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MASTER

A TRAINING PROGRAM FOR ENERGY CONSERVATION IN NEW BUILDING CONSTRUCTION VOLUME IV

**ENERGY CONSERVATION TECHNOLOGY
ADVANCED COURSE FOR PLAN EXAMINERS**

DECEMBER 1977

**ENERGY CONSERVATION TECHNOLOGY
SERIES 300**

**Prepared For The
U.S. DEPARTMENT OF ENERGY
Washington, D.C.**

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A TRAINING PROGRAM FOR ENERGY CONSERVATION IN NEW- BUILDING CONSTRUCTION,

VOLUME IV,

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ENERGY CONSERVATION TECHNOLOGY;
ADVANCED COURSE FOR PLAN EXAMINERS

44 ENERGY CONSERVATION TECHNOLOGY SERIES 300

MASTER

DEVELOPED BY

BUILDING OFFICIALS & CODE ADMINISTRATORS INTERNATIONAL, INC.
INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS
SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL, INC.
NATIONAL ACADEMY OF CODE ADMINISTRATION

FOR

NATIONAL CONFERENCE OF STATES ON BUILDING CODES AND STANDARDS, INC.

DECEMBER 1977

PREPARED FOR THE
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ABSTRACT

Under the sponsorship of the United States Department of Energy, a Model Code for Energy Conservation in New Building Construction has been developed by those national organizations primarily concerned with the development and promulgation of model codes. The technical provisions are based on ASHRAE Standard 90-75 and are intended for use by state and local officials.

The subject of regulation of new building construction to assure energy conservation is recognized as one in which code officials have not had previous exposure. It was also determined that application of the model code would be made at varying levels by officials with both a specific requirement for knowledge and a differing degree of prior training in the state-of-the-art.

The above described national organizations consisting of National Conference of States on Building Codes and Standards, Inc. (NCSBCS), Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), Southern Building Code Congress International, Inc. (SBCC), and the National Academy of Code Administration (NACA), developed a training program and instructional materials for code officials to assist them in the implementation and enforcement of energy efficient standards and codes. The training programs prepared are:

- VOLUME I Energy Conservation Technology - Management and Energy Conservation (ECT Series 000);
- VOLUME II Energy Conservation Technology for the Building Inspector (ECT Series 100);
- VOLUME III Energy Conservation Technology for Plan Examiners and Code Administrators (ECT Series 200);
- VOLUME IV Energy Conservation Technology - Advanced Course for Plan Examiners (ECT Series 300).

Key words: Administrative procedures; ASHRAE 90-75; Educational material - codes; Buildings; Building Codes; Energy conservation; Model codes; Training programs - energy conservation.

PREFACE

Under the sponsorship of the United States Department of Energy (DOE) the National Conference of States on Building Codes and Standards, Inc. (NCSBCS), in conjunction with the three model code groups, Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), Southern Building Code Congress International, Inc. (SBCC), developed a Model Code for Energy Conservation in New Building Construction. The technical provisions of this document are based on ASHRAE 90-75 and it is intended for use by state and local building officials in the implementation of a statewide energy conservation program.

In addition, the NCSBCS, the Model Code Groups, and the National Academy of Code Administration (NACA) have developed instructional materials and a training program for state and local building code officials which will assist them in the implementation and enforcement of energy efficient standards and codes. The instructional materials were edited by Glendon R. Mayo, P. E. Briefly, the training program consists of the following Energy Conservation Technology (ECT) courses:

<u>Intended Audience</u>	<u>ECT Series Number</u>	<u>Volume</u>	<u>Title</u>
Code Policy Administrators	000	I	ENERGY CONSERVATION TECHNOLOGY - MANAGEMENT AND ENERGY CONSER- VATION
Building Inspectors	100	II	ENERGY CONSERVATION TECHNOLOGY FOR THE BUILDING INSPECTOR 100 Introduction to Energy Conservation 101 Energy Fundamentals 102 Model Energy Code 103 Model Energy Code Application
Plan Examiners and Code	200	III	ENERGY CONSERVATION TECHNOLOGY FOR PLAN EXAMINERS AND CODE ADMINISTRATORS 200 Introduction to Energy Conservation 201 Energy Fundamentals 202 Model Energy Code 203 Model Energy Code Application

Plan Examiners 300 IV ENERGY CONSERVATION TECHNOLOGY -
ADVANCED COURSE FOR PLAN EXAMINERS
300 Introduction to Energy
Conservation
301 Energy Fundamentals
302 Model Energy Code
303 Model Energy Code Application

COURSES

VOLUME I ENERGY CONSERVATION TECHNOLOGY - MANAGEMENT AND ENERGY CONSERVATION

SERIES 000

Intended Audience: Appointed and elected administrators of state and local governments.

Course Descriptions:

ECT-000. Management and Energy Conservation. Designed to acquaint public administrators at the policy making level with the meaning and implications for government of legislation relative to energy conservation standards for buildings, to underscore the need for training for employees responsible for implementing the new Model Energy Conservation Technology educational program now available. Optimization of agency resources and development of ability to handle technical demands will be considered as will the new technical skills required.

VOLUME II - ENERGY CONSERVATION TECHNOLOGY FOR THE BUILDING INSPECTOR

SERIES 100

Intended Audience: Personnel engaged in the inspection of buildings for compliance with approved plans.

Course Descriptions:

ECT-100. Introduction to Energy Conservation. Review of the energy situation, nationally and worldwide, establishing the importance of energy conservation in building construction. Discussion of recent research and trends. Illustrated with examples of buildings designed with energy conservation in mind.

ECT-101. Energy Fundamentals. Review of Energy Terminology and applications including heat transfer and insulation terms and practices involved in building so as to conserve energy.

ECT-102. Model Energy Conservation Code. An analysis of the Model Energy Conservation Code's requirements covering its administrative, plan review and inspection provisions and their impact on building construction.

ECT-103. Model Energy Conservation Code Application. Application of the Model Energy Conservation Code to achieve the building standards and inspection standards anticipated in ECT-102. Product recognition (labeling and approvals) and installation requirements will be included. The application of the Code's requirements to building, mechanical, plumbing and electrical inspections will be identified. The administrative, plan review and enforcement factors involved in achieving the code requirements also will be covered. Plan review is to include accepted practices for achieving the code requirements. The course will include practical examples of how these concepts can be applied to on-the-job situations.

VOLUME III - ENERGY CONSERVATION TECHNOLOGY FOR PLAN EXAMINERS AND CODE ADMINISTRATORS

SERIES 200

Intended Audience: Personnel involved in the review of plans or inspection of conventional residential buildings and small commercial and industrial buildings.

Course Description:

ECT-200. Introduction to Energy Conservation. Review of the energy situation, nationally and worldwide, establishing the importance of energy conservation in building construction. Discussion of recent research and trends. Illustrated with examples of buildings designed with energy conservation in mind.

ECT-201. Energy Fundamentals. Introduction and application of energy terminology and formulas including basic principles of heat flow in building construction.

ECT-202. Model Energy Conservation Code. An analysis of the Model Energy Conservation Code's administrative, plan review and inspection provisions and their impact on building construction.

ECT-203. Model Energy Code Application. Application to the Model Energy Conservation Code provisions and requirements to accomplish its energy conservation objectives. Product recognition (labeling and approvals), installation requirements and review of sample plans that illustrate principles and practices involved in designing energy conserving buildings will be included. The building, mechanical, plumbing and electrical inspections involved in applying the Code's requirements also will be identified. Incorporation of the code's administrative, plan review, inspection and enforcement provisions in the regular operations of the code administration agency will be discussed. Plan review will cover design provisions and accepted practices that meet the energy conservation requirements set forth in the Code.

VOLUME IV - ENERGY CONSERVATION TECHNOLOGY - ADVANCED COURSE FOR PLAN EXAMINERS

SERIES 300

Intended Audience: Personnel involved in review of plans or inspection of all buildings including those incorporating complex systems.

Course Description:

ECT-300. Introduction to Energy Conservation. Review of the energy situation, nationally and worldwide, establishing the importance of energy conservation in building construction. Discussion of recent research trends. Illustrated by examples of buildings designed with energy conservation in mind.

ECT-301. Energy Fundamentals. College level review of thermo-environmental energy principles that relate to energy conservation including energy terminology and formulas.

ECT-302. Model Energy Conservation Code. An analysis of the Model Energy Conservation Code's requirements covering its administrative, plan review and inspection provisions and their impact on building construction. Emphasis will be placed on systems analysis, design provisions and accepted practices.

ECT-303. Model Energy Conservation Code Application. Application of the Model Energy Conservation Code to the plan review process and in the design of energy conserving buildings. Information will be provided relative to performance and innovative design approaches and to product acceptance systems. The effect of this code upon the regular administrative, plan review, inspection and enforcement activities of the code administration agency will be indicated.

INTRODUCTION

One of the major goals set forth in the contract between the United States Department of Energy and the National Conference of States on Building Codes and Standards, Inc. (NCSBCS), together with the major model code groups, concerning the development of a Model Code for Energy Conservation in New Building Construction was filling the recognized need to provide uniform training in the implementation and enforcement of this code by the building officials.

It is recognized that the field of energy conservation was an area not previously entered into by code officials. Further, it was recognized that those presently serving their states and communities as well as those who would necessarily become involved in the future would be at differing levels at the curve of understanding the subject.

It was also determined that a specific introduction into the subject of energy conservation as would be encountered in applying codes and standards was needed for those in a policy-making position in the various states. The rationale for an orderly and coherent adoptive process for a uniform method of energy conservation enforcement appeared the most positive method to quickly assure that a start would be made on energy conservation methods in buildings.

A successive series of training manuals was developed in conjunction with Building Officials & Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), Southern Building Code Congress International, Inc. (SBCC), and the National Academy of Code Administration (NACA), by the National Conference of States on Building Codes and Standards, Inc., for the United States Department of Energy, using personnel who were both well acquainted with the topic and who were currently involved in the continuing educational process for code officials. The results are presented in four volumes, each of which is oriented toward a specific audience and their need-to-know. The training program is entitled:

A TRAINING PROGRAM FOR ENERGY CONSERVATION IN NEW BUILDING CONSTRUCTION

VOLUME I - ENERGY CONSERVATION TECHNOLOGY - MANAGEMENT AND ENERGY CONSERVATION (ECT Series 000)

This training manual is both an introduction to the need for energy conservation in buildings and a definition of the need for and the role of the enforcement of official for energy conservation.

VOLUME II - ENERGY CONSERVATION TECHNOLOGY FOR THE BUILDING INSPECTOR
(ECT Series 100)

This training manual contains the basic information necessary to acquaint the field building inspector with the concepts of energy conservation in buildings and instructs him in the basic techniques of field inspection of energy compliance.

VOLUME III - ENERGY CONSERVATION TECHNOLOGY FOR PLAN EXAMINERS AND CODE ADMINISTRATORS (ECT Series 200)

This manual contains a more in-depth training in the review techniques and concepts required by the plan examiners and code officials in administering the code for conventional (buildings of 3 stories or less) construction.

VOLUME IV - ENERGY CONSERVATION TECHNOLOGY - ADVANCED COURSE FOR PLAN EXAMINERS (ECT Series 300)

This manual contains training material that will be needed by plan examiners in the building departments involved in major or complex structures who are thoroughly familiar with the conventional principles and application of energy conservation requirements in building construction, but who will be faced with the responsibility of reviewing and approving involved complex technical alternative solutions to the problem of conserving energy in buildings.

These training modules are prepared on the basis of the assumed level of comprehension of the student. It is entirely possible that they may be used individually or in toto, depending upon the level of the student.

Comments and recommendations by instructors and participants are invited to assure that the revisions of these training materials which will be undertaken on a periodic basis are responsive to the needs of state and local building officials.

TABLE OF CONTENTS

	<u>Page</u>
CHAPTER 1 INTRODUCTION TO ENERGY CONSERVATION (ECT-300)	9
PART 1 THE ENERGY CRISIS.	9
PART 2 TYPICAL EXAMPLE OF AN INDUSTRIAL STATE	10
I The State of Ohio Energy Supply and Demand	10
II Relief of Ohio's Energy Shortage	12
PART 3 U.S. ENERGY DEMAND BY CONSUMING SECTOR	14
PART 4 TOTAL U.S. ENERGY SUPPLY	14
PART 5 ILLUSTRATED EXAMPLES OF BUILDINGS DESIGNED WITH ENERGY CONSERVATION IN MIND.	17
REFERENCES	20
APPENDIX A	21
 CHAPTER 2 ENERGY FUNDAMENTALS (ECT-301)	 48
I AIR AND HUMIDITY CALCULATIONS.	48
A. Psychrometric Properties of Air.	48
B. Humidity	49
C. Temperatures	50
D. Enthalpy of Air.	51
E. Air Humidification Process	52
F. Adiabatic Saturation	52
G. Psychrometric Chart.	53
H. Use of Psychrometric Chart at Varying Barometric Pressures.	54
I. Air Mixing	54

	<u>Page</u>
II PSYCHROMETRIC PROCESSES.	55
A. Sensible Heating	55
B. Sensible Cooling	56
C. Latent Heating	57
D. Latent Cooling	57
E. Sensible Heat Ratio.	58
F. Air Mixing	58
G. Air Supply Conditions.	59
III PROCESS COMBINATIONS	61
A. Heating and Humidifying Process.	61
B. Cooling and Dehumidifying Process.	63
C. Process Directions	64
IV FACTORS AFFECTING HUMAN COMFORT.	64
A. Comfort Air Conditioning	64
B. Heat Production and Regulation in Man.	65
C. Environmental Indices.	65
D. Effective Temperature.	66
E. New ASHRAE Comfort Chart	66
F. Airborne Contaminants.	69
V HEATING LOAD	71
A. Design Conditions.	71
B. Calculation of Heating Load.	72
C. Summation of Heat Loss	78
D. Seasonal Heat and Fuel Requirements.	79

	<u>Page</u>
VI AIR CONDITIONING COOLING LOAD.	85
A. Design Conditions.	85
B. Solar Radiation.	85
C. Equivalent Temperature Differential.	86
D. Instantaneous Heat Gains	87
E. Heat Gains From Ventilation and Infiltration	99
F. Heat Gain from Lights and Equipment.	100
VII PRINCIPLES OF STEAM HEATING.	100
A. Steam in Heating Systems	100
B. Types of Steam Systems	101
VIII HOT WATER HEATING.	104
A. Hot Water Systems.	104
B. Advantages of Hot Water Heating.	104
C. Piping System Design	105
D. High-Temperature, High-Pressure Water.	107
IX HEAT TRANSFER ELEMENTS	107
A. Radiators and Convectors	107
B. Baseboard Radiation.	108
C. Unit Heaters and Coolers	108
X FUELS AND COMBUSTION	108
A. Fundamental Principles of Combustion	108
B. Fuels.	109

	<u>Page</u>
XI HEATING AND COOLING AIR SYSTEMS.	110
A. Single Zone.	110
B. Multi-Zone	110
C. Dual-Duct.	111
D. Terminal Reheat.	112
E. Variable Air Volume.	112
F. Induction.	112
XII PRINCIPLES OF DUCT DESIGN AND AIR DISTRIBUTION SYSTEMS	113
A. Principles of Fluid Flow	113
B. Duct Design Procedure.	123
C. Air Delivery and Distribution.	125
XIII HEAT PUMP SYSTEMS.	125
A. Definition	125
B. Comparison to Vapor-Compression.	125
C. Cycles	125
D. Ideal Refrigeration and Heat Pump.	125
E. Rankine Cycle.	126
F. P-H Diagrams and Refrigeration Cycles.	129
REFERENCES	131
APPENDICES	
A. Example Problems	132
B. Steam Tables	165

C. Psychrometric Charts.	<u>Page</u> 172
D. Weather Data and Design Conditions Material Thermal Properties	174
CHAPTER 3 INTRODUCTION TO ENERGY CONSERVATION (ECT-302).	198
PART 1. INTRODUCTION	198
I Energy Conservation	198
PART 2. BUILDING DESIGN AND SYSTEMS ANALYSIS.	200
I GENERAL	200
II SYSTEMS ANALYSIS PROCEDURE.	201
A. Computer Programs.	201
B. ASHRAE Algorithms for Building Heat Transfer Subroutines	204
C. The ASHRAE Load Verification Program	211
D. Comparison of Simulated Versus Measured Energy Consumption	212
III BUILDINGS USING NONDEPLETABLE ENERGY SOURCES.	213
A. General.	213
B. Documentation.	213
REFERENCES	216
CHAPTER 4 MODEL ENERGY CONSERVATION CODE APPLICATION (ECT-303) . . .	217
PART 1. MODEL CODE TESTING	217
I. IMPACT ON BUILDING ENERGY USAGE AND ECONOMICS	217
A. Methodology, Assumptions	217

	<u>Page</u>
B. Impact on Consumption.	219
C. Physical Characteristics	225
D. Building Economics	226
II POTENTIAL IMPACT ON NATIONAL ENERGY DEMAND.	229
A. Annual Energy Demand	229
B. Impact of AHSRAE 90.	231
PART 2 BUILDING DESIGN BY SYSTEMS ANALYSIS APPROACH	234
I REVIEW OF CODE REQUIREMENTS	234
II ENERGY ESTIMATING METHODS	234
A. General Considerations	234
B. The Degree Day Method.	235
C. Modified Degree Day Procedure.	242
D. Equivalent Full-Load Hours	243
E. Bin Method Procedure	244
F. Hour-by-Hour Calculations.	244
III COMPUTERIZED LOAD AND ENERGY ANALYSIS	247
A. Computer Programs.	247
B. ASHRAE Algorithms for Building Heat Transfer Subroutines	250
C. The ASHRAE Load Verification Program	255
D. Comparison of Simulated Versus Measured Energy Consumption	256
IV PRINCIPLES FOR A SIMPLIFIED ENERGY CALCULATION PROCEDURE FOR USE IN ENERGY CONSERVATION STANDARD ACTIVITIES.	256
A. Brief Description of the Analysis Procedure.	258

	<u>Page</u>
PART 3. ENERGY CONSERVATION IN BUILDINGS UTILIZING NONDEPLETING ENERGY SOURCES.	260
I SOLAR ENERGY COLLECTORS	261
A. Flat Plate Collector	261
B. Concentrating Collectors	261
II ENERGY STORAGE.	263
A. Liquids.	263
B. Solids	263
C. Phase Change Storage	263
III ENERGY CONSERVATION IN WATER HEATING SYSTEMS UTILIZING SOLAR ENERGY.	264
A. Domestic Hot Water Heaters	264
B. Industrial Hot Water Heaters	265
IV ENERGY CONSERVATION BY UTILIZING SOLAR ASSISTED HEATING SYSTEMS.	265
V AVAILABILITY OF SOLAR ENERGY.	265
VI SOLAR SYSTEMS	267
VII ECONOMICS OF SOLAR HEATING AND COOLING.	267
VIII FINANCING SOLAR SYSTEMS	267
IX ARCHITECTURAL CONSIDERATIONS.	274
PART 4 ACCEPTED PRACTICES	274
I GENERAL	274
II BUILDING ENCLOSURE, ELEMENTS.	274
A. Orientation and Shape.	274
B. Building Thermal Envelope.	274

	<u>Page</u>
C. Infiltration	299
D. General Discussion of Lighting Design.	300
III BUILDING MECHANICAL SYSTEMS	305
A. Application of Energy Reduction Techniques For HVAC Systems	305
B. Automatic Temperature Controls	321
C. Distribution System Design	321
PART 5 CASE STUDIES OF ENERGY CONSERVATION IN COMMERCIAL BUILDINGS	322
I OHIO LEGAL CENTER (LEGAL AIDS) BUILDING	322
A. Boiler Efficiencies.	322
II CASE STUDIES OF 35 BUILDINGS ON THE OHIO STATE UNIVERSITY CAMPUS	325
A. Allied Medical Building.	325
B. McCampbell Hall.	339
REFERENCES.	348
APPENDICES	
A. Material Identification and Field Inspection.	351
B. Plan Check Examples	361
C. Cooling Examples.	398

CHAPTER 1

INTRODUCTION TO ENERGY CONSERVATION

(ECT-300)

PART 1 THE ENERGY CRISIS¹

The United States passed through an era in 1972 during which energy was cheap and abundant. During that era demand for energy was very high. Beginning in the 1930's, the United States government adopted measures and practices which have encouraged energy consumption, but did not encourage the efficient utilization of that energy. For example, low-cost and plentiful power was promoted and its distribution and consumption were encouraged by the Tennessee Valley Authority and later by the Rural Electrification Administration. In 1954, the wellhead price of natural gas was placed under the jurisdiction of the Federal Power Commission (FPC) as the result of a Supreme Court decision.

When low-cost Middle Eastern oil became available in the 1950's, import restrictions were applied to protect domestic production. Also, during this era, the federal government placed increasing controls on domestic oil production. As a result, domestic production decreased and the growth in demand for petroleum fuels and feedstocks was increasingly met by foreign oil supplies. Since 1970, essentially all growth in national demand for energy has been met by imported oil and nuclear power plants.

Low-cost fuels and the resulting cheap and plentiful energy provided an important base for the accelerated growth and prosperity of this country between 1930 and 1970. Consequently, the federal government's policies did have their intended desirable effects. There were, however, a number of significant and deleterious side effects. The consequences of these effects have only recently become evident.

A most important long-term effect of federal energy policies was the creation of an imbalance in fuel consumption. Cheap oil and natural gas gradually began to edge coal out of the energy market. Coal production is more labor intensive than is oil production. As labor costs went up, coal became less competitive.

The costs of domestic petroleum production also increased and the oil industry went abroad for cheaper foreign oil, further weakening coal's ability to compete in the energy market place. The result was a national economy with a significant dependence on oil (much of it from

foreign sources) and decreasing coal production.

Another result of depressed (and artificial) fuel prices was the obscuring of the comparative energy values of different fuels. There has been no economic matching of fuels to their most efficient uses. For example, natural gas, a high-form value fuel, is still being used in many states to generate electricity. With the necessary equipment, the utility could use more abundant and lower form value fuels, e.g. coal and nuclear. The nation and Ohio are currently facing serious economic dislocations as natural gas consumption patterns are being reordered.

PART 2 TYPICAL EXAMPLE OF AN INDUSTRIAL STATE

I. The State of Ohio Energy Supply and Demand^{2,3,4}

Ohio had ample energy supplies to satisfy the needs of all consuming sectors until 1972. In that year, Ohio consumed approximately 3.3 Quadrillion Btu (Q) which amounted to approximately 5% of the total amount of energy consumed in the United States. Of the States, Ohio was the fifth largest user of energy.

Ohio ranks first in coal consumption, third in natural gas consumption, fourth in electric power generation and ninth in petroleum consumption.

Table 300-2-1 shows the sectoral energy dependency for Ohio. Coal is used principally in the industrial and power generating sector. Very little coal is used in the residential and commercial sectors.

TABLE 300-2-1²

OHIO ENERGY USAGE BY CONSUMING SECTOR (%)*

<u>Sector</u>	<u>Coal</u>	<u>Oil</u>	<u>Gas</u>
Residential/Commercial	1	19	58
Industrial	42	8	42
Transportation	—	72	—
Power Generation	57	1	—

*1974-latest year for complete statistics

The use of petroleum is focused mainly in the transportation sector and the residential/commercial sector. Very little oil (8%) is used to satisfy industrial energy demands. This low level of industrial petroleum dependency has done much to protect Ohio industry from the adverse consequences of foreign oil dependency. However, with increasing natural gas curtailment, the limited use of petroleum for industry places a burden on the oil transportation and storage facilities.

The use of natural gas is concentrated in all sectors, i.e. residential, commercial, and industrial. The high degree of industrial dependency on natural gas, coupled with regulatory priorities favoring the residential sector, places the industrial sector in a precarious position during periods of natural gas shortage-particularly if there is no capability of substitute fuels.

TABLE 300-2-2³

ENERGY SUPPLY/DEMAND PROJECTIONS FOR OHIO - BUSINESS AS USUAL

DEMAND SECTOR	1972			1980			1990		
	COAL	GAS	OIL	COAL	GAS	OIL	COAL	GAS	OIL
Residential/ Commercial	.0159	.696	.1995	.0163	.9454	.3097	.0274	1.58	.52
Industrial	.6678	.504	.080	.8022	.605	.1528	1.16	.88	.22
Transportation	--	--	.760	--	--	1.02	--	--	1.48
Power Generation	.906	NIL	.01	1.08	--	--	1.10	--	--
Demand Total	1.59	1.20	1.05	1.90	1.55	1.49	2.28	2.46	2.22
Projected Supply	1.59	1.20	1.05	2.04	0.72	1.15	2.67	0.87	1.19
Deficiency (excess)	0%	0%	0%	(7%)	53%	23%	(17%)	65%	46%

NOTE: Energy Supply/Demand Given in Quadrillion BTU

Table 300-2-2 shows the projected energy supply/demand for Ohio to 1990. This projection is based on a premise of 1972 "business as usual" conditions. Energy supply is estimated using data and projections made by the Federal Energy Administration, U.S. Bureau of Mines, the Federal Power Commission, and other sources. The sectoral demand projections were made from Ohio's historical demand growth patterns. Coal supply is projected to increase and will satisfy the state's need well into the future. In fact, Ohio is projected to have a net excess of coal supply by 1980 and beyond.

