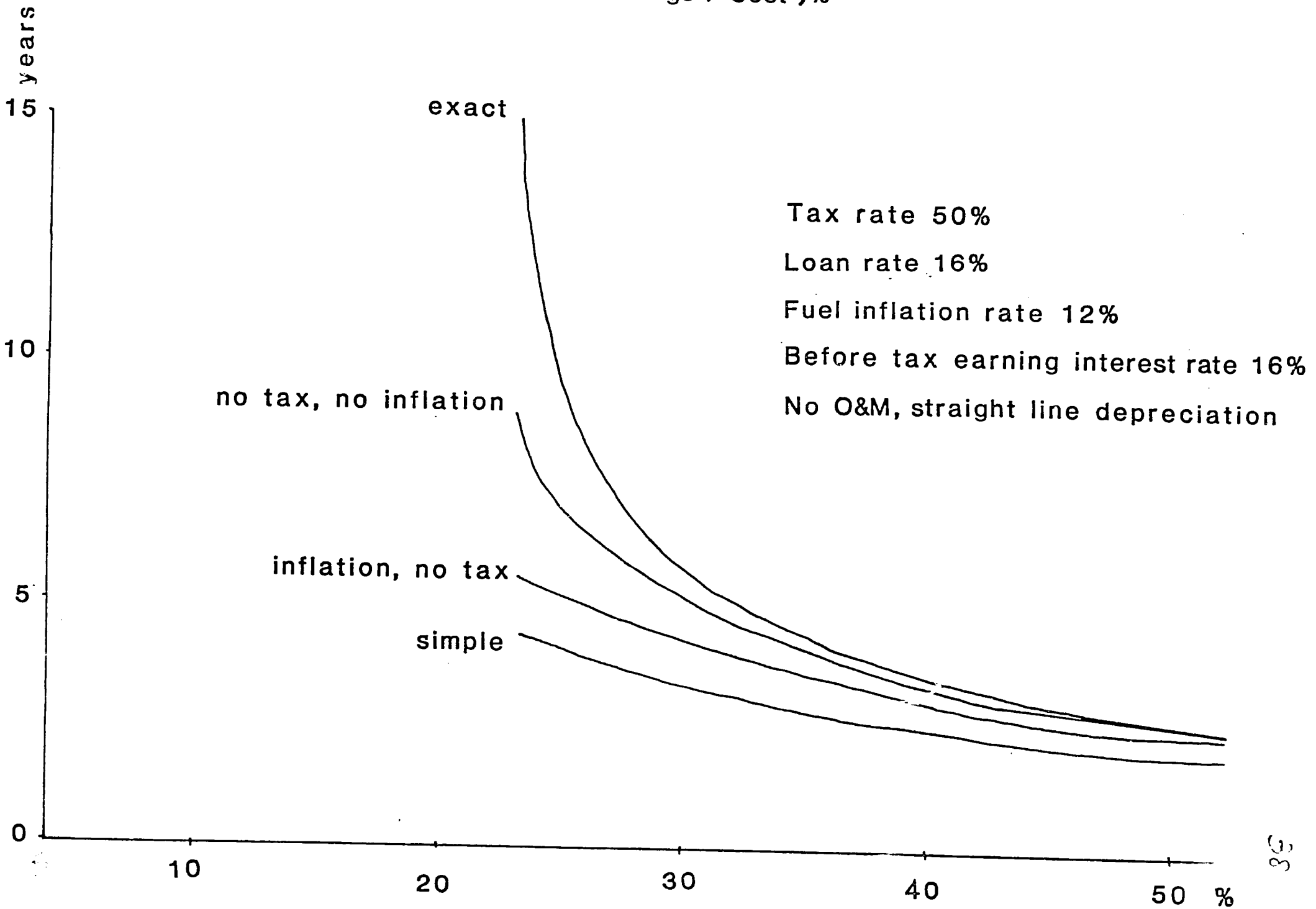
THE SIMPLE PAYBACK PERIOD CAN BE VERY MUCH IN ERROR. THE ACTUAL PAYBACK PERIOD CAN BE MUCH LONGER.

SLIDE 51 SHOWS AN EXAMPLE OF THE PAYBACK PERIOD AS A FUNCTION OF THE RATIO OF THE VALUE OF THE FIRST YEAR'S ENERGY SAVINGS TO THE PRINCIPAL AMOUNT BORROWED UNDER THE FOLLOWING CONDITIONS:

TAX RATE $R_T = 50\%$.
DEPRECIATION IS STRAIGHT LINE.
$I = I_B = 16\%$.
$F_1 = 12\%$, $M = 0$.