A petroleum supply deficiency of approximately 23% is projected as early as 1980. The major factor underlying this projected deficiency is the assumption of import restrictions and reduced reliance on foreign supplies as noted in the federal Project Independence Report. The events of the past year clearly show that oil imports are increasing rather than decreasing. Consequently, the projected shortages of petroleum will in all likelihood not materialize.

The shortage of natural gas is projected to reach 53% of demand by 1980. The total supply of natural gas is projected at 9.72 Q while the demand is projected at 1.55 Q. Natural gas will not even satisfy the total demands of the residential/commercial sectors. This means there would be no natural gas available for industrial sector. The industrial sector does not have the capacity to make this much of a massive conversion to alternative energy forms as a means of abating the natural gas supply deficiency. Moreover, the expense involved, coupled with the mature nature of Ohio's industrial sector, could lead to substantial losses of employment and industrial dislocation.

II. Relief of Ohio's Energy Shortage^{5,6}

Inasmuch as natural gas supply is Ohio's primary problem, we have evaluated alternative approaches to relieve the gas supply problem.

The alternatives we have considered are:

1. Increase Natural Gas Supply - historic and non-historic
2. Reduce natural gas demand
3. Encourage coal/oil/electricity conversions
4. Apply advanced technology (e.g. solar)
5. Accelerate nuclear energy application for power generation
6. Advanced substitute fuels (e.g. hydrogen or methanal)

7. Policy options - e.g. mandatory curtailment of the residential sector.

Each of the alternatives noted above can play a meaningful part in relieving Ohio's energy shortage. However, each of the alternatives noted will impact on the other energy sectors. Figure 300-2-1 is a general schematic showing the relationship of natural gas supply/demand alternatives in the entire energy picture.

Actions to stimulate natural gas supply and reduce natural gas demand, assuming total energy demand is constant, should not be considered as independent events. For example, coal conversion and coal supply are impacted by sectoral conversions away from gas. Increased gas production through coal gasification impacts on coal supplies. Figure 300-2-1 sets out the scope of activities which are required to solve the key problem in Ohio's energy picture (natural gas). Although natural gas is the key problem the schematic puts other energy forms in perspective. The schematic clearly shows that to solve Ohio's energy problems some paths are better than others. For example, relying on coal conversion to provide gas (or for direct combustion) will require an increase in coal production, which impacts on Ohio and the rest of the country. Increases in SNG (Substitute Natural Gas) supply are limited by the availability of coal conversion plants and new mine openings. Both coal conversion facilities and new coal mines are capital intensive and require long lead times. This is a constraint that must be recognized when formulating a program to relieve Ohio's energy problems. The same holds true for new power generating facilities. The Ohio Power Siting Commission estimates that on a peak day many Ohio electric utilities have in excess of 40% generating capacity remaining. Even if 70% of all new residential and commercial customers are "all electric" OPSC estimates current generating capacity in the state is ample until at least 1985. New plants which are under construction will soon be coming on line. It is estimated by OPSC that Ohio will have ample generating capacity, including these new plants, to satisfy state needs for 25 years. Currently it is difficult to predict whether new plants - i.e., those which are not yet planned - will be fossil or nuclear. The cost of enriched uranium has risen to \$27 per pound in 1975 from 1973 levels of \$3 to \$5 per pound. Consequently, the fuel costs, which used to be negligible, must be considered when planning new generating facilities. This coupled with the high initial capital investment required by the utilities for nuclear plants are causing utilities to be very wary of installing nuclear over fossil plants. Initial investment is a serious problem with utilities. For example, the Zimmer nuclear plant is 33 percent completed and all of the original budgeted capital for the entire plant is gone!

PART 3 U.S. ENERGY DEMAND BY CONSUMING SECTOR⁷

Total U.S. energy demand is projected to increase from an estimated 38 million barrels per day oil equivalent in 1976 to 56 million barrels per day in 1990. (See Figure 300-3-1.)

High energy costs, conservation efforts, and slower economic growth over the forecast period will cause the growth in U.S. energy demand to average about 2.8% annually, compared with 4% during the 13 years prior to the embargo, 1960-73. For purposes of evaluation:

Non-Energy. The Non-Energy sector reflects the utilization of oil, gas, and metallurgical coal as feedstock or raw materials, rather than as fuel, in the manufacture of such products as petrochemicals, asphalt, wax, carbon black and steel. The energy demand growth rate in this sector will show little change from historic rates.

Industrial. This sector includes all mining and manufacturing industries. The growth rate in industrial energy demand will decline sharply through 1980, due in part to rapid improvements in energy-use efficiency and slower economic growth, then increase as efficiency improvement slows and economic growth continues. Gas, oil, coal, and electricity contribute to the sector, with gas continuing as the predominant fuel but declining in its share of total sector demand from about 50% in 1976 to about 30% in 1990.

Transportation. Transportation is almost entirely dependent on oil. Average annual energy demand growth will drop significantly below the historic rate. This sector will account for about half of total oil consumed through 1990. Motor gasoline currently accounts for three-quarters of transportation demand; remaining demand is for aviation and diesel fuels, heavy fuel oil, and liquefied petroleum gas.

Residential/Commercial. This sector includes homes, stores, office buildings, hospitals, and schools. The sector's projected growth rate in energy demand will decline from that of the 1960-73 period. Demand growth will be met primarily by gas and electricity. Heating oil consumption will increase only moderately.

PART 4 TOTAL U.S. ENERGY SUPPLY⁷ (See Figure 300-4-1.)

Nuclear. Nuclear energy is confined to electric utility use. Although its development continues to be plagued by construction, regulatory, and siting delays, nuclear energy is expected to be the nation's fastest growing source of energy, supplying 16% of total U.S. energy demand by 1990, compared with about 3% in 1976.

QBTU/Y*

125

MB/DOE*

60

U.S. ENERGY DEMAND BY CONSUMING SECTOR

GROWTH RATES, %/YEAR

	N.E.	IND.	TRAN.	R/C	TOTAL
1960-1973	4.0	3.6	4.1	4.5	4.0
1973-1976	(2.7)	(0.3)	0.6	2.0	0.5
1976-1990	3.9	2.6	1.9	3.4	2.8

100

50

75

40

50

30

25

20

0

0

1960

1965

1970

1975

1980

1985

1990

TRANSPORTATION

INDUSTRIAL

RESIDENTIAL/COMMERCIAL

NON-ENERGY

*2 Quadrillion British Thermal Units/Year = 1 Million Barrels/Day Oil Equivalent

U.S. ENERGY DEMAND BY CONSUMING SECTOR

FIGURE 300-3-1
15

QBTU/Y*

MB/DOE*

*2 Quadrillion British Thermal Units/Year = 1 Million Barrels/Day Oil Equivalent

FIGURE 300-4-1
16

Hydro and Geothermal. Hydro and geothermal power will supply about 3% of total U.S. energy requirements by 1990, down slightly from today's share. Hydro power's share of electric power generation will decline from a current 16% to 10% by 1990. The contribution of geothermal power to total electric power generation is expected to remain negligible through 1990. These two energy sources have limited growth potential due to technological problems and insufficient site availability.

Coal. Coal supply will essentially be determined by demand. Coal use by electric utilities is expected to increase rapidly through 1980, then level off as nuclear power captures most of the growth. After 1980, the most rapidly expanding use of coal will be as an industrial fuel.

Gas. Limited availability of gas will place additional burdens on other energy resources, particularly oil, to meet industrial fuel needs. Gas consumption by the electric utility sector will decline as coal-fired and nuclear-powered generators become dominant. Gas imports are not expected to increase significantly in the future.

Oil. Oil will remain the predominant fuel through 1990, although its share of total energy demand will return to the 1960 level of 44%. Oil consumption by electric utilities in particular will decline from today's levels. Oil imports are projected to increase to 50% of total oil demand by 1980 and begin to level off thereafter.

Alternate Energy Sources. Potential energy sources such as solar power and the breeder reactor are not expected to be commercially available on a significant scale before 1990. One or more of these sources, however, could begin to make an important contribution before the end of this century. Energy from nuclear fusion could become commercially available early in the next century.

PART 5 ILLUSTRATED EXAMPLES OF BUILDINGS DESIGNED WITH ENERGY CONSERVATION IN MIND

I. The Arthur D. Little report - An Impact Assessment of ASHRAE Standard 90-75 (Appendix 300-A)

ASHRAE 90's impact on the construction industry in general and on energy consumption, initial cost, and operating costs of projects in particular was determined on the basis of impact on each of five types of buildings in one location in each of the four major census regions. The five building types investigated were:

- Single-Family Detached Residence
- Low-Rise Apartment Building
- Office Building

Retail Store
School Building

Thus, there were 20 prototypical building type/location projects investigated. The study results represent the maximum impact which would occur under adoption of the standard.

For each case, ADL estimated annual energy consumption using established manual methods for single-family residences and computer-based simulation techniques for nonresidential structures. Two sets of calculations were made: one for the "conventional" building and one for the "ASHRAE 90 modified" building. Next, the comparative impact of ASHRAE 90 on each of the following was determined:

- physical characteristics of the building,
- type and amount of commodity building materials,
- HVAC system size and configuration,
- annual energy consumption (by end use),
- annual operating economics, and
- initial capital cost of the project.

The impact of the standard on the construction industry was evaluated by subdividing the industry into several subsectors and applying the changes in initial cost and/or demand for building materials and specialty equipment compiled from the 20 prototypical examples. These subindustries can be roughly categorized into three groups:

Building Materials Suppliers:

- Insulation
- Siding Materials
- Window Glass

Building Equipment Suppliers:

- Electric Lamps
- Lighting Fixtures
- Gas and Electric Meters
- Hot Water Heaters

HVAC Systems Suppliers:

- HVAC Equipment
- HVAC Controls

In addition, the potential impact of the standard on residential builders and developers, architectural/engineering design firms, and code authorities was also investigated.

Finally, the impact of ASHRAE 90 on indoor air quality was evaluated through an extensive literature search, consultation with outside experts, and the in-house expertise of ADL in this area.

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for

ECT-300

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APPENDIX A
INTRODUCTION TO ENERGY CONSERVATION
AN IMPACT OF ASSESSMENT OF ASHRAE STANDARD 90-75
(ECT-300)

AN IMPACT ASSESSMENT OF ASHRAE STANDARD 90-75,
"ENERGY CONSERVATION IN NEW BUILDING DESIGN"

Report to

FEDERAL ENERGY ADMINISTRATION

December 1975

C-78309

PREFACE

The Federal Energy Administration (FEA), through its mandate from Congress, is active in investigating those areas related to the energy and economic impact due to the adoption of reference codes to promote energy conservation in buildings. One recent effort in developing a document governing energy usage in all types of new construction was undertaken by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) following a request by the National Conference of States on Building Codes and Standards (NCSBCS) in February, 1974. During the past eighteen months, ASHRAE has undertaken a methodological approach in developing a voluntary standard. They have issued two working drafts for public comment and subsequently fielded numerous suggestions for improvement from both ASHRAE members and other representatives of the design/construction industry. Now in its final form, the document is entitled, ASHRAE Standard 90-75: ENERGY CONSERVATION IN NEW BUILDING DESIGN, and was released by ASHRAE's Committee on Standards in August, 1975.

To date, ASHRAE 90-75 is the first major voluntary consensus standard concerning energy utilization in new buildings available for optional acceptance by the individual state and local governments even though the standard has yet to enter the approval process of the American National Standards Institute (ANSI). Both its format and much of its content is based upon a previous document released in February, 1974, by the National Bureau of Standards (NBS), again at the request of NCSBCS.

To lay the foundation for an evaluation of ASHRAE 90-75, the Federal Energy Administration (FEA) retained Arthur D. Little, Inc. (ADL) in May, 1975, to investigate the potential energy and economic impact the standard would have on the nation's construction industry. This included an investigation of the effects on building energy consumption for a variety of building types and geographical locations, the effect on initial (capital) and operating costs of new buildings, the possible influence on building habitability, the reduction in the nation's annual energy requirements, and the potential economic impact on selected sectors within the construction industry. This latter task was to include several selected subindustries dealing in commodity building materials and specialty equipment in addition to key industry participants such as residential homebuilders, architectural and engineering firms, code authorities, etc.

The primary objective of the study was a detailed understanding of all the implications brought about by the possible widespread adoption of ASHRAE 90-75 as a voluntary energy conservation standard. It was not within the scope of work to either technically evaluate ASHRAE 90-75 or to make a case for or against its adoption as an energy conservation guideline.

CHAPTER I

EXECUTIVE SUMMARY

A. OBJECTIVES

The purpose of this investigation by Arthur D. Little, Inc. (ADL), was to analyze the various energy, economic, and institutional impacts that might occur following the broad voluntary adoption of ASHRAE Standard 90-75¹ by individual building regulatory authorities. It was the intent of the study to quantify those impacts in the energy and economic sectors as well as possible, and to qualitatively assess their impact in the institutional sector.

B. METHODOLOGY

In order to study the applicability and impact of the document to each of the foregoing, ASHRAE 90 was subdivided into three approaches to facilitate the analysis:

- Standard Prescriptive/Performance Approach (Sections 4-9): Well-defined performance criteria, based upon an element-by-element design analysis, are applied in this approach to the selection of building materials and systems.
- Systems Analysis Approach (Section 10): An alternative to the above, this approach allows for compliance if the building's energy consumption is shown to be equal to or lower than that achievable through the standard prescriptive/performance approach of Sections 4 through 9.
- Energy Augmentation Approach (Section 11): This alternative allows for the use of solar- or wind-powered systems, or other nondepletable energy sources, to supplement the energy usage of the building by including a "credit" for the energy supplied by such systems.

¹Called ASHRAE 90 hereafter, this refers to the document entitled, "Energy Conservation in New Building Design," the final draft of which was released in August, 1975. Major modifications made to the document after this date could not be incorporated into the analysis.

The quantitative analysis focused on the first and third approaches.²

ASHRAE 90's impact on the construction industry in general and on energy consumption, initial cost, and operating costs of projects in particular was determined on the basis of impact on each of five types of buildings in one location in each of the four major census regions. The five building types investigated were:

Single-Family Detached Residence
Low-Rise Apartment Building
Office Building
Retail Store
School Building

Thus, there were 20 prototypical building type/location projects investigated. The study results represent the maximum impact which would occur under adoption of the standard.

For each case, ADL estimated annual energy consumption using established manual methods for single-family residences and computer-based simulation techniques for nonresidential structures. Two sets of calculations were made: one for the "conventional" building and one for the "ASHRAE 90 modified" building. Next, the comparative impact of ASHRAE 90 on each of the following was determined.

- Physical characteristics of the building,
- type and amount of commodity building materials,
- HVAC³ system size and configuration,
- annual energy consumption (by end use),
- annual operating economics, and
- initial capital cost of the project.

On the basis of the resulting data and the data base developed in a previous ADL report,⁴ estimates were developed of the impact of ASHRAE 90 on total energy demand within the building sector for the period 1976 to 1990.

²The full report, however, does discuss the implications of the systems analysis approach on design architects and engineers.

³Heating, Ventilating, and Air-conditioning.

⁴"Residential and Commercial Energy Use Patterns, 1970-1990." Arthur D. Little, Inc., report to the Council of Environmental Quality and the Federal Energy Administration, November, 1974.

The impact of the standard on the construction industry was evaluated by subdividing the industry into several subsectors and applying the changes in initial cost and/or demand for building materials and specialty equipment compiled from the 20 prototypical examples. These subindustries can be roughly categorized into three groups:

Building Materials Suppliers:

- Insulation
- Siding Materials
- Windows
- Window Glass

Building Equipment Suppliers:

- Electric Lamps
- Lighting Fixtures
- Gas and Electric Meters
- Hot Water Heaters

HVAC Systems Suppliers:

- HVAC Equipment
- HVAC Controls

In addition, the potential impact of the standard on residential builders and developers, architectural/engineering design firms, and code authorities was also investigated.

Finally, the impact of ASHRAE 90 on indoor air quality was evaluated through an extensive literature search, consultation with outside experts, and the in-house expertise of ADL in this area.

C. KEY ASSUMPTIONS

The continuing scarcity of data on building energy usage, the generally poor economic condition of the domestic construction industry, and the fact that ASHRAE 90 had to be interpreted for the first time in a design situation required that several critical assumptions be made:

Interpretation of the Standard: For the purposes of this analysis, a strict interpretation of ASHRAE 90's impact on the conventional buildings was adopted. As an example, where the document only "recommended," rather than "required," that certain measures be taken, the recommendation was interpreted to be a requirement. This leads to the maximum impact on the conventional design process.

"Conventional" Buildings: The configuration, materials composition, physical characteristics, and HVAC systems selected for the "conventional" buildings represent that which was considered typical in new construction. For the most part, selections were based on various public and proprietary statistics. The buildings should be considered "prototypical," since there is no such thing as an "average" building. The actual operating conditions of the "conventional" building were assumed to reflect the conditions prevalent within the construction industry prior to the oil embargo of 1973/74, and might be referred to as "1973 vintage" conditions. Using this period as a benchmark is consistent with other policy studies undertaken by FEA, and emphasizes the rationale for investigating the maximum impact as conservation-oriented design changes within the construction industry have become more prevalent since 1973. Inasmuch as ASHRAE 90 does not dictate how buildings should be operated, the identical operating conditions were retained for both the "conventional" and the "ASHRAE 90 modified" buildings.

"ASHRAE 90 Modified" Buildings: In modifying the prototypical conventional buildings to meet the requirements of ASHRAE 90, the principal criterion for making the decision among alternatives was initial building cost with the rule being to select that alternative which offered the minimum effect on initial building cost. To maintain the aesthetic looks of the building, minimum limits on glass areas were adopted. When confronted with a trade-off in this area, the composition of the opaque wall was changed rather than any further reduction of fenestration.

A second consideration in modifying the conventional buildings was the amount of change needed in component performance. The philosophy employed was to meet, but not purposely exceed, the standard since a client and/or members of the design community would most probably not choose to adopt major modifications in either building appearance or system performance. To determine the economic consequence of exceeding the standard was beyond the scope of this study.

Construction Industry: The analysis of the impact of ASHRAE 90 on the various markets for materials and equipment was based upon an ADL forecast of the construction industry in 1976. ADL assumed a slight rebound in residential housing starts to 1.5 million units, and a leveling of nonresidential construction activity until late 1976.

D. CONCLUSIONS

Within the report are many findings, observations, and recommendations concerning ASHRAE 90's effect on building energy consumption, its influences on physical changes in the buildings, its implications on the owning and operating costs of buildings, its potential impact on the nation's energy consumption in construction, its possible economic impact on several selected markets and participants within the construction sector, and its impact on building habitability. The more important conclusions are as follows:

1. Impact on Building Energy Consumption

Under a strict interpretation of the standard, ASHRAE 90 is very effective in reducing annual energy consumption in all building types and locations. The unweighted average reduction in annual energy consumption relative to 1973 construction and operational practices across the four locations investigated were as follows:

Single-Family Residence	- 11.3%
Low-Rise Apartment Building	- 42.7%
Office Building	- 59.7%
Retail Store	- 40.1%
School Building	- 48.1%

ASHRAE 90 may be seen as less effective in reducing annual energy demand in the detached single-family residence than in the larger residential and nonresidential buildings. This lower effectiveness may be explained in part by the moderately high overall thermal efficiency assumed for the conventional residences. However, the ASHRAE 90 modified residences in both the Northeast (New York City), North Central (Omaha) locations met the standard with single glazing and a minimum reduction in glass area.

The standard appears to be more effective in the colder climates because of the larger percentage of annual energy demand in all construction accounted for by space heating and the inherent effectiveness of ASHRAE 90 in reducing annual heating requirements. In general, the decrease in space heating requirements accounted for 60 to 75% of the total reduction in actual energy consumption.

The lowest unit-energy consumption obtainable in the prototypical buildings after the prescriptive/performance approach (Sections 4 through 9) had been made was on the order of 67,000 to 72,000 Btu per square foot. This consumption is considerably greater than the General Services Administration announced "goal" of 55,000 Btu per square foot. ADL does not believe the implementation of ASHRAE 90 alone would suffice to meet the GSA goal for any building type similar to those investigated.

If measured in terms of energy reduction potential, the most "effective" sections in the document will vary by type of building. With few exceptions, all of the sections have some influence on the reduction in annual energy consumption. Changes in winter design conditions (Section 5) and supplied domestic hot water temperatures (Section 7) appear to be the most effective parameters for the single-family residence, while those chapters dealing with HVAC equipment, systems, and control (Sections 5 and 6) appear to be most effective in nonresidential construction.

2. Impact on Physical Characteristics

The application of ASHRAE 90 brought about the following physical differences in the conventional versus ASHRAE 90 modified buildings:

Exterior Glass - Glass area (percent fenestration) was reduced in approximately two-thirds of the buildings. Reductions were as much as 30%, but most were less than 20%. One region--the North Central--required reductions in glass area for all buildings.

Exterior Wall - Decreases in glass area were balanced by increases in net wall area; virtually all increases were less than 8%.

Insulation - Additional insulation requirements for residential construction varied from 80 to 300 pounds per unit. Increased requirements for insulation in commercial construction were even greater than those needed in residential construction.

Lighting - Reductions in lamps and lamp fixtures varied by building type, and averaged 24% and 22%, respectively, for nonresidential construction.

HVAC System Capacities - Reductions in heating system capacities were significant, averaging 42%, while reductions in cooling systems were generally less, averaging 31%. The greatest reductions were found in the school building. Auxiliary HVAC equipment, including pumps, towers, fans, supply fans, etc., also showed a significant reduction, averaging 44% in rated kilowatt capacity.

3. Impact on Building Economics

Based on 1975 energy costs compiled by ADL, annual savings in operating costs ranged between \$0.05 and \$1.05 per square foot, but were generally within the range between \$0.20 and \$0.70 per square foot. Savings in single-family residences (\$0.05 to \$0.14 per square foot) were lower and less broader than those for commercial construction (\$0.12 to \$1.05 per square foot). Percent savings in annual energy costs ranged from 9-15% in the single-family house to 30-45% for commercial buildings.

The savings may be large enough to induce building owners to follow the standard on a voluntary basis providing they had such decision information available to them and providing financial institutions recognize that the loan quality is improved.

The initial construction costs of those buildings modified under the standard prescriptive/performance approach were shown to be less than those of conventional buildings. Unit savings range from \$0.04 to \$0.94 per square foot, with the greatest savings experienced in office buildings.

ASHRAE 90 generally increases the cost of the exterior wall, floors, roof, and domestic hot water system. Glazing costs may be higher or lower depending upon building type. Unit costs for lighting, and particularly HVAC equipment and distribution systems, were significantly lower and tended to offset the increase in other costs.

Average changes in unit costs are as follows:

	<u>Dollars Per Square Foot</u>
Single-Family Residence	- 0.02
Multi-Family Residence	- 0.41
Office Building	- 0.63
Retail Store	- 0.18
School Building	- 0.44

For the prototypical buildings investigated, the cost of additional design effort was found to be between \$0.09 and \$0.36 per square foot of floor area. With the exception of the single-family residence, the straight payback of design services due to energy cost savings was found to be less than one year, and less than six months in most cases. Average additional design costs were as follows:

	<u>Dollars Per Square Foot</u>		
	<u>Annual Energy Savings</u>	<u>Additional Design Services</u>	<u>Straight Payback</u>
Single-Family Detached Residence	0.07	0.24	2.9 years
Low-Rise Apartment	0.31	0.09	3.4 months
Office Building	0.40	0.16	2.5 months
Retail Store	0.68	0.09	7.6 months
School	0.70	0.15	4.6 months

Thus, savings in initial cost can be offset by increased design fees; consequently it appears that the ASHRAE 90 modified buildings should cost no more to build and will have significantly less annual energy costs. Furthermore, even if total initial cost did increase, the savings in operating cost (over those of conventionally-designed buildings) would more than recover such costs in a couple of months.

4. National Energy Consumption

If instituted by all states, ASHRAE 90 could reduce the annual energy consumed in new construction by about 27%, and if instituted in 1976, the standard would reduce ADL estimates of the growth of energy consumption in the building sector over the period 1976 to 1990 from 2.3% to 1.4%.

The potential energy which could be saved by the adoption of ASHRAE 90, equals 4%, 8%, and 12% of total estimated annual energy consumption in the nation's buildings for the years 1980, 1985, and 1990, respectively. However, the standard will not cause a decline in the nation's future demand for energy in the building sector.

The potential energy saved by ASHRAE 90 was found to be greater in the North Central region, and again, this is related to the annual demand accounted for by space heating.