SLIDE 51

PAYBACK PERIOD v (Annual Savings / Cost)%



SLIDE 52

IN THIS EXAMPLE AN ENERGY SAVINGS WHICH HAS A REAL PAYBACK PERIOD OF FIVE YEARS WOULD HAVE THE AFTER-TAX RATE OF RETURN ON INVESTMENT $\bar{R} = 12\%$. IF THE ENERGY SAVINGS HAD BEEN LESS SO THAT THE PAYBACK PERIOD WAS 10 YEARS, THEN $\bar{R} = 7.8\%$ WOULD HAVE RESULTED. (NOTE THAT FOR THIS EXAMPLE THERE IS A REAL 10-YEAR PAYBACK PERIOD, A SIMPLE PAYBACK PERIOD OF 4.2 YEARS, AND AN APPARENT BUT FALSE RATE OF RETURN OF 24%.)

SLIDE 53

LIFE CYCLE COSTING

TAKE THE ACCUMULATED COSTS AND BENEFITS AT YEAR N AND COMPUTE PRESENT WORTH BY MULTIPLYING BY DISCOUNT RATE FACTOR

$$(1 + D)^{-N} \quad \text{WHERE D IS THE DISCOUNT RATE.}$$

EXAMPLE:

COSTS FOR DESIGN 1 WITHOUT ENERGY-EFFICIENCY ARE THE SUM OF ENERGY COSTS FOR EACH YEAR REDUCED BY THE TAX RATE.

YEAR 1	YEAR 2	YEAR 3
$\bar{E}_1$	$\bar{E}_1(1 + \bar{I}) + \bar{E}_1(1 + F)$	$[\bar{E}_1(1 + \bar{I}) + \bar{E}_1(1 + F)](1 + \bar{I}) + \bar{E}_1(1 + F)^2$

$$\text{PRESENT VALUE} = \frac{\bar{E}_1}{(\bar{I} - F)} [(1 + \bar{I})^N - (1 + F)^N]/(1 + D)^N$$

$$\bar{E}_1 = E_1(1 - R_T) \qquad \bar{I} = I(1 - R_T)$$

Slide 54

Design 2

Present value costs with an energy-efficiency strategy having initial cost P are:

$$\text{Present value} = [E_2/(\bar{I} - F)][(1 + \bar{I})^N - (1 + F)^N]/(1 + D)^N + P(1 + I)^N/(1 + D)^N - (B + C + D - E)/(1 + D)^N$$

B is the depreciation factor.
C is the interest factor.
D is the salvage value.
E is the O & M factor.

Slide 55

Example of Life Cycle Costing for an Office Building in Denver, Colorado (AIA Research Corp.)

Compare two designs for 102,000 FT^2 building.

Design 1	Design 2
Lighting 2.6 watts/FT^2	Lighting 1.6 watts/FT^2
Standard thermostat	10°F deadband thermostat
	Reduce air quantities by 17% (total CFM)

Annual energy saved = 44%
(49,424 Btu's/FT^2 ⇒ 27,693 Btu's/FT^2)

Cost for design 2 is $34,000 less than that for Design 1.

Savings from installed lighting more than compensate for the new thermostat.

SLIDE 56

OVER A 40-YEAR LIFE CYCLE WITH ELECTRICITY COSTING 3.5¢ PER KWH IN 1978, A FUEL COST ESCALATION RATE OF 8%, AND A 9.5% DISCOUNT RATE, THE LIFE CYCLE SAVINGS IS $700,000 (DISREGARDING INCOME TAXES).

BEST CHOICES FOR ENERGY SAVINGS:

DEADBAND THERMOSTAT	8%
DAYLIGHTING WITH CONTROLLED DIMMING	16%
INTRODUCTION OF TASK LIGHTING	18%

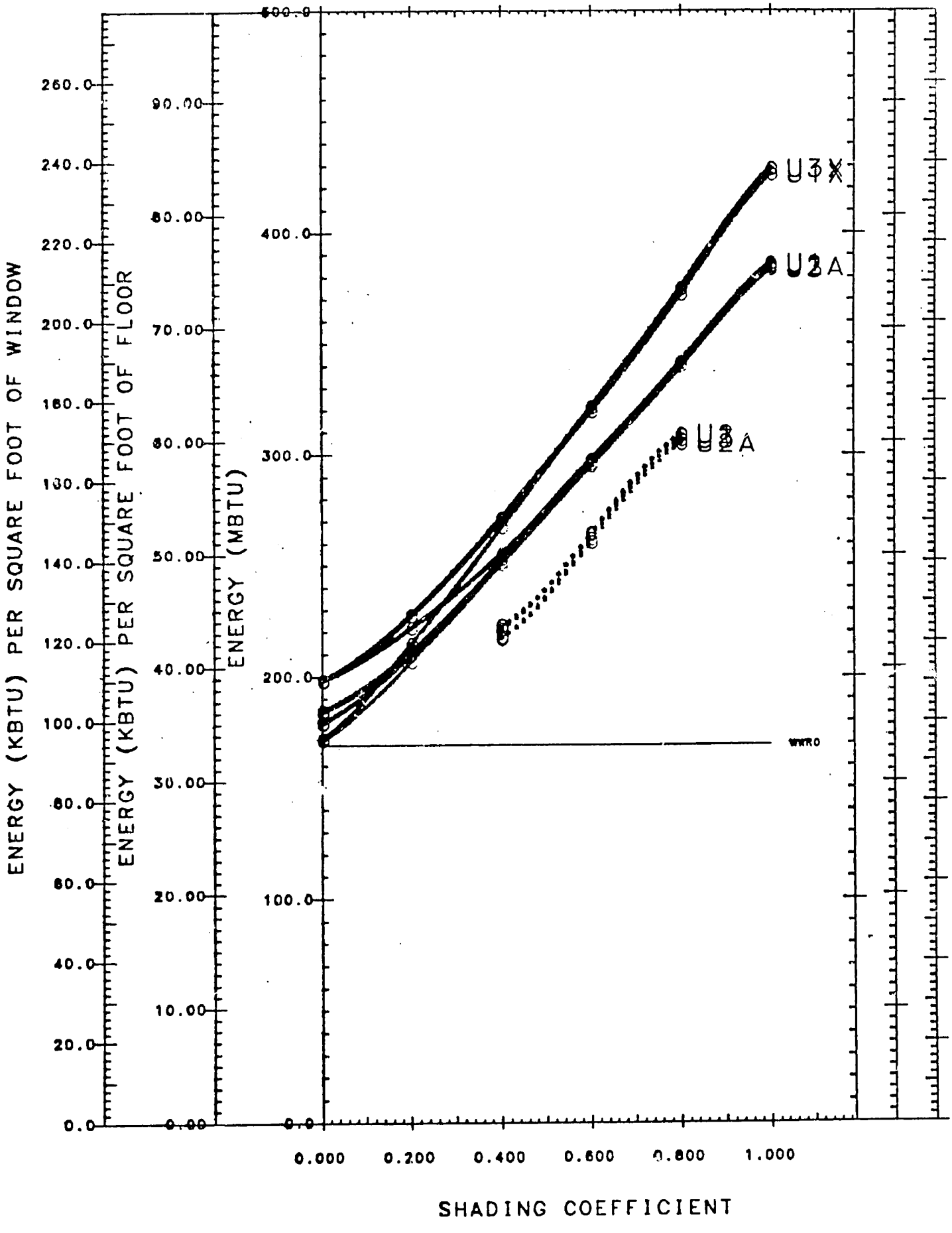
SOLAR HOT WATER (92% PLUS 20% SPACE HEAT) GIVES ONLY AN 8% REDUCTION IN ENERGY WITH A LONG PAYBACK PERIOD.

SLIDE 57

IN TEMPERATE CLIMATES SHADING THE DIRECT SUN IS ESPECIALLY IMPORTANT IF ENERGY USE IS TO BE REDUCED. SLIDE 58 SHOWS AN EXAMPLE OF ENERGY CONSUMPTION FOR A BUILDING MODULE PLACED IN MIAMI AS THE SHADING COEFFICIENT OF THE GLASS VARIES FROM 0 TO 1 FOR A WINDOW TO WALL RATIO OF 0.9.

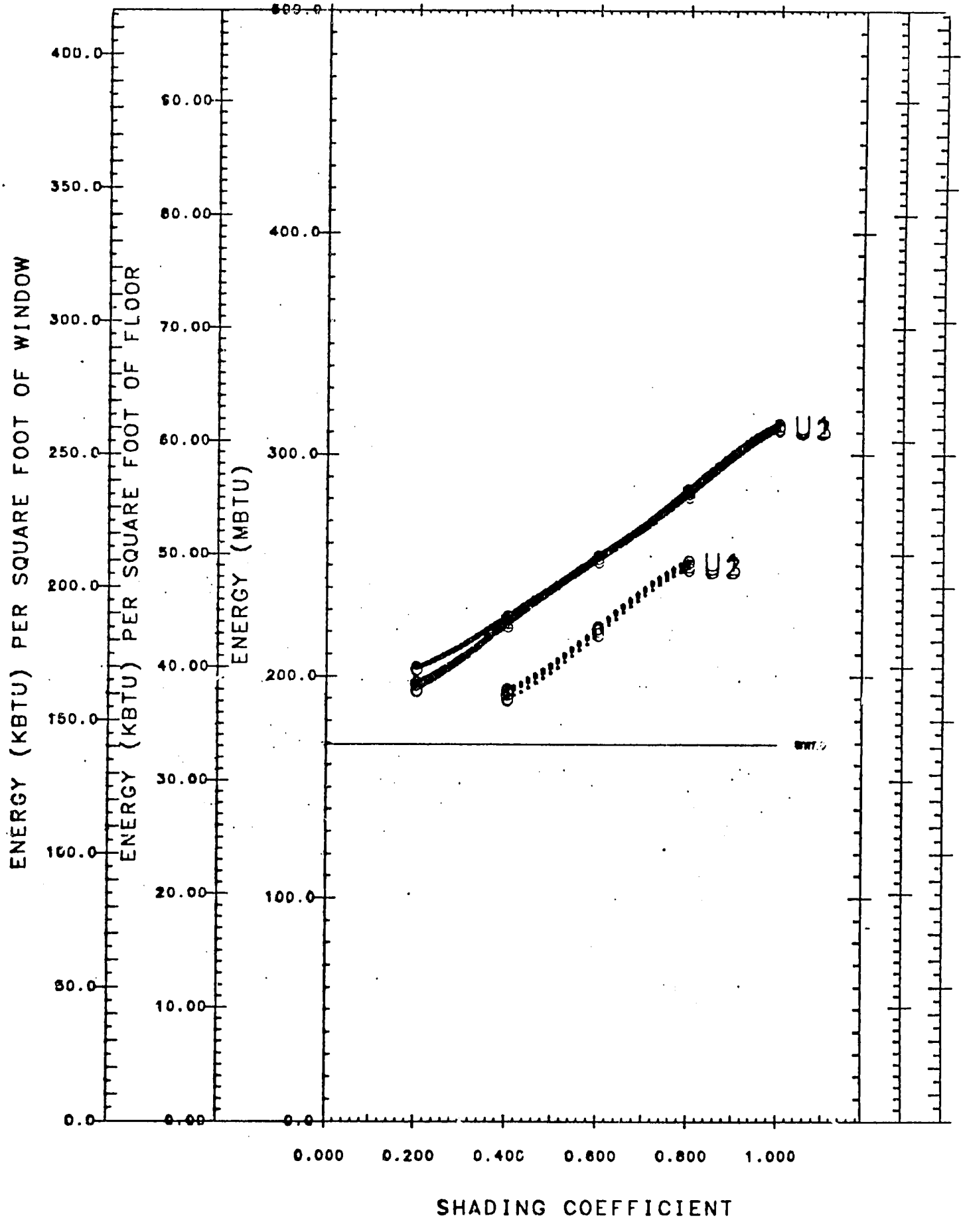
(THE SHADING COEFFICIENT IS THE ENERGY TRANSMITTED RELATIVE TO STANDARD CLEAR GLASS.)