ASHRAE 90 could reduce energy consumption significantly even if it were adopted (and enforced) only by those 29 states that presently have mandatory or voluntary statutes or that have bills pending, since 75% of the volume of affected construction lies within these 29 states.

5. Impact on Building Materials and Building Equipment Markets

Of the estimated \$168.5 billion in construction expenditures in 1976, the study estimates \$88.3 billion, or 52%, could be affected by ASHRAE 90. Of this, \$80 billion is construction put-in-place, and \$8.3 billion is attributable to mobile homes.

ASHRAE 90 would upgrade the building's thermal shell, lower lighting and ventilation levels, and reduce HVAC equipment capacities. The direct economic impact attributable to ASHRAE 90 appears to be limited to a few specific industry sectors. (See Table I-1). In general, the adoption of ASHRAE 90 will create opportunities for suppliers of commodity building materials at the expense of reducing those markets for general building equipment and HVAC systems.

The most favorable impact appears to be on building insulation suppliers, who could realize as much as \$179 million in new markets, an

TABLE I-1

SUMMARY OF ECONOMIC IMPACTS DUE TO ASHRAE 90

	<u>Total Annual Market (\$MM)</u>	<u>Market Affected by ASHRAE 90 (\$MM) (X)</u>	<u>Maximum Potential Impact of ASHRAE 90 (\$MM)</u>	<u>Percent of Total Market (X)</u>	<u>Percent of Affected Market (X)</u>
Building Materials Suppliers:					
Insulation:	1,000	595	+179	+18	+30
• Batt	470	270	+ 45	+10	+17
• Rigid Board	460	280	+128	+28	+46
• Loose Fill	70	45	+ 6	+ 9	+13
Siding Materials	1,000	850	+ 12	+ 1	+ 1
Flat Glass	1,247	146	+ 7	+ 1	+ 5
Windows	903	720	- 19	- 2	- 3
Building Equipment Manufacturers:					
Electric Lamps	1,177	176	- 16	- 1	- 9
Lighting Fixtures	1,450	830	-175	-12	-21
Gas and Electric Meters	173	159	+ 3	+ 2	+ 2
Hot Water Heaters	289	117	+ 4	+ 3	+ 3
HVA/C Systems Manufacturers:					
HVA/C Equipment	2,308	1,720	-135	- 8	-11
HVA/C Controls	550	410	+ 21	+ 4	+ 5

SOURCE: Arthur D. Little, Inc., estimates.

increase in their overall annual sales of approximately 18%. Likewise, HVAC equipment manufacturers face an annual potential loss of \$185 million, 8% of their total market, while lighting fixtures manufacturers face a potential loss of \$175 million, 12% of their total market. The remaining market sectors will receive only a minimal impact, typically ranging from -2% to +4% to their annual market.

HVAC equipment manufacturers, unlike commodity materials suppliers, are heavily oriented towards new construction. Few, if any, large secondary markets are available to HVAC component suppliers that can offset a major loss in the potential sales volume from conservation-oriented design. Although manufacturers may be able to moderate this negative impact, they will nevertheless be adversely affected by any type of effective energy conservation legislation, be it ASHRAE 90 or some similar design standard.

Most of those companies associated with the construction industry have experienced other sudden and significant impacts on their markets and still survived. The situation investigated here is comparable to those sudden annual downturns resulting from annual residential cyclicity or safety-oriented fire modifications. ADL anticipates these sectors will again be able to adapt.

6. Impact on Key Industry Participants

The study concludes that the successful implementation of ASHRAE 90 will have an insignificant impact on residential homebuilders. Large builders can meet the standard at an insignificant design cost, and the small, local builders--while initially experiencing difficulty in interpreting the document--will probably be assisted by the local Homebuilders Association or building materials suppliers through manuals of accepted practice.

Wise builders seeking profit opportunities on sales may well use the energy crisis as a sales tool to sell extras, but these, for the most part, will have to be visible.

The adoption of ASHRAE 90 will tend to load-up the "front end" of the design process. It will result in more calculations, further technical and economic evaluation of systems, additional internal and external meetings of the design team, and more interaction with code authorities. This effect on the design process need not affect the project schedule, provided that the mechanical engineer is included in the design team at the very beginning.

ASHRAE 90 will generally encourage the use of electronic computation on all projects, and thereby create a major market for energy-oriented computer programs and services.

Total A/E design billings in 1976 are estimated to be \$7.4 billion, approximately 40% of which could be affected by ASHRAE 90. The net impact of adopting the standard would be a potential increase of \$92 million in billings for mechanical/electrical engineers and \$60 million for design architects. It seems likely that the A/E's ability to collect for additional services will depend strongly upon the health of the construction industry at the time.

Perhaps more than any previous event in the design industry, the advent of ASHRAE 90, or some similar standard, will demand a major overhaul in the industry's fee structure, particularly for mechanical/electrical design engineering services which historically have been based on a percentage of the mechanical systems cost of the project.

From a professional standpoint, possibly the most significant impact of ASHRAE 90 is that the design engineer will become a more important and integral member of the design team.

Concerning code authorities, ASHRAE 90 faces two problems: implementation and enforcement. It would not be surprising if a standard dealing with an abstract objective—achieving national energy self-sufficiency—were not to succeed, since more concrete concerns with such visible problems as consumer and third-party health and safety have failed to motivate institutional change and code effectiveness. Those institutional barriers that have so far prohibited the adoption of a model code on a more limited basis, will continue to create barriers for the implementation of ASHRAE 90 or allow it to be implemented only in cannibalized form. These problems could be moderated with financial or economic arguments.

Experience has shown that, because of limited resources, manpower, and commitment, enforcement of state codes is weak. ADL concludes that a combination of financial incentives, probably built into the utility rate structure and tied to the implementation of energy-conserving construction methods, and of penalties aimed at the energy user to achieve the same results, must be actively considered if energy conservation in building design is truly to be achieved on a widespread basis. An alternative, not investigated here, is to encourage long-term financing institutions to demand energy efficient structures.

7. Impact on Building Habitability

The principal impact of ASHRAE 90 on the health, safety, and welfare of building occupants will result from reduced ventilation and infiltration called for in the standard. Reduced humidity in winter will lead to some discomfort, but with the exception of certain medical facilities, no health hazard would result.

The standard is likely to increase greatly the importance of indoor air pollution sources, and to result in excessively increased exposures of nonsmokers to cigarette smoke particles, increased complaints about odors, and demand for separate smoking and nonsmoking areas. Additional similar problems are expected to arise under ASHRAE 90, though insufficient data are available to permit quantitative evaluation of these problems at this time.

IMPACT OF ASHRAE 90 ON:

- BUILDING ENERGY CONSUMPTION
- BUILDING ECONOMICS
- NATIONAL ENERGY CONSUMPTION
- SELECTED INDUSTRIES
- KEY INDUSTRY PARTICIPANTS
- BUILDING HABITABILITY

KEY ASSUMPTIONS:

- STRICT INTERPRETATION OF THE STANDARD
- PROTOTYPICAL CONVENTIONAL BUILDINGS
- SELECTION OF LEAST COSTLY BUILDING MODIFICATION
- MEET, BUT NOT EXCEED, THE STANDARD
- SLIGHT REBOUND IN 1976 CONSTRUCTION EXPENDITURES

IMPACT ON BUILDING ECONOMICS:

\$/Sq.Ft.

Savings in Annual Energy Costs

Single-Family Residences	0.05-0.14
Commercial Construction	0.12-1.05

Savings in Initial Project Cost (Average)

Single-Family Residence	0.02
Apartment Building	0.41
Office Building	0.63
Retail Store	0.18
School Building	0.44

IMPACT ON BUILDING ENERGY CONSUMPTION:

	Percent
SINGLE-FAMILY RESIDENCE	-11.3
LOW-RISE APARTMENT BUILDING	-42.7
OFFICE BUILDING	-59.7
RETAIL STORE	-40.1
SCHOOL BUILDING	-48.1

REDUCTION IN ANNUAL ENERGY CONSUMPTION,
BY BUILDING TYPE AND GEOGRAPHICAL LOCATION

	<u>Northeast</u>	<u>North Central</u>	<u>South</u>	<u>West</u>
Single-Family Residence	14.7	15.1	7.7	7.5
Low-Rise Apartment Building	51.0	32.2	42.3	45.4
Office Building	61.5	61.2	58.7	56.9
Retail Store	41.6	42.5	37.9	38.5
School Building	45.6	44.4	51.5	51.1

PARAMETERS ATTRIBUTABLE TO ENERGY REDUCTION
(Percent)

	<u>Single-Family Residence</u>	<u>Low-Rise Apartment</u>	<u>Office Building</u>	<u>Retail Store</u>	<u>School</u>
Summer Design Conditions	1.8	4.6	3.4	3.4	2.5
Winter Design Conditions	3.9	8.8	12.4	7.3	7.6
Overall Thermal Requirements- U_o	0.9	8.0	8.0	4.0	4.0
Lighting	0	1.8	6.3	8.6	4.4
Ventilation	0	2.3	7.0	5.5	13.0
Infiltration	1.3	0.8	1.5	1.0	2.5
Domestic Hot Water	2.5	5.0	1.0	0.5	3.0
HVAC Equipment, Systems, And Control	0.9	11.4	20.0	9.5	11.1
Total Reduction	11.3	42.7	59.6	40.1	48.1

ESTIMATED CHANGE IN UNIT COST OF CONVENTIONAL
VS.

ASHRAE 90 MODIFIED BUILDINGS

(Dollars Per Sq. Ft. of Floor Space)

	<u>Northeast</u>	<u>North Central</u>	<u>South</u>	<u>West</u>	<u>Unweighted Average</u>
Single-Family Residence	+0.01	-0.04	-0.04	+0.01	-0.02
Multi-Family, Low Rise	-0.45	-0.54	-0.28	-0.36	-0.41
Office Building	-0.35	-0.29	-0.94	-0.93	-0.63
Retail Store	-0.11	+0.04	-0.32	-0.33	-0.18
School	-0.56	-0.39	-0.46	-0.33	-0.44

REDUCTION IN GLASS AREA ATTRIBUTABLE TO APPLICATION
OF ASHRAE 90 TO THE PROTOTYPICAL BUILDINGS

(Percent Fenestration)

	<u>Northeast</u>	<u>North Central</u>	<u>South</u>	<u>West</u>
Single-Family Residence	0	-4.1	0	-1.3
Low-Rise Apartment Building	-11.0	-21.3	0	-6.0
Office Building	-16.7	-3.3	-30.6	-28.2
Retail Store	0	-13.3	0	0
School	-7.5	-20.0	0	0

OFFICE BUILDING, OMAHA

Change in Cost
(Dollars Per Square Foot
Floor Area)

Exterior Walls	+ 0.33
Exterior Glass	+ 0.24
Roof	+ 0.15
HVAC Equipment	- 0.39
HVAC Distribution	- 0.48
HVAC Controls	+ 0.12
Lighting	- 0.04
Electrical Distribution	- 0.28
Domestic Water Heating	+ 0.02
Hot Water Distribution	+ 0.04
	<hr/>
Net Change	- 0.29

IMPACT ON PHYSICAL CHARACTERISTICS:

Exterior Glass:

- Reduced in Two Thirds of Buildings Investigated
- Reductions Up to 30%, Generally Less Than 20%
- Increases in Exterior Opaque Walls Up to 8%

Insulation:

- Additional Insulation Requirements for Both Residential and Commercial Construction

Lighting:

- Lamp Reductions Average 24%
- Lighting Fixture Reductions Average 22%

HVAC System Capacities:

- Heating Capacity Reductions Averaged 42%
- Cooling Capacity Reductions Averaged 31%
- Auxiliary HVAC Equipment Reductions Averaged 44%

INCREASED A/E DESIGN SERVICES:

\$/Sq.Ft.

SINGLE-FAMILY RESIDENCES 0.24

LOW-RISE APARTMENT BUILDING 0.09

OFFICE BUILDING 0.16

RETAIL STORE 0.09

SCHOOL BUILDING 0.15

RECAPTURING ADDITIONAL DESIGN SERVICES:

	Straight Payback
SINGLE-FAMILY RESIDENCE	2.9 yrs.
LOW-RISE APARTMENT BUILDING	3.4 mos.
OFFICE BUILDING	2.5 mos.
RETAIL STORE	7.6 mos.
SCHOOL BUILDING	4.6 mos.

CHAPTER 2
ENERGY FUNDAMENTALS
(ECT-301)

I. AIR AND HUMIDITY CALCULATIONS

A. Psychrometric Properties of Air

1. Psychrometrics is the determination of the thermodynamic properties of moist air and the utilization of those properties in the analysis of conditions and processes involving moist air.
2. Moist air is considered to be a binary mixture of dry air and water vapor (or steam).
3. For a gaseous mixture, the total pressure of the mixture is equal to the sum of the partial pressures of the constituent gases. For moist air:

$$P_b = P_{da} + P_w$$

4. The perfect gas relationship

$$pV = mRT$$

is useful in relating the pressure, volume and temperature of a gas. It can be applied to moist air as a mixture, or more conveniently, to each of the constituent gases (dry air and water vapor) individually. "R" is the Universal Gas Constant and for air:

$$R = 53.35 \frac{\text{ft-lbf}}{\text{lb}_{\text{mass}} \text{ } ^\circ\text{R}}$$

for water:

$$R = 85.7 \frac{\text{ft-lbf}}{\text{lb}_{\text{mass}} \text{ } ^\circ\text{R}}$$

5. A thermodynamic property is any observable, measurable, or calculable characteristic of a substance that is a function only of the state of the substance. Several properties of moist air can be directly measured or easily calculated from the perfect gas relationship.

- a. Temperature is easily measured with a thermometer.
- b. Ambient pressure is easily measured with a barometer.
- c. Density is calculated by:

$$\rho \triangleq \frac{m}{V} = \frac{P}{RT}$$

The density of moist air is:

$$\rho_{ma} = \left(\frac{P}{RT} \right)_{\text{dry air}} + \left(\frac{P}{RT} \right)_{\text{water vapor}}$$

(See Example 1, Appendix 301-A.)

- d. Specific volume is calculated by:

$$V \triangleq \frac{V}{m} = \frac{RT}{P}$$

(See Example 2, Appendix 301-A.)

B. Humidity

1. Humidity is a term which is used to describe the amount of water vapor (steam) that is mixed with the dry air in the atmosphere.
2. Relative humidity is a ratio of the amount of water vapor in the air to the maximum amount of water vapor that the air can hold at that particular temperature and pressure. It is calculated from:

$$\phi = \left(\frac{P_w}{P_{w,s}} \right)_{t_{db}} \times 100$$

(See Example 3, Appendix 301-A.)

and is expressed as a percentage.

3. Moist air is said to be "saturated" when the dry air holds the maximum amount of water vapor. That is, the addition of any more water vapor to moist air that is saturated would result in condensation of some of the moisture from the air. The properties of water at saturation are conveniently tabulated. (See Appendix 301-B for Steam Tables.)
4. Humidity ratio is the ratio of the mass of water vapor contained in a sample of moist air to the mass of the dry air. Using the perfect gas relationship, humidity ratio can be expressed as:

$$W = 0.622 \frac{P_w}{P_b - P_w}$$

with the units pounds of water vapor per pound of dry air (lb_w/lb_{da}). It may also be expressed as grains of moisture per pound of dry air. There are 7000 grains in one pound. (See Example 4, Appendix 301-A.)

5. Saturation ratio (or degree of saturation) is the humidity ratio of moist air divided by the humidity ratio of the same air at saturation at the same temperature and pressure. It is written:

$$\mu = \left(\frac{W}{W_s} \right)_{t_{db}} \times 100$$

and is expressed as a percentage. (See Example 5, Appendix 301-A.)

C. Temperatures

1. Dry-bulb temperature (t_{db}) of air refers to the temperature of air in a closed or open space where the effects of radiation and air motion are not significant. This is the temperature registered by an ordinary thermometer.
2. Dew-point temperature (t_{dp}) is the temperature at which moist air becomes saturated when it is cooled at constant pressure and constant humidity ratio. Any further cooling past this point results in the appearance of a fog or the deposition of moisture. (See Example 6, Appendix 301-A.)
3. Wet-bulb temperature
 - a. Thermodynamic wet-bulb temperature (t_{wb}) is the temperature

at which water may be evaporated into air to bring the air to saturation at that same temperature. Physically, air is humidified to the saturation point by the evaporation of water at the wet-bulb temperature:

This process is called an adiabatic saturation process.

- b. Psychrometric wet-bulb temperature is determined using a sling psychrometer, which is a dry-bulb and a wet-bulb thermometer mounted in such a manner that they can be whirled through the air. The wet-bulb thermometer is a thermometer with a wetted wick over the bulb. This yields a wet-bulb temperature very close to the thermodynamic wet-bulb temperature.
- c. The Carrier equation relates the wet-bulb temperature to the partial pressure of the water vapor in the air:

$$p_w = p_{w,s_{wbt}} - \frac{(p_b - p_{w,s_{wbt}})(t_{db} - t_{wb})}{2800 - 1.3t_{wb}}$$

(See Example 7, Appendix 301-A.)

D. Enthalpy of Air

1. Considering air as a perfect gas, the enthalpy of moist air is found by adding the enthalpy of the dry air to the enthalpy of the water vapor associated with the dry air:

$$h_{\text{moist air}} = h_{\text{dry air}} + h_{\text{water vapor}}$$

2. For the temperature range encountered in HVAC work, the enthalpy of moist air may be calculated from:

$$h = 0.24 t_{db} + W(1061 + 0.45t_{db})$$

(See Example 8, Appendix 301-A.)

E. Air Humidification Process

1. Humidification can be accomplished by introducing either steam or water into a moving stream of air.
2. A humidification process may be depicted:

Typically, the air would be passed through a large chamber where the moisture would be sprayed into the air.

3. The following equations describe the humidification process, assuming that there is no external heat transfer to or from the chamber:

$$m_1 = m_2 \quad (\text{dry air})$$

$$m_3 = m_1(W_2 - W_1)$$

$$h_2 = h_1 + (W_2 - W_1)h_3$$

(See Example 9, Appendix 301-A.)

F. Adiabatic Saturation

1. The process described in the definition of the wet-bulb temperature I.C.3.a is an adiabatic saturation process, which accomplishes humidification of air by the evaporation of water without the addition of any external heat. This process is analyzed in the same manner as the air humidification process described above I.E.;
2. However, adiabatic saturation is not an efficient humidification process from a practical standpoint, but, when water is used as the moisture source in the humidification process described above I.E.2, this process closely approximates the

adiabatic saturation process and is a constant wet-bulb temperature process;

3. Such a device, in which water is sprayed into a moving air stream, is termed an air washer. Since no process is ideal, the exit air from the washer will not be saturated. Thus, it is convenient to define a washer efficiency:

$$\eta_{\text{washer}} = \frac{W_2 - W_1}{W_{2,s} - W_1}$$

which is a ratio of the actual amount of moisture added to the air to the amount that would have been added if the air had been brought to saturation. (See Example 10, Appendix 301-A.)

G. Psychrometric Chart

1. The calculation of values of the various properties of moist air is not complicated, but can be lengthy and time consuming. In order to facilitate the determination of these properties, a special graph (or chart) can be produced for moist air. Such a chart is called a psychrometric chart. (See Appendix 301-C.)
2. The psychrometric chart has dry-bulb temperature as the horizontal axis, humidity ratio as the vertical axis, and enthalpy as a diagonal axis.
3. Also displayed on the chart are relative humidity, specific volume and wet-bulb temperature.
4. Recall that barometric pressure appeared directly or indirectly in many of the calculations of property values. It should be noted that a psychrometric chart is valid for only one barometric pressure. The standard psychrometric chart is based on a barometric pressure of 14.7 psia (29.92 inches of mercury).
5. Knowledge of any two properties of moist air permits location of the state-point of that air on the psychrometric chart. Any other properties may then be read directly from the chart. (See Example 12, Appendix 301-A.)
6. Dew-point temperature is found, after locating the state-point of the air, by following a horizontal line of constant humidity

humidity ratio to the saturation line (the 100% relative humidity line). The saturation temperature at that point is the dew point of the moist air. (See Example 13, Appendix 301-A.)

7. In addition to giving the properties of air at various conditions, it will be shown later that psychrometric processes involving moist air can be depicted, and even solved, on the chart.

H. Use of the Psychrometric Chart at Varying Barometric Pressures

1. Psychrometric charts are available for varying conditions. ASHRAE offers a series of four. (See Appendix 301-C.)
 - a. Normal temperature, standard pressure
 - b. Low temperature, standard pressure
 - c. High temperature, standard pressure
 - d. Normal temperature, high altitude (24.89" Hg). (See Example 14, Appendix 301-A.)
2. When using the standard pressure chart, the enthalpy, humidity ratio, and dry-bulb temperature lines can be considered as applicable for any barometric pressure. However, the relative humidity, specific volume, and wet-bulb temperature lines are applicable only to the barometric pressure of 14.7 psia (29.92" Hg).
3. The psychrometric chart can be used without significant error for pressure variations of less than one inch of mercury (one-half psi).

I. Air Mixing

1. When two quantities of air with different humidities and enthalpies are mixed, the resultant condition of the mixed air is dependent on the masses of the original air quantities.
2. Consider the mixing of two quantities of air:

From a mass balance on dry air:

$$m_1 + m_2 = m_3$$

From a mass balance on water:

$$m_1 W_1 + m_2 W_2 = m_3 W_3$$

From an energy balance:

$$m_1 h_1 + m_2 h_2 = m_3 h_3$$

3. Assuming specific heat does not vary significantly with temperature in the range of this work, the energy balance can be rewritten:

$$m_1 t_1 + m_2 t_2 = m_3 t_3$$

4. Thus, the final mixed condition can be determined by:

$$m_3 = m_1 + m_2$$

$$W_3 = \frac{m_1 W_1 + m_2 W_2}{m_3}$$

$$h_3 = \frac{m_1 h_1 + m_2 h_2}{m_3}$$

$$t_3 = \frac{m_1 t_1 + m_2 t_2}{m_3}$$

(See Example 11, Appendix 301-A.)

II. PSYCHROMETRIC PROCESSES

A. Sensible Heating

1. The heating of air without the addition of moisture (i.e., at a constant humidity ratio) is called "sensible" heating.
2. On a psychrometric chart, this process is shown as a horizontal line:

3. An energy balance on the sensible heating process results in the following expression for the amount of heat required:

$$q_{1-2} = m_{da} \left(c_{p_{da}} + c_{p_{wv}} W \right) (t_2 - t_1)$$

which can be rewritten:

$$q_{1-2} = m_{da} C_p (t_2 - t_1)$$

Where C_p is called "humid heat" and represents the composite term $(c_{p_{da}} + c_{p_{wv}} W)$. A typical value of humid heat is 0.244 Btu/lb-°F. Thus:

$$q_{sens} = 0.244 m_{da} (t_2 - t_1)$$

(See Example 15, Appendix 301-A.)

B. Sensible Cooling

1. The cooling of air without any change in humidity ratio is called "sensible" cooling.
2. In order to decrease the temperature of moist air without the condensation of moisture, it is necessary that the air not be cooled below its dew-point temperature.
3. Psychrometrically, a sensible cooling process is depicted as a horizontal line:

4. And the amount of heat removed from the air is given by:

$$q_{\text{sens}} = 0.244 m_{\text{da}}(t_1 - t_2)$$

(See Example 15, Appendix 301-A.)

C. Latent Heating

1. The process of increasing the moisture content of air while maintaining its dry-bulb temperature at a constant value is termed "latent" heating.
2. Such a process can be shown as a straight vertical line on the psychrometric chart:

3. An energy balance for this process reduces to:

$$q_{1-2} = m_{\text{da}}(W_2 - W_1) h_v$$

and taking the enthalpy of the water vapor in the air to be about 1100 Btu/lb, we may write:

$$q_{\text{lat}} = m_{\text{da}} (W_2 - W_1) 1100$$

(See Example 16, Appendix 301-A.)

D. Latent Cooling

1. The reduction of the moisture content of air while the dry-bulb temperature remains constant is called a "latent" cooling process.
2. Psychrometrically, this process is a vertical line:

3. And the amount of heat removed from the air may be expressed as:

$$q_{lat} = m_{da} (W_1 - W_2) 1100$$

(See Example 16, Appendix 301-A.)

E. Sensible Heat Ratio

1. For a given psychrometric process, we may model the entire process by a combination of a sensible process and a latent process. This may be shown by the schematic:

2. In such a case, there is a particular relationship that exists between the total heat that would be required to go from ① to ② and the corresponding latent and sensible heats that would be required to go from ① to x to ②. In either case, it can be seen that the resultant statepoint is the same.
3. The relationship between these three quantities is given the name "sensible heat ratio" and is expressed as:

$$SHR = \frac{q_{sens}}{q_{total}} = \frac{q_{sens}}{q_{sens} + q_{lat}}$$

(See Example 17, Appendix 301-A.)

4. In effect, then, knowledge of the sensible heat ratio fixes the direction of the process between the points ① and ②.
5. It will be seen later that the ability to break a total process down into its latent and sensible components is both a valuable and convenient tool to have at our disposal.

F. Air Mixing

1. Consider again the concept of the mixing of two streams of moist air.

2. It was shown above I.I.4 that the resultant mixture properties can be calculated from the initial conditions and masses.
3. Each of the initial stream conditions may be located on the psychrometric chart. The resultant condition must lie on a straight line connecting the state-points of the two original quantities:

If the length of the line connecting the two points is L , then the resultant point may be located as shown, by measuring off a distance proportional to the ratios of the individual masses to the total mass. (See Example 18, Appendix 301-A.)

4. The resulting mixed condition may be found graphically, analytically, or by a combination of the two methods.

G. Air Supply Conditions

1. Consider an enclosure or space that has some total heat gain into the space. For convenience, let us break the total heat load into its constituent sensible and latent components: Thus

$$q_{\text{total}} = q_{\text{sens}} + q_{\text{lat}}$$

2. These gains to the space may be shown as:

3. It is desired to maintain the condition of the air within this space at some pre-selected design values of temperature and humidity (t_d and W_d).

4. In order to maintain these design conditions, it will be necessary to supply cooler, drier air to the space to offset the thermal and latent gains to the space. So:

It will also be necessary to extract air from the space at the same rate that it was supplied in order to maintain steady-state conditions. This return air will be at the design conditions.

5. The following equations may be written describing this process:

$$q_{\text{sens}} = 0.244 m_{\text{da}} (t_d - t_s)$$

$$q_{\text{lat}} = m_{\text{da}} (W_d - W_s) 1100$$

(See Example 19, Appendix 301-A.)

6. Thus, knowledge of the gains to the space and the design parameters would allow us to calculate the necessary condition of the supply air.
7. Psychrometrically this process would be shown as:

8. Notice that again we have the particular relationship between the total, latent and sensible loads. We may make the valuable observation that the sensible heat ratio must pass through both the design and supply points if the heat gains to the space are to be met and the design conditions maintained.

9. The semicircular protractor on the psychrometric chart simplifies the procedure and allows us to construct the sensible heat ratio line with ease:

(See Example 19, Appendix 301-A.)

10. Also note that the equations for the process may also be written in terms of enthalpy:

$$q_{\text{total}} = m_{\text{da}} (h_d - h_s)$$

$$q_{\text{sens}} = m_{\text{da}} (h_x - h_s)$$

$$q_{\text{lat}} = m_{\text{da}} (h_d - h_x)$$

III. PROCESS COMBINATIONS

A. Heating and Humidifying Process

1. A commonly encountered process in the conditioning of air is one which accomplishes heating and humidification.
2. Such a process would have the general psychrometric direction as shown:

3. And the total heat added to the air is given by:

$$q_{1-2} = m_{da} (h_2 - h_1)$$

4. Such a process could be accomplished by the injection of steam into the moving air stream:

5. From I.E we saw that the equation representing this process is:

$$h_1 + (W_2 - W_1)h_3 = h_2$$

6. Rearranging this:

$$h_3 = \frac{h_2 - h_1}{W_2 - W_1}$$

which relates the changes in enthalpy and humidity ratio of the air to the enthalpy of the steam, a value easily determined.

7. Note that the semi-circular protractor on the psychrometric chart is also calibrated in units of $\Delta h/\Delta W$ as well as sensi-

ble heat ratio (SHR). Thus, this device allows us to easily solve this type of problem in a graphical manner directly on the chart. (See Example 20, Appendix 301-A.)

B. Cooling and Dehumidifying Process

1. Another commonly encountered psychrometric process is that which accomplishes cooling and dehumidification of the air.
2. Whenever air is cooled to a temperature lower than its original dew point, a portion of the water vapor in the air must necessarily condense.
3. Psychrometrically this process has the general direction shown here:

and may be shown schematically as:

where ③ is the condensate removed during the process.

4. The equation describing this process is derived from an energy balance:

$$m_{da}h_1 - q_{1-2} = m_{da}h_2 + m_{da}(W_2 - W_1)h_3$$

and the heat removed during the process is:

$$q_{1-2} = m_{da}[(h_1 - h_2) - (W_1 - W_2)h_3]$$

(See Example 21, Appendix 301-A.)

C. Process Directions

1. The psychrometric chart offers a visual aid in "seeing" what happens to the air during any process that it may undergo.
2. It may help to picture the chart as being divided into quadrants:

Any process proceeding diagonally upwards results in an increase in temperature and an increase in moisture content. A process progressing horizontally to the left results in a decrease in temperature with the humidity ratio remaining constant. And so on.....

IV. FACTORS AFFECTING HUMAN COMFORT

A. Comfort Air Conditioning

1. Air conditioning is a general term which implies the effective control of the physical and chemical properties of the air.
2. Comfort air conditioning specifically refers to the effective control of the properties of air in order to produce conditions most suitable to the comfort and health of human beings.
3. Factors affecting human comfort are:
 - a. Temperature
 - b. Humidity

- c. Air motion and distribution
 - d. Purity (or quality, with regard to odors, dusts, particulates, toxic gases and fumes, etc.)
 - e. Noise
4. In the normal course of HVAC work, barring any unusual circumstances, we are primarily concerned with the first three of the above-listed factors.
- B. Heat Production and Regulation in Man
- 1. The basic functioning of the internal body organs produces heat within the body such that the body temperature is normally above the temperature of the atmosphere.
 - 2. This internal heat production of the body is referred to as "metabolism".
 - 3. The objective of comfort conditioning is to maintain an atmosphere to which the body can lose enough heat to permit proper functioning of the metabolic process, but not at a rate great enough to cause chilling.
 - 4. The body dissipates heat in several ways:
 - a. Conduction and convection to the air moving past it
 - b. Radiation to colder objects
 - c. Evaporation from skin surface
 - d. Respiration
 - 5. A complex regulating mechanism in the body keeps its temperature at or near 98.6°F. The two general directions of this mechanism are:
 - a. Increase or decrease body metabolism.
 - b. Control rate of heat dissipation by varying cutaneous blood circulation and motivating sweat glands.
- C. Environmental Indices
- 1. A number of indices have been proposed to describe an

environment and its effect on human occupants. A few of the more common ones will be listed here:

- a. Dry-bulb temperature (t_{db})
 - b. Effective Temperature (ET)
 - c. Wind-Chill Index
 - d. Wet-Bulb Globe Temperature Index (WBGT)
 - e. Belding-Hatch Heat Stress Index (HSI)
2. Many of these indices are valid for only particular types of environments or for specific conditions. No single index is sufficient to describe comfort conditions in every environment.

D. Effective Temperature

1. The index of effective temperature is probably the most comprehensive of the available indices for interior environments intended for human occupancy.
2. Effective Temperature (ET) is an empirical sensory index which combines the thermal effects of:
 - a. Dry-bulb temperature
 - b. Humidity
 - c. Air motion
3. Combinations of the above three factors which produce the same subjective thermal sensation are assigned the same value of effective temperature.
4. The ET index is most useful in warm atmospheres where the mean radiant temperature is equal to the dry-bulb temperature.

E. New ASHRAE Comfort Chart (See Figure IV.1.)

1. Changes in the manner in which effective temperature is determined have lead ASHRAE to denote those values obtained by the newest procedures as ET* (or CHI for Comfort-Health Index).

*The envelope applies for lightly clothed, sedentary individuals in spaces with low air movement, where the MRT equals air temperature; for other cases, see Fig. J7.
 New Effective Temperature Scale (ET*)

Fig. IV.1 The New ASHRAE Comfort Chart¹

Fig. IV.2¹ Scale of ET* or Comfort-Health Index (CHI) and Related Sensory, Physiological, and Health Responses in Man for Prolonged Exposures

2. Values of ET^* may be determined by reference to the "New ASHRAE Comfort Chart." The shaded area at the center of the chart represents those conditions within the recommended ASHRAE comfort standards. A point is located on the Comfort Chart in the same manner that a point is located on the psychrometric chart. (See Example 22, Appendix 301-A.)
3. The relationship of ET^* values to parameters of sensation, physiology and health is also provided for reference. (See Figure IV.2.)

F. Airborne Contaminants

1. Atmospheric Impurities

- a. Varying amounts of foreign materials are contained in normal air and are referred to as permanent atmospheric impurities. These materials arise from natural processes (wind, erosion, volcanic eruption, etc.) and are usually found at low concentration levels.
- b. A large amount of contaminants (often at high concentration levels) are man-made, being produced by the many processes associated with human activity. This includes combustion, transportation, agriculture, smelting, construction, etc.
- c. Excessive concentrations of any foreign matter in the air can change the composition and quality of the air and may render it unfit for man's use.

2. Classification of Air Contaminants

a. Solid Particulates

- (1) Dusts
- (2) Fumes
- (3) Smokes

b. Liquid Particulates

- (1) Mists
- (2) Fogs

- c. Non-Particulates
 - (1) Vapors
 - (2) Gases
- . The physiological effect of particulates is a function of:
 - a. Particle size
 - b. Concentration of particulate
 - c. Characteristics of material
- . Physiologically, the effect of airborne contaminants can range from being harmless to being a cause of death. Some of the possible harmful effects are:
 - a. Irritations
 - b. Allergic reactions
 - c. Respiratory ailments
 - d. Infections
 - e. Poisoning
- 5. It should also be realized that certain contaminants, when present in the proper proportion with oxygen in the air will result in the formation of a combustible mixture.
- 6. Recommended acceptable concentration levels are published and available for many of the contaminants encountered as a result of both natural and man-made activities.
- 7. Odors
 - a. Odor is defined as that property of a substance which stimulates the sense of smell. These substances are usually in a gas or vapor state.
 - b. Odors themselves are not the cause of organic disease, though they can be termed pleasant or unpleasant.
 - c. Obnoxious odors can be the cause of temporary ill effects such as:

- (1) Lowered appetite
 - (2) Lowered water consumption
 - (3) Impaired respiration
 - (4) Nausea and vomiting
 - (5) Insomnia
- d. Odors can be controlled by:
- (1) Containment of the source
 - (2) Prevention of migration
 - (3) Isolation of sensor

V. HEATING LOAD

A. Design Conditions

1. Indoor design temperature

- a. The inside temperature used in the calculation of the heating load on a space is the indoor design temperature.
- b. This temperature is meant to apply at the breathing line, three to five feet above the floor.
- c. Typically, a value of 72°F may be taken as the indoor design condition. This may be varied for the particular use, type and size of space under consideration. For example, a natatorium should have a higher inside design (75°F) while a gymnasium should be somewhat lower (60-68°F).

2. Outdoor design conditions

- a. Tabulations of outdoor design conditions are available for various locations. (See Table D.1, Appendix 301-D.) This material should be considered as design information and is not to be confused with minimum or maximum extremes for a given locality. Such extremes are rare and are not typical.
- b. It is common practice to use the 97-1/2% value in selecting the winter outdoor design temperature. This says that the outdoor temperature will fall below the design

temperature only 2-1/2% of the time during December, January and February.

- c. Usually some information is listed regarding prevailing winds. Wind direction and velocity vary so much that this information should be regarded as an indication only.

B. Calculation of Heating Load

1. Wall transmission loss

- a. The heat loss through a given construction is given by:

$$q = UA(t_i - t_o)$$

where U is the overall air-to-air heat transfer coefficient, A is the area, and t_i and t_o are the inside and outside design temperatures.

- b. This calculation must be made for each different type of wall, window, or door section contained in the structure for which the heating load is being calculated.

2. Heat transfer coefficient

- a. The overall heat transfer coefficient is defined as:

$$U = \frac{1}{R_t}$$

where R is the total thermal resistance of the wall section.

- b. For a composite wall, a general expression for the resistance is:

$$R_t = \frac{1}{f_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \dots + \frac{x_n}{k_n} + \frac{1}{f_o}$$

where the x's and k's denote, respectively, the thickness and thermal conductivity of each element of the composite.

- c. In the above expression, the film coefficients at the inner and outer surfaces are denoted f_i and f_o . In general, it is assumed that the air at the inside surface is still (15 to 25 fpm velocity) and that the outside surface is exposed to a 15 mph wind. Under these conditions the values are:

	f	$R = \frac{1}{f}$
inner surface	1.46	0.68
outer surface	6	0.17
	$\frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$	$\frac{\text{hr-ft}^2\text{-}^\circ\text{F}}{\text{Btu}}$

- d. Material thermal properties

- (1) Values for thermal conductivity (k) can be obtained from manufacturer's data or from general material property tables. (See Table D.2, Appendix 301-D.) It has the units:

$$\frac{\text{Btu}}{(\text{hr})(\text{ft}^2)(^\circ\text{F})}$$

(See Example 23, Appendix 301-A.)

- (2) Often this property will be listed for a specific thickness of material, and in such cases, the value is denoted as conductance (C). Resistance is then just the reciprocal of conductance:

$$R = \frac{1}{C}$$

- e. Parallel heat flow

- (1) In some cases there may be parallel paths of heat flow. This would be the case in a framed wall:

One heat transfer path is through the studding, the second is through the air space (or insulation) between the studs.

- (2) The U-value for each of these paths may be calculated in the manner described above.
- (3) An average U-value for the framed wall section is given by:

$$U_{avg} = \frac{A_{nf} U_{nf} + A_f U_f}{A_{nf} + A_f}$$

in which the subscripts "f" and "nf" denote the framed and non-framed heat flow paths. (See Example 24, Appendix 301-A.)

- (4) It is useful to note that 2 x 4 inch studs on 16-inch centers cover about 10% of the wall area; on 18-inch centers they cover approximately 8%.

3. Window and door transmission loss

- a. Windows and doors are handled in the same general manner as are walls, using the equation:

$$q = UA(t_i - t_o)$$

- b. Typically, U for a window or door need not be calculated repeatedly. (See Tables V.1, V.2.) They are tabulated for various thicknesses and types of glass and door construction. These tabulated U-values are air-to-air heat transfer coefficients and do include already the inside and outside

film coefficients. (See Example 25, Appendix 301-A.)

4. Temperatures of unheated interior spaces

- a. The temperature of an unheated space adjacent to a heated space may be taken to be:

$$t_{\text{unheated space}} = t_i - 0.5(t_i - t_o)$$

- b. For floors directly on the ground, a ground temperature of 50 to 55°F may be assumed.
- c. Attic temperatures are a function of construction as well as inside and outside temperatures. Attic temperature may be calculated from:

$$t_{\text{attic}} = \frac{U_c t_i + nU_r t_o}{U_c + nU_r}$$

where the subscripts "c" and "r" refer to the ceiling and roof, and "n" is the ratio of the area of the roof (A_r) to the area of the ceiling (A_c).

5. Floor slabs and below-grade walls

- a. It is difficult to accurately compute the losses through basement walls and floors due to the variance of ground temperature with depth, season and climate. Normally, subsurface ground temperatures are between 40 and 60°F. (See Table V.3.) Coupling this information with a representative U-value of 0.10 Btu/ft²-°F, it is possible to estimate the heat loss values for basement wall and floors on an area basis. (See Example 26, Appendix 301-A.)
- b. Heat loss from a concrete slab floor is more nearly proportional to its perimeter than its area. (See Table V.4.) The heat loss can be estimated from:

$$Q_{\text{slab}} = FP$$

where:

F = heat loss coefficient, Btu/h/ft
P = perimeter, ft.

(See Example 27, Appendix 301-A.)

Coefficients of Transmission (*U*) for Slab Doors

Thickness ^a	Btu per (hr · ft ² · °F)			
	Winter		Summer	
	Solid Wood, No Storm Door	Storm Door ^b Wood Metal	No Storm Door	
1-in.	0.64	0.30 0.39	0.61	
1.25-in.	0.55	0.28 0.34	0.53	
1.5-in.	0.49	0.27 0.33	0.47	
2-in.	0.43	0.24 0.29	0.42	
Steel Door ^{1d}				
1.75 in.				
A ^c	0.59	— —	0.58	
B ^d	0.19	— —	0.18	
C ^e	0.67	— —	0.46	

^aNominal thickness.^bValues for wood storm doors are for approximately 50% glass; for metal storm door values apply for any percent of glass.^cA = Mineral fiber core (2 lb/ft³).^dB = Solid urethane foam core with thermal break.^eC = Solid polystyrene core with thermal break.Table V.1¹Coefficients of Transmission (*U*) of Windows, Skylights, and Light Transmitting PartitionsThese values are for heat transfer from air to air, Btu/(hr · ft² · °F). To calculate total heat gain including solar transmission, see Chapter 28.

PART A—VERTICAL PANELS (EXTERIOR WINDOWS, SLIDING PATIO DOORS, AND PARTITIONS)—FLAT GLASS, GLASS BLOCK, AND PLASTIC SHEET				PART B—HORIZONTAL PANELS (SKYLIGHTS)—FLAT GLASS, GLASS BLOCK, AND PLASTIC DOMES			
Description	Exterior ^a			Description	Exterior ^a		
	Winter	Summer	Interior		Winter ^d	Summer ^d	Interior ^d
Flat Glass ^b single glass	1.10	1.04	0.73	Flat Glass ^b single glass	1.23	0.83	0.96
insulating glass—double ^c 0.1875-in. air space ^d	0.62	0.65	0.51	insulating glass—double ^c 0.1875-in. air space ^d	0.70	0.57	0.62
0.25-in. air space ^d	0.58	0.61	0.49	0.25-in. air space ^d	0.65	0.54	0.59
0.5-in. air space ^d	0.49	0.56	0.46	0.5-in. air space ^d	0.59	0.49	0.56
0.5-in. air space, low emittance coating ^f <i>e</i> = 0.20	0.32	0.38	0.32	0.5-in. air space, low emittance coating ^f <i>e</i> = 0.20	0.48	0.36	0.39
<i>e</i> = 0.40	0.38	0.45	0.38	<i>e</i> = 0.40	0.52	0.42	0.45
<i>e</i> = 0.60	0.43	0.51	0.42	<i>e</i> = 0.60	0.56	0.46	0.50
insulating glass—triple ^c 0.25-in. air spaces ^d	0.39	0.44	0.38	Glass Block ^b 11 × 11 × 3 in. thick with cavity divider	0.53	0.35	0.44
0.5-in. air spaces ^d	0.31	0.39	0.30	12 × 12 × 4 in. thick with cavity divider	0.51	0.34	0.42
storm windows 1-in. to 4-in. air space ^d	0.50	0.50	0.44	Plastic Domes ^b single-walled	1.15	0.80	—
Plastic Sheet single glazed 0.125-in. thick	1.06	0.98	—	double-walled	0.70	0.46	—
0.25-in. thick	0.96	0.89	—	PART C—ADJUSTMENT FACTORS FOR VARIOUS WINDOW AND SLIDING PATIO DOOR TYPES (MULTIPLY <i>U</i> VALUES IN PARTS A AND B BY THESE FACTORS)			
0.5-in. thick	0.81	0.76	—				
insulating unit—double ^c 0.25-in. air space ^d	0.55	0.56	—				
0.5-in. air space ^d	0.43	0.45	—				
Glass Block ^b 6 × 6 × 4 in. thick	0.60	0.57	0.46				
8 × 8 × 4 in. thick	0.56	0.54	0.44				
—with cavity divider	0.48	0.46	0.38				
12 × 12 × 4 in. thick	0.52	0.50	0.41				
—with cavity divider	0.44	0.42	0.36				
12 × 12 × 2 in. thick	0.60	0.57	0.46				

Heat Loss through Basement Floors
[Btu/(h)(ft²)(F)]

Depth of Foundation Wall below Grade (ft)	Width of House			
	20 (ft)	24 (ft)	28 (ft)	32 (ft)
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

Heat Loss below Grade in Basement Walls* [Btu/(ft²)(F)]

Depth (ft)	Path Length through Soil (ft)	Heat Loss			
		Uninsulated	Insulation		
			1-in.	2-in.	3-in.
0-1 (1st)	0.68	0.410	0.152	0.093	0.067
1-2 (2nd)	2.27	0.222	0.116	0.079	0.059
2-3 (3rd)	3.88	0.155	0.094	0.068	0.053
3-4 (4th)	5.52	0.119	0.079	0.060	0.048
4-5 (5th)	7.05	0.096	0.069	0.053	0.044
5-6 (6th)	8.65	0.079	0.060	0.048	0.040
6-7 (7th)	10.28	0.069	0.054	0.044	0.037

$$k_{\text{soil}} = 9.6(\text{Btu} \cdot \text{h})/(\text{ft} \cdot ^\circ \text{F}); \quad k_{\text{insulation}} = 0.24(\text{Btu} \cdot \text{h})/(\text{ft} \cdot ^\circ \text{F}).$$

Table V.3¹

**Heat Loss of Concrete Floors at or Near
Grade Level per Foot of Exposed Edge**

Outdoor Design Temperature, F	Heat Loss per Foot of Exposed Edge, Btu/h	
	Recommended 2-in. Edge Insulation	1-in. Edge Insulation
-20 to -30	50	55
-10 to -20	45	50
0 to -10	40	45
Outdoor Design Temperature, F	1-in. Edge Insulation	No Edge Insulation*
-20 to -30	60	75
-10 to -20	55	65
0 to -10	50	60

*This construction not recommended; shown for comparison only.

**Floor Heat Loss to be Used When Warm
Air Perimeter Heating Ducts Are Embedded in Slabs***
Btu/h per (linear foot of heated edge)

Outdoor Design Temperature, F	Edge Insulation		
	1-in. Vertical Extending Down 18 in. Below Floor Surface	1-in. L-Type Extending at Least 12 in. Deep and 12 in. Under	3-in. L-Type Extending at Least 12 in. Down and 12 in. Under
-20	105	100	85
-10	95	90	75
0	85	80	65
10	75	70	55
20	65	57	45

* Factors include loss downward through inner area of slab.

Table V.4¹

6. Infiltration

- a. The heat loss due to infiltration is given by:

$$q_{inf} = 0.018BL(t_i - t_o)$$

where:

B = air leakage, cfm per foot of crack

L = total crack length, feet

(See Example 28, Appendix 301-A.)

- b. The leakage coefficients (B) have been determined by experimentation for several construction types and are listed in tabular form for convenience. (See Table V.5.)
- c. In general, the particular exposure of the structure that offers the greatest crack length is used for the infiltration calculation.

However, in no case should less than one-half of the total crack length of the entire building be used.

C. Summation of Heat Loss

1. The total heat load for any structure is simply a summation of the heat losses through each of the construction types of which the structure is composed.
2. The individual loads (or losses) to be summed are, in general:
 - a. Heat loss through exposed wall areas, including losses to unheated spaces
 - b. Heat loss through glass surfaces and doors
 - c. Heat loss due to infiltration
 - d. Miscellaneous loads due to unusual conditions or special circumstances associated with the use of the building
3. A systematic approach to the calculation of the total heat loss is necessary. The most convenient method is to use a tabular form that permits the listing and summing of the various losses.

D. Seasonal Heat and Fuel Requirements

1. Since the design heat loss for any structure is based upon relatively maximal conditions in order to size the HVAC equipment, much of the time this equipment will be operating at part-load. For this reason, it is convenient to have some measure of the seasonal heating requirements in order that fuel consumptions and costs for a structure may be estimated. One such method is the "Degree Day Method."
2. Fuel consumption in residences and public buildings varies nearly directly with the difference between the outside temperature and 65°F. That is, at 65°F outside temperature, practically no heat need be supplied to the building.
3. Thus the difference between the average outside temperature and 65°F is an index of the heating requirements for a building and is the basis of the degree day method.
4. A "degree day" accrues for every degree the average outside temperature is below 65°F for a 24-hour period. Thus, if for a given locality the outside temperature averaged 45°F for 30 days, the degree days for that period would be $(65-45) \times (30)$, or 600. Average values of degree days are tabulated for many localities. (See Table V.6.)
5. A normal heating season in the United States is considered to be from October 1 to May 1 (212 days).
6. The heat loss per degree of temperature difference is calculated:

$$Q_D = \frac{Q_T}{t_i - t_o}$$

where:

Q_D = heat loss per degree of temperature difference, Btuh/°F

Q_T = design heat loss for a building, Btuh

t_i = inside design temperature, °F

t_o = outside design temperature, °F

7. Fuel consumption may then be estimated from:

$$FC = \frac{(QD)(DD)(24)}{(HV)(\eta)}$$

where:

FC = fuel consumption for period of interest

DD = number of degree days for period of interest

HV = heating value of fuel being used

η = efficiency of heating unit

8. Some general values for the heating values of fuels and the efficiencies of the associated equipment are:

<u>Fuel</u>	<u>Heating Value</u>	<u>Efficiency</u>
steam	1,000 Btu/lb	
coal	13,000 Btu/lb	45-70%
oil	144,000 Btu/gal	60-85%
gas	1,000 Btu/cu.ft.	75-85%

(See Example 29, Appendix 301-A.)