SLIDE 58



MIAMI SOUTH ZONE WWR = 0.9

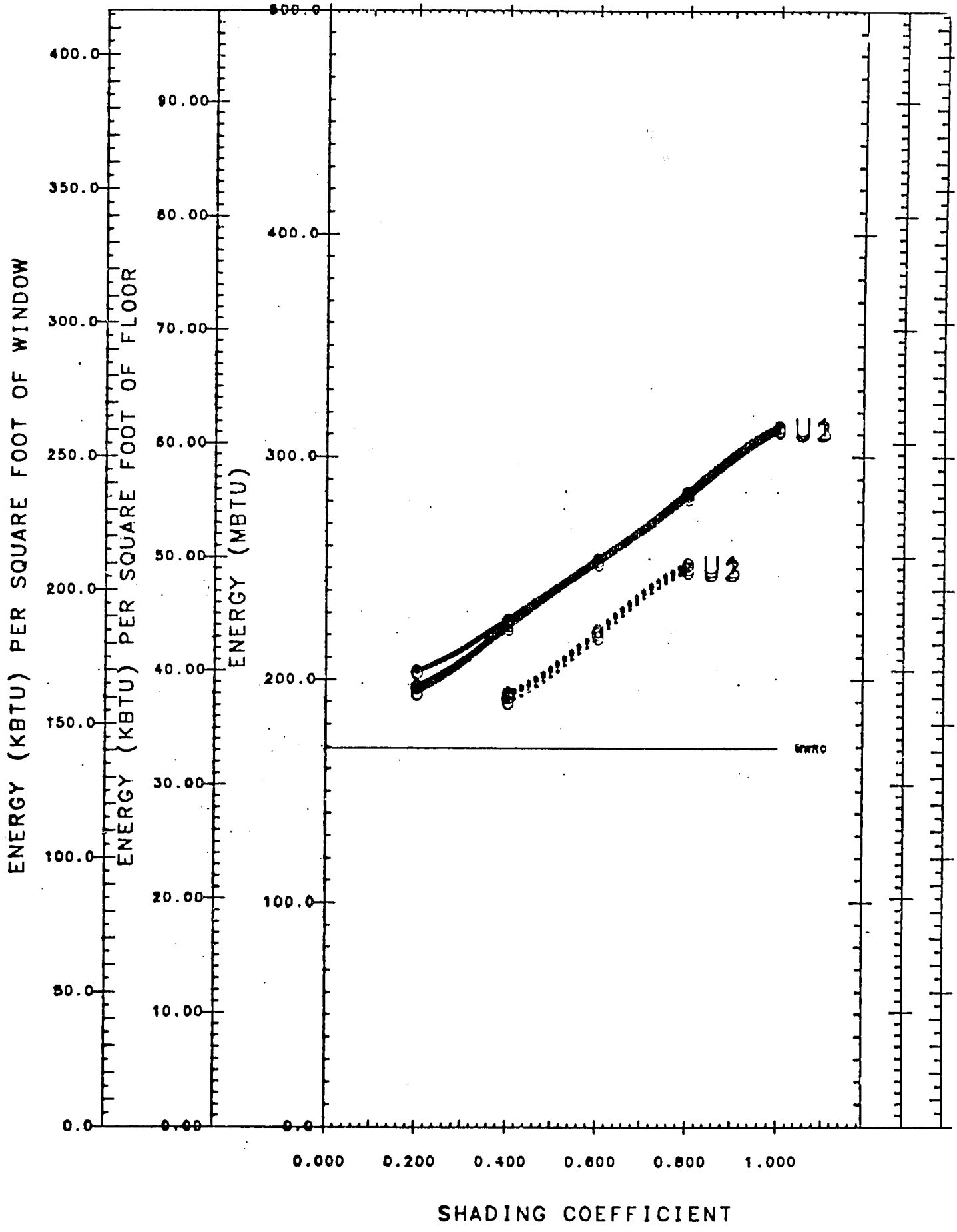
SLIDE 59



MIAMI SOUTH ZONE WWR = 0.6

45

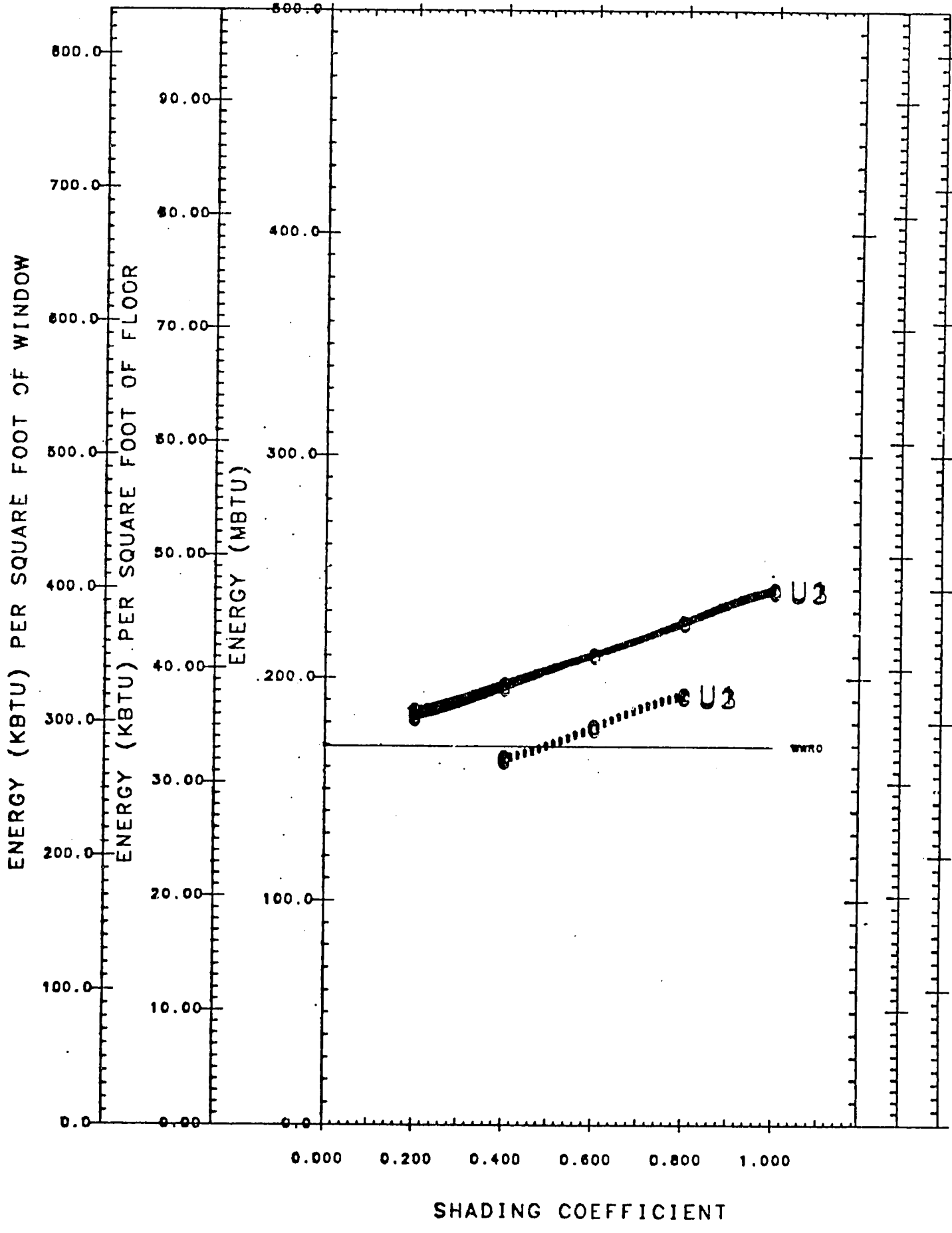
SLIDE 59



MIAMI SOUTH ZONE WWR = 0.6

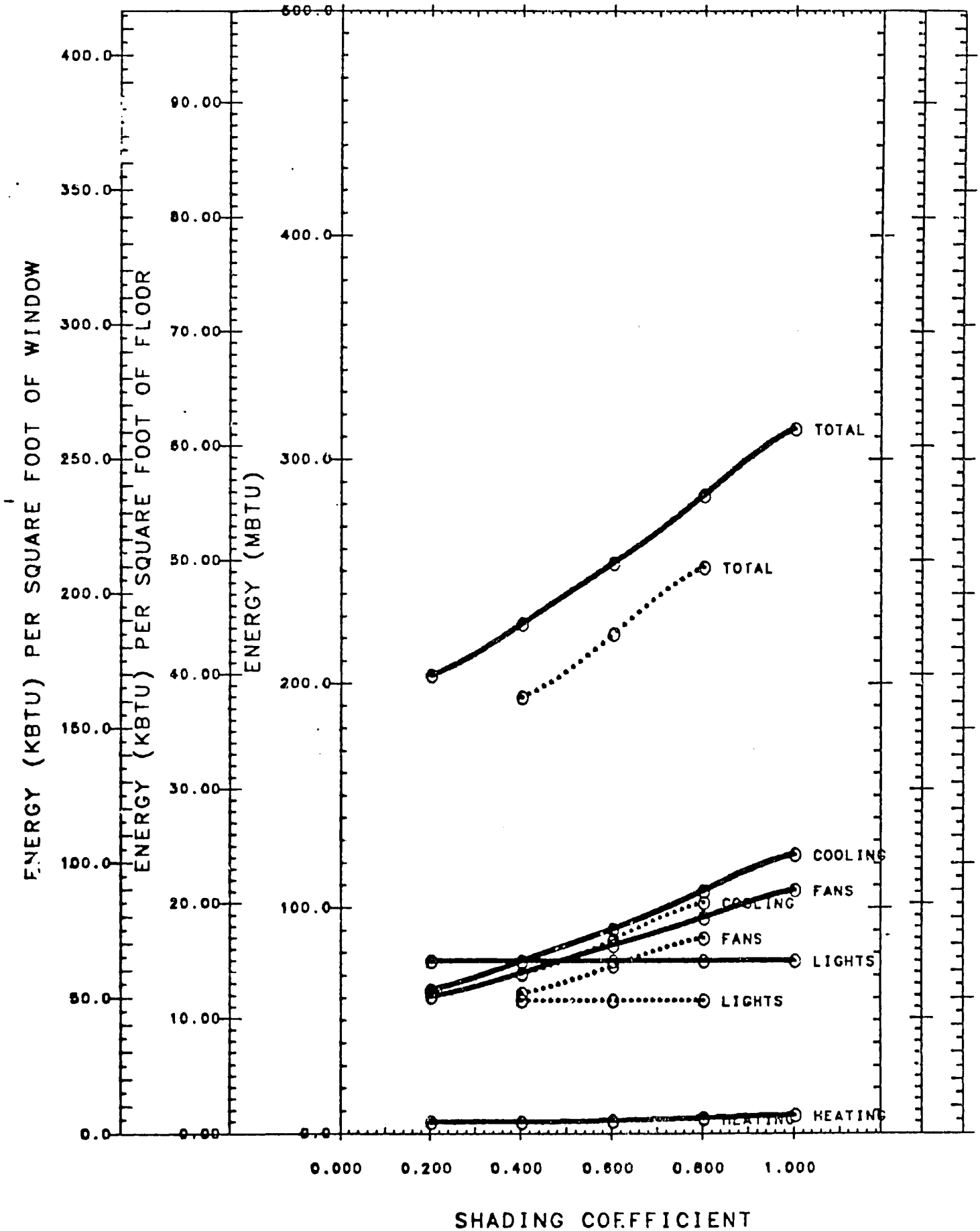
4b

SLIDE 60



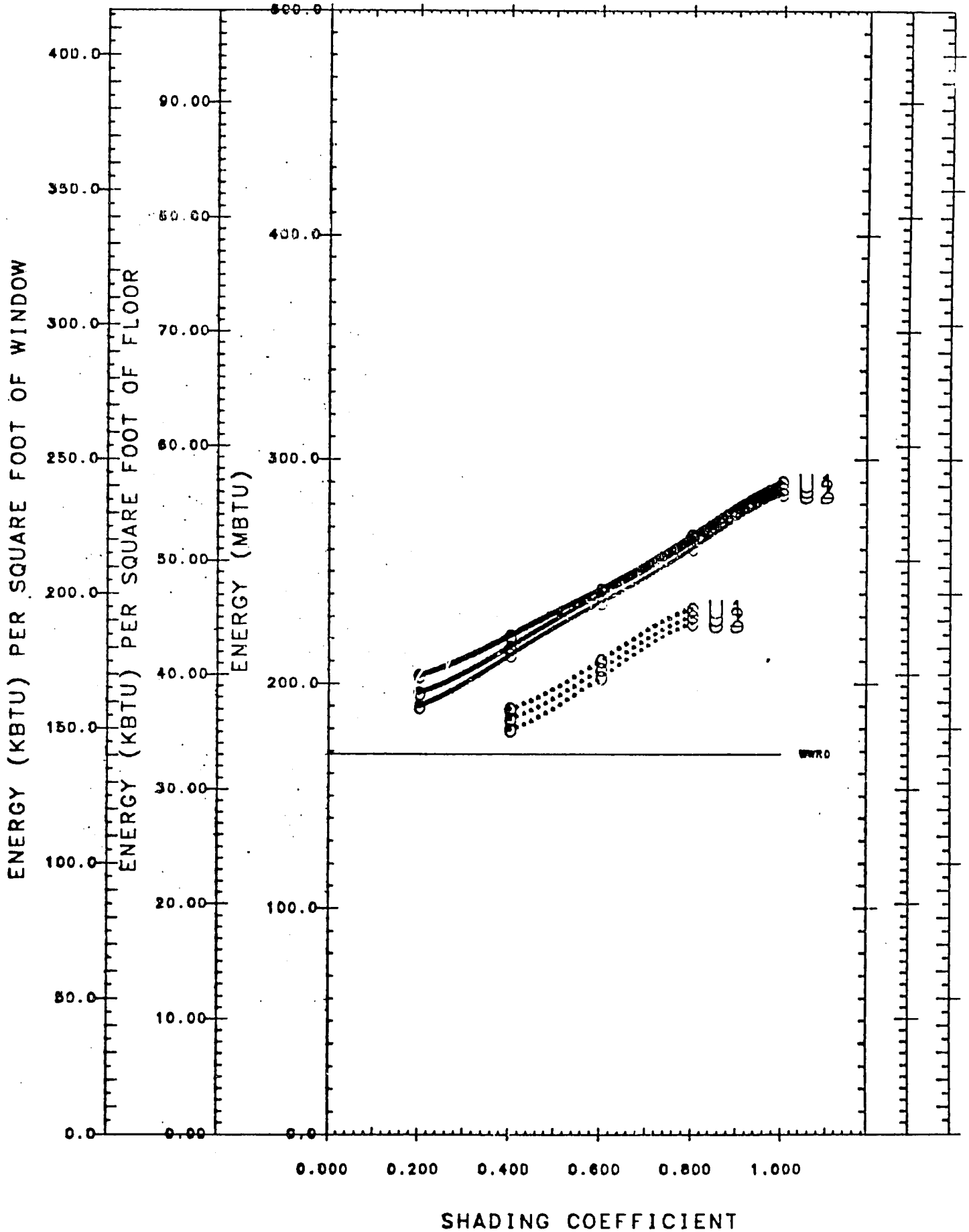
MIAMI SOUTH ZONE WWR = 0.3

SLIDE 61



MIAMI SOUTH ZONE WWR = 0.6 U1

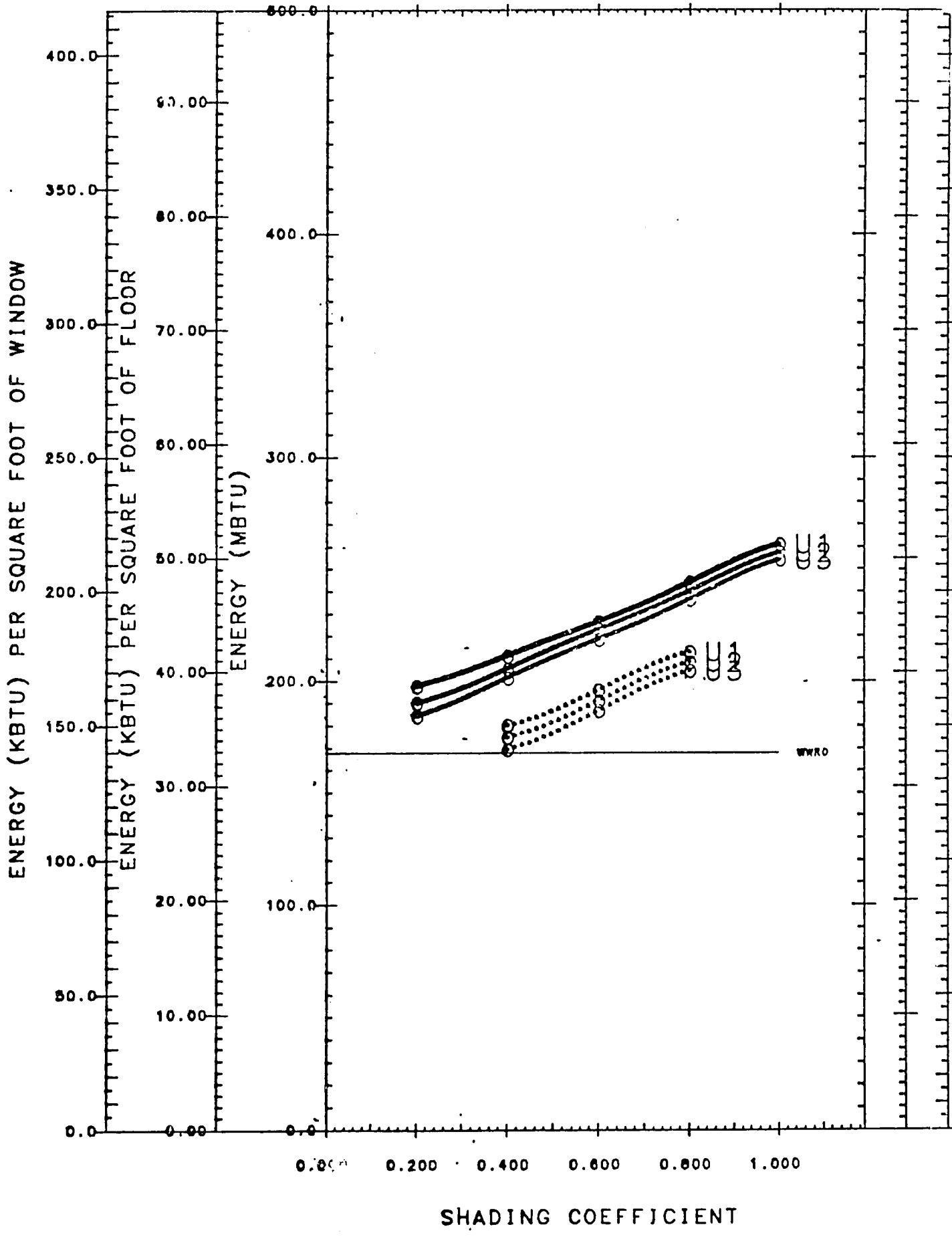
SLIDE 62



MIAMI EAST ZONE WWR = 0.6

49

SLIDE 63



MIAMI NORTH ZONE WWR = 0.6

50

SLIDE 64

BARRIERS TO IMPLEMENTING ENERGY-EFFICIENCY

1. THE 'SPEC' BUILDING -- BUILDER ONLY CONSIDERS FIRST COSTS.