INFILTRATION THROUGH WINDOWS

Expressed in cubic feet per foot of crack per hour^a

LINEAR INTERPOLATION

WIND VELOCITY, MILES PER HR.

TYPE OF WINDOW	REMARKS	5	10	15	20	25	30
Double-Hung Wood Sash Windows (Unlocked)	Around frame in masonry wall - not caulked ^b	3	8	14	20	27	35
	Around frame in masonry wall - caulked ^b	1	2	3	4	5	6
	Around frame in wood frame construction ^b	2	6	11	17	23	30
	Total for average window, non-weatherstripped, 1/16 in. crack and 3/64 in. clearance. ^c Includes wood frame leakage ^d	7	21	39	59	80	104
	Ditto, weatherstripped ^d	4	13	24	36	49	63
	Total for poorly fitted window, non-weatherstripped, 3/32 in. crack and 3/32 in. clearance. ^e Includes wood frame leakage ^d	27	69	111	154	199	249
	Ditto, weatherstripped ^d	6	19	34	51	71	92
Double-Hung Metal Windows ^f	Non-weatherstripped, locked	20	45	70	96	125	154
	Non-weatherstripped, unlocked	20	47	74	104	137	170
	Weatherstripped, unlocked	6	19	32	46	60	76
Rolled Section Steel Sash Windows ^k	Industrial pivoted, 1/16 in. crack ^g	52	108	176	244	304	372
	Architectural projected, 1/32 in. crack ^h	15	36	62	86	112	139
	Architectural projected, 3/64 in. crack ^h	20	52	88	116	152	182
	Residential casement, 1/64 in. crack ⁱ	6	18	33	47	60	74
	Residential casement, 1/32 in. crack ⁱ	14	32	52	76	100	128
	Heavy casement section, projected, 1/64 in. crack ^j	3	10	18	26	36	48
	Heavy casement section, projected, 1/32 in. crack ^j	8	24	38	54	72	92
Hollow Metal, Vertically Pivoted Window ^l		30	88	145	186	221	242

Table V.5

Notes for Table V.5

- a. The values given in this table, with the exception of those for double-hung and hollow metal windows are 20 percent less than test values to allow for building up of pressure in rooms, and are based on test data, reported in the papers listed in chapter footnotes.
- b. The values given for frame leakage are per foot of sash perimeter, as determined for double-hung wood windows. Some of the frame leakage in masonry walls originates in the brick wall itself, and cannot be prevented by caulking. For the additional reason that caulking is not done perfectly and deteriorates with time, it is considered advisable to choose the masonry frame leakage values for caulked frames as the average determined by the caulked and non-caulked tests.
- c. The fit of the average double-hung wood window was determined as 1/16 in. crack and 3/64 in. clearance by measurements on approximately 600 windows under heating season conditions.
- d. The values given are the totals for the window opening per foot of sash perimeter, and include frame leakage and so-called elsewhere leakage. The frame leakage values included are for wood frame construction, but apply as well to masonry construction assuming a 50 percent efficiency of frame caulking.
- e. A 3/32 in. crack and clearance represent a poorly fitted window, much poorer than average.
- f. Windows tested in place in building, so that no reduction from test values is necessary, as mentioned in footnote a.
- g. Industrial pivoted window generally used in industrial buildings. Ventilators horizontally pivoted at center or slightly above, lower part swinging out.
- h. Architecturally projected made of same sections as industrial pivoted, except that outside framing member is heavier, and it has refinements in weathering and hardware. Used in semi-monumental buildings such as schools. Ventilators swing in or out and are balanced on side

arms. $1/32$ in. crack is obtainable in the best practice of manufacture and installation, $3/64$ in. crack considered to represent average practice.

- i. Of same design and section shapes as so-called heavy section casement, but of lighter weight. $1/64$ in. crack is obtainable in the best practice of manufacture and installation, $1/32$ in. crack considered to represent average practice.
- j. Made of heavy sections. Ventilators swing in or out and stay set at any degree of opening. $1/64$ in. crack is obtainable in the best practice of manufacture and installation, $1/32$ in. crack considered to represent average practice. Known as Intermediate Windows by steel window manufacturers.
- k. With reasonable care in installation, leakage at contacts where windows are attached to steel framework and at mullions, is negligible. With $3/64$ in. crack, representing poor installation, leakage at contact with steel framework is about one-third, and at mullions, about one-sixth of that given for industrial pivoted windows in the table.

AVERAGE MONTHLY DEGREE - DAY VALUES FOR SELECTED CITIES

CITY	AUG. SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE JULY	TOTAL
BALTIMORE	33	227	526	855	921	837	637	343	95	12	4487
CHICAGO	95	337	712	1116	1218	1080	861	531	259	73	6282
CLEVELAND	107	354	684	1045	1143	1067	876	553	252	63	6144
LOS ANGELES	5	43	110	225	272	235	212	158	103	28	1391
MINNEAPOLIS	190	481	942	1415	1587	1372	1072	577	260	70	7966
NEW YORK	54	272	594	940	1028	953	771	465	172	31	5280

Table V.6

VI. AIR-CONDITIONING COOLING LOAD

A. Design Conditions

1. Indoor Design Parameters

- a. The indoor temperature and relative humidity used in the calculation of a cooling load are referred to as the indoor design conditions.
- b. Typically these conditions are taken to be 72°F dry-bulb temperature and 50% relative humidity. Again, these conditions may be varied to suit the requirements of particular or unusual use.

2. Outdoor Design Conditions

- a. Tabulations of summer outdoor design parameters are available and similar to that for winter conditions. (See Table D.1, Appendix 301-D.)
- b. Summer outdoor design temperatures are usually listed as 1%, 2-1/2%, and 5% values. This means, for instance, that the actual temperature will exceed the design only 2-1/2% of the time during June, July and August.
- c. Accompanying each of the dry-bulb design temperatures will be a wet-bulb design temperature. Due to the relatively large latent loads which occur during the summer months, it is necessary to specify indoor and outdoor humidity conditions in order that the HVAC equipment be sized to handle the load.
- d. It is not uncommon to select the 1% design values for purposes of cooling load calculations.

B. Solar Radiation

1. Calculation of the heat gain into a space is basically the same as the calculation of the heat loss from that same space; the notable difference is that the direction of heat flow is reversed.
2. A second difference is that during the daylight hours, we must also include the effects of solar radiation. This will be seen as a direct heat gain through windows and as a source of heat gain to the exterior surfaces of buildings.

3. The solar radiation incident on a given surface or object is the sum of the direct and the diffuse radiation received by that surface. The total amount of radiant energy incident upon a surface is referred to as the total solar radiation. Thus:

$$q_{\text{total solar}} = q_{\text{direct solar}} + q_{\text{diffuse solar}}$$

4. Consider a fenestration (window) exposed to sunlight. In addition to the conduction of heat through the glass, we must also account for the radiant energy passing through the glass. This may be expressed as:

$$q = A[U(t_o - t_i) + (SC)(SHGF)]$$

where: SC= shading coefficient for a given window,
dimensionless

SHGF = solar heat gain factor, Btuh/ft²

(See Table VI.2, for window U-values.)

(See Example 30, Appendix 30I-A.)

5. Solar heat gain factors are a function of time of day, day of the year, and latitude and orientation of the building. These values are tabulated for convenience and are listed for the 21st day of each month. (See Table VI.1.)
6. Shading coefficients are the ratio of the amount of radiant energy passed through a given window (glass) to the amount of radiant energy passing through single-strength clear glass. These values are determined experimentally and are listed for reference. (See Table VI.3,4,5.)

C. Equivalent Temperature Differential

1. For non-opaque surfaces (walls and roofs), the basic mode of heat transfer is still conduction. But in the presence of radiant energy (sunlight), the outer surface can be raised to a temperature greater than that of the ambient air. The conduction heat flow through the wall is increased due to the greater temperature differential across the wall.
2. In order to simplify the determination of the heat flow through a sunlit wall (or roof), it is convenient to define an artificial air temperature of the outside air which when used in the conventional $UA(t_o - t_i)$ form, will yield a heat transfer

equal to that of the combined conduction- radiation process. Since it is actually the temperature differential that is of importance, it is this value that is determined and given the name Total Equivalent Temperature Differential (TETD).

3. TETD values are not only a function of solar radiation, but a function of construction type as well. These values, too, have been determined for a variety of construction types and tabulated for reference. (See Tables VI.6, 7A, 7B.)
4. Upon determination of the TETD value for a particular construction, the heat transfer through that section is given by:

$$q = UA(TETD)$$

(See Example 31, Appendix 301-A.)

D. Instantaneous Heat Gains

1. The instantaneous heat gain for a building or space is obtained by summing the heat transfer through each of the component sections comprising the structure. (See Table D.2, Appendix 301-D for material properties.)
2. Note that U-values are obtained in the same manner as described previously (V.B.2) with the exception that the outside wind velocity for the summer is taken to be 7-1/2 mph. Thus at the outer surface we have

$$f_o = 4.0 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

$$R = \frac{1}{f_o} = 0.25 \frac{\text{hr-ft}^2\text{-}^\circ\text{F}}{\text{Btu}}$$

3. Treatment of unconditioned spaces, attics and basement walls and floors follows the same procedures already outlined (V.B.4-5).
4. Typically, the temperature differential for cooling load calculations is written ($t_o - t_i$) since the outdoor temperature is generally greater than the indoor design.
5. We have seen that the magnitude of a cooling load is influenced by the intensity of the incident solar radiation, which

Solar Intensity and Solar Heat Gain Factors* for 24 Deg North Latitude

Date	Solar Time am	Direct Normal Inc. Btu/hr	Solar Heat Gain Factors, Btu/hr ²																	Solar Time pm
			N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	HOR	
Jan 21	7	71	2	3	21	43	62	67	63	49	25	3	2	2	2	2	2	2	3	3
	8	229	12	12	41	128	190	221	218	181	114	28	12	12	12	12	12	12	55	4
	9	238	18	18	33	106	190	240	233	227	166	73	19	18	18	18	18	18	121	3
	10	308	23	23	34	53	144	211	243	241	200	125	38	34	23	23	23	23	172	2
	11	317	26	26	26	27	73	156	211	234	220	173	95	29	26	26	26	26	204	1
	12	320	27	27	27	27	29	82	160	210	227	210	160	81	29	27	27	27	214	12
	HALF DAY TOTALS		95	96	148	372	671	942	1076	1039	840	505	241	120	96	95	95	95	664	
Feb 21	7	153	6	12	67	114	141	143	128	90	33	6	6	6	6	6	6	6	17	3
	8	252	15	16	80	163	220	240	224	172	89	17	15	15	15	15	15	15	133	4
	9	297	21	22	46	134	208	244	243	205	133	42	22	21	21	21	21	21	153	3
	10	314	26	26	28	76	137	209	228	219	165	87	28	26	26	26	26	26	205	2
	11	321	29	29	29	31	80	148	191	203	185	137	68	31	29	29	29	29	218	1
	12	323	30	30	30	30	32	70	134	177	192	177	133	70	32	30	30	30	249	12
	HALF DAY TOTALS		113	119	237	527	806	1011	1072	963	699	374	200	127	113	113	113	113	820	
Mar 21	7	194	11	43	113	164	186	180	143	86	17	10	10	10	10	10	10	10	36	3
	8	267	18	33	124	195	234	237	204	138	48	19	18	18	18	18	18	18	112	4
	9	295	25	27	83	163	215	232	214	163	82	27	25	25	25	25	25	25	180	3
	10	309	30	31	41	103	162	194	195	168	112	47	31	30	30	30	30	30	232	2
	11	315	33	33	34	42	85	129	154	155	139	86	43	34	33	33	33	33	264	1
	12	317	34	34	34	34	35	56	96	126	137	126	95	56	35	34	34	34	275	12
	HALF DAY TOTALS		133	189	422	693	906	1011	970	778	458	249	169	139	133	133	133	133	962	
Apr 21	6	40	6	21	33	39	39	33	22	7	2	2	2	2	2	2	2	2	4	6
	7	203	20	88	151	189	197	176	127	55	15	14	14	14	14	14	14	14	58	3
	8	234	24	80	159	209	228	212	164	88	24	22	22	22	22	22	22	22	132	4
	9	280	30	54	126	181	208	203	169	105	39	29	28	28	28	28	28	28	195	3
	10	292	34	37	73	125	157	165	148	107	56	35	33	33	33	33	33	33	244	2
	11	298	36	37	40	59	83	103	106	94	70	45	38	37	36	36	36	36	274	1
	12	299	37	37	38	38	39	46	59	70	75	70	58	45	39	38	38	38	283	12
	HALF DAY TOTALS		168	379	607	826	940	934	773	494	244	180	163	157	155	155	154	154	1048	
May 21	6	86	25	79	87	84	66	38	8	6	6	6	6	6	6	6	6	6	13	6
	7	203	43	117	171	199	196	163	105	32	17	17	17	17	17	17	17	17	73	3
	8	248	38	114	178	214	218	190	132	54	26	25	25	25	25	25	25	25	142	4
	9	269	35	88	130	188	198	179	132	66	33	31	31	31	31	31	31	31	201	3
	10	280	38	59	103	137	150	141	111	67	39	36	35	35	35	35	35	35	247	2
	11	285	40	43	55	72	83	84	75	58	44	40	39	38	38	38	38	38	274	1
	12	288	41	41	41	41	42	43	44	46	46	46	44	43	42	41	41	41	282	12
	HALF DAY TOTALS		238	492	749	909	943	840	614	308	187	176	174	173	172	172	172	172	1089	
Jun 21	6	97	36	70	93	101	94	73	39	8	7	7	7	7	7	7	7	7	17	6
	7	201	53	127	177	199	192	155	94	26	18	18	18	18	18	18	18	18	77	3
	8	242	50	126	184	214	212	179	117	43	27	26	26	26	26	26	26	26	145	4
	9	263	43	102	138	189	192	168	116	33	34	32	32	32	32	32	32	32	201	3
	10	274	41	72	113	140	146	131	96	33	39	36	36	36	36	36	36	36	243	2
	11	279	42	50	65	77	82	77	64	49	42	41	40	39	39	39	39	39	271	1
	12	281	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	279	12
	HALF DAY TOTALS		284	562	802	933	932	797	544	235	187	181	180	179	179	179	180	180	1096	
Jul 21	6	81	26	56	76	84	80	63	36	8	6	6	6	6	6	6	6	6	13	6
	7	193	43	116	168	194	190	158	101	31	18	18	18	18	18	18	18	18	73	3
	8	239	41	115	176	210	213	185	128	52	27	26	26	26	26	26	26	26	141	4
	9	261	37	99	148	185	195	171	129	64	34	32	32	32	32	32	32	32	198	3
	10	272	39	62	104	137	149	139	108	63	39	37	36	36	36	36	36	36	243	2
	11	278	41	44	58	73	83	83	73	57	44	41	40	39	39	39	39	39	270	1
	12	280	42	42	42	43	43	44	45	46	46	46	46	45	45	45	45	45	278	12
	HALF DAY TOTALS		247	498	746	877	925	820	595	300	191	181	178	177	177	177	181	181	1076	
Aug 21	6	35	6	20	30	35	35	30	19	6	2	2	2	2	2	2	2	2	4	6
	7	186	22	87	144	179	186	165	119	51	16	15	15	15	15	15	15	15	58	3
	8	241	26	82	156	203	220	204	137	84	26	24	24	24	24	24	24	24	130	4
	9	265	32	57	126	178	202	197	162	101	39	31	30	30	30	30	30	30	191	3
	10	278	36	40	78	123	153	161	143	103	53	37	35	35	35	35	35	35	239	2
	11	284	38	39	42	61	85	101	104	91	68	46	40	38	37	37	37	37	268	1
	12	286	38	39	40	40	41	47	58	69	72	68	58	47	41	40	40	40	277	12
	HALF DAY TOTALS		179	347	601	806	910	889	740	473	243	186	171	165	164	163	163	163	1028	
Sep 21	6	248	19	36	119	185	222	225	194	132	48	20	19	19	19	19	19	19	108	4
	7	278	26	28	84	160	207	223	206	158	81	28	26	26	26	26	26	26	174	3
	8	292	31	32	42	101	158	188	190	163	110	48	32	31	31	31	31	31	224	2
	9	299	34	34	34	35	43	84	127	131	128	86	44	35	34	34	34	34	256	1
	10	301	35	35	35	36	37	37	99	134	134	124	94	57	37	36	35	35	266	12
	HALF DAY TOTALS		139	190	406	661	863	964	927	749	431	251	174	145	139	138	138	138	930	
Oct 21	7	138	6	12	62	104	129	133	117	83	31	7	6	6	6	6	6	6	17	3
	8	247	16	17	79	159	211	230	214	169	115	17	16	16	16	16	16	16	132	4
	9	284	22	23	47	135	202	237	237	198	128	41	23	22	22	22	22	22	150	3
	10	301	27	27	29	77	154	204	222	207	160	85	29	27	27	27	27	27	201	2
	11	309	30	30	30	33	80	143	186	198	180	133	67	32	30	30	30	30	233	1
	12	311	31	31	31	31	33	70	131	173	187	172	130	69	33	31	31	31	244	12
	HALF DAY TOTALS		116	123	255	512	778	974	1022	929	675	367	200	131	117	116	116	116	804	
Nov 21	7	67	2	3	20	43	59	64	63	46	24	3	2	2	2	2	2	2	3	3
	8	232	13	13	42	126	186	216	213	177	111	28	12	12	12	12	12	12	55	4
	9	262	19	23	106	187	236	249	236	203	123	38	17	16	16	16	16	16	132	3
	10	303	23	23	34	53	143	209	241	237	197	123	37	34	23	23	23	23	171	2
	11	312	26	26	26	28	73	154	209	230	217	171	93	29	26	26	26	26	202	1
	12	315	27	27	27	27	29	81	158	207	224	207	158							

Solar Intensity and Solar Heat Gain Factors* for 32 Deg North Latitude

Date	Solar Time	Direct Normal Inc. Btu/hr ft ²	Solar Heat Gain Factors, Btu/hr ft ²																Solar Time
			N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
Jan 21	7	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	5
	8	203	9	9	29	103	160	189	199	199	103	28	9	9	9	9	9	32	4
	9	269	15	15	17	91	173	229	246	225	169	82	17	15	15	15	15	83	3
	10	286	20	20	20	41	133	209	249	230	211	141	46	20	20	20	20	136	2
	11	306	23	23	23	24	68	159	221	249	238	191	110	29	23	23	23	166	1
Feb 21	7	112	4	7	47	82	102	105	95	87	25	4	4	4	4	4	4	9	5
	8	245	13	14	65	149	205	228	216	170	95	17	13	13	13	13	13	64	4
	9	287	19	19	12	122	199	242	248	216	149	53	20	19	19	19	19	127	3
	10	305	24	24	25	42	151	213	241	232	189	112	31	24	24	24	24	176	2
	11	314	26	26	26	28	76	156	208	227	212	163	87	28	26	26	26	207	1
Mar 21	7	185	10	10	37	105	133	173	173	142	88	20	9	9	9	9	9	32	5
	8	260	17	25	107	183	227	237	209	150	62	18	17	17	17	17	17	100	4
	9	290	23	25	64	151	210	237	227	183	107	30	23	23	23	23	23	164	3
	10	304	28	28	30	87	153	202	215	195	144	70	29	28	28	28	28	111	2
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	142	1
Apr 21	7	253	17	27	27	27	27	27	27	153	204	231	204	153	79	29	27	217	12
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
May 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Jun 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Jul 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Aug 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Sep 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Oct 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Nov 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
Dec 21	7	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1
	8	280	23	32	32	32	32	32	32	162	176	162	122	66	33	32	32	252	12
	9	297	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	10	304	28	34	34	34	34	34	34	168	188	168	120	59	33	31	31	242	1
	11	311	31	31	31	34	82	142	170	188	168	120	59	33	31	31	31	242	1

Half Day Totals computed by Simpson's Rule with time interval equal to 10 minutes.
 *Total Solar Heat Gains for DS (0.125 in.) sheet glass.

Based on a ground reflectance of 0.20 and values in Tables 1 and 2A.

Table VI.1B1

Solar Intensity and Solar Heat Gain Factors* for 40 Deg North Latitude

[illegible]

Half Day Totals computed by Simpson's Rule with time interval equal to 10 minutes.
*Total Solar Heat Gains for DS (0.125 in.) shown above.

Based on a ground reflectance of 0.20 and values in Tables 1 and 26.

Table VI.1C¹

Solar Intensity and Solar Heat Gain Factors* for 48 Deg North Latitude

Date	Solar Time am	Direct Normal Inc. Btu/h ft ²	Solar Heat Gain Factors, Btu/h ft ²																Solar Time pm	
			N	NNW	NW	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW		NOR
Jan 21	8	37	1	1	4	10	29	34	33	30	20	6	1	1	1	1	1	1	2	4
	9	185	8	8	8	33	118	160	176	166	129	69	10	8	8	8	8	8	25	3
	10	239	12	12	12	22	108	173	218	223	195	136	50	12	12	12	12	12	33	2
	11	261	14	14	14	15	53	144	208	239	233	190	116	28	14	14	14	14	77	1
	12	267	15	15	15	15	16	86	171	226	245	226	171	86	16	15	15	15	85	12
HALF DAY TOTALS			43	43	46	117	316	567	729	776	701	512	259	83	43	43	43	43	203	
Feb 21	7	4	0	0	1	3	3	3	3	2	1	0	0	0	0	0	0	0	0	3
	8	180	8	8	8	36	103	149	170	166	136	82	17	8	8	8	8	8	25	4
	9	247	13	13	16	90	168	216	230	209	155	71	14	13	13	13	13	13	66	3
	10	273	17	17	17	38	131	203	242	244	207	138	44	18	17	17	17	17	105	2
	11	288	19	19	19	20	65	158	221	249	239	192	113	27	19	19	19	19	130	1
HALF DAY TOTALS			68	68	68	107	274	541	816	968	967	813	531	261	104	68	68	68	395	
Mar 21	7	153	7	7	22	80	123	145	145	123	80	23	7	7	7	7	7	7	20	5
	8	236	14	15	16	154	204	232	206	158	82	15	14	14	14	14	14	14	68	4
	9	270	19	19	19	3	121	193	234	239	207	142	52	20	19	19	19	19	118	3
	10	282	23	23	24	58	146	208	237	231	189	113	33	23	23	23	23	23	156	2
	11	295	25	25	25	26	74	156	210	232	218	172	94	28	25	25	25	25	180	1
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Apr 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
May 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Jun 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Jul 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Aug 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Sep 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Oct 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Nov 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	
Dec 21	6	108	12	12	33	86	105	107	93	64	23	6	6	6	6	6	6	6	18	6
	7	225	15	15	41	132	180	199	189	148	84	11	14	14	14	14	14	14	60	5
	8	247	20	20	32	111	179	219	225	196	138	55	21	20	20	20	20	20	114	3
	9	268	25	26	60	141	197	223	215	176	106	33	25	23	23	23	23	23	161	3
	10	280	28	28	31	77	148	193	209	194	150	80	31	28	28	28	28	28	196	2
HALF DAY TOTALS			100	118	250	494	773	1012	1100	1014	767	463	244	126	101	100	100	100	636	

Half Day Totals computed by Simpson's Rule with time interval equal to 10 minutes.

*Total Solar Heat Gains for OS (0.125 in.) sheet glass.

Based on a ground reflectance of 0.20 and values in Tables 1 and 26.

Table VI.1d¹

Solar Intensity and Solar Heat Gain Factors* for 56 Deg North Latitude

Date	Solar Time am	Direct Normal Irradiance Btu/hr-ft ²	Solar Heat Gain Factors, Btu/hr-ft ²																Solar Time pm	
			N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	HOR	
Jan 21	9	78	3	3	3	21	49	67	74	70	53	30	4	3	3	3	3	3	3	3
	10	170	7	7	7	13	74	126	156	162	143	100	38	7	7	7	7	7	7	21
	11	207	9	9	9	10	40	116	169	194	190	156	96	21	9	9	9	9	9	34
	12	217	10	10	10	10	11	71	144	190	205	190	144	71	11	10	10	10	10	40
	13	217	10	10	10	10	11	71	144	190	205	190	144	71	11	10	10	10	10	40
Feb 21	9	115	4	4	4	21	64	95	109	107	88	55	12	4	4	4	4	4	4	36
	10	203	10	10	11	71	139	183	197	182	154	66	10	10	10	10	10	10	10	36
	11	262	13	13	13	13	16	57	148	210	239	232	188	112	25	15	15	15	15	84
	12	267	16	16	16	16	17	86	171	223	244	223	171	86	17	16	16	16	16	91
	13	267	16	16	16	16	17	86	171	223	244	223	171	86	17	16	16	16	16	91
Mar 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Apr 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
May 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Jun 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Jul 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Aug 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Sep 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Oct 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Nov 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142
Dec 21	9	128	6	6	6	101	121	122	105	70	21	6	6	6	6	6	6	6	6	14
	10	215	12	12	12	61	136	183	205	194	152	84	15	12	12	12	12	12	12	49
	11	253	16	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89
	12	272	19	19	19	30	46	136	203	238	236	198	128	39	20	19	19	19	19	122
	13	282	21	21	21	32	68	156	215	241	230	184	106	27	21	21	21	21	21	142

Half Day Totals computed by Simpson's Rule with time interval equal to 10 minutes.