2. RENTER PAYS UTILITY COSTS.
3. MANAGING AGENCY COMMISSIONS BASED ON MONTHLY COSTS.
4. MISSING INFORMATION ON HOW TO ACHIEVE COST-EFFECTIVE ENERGY SAVINGS.

REFERENCES

Books

Thumann, A. 1977. Plant engineers guide to energy conservation. Van Nostrand.

Dubin, F. and Long, C. 1978. Energy conservation standards for building design, construction, and operation. McGraw-Hill.

Brown, R. and Yanuck, R. 1980. Life cycle costing: a practical guide for energy managers. Fairmont Press.

Fazzolare, R. and Smith, C. 1981. Beyond the energy crisis. Pergamon Press.

Solar Energy Research Institute. 1981. A new prosperity: building a sustainable energy future. The SERI Solar/Conservation Study. Brick House.

Reports

Ross, H. and Whalen, S. 1981. Building energy use compilation and analysis. Part C, conservation progress in retrofitted commercial buildings. U.S. Department of Energy.

Hirst, E. 1979. Analysis of engineering audits at state owned buildings in Minnesota. Oak Ridge National Laboratory, Minnesota Energy Agency.

Hollowell, C. and Miksch, R. 1981. Sources and concentrations of organic compounds in indoor environments. Lawrence Berkeley Laboratory.

Hollowell, C. 1981. Indoor air quality. Lawrence Berkeley Laboratory.

Diamond, S. and Hunn, B. 1980. DOE-2 verification project phase I interim report. Los Alamos Scientific Laboratory.

Hirst, E. et al. 1981. Improving energy efficiency: the effectiveness of government action. Oak Ridge National Laboratory.

Lawrence Berkeley Laboratory. 1981. Technical opportunities for energy-efficient buildings: a least cost scenario 1980-2000. EEB-81-6. Lawrence Berkeley Laboratory.

AIA Research Corporation. 1979. Life cycle cost study of commercial buildings. AIA Research Corporation.

Heating/Piping/Air Conditioning Journal. August 1981.