*Total Solar Heat Gains for DS (0.125 in.) sheet glass.

Based on ground reflectance of 0.20 and values in Tables 1 and 26.

Table VI.1E1

Overall Coefficients of Heat Transmission (U-Factor) of Windows

PART A. Exterior Vertical Panels				
Description	Winter^a	Summer^{a*}	Winter^a	Summer^{a*}
Flat Glass^b	No Shade	No Shade	Indoor Shade^{***}	Indoor Shade^{***}
Single Glass	1.10	1.04	0.83	0.81
Insulating Glass; Double ^c				
3/16-in. air space ^d	0.62	0.63	0.52	0.58
1/4-in. air space ^d	0.58	0.61	0.48	0.55
1/2-in. air space ^d	0.49	0.56		
1/2-in. air space, low emittance coating ^f			0.42	0.52
$\epsilon=0.20$	0.32	0.38	0.30	0.37
$\epsilon=0.40$	0.38	0.43	0.36	0.44
$\epsilon=0.60$	0.43	0.51	0.38	0.48
Insulating Glass; Triple ^c				
1/4-in. air space ^d	0.39	0.44	0.31	0.40
1/2-in. air space ^d	0.31	0.39	0.26	0.36
Storm Windows				
1-in. to 4-in. air spaces ^d	0.50	0.50	0.42	0.48

^aSee Part C for adjustments for various windows and sliding patio doors.

^bEmissivity of uncoated glass surface = 0.84.

^cDouble and triple refer to number of lights of glass.

^d0.125-in. glass.

^e0.25-in. glass.

^fCoating on either glass surface facing air space; all other glass surfaces uncoated.

^gWindow design: 0.25-in. glass, 0.125-in. glass, 0.25-in. glass.

^hRefers to windows with negligible opaque areas.

ⁱFor heat flow up.

^jFor heat flow down.

^kBased on area of opening, not total surface area.

^lValues will be less than these when metal sash and frame incorporate thermal breaks. In some thermal break designs U values will be equal to or less than those for the glass. Window manufacturers should be consulted for specific data.

^m15 mph outdoor air velocity; 0 F outdoor air; 70 F inside air temp natural convection.

ⁿ7.5 mph outdoor air velocity; 89 F outdoor air; 75 F inside air natural convection; solar radiation 248.3 Btu/h/ft².

^oValues apply to tightly closed venetian and vertical blinds, draperies, and roller shades.

Table VI.2

Shading Coefficients for Single Glass and Insulating Glass^a

A. Single Glass				
Type of Glass	Nominal Thickness^b	Solar Trans.^b	Shading Coefficient	
			$h_o=4.0$	$h_o=3.0$
Clear	1/8 in.	0.84	1.00	1.00
	1/4 in.	0.78	0.94	0.95
	3/8 in.	0.72	0.90	0.92
	1/2 in.	0.67	0.87	0.88
Heat Absorbing	1/8 in.	0.64	0.83	0.85
	1/4 in.	0.46	0.69	0.73
	3/8 in.	0.33	0.60	0.64
	1/2 in.	0.24	0.53	0.58
B. Insulating Glass				
Clear Out, Clear In	1/8 in. ^c	0.71 ^e	0.88	0.88
Clear Out, Clear In	1/4 in.	0.61	0.81	0.82
Heat Absorbing ^d Out, Clear In	1/4 in.	0.36	0.55	0.58

^aRefers to factory-fabricated units with 3/16, 1/4, or 1/2-in. air space or to prime windows plus storm sash.

^bRefer to manufacturer's literature for values.

^cThickness of each pane of glass, not thickness of assembled unit.

^dRefers to gray, bronze, and green tinted heat-absorbing float glass.

^eCombined transmittance for assembled unit.

Table VI.3¹

Shading Coefficients for Single Glass with Indoor Shading by Venetian Blinds or Roller Shades

	Nominal Thickness ^a	Solar Trans. ^b	Type of Shading				
			Venetian Blinds		Roller Shade		
			Medium	Light	Opaque	Translucent	
Clear	3/32 to 1/4	0.87 to 0.80					
Clear	1/4 to 1/2	0.80 to 0.71					
Clear Pattern	1/8 to 1/2	0.87 to 0.79	0.64	0.55	0.59	0.25	0.39
Heat-Absorbing Pattern	1/8	—					
Tinted	3/16, 7/32	0.74, 0.71					
Heat-Absorbing ^d	3/16, 1/4	0.46					
Heat-Absorbing Pattern	3/16, 1/4	—	0.57	0.53	0.45	0.30	0.36
Tinted	1/8, 7/32	0.59, 0.45					
Heat-Absorbing or pattern	—	0.44 to 0.30	0.54	0.52	0.40	0.28	0.32
Heat-Absorbing ^d	3/8	0.34					
Heat-Absorbing or Pattern	—	0.29 to 0.15	0.42	0.40	0.36	0.28	0.31
Reflective Coated Glass							
SC ^c = 0.30			0.25	0.23			
0.40			0.33	0.29			
0.50			0.42	0.38			
0.60			0.50	0.44			

^a Refer to manufacturer's literature for values.

^b For vertical blinds with opaque white and beige louvers in the tightly closed position, SC is 0.25 and 0.29 when used with glass of 0.71 to 0.80 transmittance.

^c SC for glass with no shading device.

^d Refers to grey, bronze, and green tinted heat-absorbing glass.

Table VI.4¹

Shading Coefficients for Insulating Glass^a with Indoor Shading by Venetian Blinds or Roller Shades

Type of Glass	Nominal Thickness in., each light	Solar Trans. ^b		Type of Shading				
				Venetian Blinds ^c		Roller Shade		
		Outer Pane	Inner Pane	Medium	Light	Opaque	Translucent	
Clear Out	3/32, 1/8	0.87	0.87					
Clear In				0.57	0.51	0.60	0.25	0.37
Clear Out								
Clear In	1/4	0.80	0.80					
Heat-Absorbing ^d Out	1/4	0.46	0.80	0.39	0.36	0.40	0.22	0.30
Clear In								
Reflective Coated Glass								
SC ^c = 0.20				0.19	0.18			
0.30				0.27	0.26			
0.40				0.34	0.33			

^a Refers to factory-fabricated units with 3/16, 1/4, or 1/2-in. air space, or to prime windows plus storm windows.

^b Refer to manufacturer's literature for exact values.

^c For vertical blinds with opaque white or beige louvers, tightly closed, SC is approximately the same as for opaque white roller shades.

^d Refers to bronze, or green tinted, heat-absorbing glass.

Table VI.5¹

Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs

Roof No	Description of Construction	Weight lb/sq ft	U-value Btu/hr sq ft °F	Solar Time, hr																								Hour of Max. Diff.	Max. Diff. °F	CLTD		
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24					
Without Suspended Ceiling																																
1	Steel sheet with 1-in. (for 2-in.) insulation	7	0.213 (0.134)	-2	-3	-3	-3	-3	-3	6	19	34	49	61	71	78	79	77	70	59	43	30	18	12	8	5	3	14	-5	79	84	
2	1-in. wood with 1-in. insulation	8	0.170	6	3	0	-1	-3	-3	-2	4	14	27	39	52	62	70	74	74	70	62	51	38	28	20	14	9	16	-3	74	77	
3	4-in. l.w. concrete	18	0.213	9	5	2	0	-2	-3	-3	1	9	20	32	44	53	64	70	73	71	66	57	45	34	25	19	13	16	-3	73	76	
4	2-in. h.w. concrete with 1-in. (for 2-in.) insulation	29	0.206 (0.122)	12	8	5	3	0	-1	-1	3	11	20	30	41	51	59	65	66	62	54	45	36	29	22	17	16	-1	67	68		
5	1-in. wood with 2-in. insulation	19	0.109	3	0	-3	-4	-5	-7	-6	-3	5	16	27	39	49	57	63	64	62	57	48	37	26	18	11	7	16	-7	64	71	
6	4-in. l.w. concrete	34	0.150	22	17	13	9	5	3	1	1	3	7	13	23	33	43	51	58	62	64	62	57	50	42	35	28	18	1	54	63	
7	2.5-in. wood with 1-in. insulation	13	0.130	29	24	20	16	13	10	7	6	6	9	13	20	27	34	42	48	53	55	56	54	49	44	39	34	19	6	56	50	
8	8-in. l.w. concrete	31	0.126	35	30	26	22	18	14	11	9	7	9	13	19	25	33	39	46	50	53	54	53	49	43	40	20	7	54	47		
9	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	52	0.200 (0.120)	25	22	18	15	12	9	8	8	10	14	20	26	33	40	46	50	53	53	52	48	43	38	34	30	18	8	53	45	
10	2.5-in. wood with 2-in. insulation	13	0.093	30	26	23	19	16	13	10	9	8	9	13	17	23	29	36	41	46	49	51	50	47	43	39	35	19	8	51	43	
11	Roof terrace system	75	0.106 (0.078)	31	28	25	22	19	16	14	13	13	15	18	22	26	31	36	40	44	45	45	45	43	40	37	20	13	46	33		
12	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	75	0.192 (0.117)	31	28	25	22	20	17	15	14	14	16	18	22	26	31	36	40	43	45	45	44	42	40	37	34	19	14	45	31	
13	4-in. wood with 1-in. (for 2-in.) insulation	17	0.106 (0.078)	36	33	30	28	25	22	20	18	17	16	17	18	21	24	28	32	36	39	41	43	43	42	40	22	16	43	27		
With Suspended Ceiling																																
1	Steel Sheet with 1-in. (for 2-in.) insulation	9	0.134 (0.092)	2	0	-2	-3	-4	-4	-1	9	23	37	50	62	71	77	78	74	67	56	42	28	18	12	8	5	15	-4	78	82	
2	1-in. wood with 1-in. insulation	10	0.115	20	15	11	8	5	3	2	3	7	13	21	30	40	48	53	60	62	61	58	51	44	37	30	25	17	2	62	60	
3	4-in. l.w. concrete	20	0.134	19	14	10	7	4	2	0	0	4	10	19	29	39	48	56	62	65	64	61	54	46	38	30	24	17	0	65	65	
4	2-in. h.w. concrete with 1-in. (for 2-in.) insulation	30	0.131	28	25	23	20	17	15	13	13	14	16	20	25	30	35	39	43	46	47	46	44	41	38	35	32	18	13	47	34	
5	1-in. wood with 2-in. insulation	10	0.083	25	20	16	13	10	7	5	5	7	12	18	25	33	41	48	53	57	57	56	52	46	40	34	29	18	5	57	52	
6	4-in. l.w. concrete	26	0.109	32	28	25	22	19	16	13	10	8	7	8	11	16	22	29	36	42	48	52	54	54	51	47	42	37	20	7	54	47
7	2.5-in. wood with 1-in. insulation	15	0.096	34	31	29	26	23	21	18	16	15	16	18	21	25	30	34	38	41	43	44	44	42	40	37	34	21	15	44	29	
8	8-in. l.w. concrete	33	0.093	39	36	33	29	26	23	20	18	15	14	15	17	20	25	29	34	38	42	45	46	45	44	42	21	14	46	32		
9	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	53	0.128 (0.090)	30	29	27	26	24	22	21	20	20	21	22	24	27	29	32	34	36	38	38	38	38	37	36	34	33	19	20	38	18
10	2.5-in. wood with 2-in. insulation	15	0.072	35	33	30	28	26	24	22	20	18	18	20	22	25	28	32	35	38	40	41	41	40	39	37	21	18	41	23		
11	Roof terrace system	77	0.082	30	29	28	27	26	25	24	23	22	22	23	25	26	28	29	31	32	33	33	33	33	33	32	22	22	33	11		
12	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	77	0.125 (0.068)	29	28	27	26	25	24	23	22	21	21	22	23	25	26	28	30	32	33	34	34	34	33	32	31	20	21	34	13	
13	4-in. wood with 1-in. (for 2-in.) insulation	19	0.082 (0.064)	35	34	33	32	31	29	27	26	24	23	22	21	22	22	24	25	27	30	32	34	35	36	37	36	23	21	37	16	

1 Application: These values may be used for all normal air-conditioning estimates; usually without correction (except as noted below) in latitude 0° to 50° North or South when the load is calculated for the hottest weather.

3 Corrections: The values in the table were calculated for an inside temperature of 78 F and an outdoor maximum temperature of 95 F, with an outdoor daily range of 21 deg F. The table remains approximately correct for other outdoor maximums (93-102 F) and other outdoor daily ranges (16-34 deg F), provided the outdoor daily average temperature remains approximately 85 F. If the room air temperature is different from 78 F and/or the outdoor daily average temperature is different from 85 F, the following rules apply: (a) For room air temperature less than 78 F, add the difference between 78 F and room air temperature; if greater than 78 F, subtract the difference. (b) For outdoor daily average temperature less than 85 F, subtract the difference between 85 F and the daily average temperature; if greater than 85 F, add the difference.

3 Antics or other spaces between the roof and ceiling: If the ceiling is insulated and a fan is used for positive ventilation in the space between the ceiling and roof, the total temperature difference for calculating the room load may be decreased by 25%. If the attic space contains a return duct or other air plenum, care should be taken in determining the portion of the heat gain that reaches the ceiling.

4 Light Colors: Multiply the CLTD's in the table by 0.5. Credit should not be taken for light-colored roofs except where the permanence of light color is established by experience, as in rural areas or where there is little smoke.

5 For solar transmission in other months: The table values of temperature differences calculated for July 21 will be approximately correct for a roof in the following months:

North Latitude	
Latitude	Months
0°	All Months
10°	All Months
20°	All Months except Nov., Dec., Jan.
30°	Mar., Apr., May, June, July, Aug., Sept.
40°	April, May, June, July, Aug.
50°	May, June, July
South Latitude	
Latitude	Months
0°	All Months
10°	All Months
20°	All Months except May, June, July
30°	Sept., Oct., Nov., Dec., Jan., Feb., Mar.
40°	Oct., Nov., Dec., Jan., Feb.
50°	Nov., Dec., Jan.

6 For each 7 F increase in R-value due to insulation added to the roof structures (Table 4), use a CLTD for a roof whose weight is approximately the same but whose CLTD has a maximum value 2 hr later. If this is not possible, due to having already selected the roof with the longest time lag, use a Δt in the load calculation equal to the difference between the 24 hr average soil-air temperature and the room air temperature.

Table VI.6¹

Wall Construction Group Description				
Group No.	Description of Construction	Weight(lb/ft ²)	U-value (Btu/(h·ft ² ·F))	Code Numbers of Layers (see Table 8)
4-in. Face Brick+(Brick)				
C	Air Space+4-in. Face Brick	83	0.358	A0, A2, B1, A2, E0
D	4-in. Common Brick	90	0.415	A0, A2, C4, E1, E0
C	1-in. Insulation or Air space+4-in. Common Brick	90	0.174-0.301	A0, A2, C4, B1/B2, E1, E0
B	2-in. Insulation+4-in. Common Brick	88	0.111	A0, A2, B2, C4, E1, E0
B	8-in. Common Brick	130	0.302	A0, A2, C9, E1, E0
A	Insulation or Air space+8-in. Common Brick	130	0.154-0.243	A0, A2, C9, B1/B2, E1, E0
4-in. Face Brick+(H. W. Concrete)				
C	Air Space+2-in. Concrete	94	0.350	A0, A2, B1, C5, E1, E0
B	2-in. Insulation+4-in. concrete	97	0.116	A0, A2, B3, C5, E1, E0
A	Air Space or Insulation+8-in. or more Concrete	143-190	0.110-0.112	A0, A2, B1, C10/11, E1, E0
4-in. Face Brick+(L. W. or H. W. Concrete Block)				
E	4-in. Block	62	0.319	A0, A2, C2, E1, E0
D	Air Space or Insulation+4-in. Block	62	0.153-0.246	A0, A2, C2, B1/B2, E1, E0
D	8-in. Block	70	0.274	A0, A2, C7, A6, E0
C	Air Space or 1-in. Insulation+6-in. or 8-in. Block	73-89	0.221-0.275	A0, A2, B1, C7/C8, E1, E0
B	2-in. Insulation+8-in. Block	89	0.096-0.107	A0, A2, B3, C7/C8, E1, E0
4-in Face Brick+(Clay Tile)				
D	4-in. Tile	71	0.381	A0, A2, C1, E1, E0
D	Air Space+4-in. Tile	71	0.281	A0, A2, C1, B1, E1, E0
C	Insulation+4-in. Tile	71	0.169	A0, A2, C1, B2, E1, E0
C	8-in. Tile	96	0.275	A0, A2, C6, E1, E0
B	Air Space or 1-in. Insulation+8-in. Tile	96	0.142-0.221	A0, A2, C6, B1/B2, E1, E0
A	2-in. Insulation+8-in. Tile	97	0.097	A0, A2, B3, C6, E1, E0
H.W. Concrete Wall+(Finish)				
E	4-in. Concrete	63	0.585	A0, A1, C5, E1, E0
D	4-in. Concrete+1-in. or 2-in. Insulation	63	0.119-0.200	A0, A1, C5, B2/B3, E1, E0
C	2-in. Insulation+4-in. Concrete	63	0.119	A0, A1, B6, C5, E1, E0
C	8-in. Concrete	109	0.490	A0, A1, C10, E1, E0
R	8-in. Concrete+1-in. or 2-in. Insulation	110	0.115-0.187	A0, A1, C10, B5/B6, E1, E0
A	2-in. Insulation+8-in. Concrete	110	0.115	A0, A1, B3, C10, E1, E0
B	12-in. Concrete	156	0.421	A0, A1, C11, E1, E0
A	12-in. Concrete+Insulation	156	0.113	A0, C11, B6, A6, E0
L.W. and H.W. Concrete Block+(Finish)				
F	4-in. Block+Air Space/Insulation	29	0.161-0.263	A0, A1, C2, B1/B2, E1, E0
E	2-in. Insulation+4-in. Block	29-37	0.105-0.114	A0, A1, B1, C2/C3, E1, E0
E	8-in. Block	47-51	0.294-0.402	A0, A1, C7/C8, E1, E0
D	8-in. Block+Air Space/Insulation	41-57	0.149-0.173	A0, A1, C7/C8, B2, E1, E0
Clay Tile+(Finish)				
F	4-in. Tile	39	0.419	A0, A1, C1, E1, E0
F	4-in. Tile+Air space	39	0.303	A0, A1, C1, B1, E1, E0
E	4-in. Tile+1-in. Insulation	39	0.175	A0, A1, C1, B2, E1, E0
D	2-in. Insulation+4-in. Tile	40	0.110	A0, A1, B1, C1, E1, E0
D	8-in. Tile	63	0.296	A0, A1, C6, E1, E0
C	8-in. Tile+Air Space/1-in. Insulation	63	0.151-0.231	A0, A1, C6, B1/B2, E1, E0
B	2-in. Insulation+8-in. Tile	63	0.099	A0, A1, B1, C6, E1, E0
Metal Curtain Wall				
G	With/without Air Space+1-in./2-in./3-in. Insulation	5-6	0.091-0.230	A0, A3, B5/B6/B12, A3, E0
Frame Wall				
G	1-in. to 3-in. Insulation	16	0.081-0.178	A0, A1, B1, B2/B3/B4, E1, E0

Table VI.7A¹

Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls

North Latitude Wall Facing	Solar Time, hr																								R of Max- imum CLTD	Min- imum CLTD	Max- imum CLTD	Differ- ence CLTD	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24					
Group A Walls																													
N	14	14	14	13	13	13	12	12	11	11	10	10	10	10	10	10	11	11	12	12	13	13	14	14	2	10	14	4	
NE	19	19	19	18	17	17	16	15	15	15	15	15	16	16	17	18	18	18	19	19	20	20	20	22	15	20	5		
E	24	24	23	23	22	21	20	19	19	19	19	20	21	22	23	24	24	25	25	25	25	25	25	22	18	25	7		
SE	24	23	23	22	21	20	19	18	18	18	18	18	19	20	21	22	23	23	24	24	24	24	24	22	18	24	6		
S	20	20	19	19	18	18	17	16	16	16	15	14	14	14	14	15	16	17	18	19	19	20	20	23	14	20	6		
SW	25	25	25	24	24	23	22	21	20	19	19	18	17	17	17	18	19	20	22	23	24	25	25	24	17	25	8		
W	27	27	26	26	25	24	24	23	22	21	20	19	19	18	18	18	18	19	20	22	23	25	26	26	1	18	27	9	
NW	21	21	21	20	20	19	19	18	17	16	16	15	15	14	14	14	15	16	17	18	19	20	21	1	14	21	7		
Group B Walls																													
N	13	14	14	13	12	11	11	10	9	9	9	9	9	9	9	10	11	12	13	14	14	15	15	15	34	8	15	7	
NE	19	18	17	16	15	14	13	12	12	13	14	15	16	17	18	19	19	20	20	21	21	21	20	20	12	21	9		
E	23	22	21	20	18	17	16	15	15	15	17	19	21	23	24	25	26	26	27	27	26	25	24	20	13	27	12		
SE	23	22	21	20	18	17	16	15	14	14	14	15	16	18	20	21	23	24	25	26	26	26	25	24	21	14	26	12	
S	21	20	19	18	17	15	14	13	12	11	11	11	12	14	15	17	19	20	21	22	22	22	21	23	11	22	11		
SW	27	26	25	24	22	21	19	18	16	15	14	14	15	16	18	20	22	23	25	27	28	28	28	24	13	28	15		
W	29	28	27	26	24	23	21	19	17	16	15	14	14	15	17	19	22	23	25	27	29	29	29	24	14	30	16		
NW	23	22	21	20	19	18	17	15	14	13	12	12	13	15	17	19	21	22	23	25	27	29	30	24	11	33	9		
Group C Walls																													
N	13	14	13	12	11	10	9	8	8	7	7	7	8	9	10	12	13	14	15	16	17	17	17	16	22	7	17	10	
NE	19	17	16	14	13	11	10	10	11	13	15	17	19	20	21	22	23	23	23	23	23	22	21	20	20	10	23	13	
E	22	21	19	17	15	14	12	12	14	16	19	22	25	27	29	30	30	30	29	28	27	26	24	18	12	30	18		
SE	22	21	19	17	15	14	12	12	13	16	19	22	24	26	28	29	29	29	29	28	27	26	24	19	12	29	17		
S	21	19	18	16	15	13	12	10	9	9	9	10	11	14	17	20	22	24	25	26	25	25	24	22	10	9	26	17	
SW	29	27	25	22	20	18	16	15	13	12	11	11	11	13	15	18	22	26	29	32	33	33	32	31	22	11	33	23	
W	31	29	27	25	22	20	18	16	14	13	12	12	13	16	20	24	29	32	35	35	35	33	32	32	22	12	35	23	
NW	25	23	21	20	18	16	14	13	11	10	10	10	10	11	12	13	15	18	22	25	27	27	27	26	22	10	27	17	
Group D Walls																													
N	13	13	12	10	9	7	6	6	6	6	6	7	8	10	12	13	15	17	18	19	19	19	18	16	21	6	19	13	
NE	17	15	13	11	10	8	7	6	6	6	6	7	8	10	12	13	15	17	18	19	19	19	18	16	21	7	25	18	
E	19	17	15	13	11	9	8	8	8	10	12	14	17	20	22	23	25	27	29	30	30	28	26	24	22	16	33	25	
SE	20	17	15	13	11	10	8	8	8	10	13	17	22	26	29	31	32	33	33	31	30	28	26	24	22	17	33	24	
S	19	17	15	13	11	9	8	7	6	6	7	9	12	16	20	24	27	29	29	29	27	26	24	22	19	6	29	23	
SW	28	25	21	19	16	14	12	10	9	8	8	8	10	12	16	21	27	32	36	38	38	37	34	31	21	9	38	30	
W	31	27	24	21	18	15	13	11	10	9	9	9	10	11	14	18	24	30	36	40	41	40	38	34	21	9	41	32	
NW	25	22	19	17	14	12	10	9	8	7	7	8	9	10	12	14	18	22	27	31	32	32	30	27	22	7	32	25	
Group E Walls																													
N	12	10	8	7	5	4	3	4	5	6	7	9	11	13	15	17	19	20	21	23	20	18	16	14	20	3	22	19	
NE	13	11	9	7	6	4	3	4	5	6	7	9	13	20	24	25	26	26	25	24	22	19	17	15	16	4	26	23	
E	14	12	10	8	6	5	4	5	6	7	9	13	20	24	25	26	26	25	24	22	19	17	15	16	4	26	23		
SE	15	12	10	8	7	5	4	5	6	7	9	13	20	24	25	26	26	25	24	22	19	17	15	16	4	26	23		
S	15	12	10	8	7	5	4	5	6	7	9	13	20	24	25	26	26	25	24	22	19	17	15	16	4	26	23		
SW	22	18	15	12	10	8	6	5	6	7	9	12	18	24	32	38	43	45	44	40	35	30	26	19	5	43	40		
W	25	21	17	14	11	9	7	6	6	7	9	11	14	20	27	36	43	49	49	45	40	34	29	20	6	49	43		
NW	20	17	14	11	9	7	6	5	5	5	6	8	10	13	16	20	26	32	37	38	36	32	28	24	20	5	38	33	
Group F Walls																													
N	8	6	5	3	2	1	2	4	6	7	9	11	14	17	19	21	22	23	24	23	20	16	13	11	19	1	23	20	
NE	9	7	5	3	2	1	2	4	6	7	9	11	14	17	19	21	22	23	24	23	19	16	13	11	11	1	30	29	
E	10	7	6	4	3	2	4	6	7	9	11	14	17	19	21	22	23	24	23	19	16	13	11	11	1	2	43	43	
SE	10	7	6	4	3	2	4	6	7	9	11	14	17	19	21	22	23	24	23	19	16	13	11	11	1	2	43	43	
S	10	8	6	4	3	2	1	1	3	7	13	20	27	34	38	39	38	35	31	26	22	18	15	12	10	1	39	38	
SW	15	11	9	6	5	3	2	2	4	5	8	11	17	26	35	44	50	53	52	45	37	28	23	18	18	2	53	48	
W	17	13	10	7	5	4	3	3	4	6	8	11	14	20	28	39	49	57	60	54	43	34	27	21	19	3	60	57	
NW	14	10	8	6	4	3	2	2	3	5	8	10	13	15	21	27	35	42	46	43	35	28	22	18	19	2	46	44	
Group G Walls																													
N	3	2	1	0	-1	2	7	8	9	12	15	18	21	23	24	24	25	26	22	15	11	9	7	5	18	-1	26	27	
NE	3	2	1	0	-1	9	27	36	39	35	30	26	27	27	27	26	25	22	18	14	11	9							

Rates of Heat Gain from Occupants of Conditioned Spaces^a

Degree of Activity	Typical Application	Total Heat Adults, Male			Total Heat Adjusted ^b			Sensible Heat			Latent Heat		
		Watts	Btu/h	kcal/hr	Watts	Btu/h	kcal/hr	Watts	Btu/h	kcal/hr	Watts	Btu/h	kcal/hr
Seated at rest	Theater, movie	115	400	100	100	330	90	60	210	55	40	140	30
Seated, very light work writing	Office, hotels, apts	140	480	120	120	400	105	65	220	55	55	190	50
Seated, eating	Restaurant ^c	150	520	130	170	580 ^d	145	75	255	60	95	325	80
Seated, light work, typing	Office, hotels, apts	185	640	160	150	510	130	75	255	60	75	255	65
Standing, light work or walking slowly	Retail Store, bank	235	800	200	185	640	160	90	315	80	90	325	80
Light bench work	Factory	255	880	220	230	780	195	100	345	90	130	435	110
Walking, 3 mph, light machine work	Factory	305	1040	260	305	1040	260	100	345	90	205	695	170
Bowling ^e	Bowling alley	350	1200	300	280	960	240	100	345	90	180	615	150
Moderate dancing	Dance hall	400	1360	340	375	1280	320	120	405	100	255	875	220
Heavy work, heavy machine work, lifting	Factory	470	1600	400	470	1600	400	165	565	140	300	1025	260
Heavy work, athletics	Gymnasium	585	2000	500	525	1800	450	185	635	160	340	1165	290

^aNote: Tabulated values are based on 78 F room dry-bulb temperature. For 80 F room dry-bulb, the total heat remains the same, but the sensible heat value should be decreased by approximately 8% and the latent heat values increased accordingly.

^bAdjusted total heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

^cAdjusted total heat value for eating in a restaurant, includes 60 Btu/h for food per individual (30 Btu sensible and 30 Btu latent).

^dFor bowling figure one person per alley actually bowling, and all others as sitting (400 Btu/h) or standing and walking slowly (750 Btu/h).

Also refer to Tables 4 and 5, Chapter 8.

All values rounded to nearest 5 watts or kcal/hr or to nearest 10 Btu/h.

Table VI.8¹

varies with the time of day and exposure of the building. Thus it is necessary to specify a design time as well as design conditions for the purpose of calculation. In some instances it will be easy to visually determine the time of maximum load; in other cases, it may be necessary to make two or more cooling load calculations in order to assure ourselves that we do know what the maximum load is.

6. The total cooling load on a space or structure can be broken down into:
 - a. Heat transmission through barriers
 - b. Heat gain from solar effects
 - c. Heat and moisture gains due to infiltration and ventilation
 - d. Heat load from occupants (sensible and latent)
 - e. Heat load from lights and equipment

E. Heat Gains from Ventilation and Infiltration

1. Infiltration occurs around windows and doors and is evaluated in the same manner as it was for the heating load (V.B.6.).

$$q_{inf} = 0.018 BL (t_o - t_i)$$

This procedure yields the heat gain associated with the infiltration of the warmer outside air. (See Example 32, Appendix 301-A.)

2. In addition to determining the heat gain associated with the infiltrated air, it is also necessary to evaluate the moisture gain. Recalling our earlier discussion of latent heating (II.C.) and combining that with our infiltration parameters, q (Btuh) is:

$$q_{lat} = 82.5 BL (W_o - W_i)$$

inf

where again:

B = air leakage, cfh per foot of crack

L = total crack length, feet

and W_o and W_i are the outside and inside design humidity ratios. This value may also be expressed as a moisture gain rather than a latent heat:

$$m_w = 0.075 BL (W_o - W_i)$$

where m_w is expressed in lb/hr. (See Example 32, Appendix 301-A.)

3. Any ventilation loads would be handled in the same way. Knowledge of the ventilation rate allows the calculation of the sensible and latent gains associated with the ventilation air. These values are then added to the infiltration loads.
4. The people occupying a conditioned space are a source of heat gain, both sensible and latent, to the space. Thus, these gains must also be included in any cooling load calculation. Heat gain from people varies with activity. These values have been determined experimentally and tabulated. (See Table VI.8.) Obviously this parameter is most important when dealing with buildings having a high population density. (See Example 33, Appendix 301-A.)

F. Heat Gain from Lights and Equipment

1. We must also consider any sources of heat or moisture gains within the spaces under consideration. In general, these sources may be classified as lights and equipment within the space.
2. Heat gain from lighting is sensible and is usually determined by counting the number of installed kilowatts of lighting. A kilowatt is equivalent to 3413 Btuh.
3. Heat gain (sensible and/or latent) from equipment can be evaluated from manufacturer's data, nameplate data or reference to charts for average gains from typical appliances.

VII. PRINCIPLES OF STEAM HEATING

A. Steam in Heating Systems

1. In a steam heating system, useful heat is rendered as a result of the condensation of the saturated steam supplied to the radiator or convector.
2. The heat of condensation (equal to the heat of vaporization, h_{fg}) is approximately 970 Btu/lb at atmospheric pressure.

3. The value of h_{fg} is only slightly affected by pressure, so pressure has little effect on the heat delivered by each unit of steam. But heat transfer is dependent on temperature difference.
 - a. Low pressure steam is low temperature steam.
 - b. Specific volume of low pressure steam is greater than that of high pressure steam.
 - c. Thus, low pressure systems require larger surface radiators and larger piping.
4. Heat output of a steam system is controlled by turning the steam on and off or by varying the temperature of the steam.
5. Steam heat transfer devices.
 - a. A radiator is a heating device placed such that it can radiate heat to part or all of the space to be heated.
 - b. A convector is a heating device which delivers heat to the air primarily by convection currents.
6. Steam flows through the system piping due to pressure differences.
7. Trapped air must be vented from radiators and piping to promote efficient heat transfer.

B. Types of Steam Systems

1. One-pipe, air-vent gravity return
 - a. Supply main starts at boiler and continues as a single pipe until it drops down at end of its run to form vertical drop leg and the wet return to the boiler.
 - b. Each radiator is connected to the supply main through an angle valve, and each radiator has an air vent.
 - c. Water and steam may surge back and forth in radiator, causing the system to be noisy.
2. Two-pipe, air-vent gravity return. (See Fig. VII.1.)
 - a. This system differs from the one-pipe system in that

separate circuits are provided for the supply and return portions of the system.

- b. Radiators may be connected directly to the main or, on upper floors, supplied by risers from the main.
 - c. Valves are required at radiator inlets and outlets, and each radiator must be vented.
3. Vapor system, simple gravity return.
- a. The primary difference between the simple vapor system and the two-pipe system is that air elimination in the vapor system is accomplished at a central point(s); thus, the radiators have no air-vent valves.
 - b. Each radiator is supplied with a trap which permits the passage of air and condensate, but prevents the passage of steam. This prohibits the steam from short-circuiting through the radiator.
 - c. These systems are usually quiet, but are typically designed for effective operation only at low steam pressures. Consequently, pipe sizes are relatively large.
4. Vapor system with return trap. (See Fig. VII.2.)
- a. Return traps (or alternating receivers) have a float-actuated mechanism which in one position closes a communicating port to the boiler above the water line and opens a corresponding port communicating with the dry return. In the other position, the port openings are reversed.
 - b. The return trap system permits operation of the vapor system at higher steam pressures and allows the use of smaller pipe sizes.
5. Vacuum return system, with vacuum pump.
- a. The vacuum system differs from the vapor system in that the vacuum system employs a vacuum-actuated pump on the return side to maintain a reduced pressure on the return side.
 - b. The pump removes the condensate and air from the return, and allows rapid circulation of the steam and the use of smaller pipe sizes.

Note: When an air eliminator or vent valve is used on a vapor system, the boiler pressure must not exceed the static head necessary for the return by gravity of the condensate.

Fig. VII.1 Typical Down Feed Two-Pipe Steam System

Fig. VII.2 Boiler Return Trap or Alternating Receiver

VIII. HOT WATER HEATING

A. Hot Water Systems

1. Hot water (hydronic) heating systems can be classified by the mode of circulation employed.
 - a. Gravity circulation (also called natural circulation or thermal circulation).
 - b. Forced circulation.
2. A further classification may be made based on piping arrangement.
 - a. In a one-pipe system, the water is circulated through the radiators in series. (See Fig. VIII.1.)
 - b. A two-pipe direct-return system employs separate supply and return circuits, with the water returning to the boiler by a direct route.
 - c. In a two-pipe reversed-return system, water travels in circuits of approximately equal length to the radiators, a feature which inherently balances the system. (See Fig. VIII.2.)

B. Advantages of Hot Water Heating

1. Advantages of the hot-water system are:
 - a. Absence of specialty appliances such as traps in steam systems.
 - b. Ease with which capacity may be varied by changing water temperature.
 - c. Use of smaller piping sizes.
 - d. Minimum of corrosion problems.
 - e. Possibility of using the same circulation system for summer cooling.
2. A disadvantage of the hot-water system is the possibility of freezing without reliable attendance or presence of a non-freeze solution.

C. Piping System Design

1. Provide means for drainage at low points and venting at high points.
2. Long straight runs require provision for expansion.
3. Water temperature drops of 25 to 30° are usually assumed for gravity systems, and 20° for forced circulation systems.
4. Water velocities should be in the range of 2 to 4 fps to avoid noise.
5. Design water supply temperatures are normally 140 to 200°F for gravity systems and 170 to 220°F for forced-circulation systems.
6. In forced-circulation systems, the design friction loss is set by the available head of the circulating pump.
7. Design friction values are usually in the range of 250 to 650 milinches per foot.
8. Large installations may require a separate circulator for each circuit.
9. Balancing valves should be inserted in each circuit.
10. Design procedure for forced-circulation system should include:
 - a. Determination of radiation for each space.
 - b. Sketch of building plans to show piping layout.
 - c. Computation of flow rate for each circuit.
 - d. Selection of circulation pump such that operating point is at peak of characteristic curve.
 - e. Determination of total equivalent length (TEL) of longest run.
 - f. Calculate the milinch friction loss per foot.
 - g. Size piping based on flow rates and friction loss.

Fig. VIII.1 One-Pipe System

Fig. VIII.2 Two-Pipe Reverse-Return System

h. Selection of radiator sizes.

D. High-Temperature, High-Pressure Water

1. High-temperature water may be used as a means of heating a space or distributing energy.
2. The boiler must operate at a pressure sufficiently high to keep the water from vaporizing (e.g., if water temperature is 500°F, the pressure must be at least 680 psia).
3. Heated water is circulated to the point of utilization by a pump, and returns to the pump at appreciably lower temperatures (150 to 250°F).
4. Cooled return water may be delivered to the boiler or mixed with supply water for temperature control.
5. Such a system can be used as the energy source for the generation of low-pressure low-temperature steam.

IX. HEAT TRANSFER ELEMENTS

A. Radiators and Convectors

1. The HVAC industry has made wide use of the terms "radiator" and "convector." Use of these two terms is sometimes inappropriate since in most cases the heat transfer takes place by both radiation and convection.
2. A convector is typically any device which gives up the greatest portion of its heat to air currents passing by it. In this case, the heating elements do not "see" the space being heated.
 - a. Convector output is dependent not only on the heater surface area but also on the stack height which influences the velocity of the convection air.
 - b. Convectors are usually rated in terms of a 65°F inlet air temperature.
 - c. Like radiators, convectors are normally placed near and below the window.
3. Radiant heat transfer is the transfer of energy between two bodies through space without any intermediary action of the

medium separating them. Any device employing this method as its primary mode of heat transfer is termed a radiator.

- a. Radiators are usually rated in Btuh per square feet of area (or Btuh for a given section) and at test conditions of 215°F in the radiator and with 70°F air.
- b. Radiators are most satisfactorily located along an exterior wall below any windows. Thus rising currents of warm air can counteract the infiltrated cooler air.

B. Baseboard Radiation

1. Baseboard heating provides a continuous band of heat around the perimeter of a room which acts to prevent cool down-drafts from exposed walls and windows.
2. The heat transfer element, normally covered by a pressed steel enclosure, consists of pipe or tubing to which metal fins are attached.
3. Baseboard units are rated in Btuh per lineal foot.

C. Unit Heaters and Coolers

1. Employing a fan to force air over a heater coil surface increases the output approximately threefold over the corresponding output of a thermal-circulation convector of equal area.
2. Such a unit can be used for heating or cooling and can be used to provide individual comfort control (hotels, schools, apartment buildings) by coupling the unit with a thermostat.
3. Unit heaters/coolers may also be dampered to allow a mixture of fresh and recirculated air.
4. Unit heaters in varying capacities (40,000 to 600,000 Btuh) are often used in factories and warehouses, with the units suspended from the ceiling or mounted at a high wall level. Such devices are used only for heating recirculated air.

X. FUELS AND COMBUSTION

A. Fundamental Principles of Combustion

1. Proper combustion is dependent upon:

- a. Proper proportioning of air to fuel.
 - b. Exposure of sufficient fuel surface to permit mixing with air.
 - c. Adequate mixture of the fuel particles with the air.
 - d. Sufficiently high temperature to assure continuous ignition.
 - e. Design of the combustion chamber such that sufficient time is allowed for the complete combustion of the fuel.
2. The amount of air required for complete combustion is theoretically determined from the chemical equations describing the combustion process. This amount of air is hardly ever enough for proper, continuous burning. Thus, a certain amount of "excess air" is also supplied to the process.
 3. In simplified notation, the chemical equation for combustion says:

$$(\text{air used}) + (\text{fuel burned}) = (\text{dry flue gas}) + (\text{water vapor})$$
 4. The quality of combustion may be determined by making an analysis of the flue gases (such as an Orsat Analysis).
 5. Heating values of fuels may be classified by the terms "higher" and "lower" heating values.
 - a. The higher heating value (HHV) represents the quantity of thermal energy released from the fuel during combustion if the resulting water vapor is condensed and the latent heat is absorbed from the product of combustion.
 - b. The lower heating value (LHV) is the amount of thermal energy released if the water vapor remains in an uncondensed gaseous form.

B. Fuels: The basic types of fuels and their approximate heating values are:

1. Solid Fuels (coal, coke, lignite)

	HHV	LHV
	(Btu/lb)	
Anthracite	13,100	12,800
Bituminous	13,400	12,900
Lignite	7,300	6,660

2. Liquid Fuels

Fuel Oil Grade	HHV (Btu/gal)
1	136,000
2	138,500
4	141,000
5	148,500
6	152,000

3. Gaseous Fuels

Gas	HHV (Btu/ft ³)
Methane (CH ₄)	990
Hydrogen (H ₂)	315
Propane (C ₃ H ₈)	2,450
Natural Gas	800-1,125

XI. HEATING AND COOLING AIR SYSTEMS

There are a multitude of possible configurations in the design and arrangement of HVAC air systems. A few of the more common ones will be discussed here.

A. Single Zone

1. The simplest arrangement of an air system is the single zone method, in which the entire structure is served by the heating/cooling unit with only a single control module (thermostat).
2. In such a system, placement of the thermostat is critical to the development of comfort conditions throughout the entire zone. The suggested location is an interior wall, approximately five feet from the floor, away from direct radiation and/or cold drafts.
3. The single zone concept is generally applied to smaller structures in which the interior is relatively open (such as a residence).

B. Multi-Zone

1. A multi-zone system is one specifically designed to solve the

problems of variable internal heat loads by separating the loads into zones.

2. Each zone would normally correspond to a space or group of similar spaces within a given structure.
3. Each zone would have its own control mechanism.
4. The simplest multi-zone structure might be a building with large east and west glass exposures. The heat load on any given space would be influenced by solar effects as a function of time of day. Thus the system may be designed for two zones, consisting of the eastern and western halves of the building. Each zone is responsive to its own load; hence, in the morning, the east zone may require cooling while the west zone requires heating.
5. All of the following systems which will be described are applicable to multi-zone design.

C. Dual-Duct

1. A dual-duct system conditions all the air at a central location and distributes it to the conditioned spaces through two parallel ducts.
2. One duct carries cold air and the other warm air, providing the capability for heating or cooling at all times.
3. Air from these ducts enters a mixing and volume-control box which delivers the air into the space. The mixing box is controlled by a thermostat located in the space.
4. The dual-duct system has been found to be quite effective in structures having zones of varying occupancy, such as office buildings, hospitals, hotels, schools, etc.
5. Because both heating and cooling are available, the system will work equally well in winter or summer.
6. It is also possible to make best use of outdoor air for between-season cooling when outdoor air temperature is suitable. This is possible through controlled dampening of outside air intakes.
7. Air flow in the system is based on the sensible heat load and sufficient capacity must be supplied in each duct to serve both the maximum summer cooling load and the maximum winter heating load.

D. Terminal Reheat

1. A terminal reheat system provides for the cooling of the supply air at a central location and subsequent reheating at the outlet terminal in the space.
2. Terminal reheat is particularly applicable where close control of light load conditions is important.
3. Since the cooling coil handles the entire quantity of supply air, this effectively means that the system is operating at maximum load. Thus operating costs may be slightly higher than with other systems.
4. Terminal reheat does, however, inherently provide excellent control of humidity. This may, in many cases, justify the extra expense of operation.

E. Variable Air Volume

1. The maintenance of design conditions in a given space with a fixed condition of supply air requires a volume of air capable of picking up the maximum load in the space.
2. As the load on the space is reduced, the room will become overcooled unless either the quantity or temperature of the supply air is changed.
3. Altering the supply air temperature will affect the conditions in all spaces of the building. Thus for fixed supply conditions, it is necessary to vary the volume of the air supplied to the space by means of a volume regulator in the terminal unit in each room.
4. A system operating in this fashion is termed a variable air volume (VAV) system.
5. Typically the terminal units are designed such that the flow rate of air will not fall below some minimum value, thus satisfying any ventilation requirements.

F. Induction

1. An induction system involves the use of units within the space which are provided with fans for circulating a mixture of inside and outside air over coils contained in the unit.

2. Normally induction units are supplied with a conditioned medium (chilled or warm water) as opposed to conditioned air.
3. Conditioning of the medium is generally accomplished at a central location and piped to the various induction units.
4. These systems are particularly applicable to multiple perimeter spaces subject to wide fluctuations in net sensible heat (or loss) where close humidity control is not required.
5. Induction systems have been successfully utilized in office buildings, schools, hotels, research facilities, etc.
6. There are many versions of induction system design. Some general classifications would be:
 - a. Air-water induction, which employs the induction unit for the conditioning of the space air and a central air handling unit.
 - (1) Two-pipe system with simply a supply and return line to each unit.
 - (2) Three-pipe system in which there is a hot and cold supply line to each unit and a single return.
 - (3) Four-pipe system where there are both supply and return lines for the hot and cold circuits.
 - b. All-air induction, where the induction unit is supplied with hot and cold conditioned air from a central location.

XII. PRINCIPLES OF DUCT DESIGN AND AIR DISTRIBUTION SYSTEMS

A. Principles of Fluid Flow

1. The normal flow of a fluid in a duct causes a pressure drop which is dependent on fluid velocity, size of the duct, surface roughness, viscosity, density, temperature, pressure and heat transfer.
2. A thin film of fluid will cling to the side of the duct and will not move appreciably. In streamline flow, each fluid particle moves parallel to the motion of the other particles. Maximum velocity occurs at the center of the duct.

3. Pressure drop in a straight duct is caused by friction and is calculated from the equation:

$$H_f = f\left(\frac{L}{D}\right)H_v$$

where:

H_f = head loss due to friction, inches of water

f = friction coefficient, dimensionless

$\frac{L}{D}$ = length to diameter ratio of conduit, dimensionless

H_v = velocity pressure of mean velocity, inches of water

4. The friction loss data is more conveniently presented in graphical fashion for round, air-carrying, galvanized ducts. (See Fig. XII.1,2.) Displayed on the graph are carrying capacity (cfm), velocity (fpm), duct diameter (inches) and pressure loss (inches of water per hundred feet). (See Example 34, Appendix 301-A.)
5. It should be noted that this graph is for standard air (0.075 lbs/ft³) flowing through average, clean, round, galvanized metal ducts with 40 joints per 100 feet.
6. Correction factors are used to account for changes in density and viscosity as a function of air temperature and for varying pipe roughnesses as a function of velocity. (See Fig. XII.3,4.) These factors are determined from the charts and applied in a multiplicative fashion:

$$h_o = Kh_c$$

where:

h_o = friction loss under actual operating conditions, inches of water

K = friction loss correction factor, dimensionless

h_c = friction loss at actual flow rate for non-standard conditions, inches of water

(See Example 35, Appendix 301-A.)

Fig. XII.1¹ Friction of Air in Straight
Ducts for Volumes of 10 to 2000 cfm

Fig. XII.3¹ Correction Factors for Density

Fig. XII.4¹ Correction Factors for Pipe Roughness

7. In order to use this frictional data for square or rectangular ducts, it is necessary to determine the circular equivalent of the rectangular duct. This data is presented in tabular fashion and equates the rectangular and round duct sizes which have the same carrying capacity and frictional loss. (See Table XII.1 A.) Note that the velocity shown on the friction chart applies only to round ducts.
8. Changes in the direction or magnitude of the velocity of the flowing air can cause turbulence which will result in a greater pressure drop than would occur in a similar length of straight duct. These losses are termed "dynamic losses" and are classified as to:
 - a. Those caused by changes in direction of the duct.
 - b. Those caused by changes in cross-sectional area of the duct.
9. Such losses associated with elbows are sometimes expressed in terms of an equivalent length of straight duct which would result in the same pressure loss caused by the elbow. (See Fig. XII.5,6.) (See Example 36, Appendix 301-A.)
10. It is also common to express dynamic loss as a fraction of the velocity head:

$$H_d = C \left(\frac{V}{4005} \right)^2$$

where:

H_d = dynamic loss of total pressure, inches of water

V = mean air velocity, ft/min

C = experimentally determined loss coefficient,
dimensionless

(See Example 37, Appendix 301-A.)

11. Some general tables exist showing the losses of various typical fittings, but more often this information is provided by the manufacturer of the ductwork and associated fittings. (See Fig. XII.7.)

Circular Equivalents of Rectangular Ducts for Equal Friction and Capacity

Dimensions in Inches

Side Rectangular Duct	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
3.0	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1	5.2	5.5	5.7	6.0	6.2	6.4	6.6	6.8	7.0
3.5	4.1	4.3	4.6	4.8	5.0	5.2	5.3	5.5	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.4	7.6
4.0	4.4	4.6	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4	6.8	7.1	7.3	7.6	7.8	8.1	8.3
4.5	4.6	4.9	5.2	5.4	5.6	5.9	6.1	6.3	6.5	6.9	7.2	7.5	7.8	8.1	8.4	8.6	8.9
5.0	4.9	5.2	5.5	5.7	6.0	6.2	6.4	6.7	6.9	7.3	7.6	8.0	8.3	8.6	8.9	9.1	9.4
5.5	5.1	5.4	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.6	8.0	8.4	8.7	9.0	9.4	9.6	9.8

Side Rectangular Duct	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30	Side Rectangular Duct	
6	6.6																				6	
7	7.1	7.7																			7	
8	7.5	8.2	8.8																		8	
9	8.0	8.6	9.3	9.9																	9	
10	8.4	9.1	9.8	10.4	10.9																10	
11	8.8	9.5	10.2	10.8	11.4	12.0															11	
12	9.1	9.9	10.7	11.3	11.9	12.5	13.1														12	
13	9.5	10.3	11.1	11.8	12.4	13.0	13.6	14.2													13	
14	9.8	10.7	11.5	12.2	12.9	13.5	14.2	14.7	15.3												14	
15	10.1	11.0	11.8	12.6	13.3	14.0	14.6	15.3	15.8	16.4											15	
16	10.4	11.4	12.2	13.0	13.7	14.4	15.1	15.7	16.3	16.9	17.5										16	
17	10.7	11.7	12.5	13.4	14.1	14.9	15.5	16.1	16.8	17.4	18.0	18.6									17	
18	11.0	11.9	12.9	13.7	14.5	15.3	16.0	16.6	17.3	17.9	18.5	19.1	19.7								18	
19	11.2	12.2	13.2	14.1	14.9	15.6	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8							19	
20	11.5	12.5	13.5	14.4	15.2	15.9	16.8	17.5	18.2	18.8	19.5	20.1	20.7	21.3	21.9						20	
22	12.0	13.1	14.1	15.0	15.9	16.7	17.6	18.3	19.1	19.7	20.4	21.0	21.7	22.3	22.9	24.1					22	
24	12.4	13.6	14.6	15.6	16.6	17.5	18.3	19.1	19.8	20.6	21.3	21.9	22.6	23.2	23.9	25.1	26.2				24	
26	12.8	14.1	15.2	16.2	17.2	18.1	19.0	19.8	20.6	21.4	22.1	22.8	23.5	24.1	24.8	26.1	27.2	28.4			26	
28	13.2	14.5	15.6	16.7	17.7	18.7	19.6	20.5	21.3	22.1	22.9	23.6	24.4	25.0	25.7	27.1	28.2	29.5	30.6		28	
30	13.6	14.9	16.1	17.2	18.3	19.3	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.7	28.0	29.3	30.5	31.6	32.8	30	
32	14.0	15.3	16.5	17.7	18.8	19.8	20.8	21.8	22.7	23.6	24.4	25.2	26.0	26.7	27.5	28.9	30.1	31.4	32.6	33.8	32	
34	14.4	15.7	17.0	18.2	19.3	20.4	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	31.0	32.3	33.6	34.8	34	
36	14.7	16.1	17.4	18.6	19.8	20.9	21.9	23.0	23.9	24.8	25.8	26.6	27.4	28.3	29.0	30.5	32.0	33.0	34.6	35.8	36	
38	15.0	16.4	17.8	19.0	20.3	21.4	22.5	23.5	24.5	25.4	26.4	27.3	28.1	29.0	29.8	31.4	32.8	34.2	35.5	36.7	38	
40	15.3	16.8	18.2	19.4	20.7	21.9	23.0	24.0	25.1	26.0	27.0	27.9	28.8	29.7	30.5	32.1	33.6	35.1	36.4	37.6	40	
42	15.6	17.1	18.5	19.8	21.1	22.3	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.4	31.2	32.8	34.4	35.9	37.3	38.6	42	
44	15.9	17.5	18.9	20.2	21.5	22.7	23.9	25.0	26.1	27.2	28.2	29.1	30.0	31.0	31.9	33.5	35.2	36.7	38.1	39.5	44	
46	16.2	17.8	19.2	20.6	21.9	23.2	24.3	25.5	26.7	27.7	28.7	29.7	30.6	31.6	32.5	34.2	35.9	37.4	38.9	40.3	46	
48	16.5	18.1	19.6	20.9	22.3	23.6	24.8	26.0	27.2	28.2	29.2	30.2	31.2	32.2	33.1	34.9	36.6	38.2	39.7	41.2	48	
50	16.8	18.4	19.9	21.3	22.7	24.0	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8	33.7	35.5	37.3	38.9	40.4	42.0	50	
52	17.0	18.7	20.2	21.6	23.1	24.4	25.6	26.8	28.1	29.2	30.3	31.4	32.4	33.4	34.3	36.2	38.0	39.6	41.2	42.8	52	
54	17.3	19.0	20.5	22.0	23.4	24.8	26.1	27.3	28.5	29.7	30.8	31.9	32.9	33.9	34.9	36.8	38.7	40.3	42.0	43.6	54	
56	17.6	19.3	20.9	22.4	23.8	25.2	26.5	27.7	28.9	30.1	31.2	32.4	33.4	34.5	35.5	37.4	39.3	41.0	42.7	44.3	56	
58	17.8	19.5	21.1	22.7	24.2	25.5	26.9	28.2	29.3	30.5	31.7	32.9	33.9	35.0	36.0	38.0	39.8	41.7	43.4	45.0	58	
60	18.1	19.8	21.4	23.0	24.5	25.8	27.3	28.7	29.8	31.0	32.2	33.4	34.5	35.5	36.5	38.6	40.4	42.3	44.0	45.8	60	
62	18.3	20.1	21.7	23.3	24.8	26.2	27.6	29.0	30.2	31.4	32.6	33.8	35.0	36.0	37.1	39.2	41.0	42.9	44.7	46.5	62	
64	18.6	20.3	22.0	23.6	25.2	26.5	27.9	29.3	30.6	31.8	33.1	34.2	35.5	36.5	37.6	39.7	41.6	43.5	45.4	47.2	64	
66	18.8	20.6	22.3	23.9	25.5	26.9	28.3	29.7	31.0	32.2	33.5	34.7	35.9	37.0	38.1	40.2	42.2	44.1	46.0	47.8	66	
68	19.0	20.8	22.5	24.2	25.8	27.3	28.7	30.1	31.4	32.6	33.9	35.1	36.3	37.5	38.6	40.7	42.8	44.7	46.6	48.4	68	
70	19.2	21.0	22.8	24.5	26.1	27.6	29.1	30.4	31.8	33.1	34.3	35.6	36.8	37.9	39.1	41.3	43.3	45.3	47.2	49.0	70	
72																39.6	41.8	43.8	45.9	47.8	49.7	72
74																40.0	42.3	44.4	46.4	48.4	50.3	74
76																40.5	42.8	44.9	47.0	49.0	50.8	76
78																40.9	43.3	45.5	47.5	49.5	51.5	78
80																41.3	43.8	46.0	48.0	50.1	52.0	80
82																41.8	44.2	46.4	48.6	50.6	52.6	82
84																42.2	44.6	46.9	49.2	51.1	53.2	84
86																42.6	45.0	47.4	49.6	51.6	53.7	86
88																43.0	45.4	47.9	50.1	52.2	54.3	88
90																43.4	45.9	48.3	50.6	52.8	54.8	90
92																43.8	46.3	48.7	51.1	53.4	55.4	92
96																44.6	47.2	49.5	52.0	54.4	56.3	96

Equation for Circular Equivalent of a Rectangular Duct:¹⁰

$$D_e = 1.30 [(ab)^{0.625} / (a + b)^{0.250}] = 1.30 \sqrt{(ab)^2 / (a + b)^2}$$

where

a = length of one side of rectangular duct, inches.

b = length of adjacent side of rectangular duct, inches.

D_e = circular equivalent of rectangular duct for equal friction and capacity, inches.

Table XII.1A¹ Circular Equivalents of Rectangular Ducts for Equal Friction and Capacity

Circular Equivalents of Rectangular Ducts for Equal Friction and Capacity (Concluded)

Side Rec- tan- gular Duct	Dimensions in Inches																		Side Rec- tan- gular Duct
	32	34	36	38	40	42	44	46	48	50	52	56	60	64	68	72	76	80	
32	35.0																		32
34	36.0	37.2																	34
36	37.0	38.2	39.4																36
38	38.0	39.2	40.4	41.6															38
40	39.0	40.2	41.4	42.6	43.8														40
42	39.9	41.1	42.4	43.6	44.8	45.9													42
44	40.8	42.0	43.4	44.6	45.8	46.9	48.1												44
46	41.7	43.0	44.3	45.6	46.8	47.9	49.1	50.3											46
48	42.6	43.9	45.2	46.5	47.8	48.9	50.2	51.3	52.6										48
50	43.5	44.8	46.1	47.4	48.8	49.8	51.2	52.3	53.6	54.7									50
52	44.3	45.7	47.1	48.3	49.7	50.8	52.2	53.3	54.6	55.8	56.9								52
54	45.0	46.5	48.0	49.2	50.6	51.8	53.2	54.3	55.6	56.8	57.9								54
56	45.8	47.3	48.8	50.1	51.5	52.7	54.1	55.3	56.5	57.8	58.9	61.3							56
58	46.6	48.1	49.6	51.0	52.4	53.7	55.0	56.2	57.5	58.8	60.0	62.3							58
60	47.3	48.9	50.4	51.8	53.3	54.6	55.9	57.1	58.5	59.8	61.0	63.3	65.7						60
62	48.0	49.7	51.2	52.6	54.2	55.5	56.8	58.0	59.4	60.7	62.0	64.3	66.7						62
64	48.7	50.4	52.0	53.4	55.0	56.4	57.7	59.0	60.3	61.6	62.9	65.3	67.7	70.0					64
66	49.5	51.1	52.8	54.2	55.8	57.2	58.6	59.9	61.2	62.5	63.9	66.3	68.7	71.1					66
68	50.2	51.8	53.5	55.0	56.6	58.0	59.5	60.8	62.1	63.4	64.8	67.3	69.7	72.1	74.4				68
70	50.9	52.5	54.2	55.8	57.3	58.8	60.3	61.7	63.0	64.3	65.7	68.3	70.7	73.1	75.4				70
72	51.5	53.2	54.9	56.5	58.0	59.6	61.1	62.6	63.9	65.2	66.6	69.2	71.7	74.1	76.4	78.8			72
74	52.1	53.9	55.6	57.2	58.8	60.4	61.9	63.3	64.8	66.1	67.5	70.1	72.7	75.1	77.4	79.9			74
76	52.7	54.6	56.3	57.9	59.5	61.2	62.7	64.1	65.6	67.0	68.4	71.0	73.6	76.1	78.4	80.9	83.2		76
78	53.3	55.2	57.0	58.6	60.3	62.0	63.4	64.9	66.4	67.9	69.3	71.8	74.3	77.1	79.4	81.8	84.2		78
80	53.9	55.8	57.6	59.3	61.0	62.7	64.1	65.7	67.2	68.7	70.1	72.7	75.4	78.1	80.4	82.8	85.2	87.5	80
82	54.5	56.4	58.2	60.0	61.7	63.4	64.9	66.5	68.0	69.5	71.0	73.6	76.3	79.0	81.4	83.8	86.2	88.6	82
84	55.1	57.0	58.9	60.7	62.4	64.1	65.7	67.3	68.8	70.3	71.8	74.5	77.2	79.9	82.4	84.8	87.2	89.6	84
86	55.7	57.6	59.5	61.3	63.0	64.8	66.4	68.0	69.5	71.1	72.6	75.4	78.1	80.8	83.3	85.8	88.2	90.6	86
88	56.3	58.2	60.1	62.0	63.7	65.4	67.0	68.7	70.3	71.8	73.4	76.3	79.0	81.6	84.2	86.8	89.2	91.6	88
90	56.9	58.8	60.7	62.6	64.4	66.0	67.8	69.4	71.1	72.6	74.2	77.1	79.9	82.5	85.1	87.8	90.2	92.6	90
92	57.4	59.4	61.3	63.2	65.0	66.8	68.5	70.1	71.8	73.3	74.9	77.9	80.8	83.4	86.0	88.7	91.2	93.6	92
94	57.9	60.0	61.9	63.8	65.6	67.5	69.2	70.8	72.5	74.1	75.6	78.7	81.7	84.3	86.9	89.6	92.1	94.6	94
96	58.4	60.5	62.4	64.4	66.2	68.2	69.8	71.5	73.2	74.3	76.3	79.4	82.6	85.2	87.8	90.5	93.0	95.6	96

Table XII.1A¹ Circular Equivalents of Rectangular Ducts for Equal Friction and Capacity

Fig. XII.5¹ Loss in 90° Elbows of Rectangular Cross Section

Fig. XII.6¹ Loss in 90° Elbows of Round Cross Section

TYPE	ILLUSTRATION	CONDI- TIONS	LOSS COEFFICIENT		TYPE	ILLUSTRATION	CONDI- TIONS	LOSS COEFFICIENT			
ABRUPT EXPANSION		A_1/A_2	C_1	C_2	ABRUPT CONTRACTION SQUARE EDGE		A_2/A_1	C_2			
		0.1	0.81	81			0.0	0.34 ²			
		0.2	0.64	16			0.2	0.32			
		0.3	0.49	9			0.4	0.25			
		0.4	0.36	2.25			0.6	0.18			
		0.5	0.25	1.00			0.8	0.08			
		0.6	0.16	0.45							
		0.7	0.09	0.18							
		0.8	0.04	0.06							
0.9	0.01	0.01									
GRADUAL EXPANSION		θ	C_2		GRADUAL CONTRACTION		θ	0.02 ³			
		5°	0.17 ³				30°	0.04			
		7°	0.22				45°	0.04			
		10°	0.28		EQUAL AREA TRANSFOR- MATION		60°	0.07			
		20°	0.45				$A_1 = A_2$	C			
30°	0.59				$\theta \leq 14^\circ$	0.15 ³					
40°	0.73										
ABRUPT EXIT		$A_2 = \infty$	$A_1/A_2 = 0.0$	1.00	FLANGED ENTRANCE		$A = \infty$	C			
								0.34 ²			
SQUARE EDGE ORIFICE EXIT			A_1/A_2	C_2	DUCT ENTRANCE		$A = \infty$	C			
		0.0	2.50 ²					0.65 ³			
		0.2	2.44		FORMED ENTRANCE		$A = \infty$	C			
		0.4	2.28					0.05 ³			
		0.6	1.96								
BAR ACROSS DUCT			E/D	C	SQUARE EDGE ORIFICE ENTRANCE		A_1/A_2	C_2			
		0.10	0.7 ³				0.0	2.50 ²			
		0.25	1.4				0.2	1.90			
		0.50	4.0				0.4	1.39			
							0.6	0.98			
PIPE ACROSS DUCT			E/D	C	SQUARE EDGE ORIFICE IN DUCT		A_2/A_1	C_2			
		0.10	0.20 ³				0.0	2.50 ²			
		0.25	0.55				0.2	1.06			
STREAM- LINED STRUT ACROSS DUCT			E/D	C			0.4	1.21			
		0.10	0.07 ³				0.6	0.64			
		0.25	0.23				0.8	0.20			
0.50	0.90						1.0	0.0			
INTERNAL TIE ROD								E			
								1/8 IN. ¹¹			
								1/4 IN.			
								5/16 IN.			
									C		
									0.0104		
								0.0255			
								0.040			

Note 1: Subscript on C indicates cross-section at which velocity is calculated.
(See, for example, Equation 17 in text.)

Note 2: Superscript numbers refer to references at end of chapter.

Note 3: For internal tie rod,

$$H = C'(L/A)(V/4005)^5$$

where

L = length of tie rod.

A = cross-sectional area of duct.

Table XII.7 Loss Coefficients for Area Changes

12. Total pressure is defined as the sum of the static pressure (P) and the velocity pressure (H_v):

$$H = P + H_v$$

These quantities are normally expressed in inches of water.

13. Velocity pressure for standard air is given by:

$$H_v = \left(\frac{V}{4005} \right)^2$$

where V is defined by:

$$V = \frac{Q}{A}$$

where:

V = mean flow velocity, ft/min

Q = air flow rate, ft³/min

A = duct cross-sectional area, ft²

If the air is not at standard density, velocity pressure is given by:

$$H_v = 0.8303\rho \left(\frac{V}{1000} \right)^2$$

where:

ρ = air density, lb/ft³

B. Duct Design Procedure

1. Several procedures have been developed for the design of air distribution systems. The primary goal of any such procedure is to systematically select the sizes of ductwork required for the efficient delivery of air from its point of conditioning to its point of use.
2. For the sake of simplicity, we will discuss here only one specific method of duct design. The principle of the Equal Friction Method is to make the pressure loss per foot of length the same for the entire system.

- a. Select a velocity in the main duct near the fan to provide a satisfactory noise level for the particular application.
- b. Since the flow rate is known, we can now establish the friction loss per 100 feet of duct from the friction chart.
- c. This same friction loss will be used throughout the design of the system.
- d. Thus, proceeding along the main duct section just past the first branch take-off, the volume of air is reduced by the amount funneled into the branch. Moving vertically downward on the friction chart to the new flow rate will yield a velocity and a diameter for that section.
- e. Note that velocity is automatically reduced in the direction of flow, thereby reducing noise problems.
- f. After sizing the entire system, the pressure loss of the longest run should be calculated. This value, together with the system flow rate, will permit selection of a fan.
- g. To keep the sound level within acceptable limits, the difference in static pressure between outlets should not exceed 0.05 inches of water.
- h. The Modified Equal Friction Method includes redesign of the system at a different frictional value to bring the outlet pressure within the specified range.

A general duct design procedure should include:

- a. Study of plan of the building and arrangement of the positions of supply outlets.
- b. A sketch of the most convenient duct system, taking into account building construction.
- c. Calculation of sizes of all mains and branches.
- d. Determination of total pressure requirements of the system.
- e. Provisions for balancing of the system.

C. Air Delivery and Distribution

1. High-Velocity, High-Pressure Systems

- a. To reduce the demand on available space, it is possible to employ high-velocity (or conduit) systems.
- b. Air is distributed at high velocity (3000-6000 fpm), usually in round ducts designed to reduce friction and noise generation.
- c. Fans convey the conditioned air at maximum static pressure (4-1/2 - 5 inches of water) to special diffuser outlets in the space.
- d. No provision is made for returning air to the conditioner, which means that the quantity of air supplied is not much in excess of ventilation requirements.

2. Low-Velocity, Low-Pressure Systems

The design of low-velocity, low-pressure air distribution systems is handled by the methods described in Sections XII.A, XII.B.

XIII. HEAT PUMP SYSTEMS

- A. Refrigeration equipment used to deliver air to a space is ordinarily termed an "air conditioning" system. Such a cycle can be referred to as a heat pump since it does abstract heat from the space and reject it, along with the heat of compression, to a heat sink outside the space.
- B. There is no fundamental difference then, between the vapor-compression refrigeration cycle and the heat pump cycle.
- C. When refrigeration equipment is used to supply heat to a space during the winter heating cycle as well as absorb heat from the space during the cooling cycle, it is termed a "heat pump".
- D. Ideal Refrigeration and Heat Pump
 1. The Carnot cycle is a cycle whose efficiency represents the best possible performance between a source and sink temperature.
 2. Such performance is physically unattainable, but represents

the upper limit of theoretical performance against which actual cycles can be measured.

3. The Carnot cycle is illustrated and explained in Fig. XIII.1.
4. The efficiency or effectiveness of performance of the cycle is called its "coefficient of performance" (COP) and is defined:

$$\text{COP} = \frac{\text{Desired Effect}}{\text{Net Work}}$$

5. The COP may be rewritten in terms of temperatures for cooling (CCOP):

$$\text{CCOP} = \frac{T_e}{T_c - T_e}$$

where T_e and T_c refer to the evaporating and condensing temperatures. And for heating, this relationship becomes:

$$\text{HCOP} = \frac{T_e}{T_c - T_e}$$

6. Comparison of heating and cooling COP values at the same source and sink temperatures reveals that HCOP is higher than CCOP by a factor of one. This is because the net work in the heat pump cycle is part of the heat rejected and, thus, part of the "desired effect". This relationship can be shown to be:

$$\text{HCOP} = \text{CCOP} + 1$$

E. The Rankine Cycle

1. A closer approximation to the actual heat pump process is the Rankine cycle shown in Fig. XIII.2.
2. The Carnot cycle net work (1-2-3a-4) is seen to be less than that of the Rankine cycle (1-2-3-4) for the same refrigeration effect.
3. Alternatively, considering path 1-2-3-4a, the Carnot refrigeration effect is greater than that of the Rankine cycle.

<u>Process</u>	<u>Description</u>
1-2	Reversible adiabatic (isentropic) compression
2-3	Isothermal condensation
3-4	Reversible adiabatic (isentropic) expansion
4-1	Isothermal absorption of heat
<u>Area</u>	
1-4-5-6	Heat absorbed by system (refrigeration effect)
2-3-5-6	Heat rejected by system
1-2-3-4	Compression work

Figure XIII.1 The Carnot Cycle

<u>Process</u>	<u>Description</u>
1-2	Reversible adiabatic (isentropic compression)
2-3	Isothermal condensation
3-4	Irreversible expansion at constant enthalpy through throttling valve
4-1	Isothermal evaporation

Figure XIII.2 The Rankine Cycle

4. In either case, the Rankine cycle has a lower COP. This is reasonable, since the Carnot cycle represents the upper limit of theoretical performance.

F. P-H Diagrams and Refrigeration Cycles

1. The primary difference between the Carnot and Rankine cycles is the expansion at constant enthalpy through the throttling valve in the Rankine cycle. Thus it is convenient to use a Molier chart in the analysis of refrigeration cycles. A skeleton P-H diagram is shown in Fig. XIII.3.
2. A simple ideal Rankine cycle is schematically shown in Fig. XIII.4, and the refrigeration components are illustrated in Fig. XIII.5.
3. Beginning at Point 1, saturated vapor enters the compressor suction inlet and is compressed to Point 2. The increase in enthalpy of the gas is the work of compression. From 2-3, heat is rejected from the cycle, first by desuperheating of the vapor and then by condensing to a saturated liquid at Point 3. The refrigerant is then expanded at constant enthalpy through a throttling valve. Note that Point 4 is a mixture of liquid and vapor refrigerant. This mixture enters the evaporator, absorbs heat and boils, leaving the evaporator as a saturated vapor. It then enters the compressor inlet and the process is repeated.

Fig. XIII.3 Skeleton P-H Diagram

Fig. XIII.4 Ideal Refrigeration Cycle

Fig. XIII.5 Refrigeration System

References

- 1 ASHRAE Handbook of Fundamentals, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, New York, 1977.
- 2 Jennings, Burgess H.; Environmental Engineering - Analysis and Practice; International Textbook Co., Scranton, Pa., 1970.
- 3 Threlkeld, James L.; Thermal Environmental Engineering; Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962.
- 4 Trane Air Conditioning Manual, published by The Trane Co., LaCrosse, Wisconsin, 1965.
- 5 ASHRAE Guide and Data Book - Systems, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, New York, 1973.

APPENDIX A
ENERGY FUNDAMENTALS
EXAMPLE PROBLEMS
(ECT-301)

Example 1

Calculate the density of moist air for which the partial pressure of the water vapor is 0.320"Hg and the temperature is 70°F. The barometric pressure is 29.92"Hg.

$$P_b = P_{da} + P_w$$

$$P_w = 0.320\text{"Hg}$$

Then

$$\begin{aligned} P_{da} &= P_b - P_w \\ &= 29.92 - 0.320 \\ &= 29.60\text{"Hg} \end{aligned}$$

Moist air density is then given by:

$$\begin{aligned} \rho_{ma} &= \left(\frac{P}{RT} \right)_{da} + \left(\frac{P}{RT} \right)_w \\ &= \frac{(29.60)(0.491)(144)}{(53.35)(460 + 70)} + \frac{(0.320)(0.491)(144)}{(85.7)(460 + 70)} \\ &= 0.0740 + 0.00050 \\ &= 0.0745 \frac{\text{lb}}{\text{ft}^3} \end{aligned}$$

Note that 1"Hg is equal to 0.491 psi and that temperature must be in degrees Rankine ($T_R = T_F + 460$).

Example 2

For the moist air of Example 1, calculate the specific volume of both the dry air and the water vapor. For the dry air:

$$\begin{aligned} v_{da} &= \left(\frac{RT}{P} \right)_{da} \\ &= \frac{(53.35)(460 + 70)}{(29.60)(0.491)(144)} \\ v_{da} &= 13.51 \frac{\text{ft}^3}{\text{lb}_{da}} \end{aligned}$$

For the water vapor:

$$v_w = \left(\frac{RT}{P} \right)_w$$

$$= \frac{(85.7)(460 + 70)}{(0.320)(0.491)(144)}$$

$$v_w = 2007.5 \frac{\text{ft}^3}{\text{lb}_w}$$

Note: Always be sure to check your units. For example, consider the dry air:

$$\left(\frac{\text{ft-lb}_f}{\text{lb}_{da} \text{ } ^\circ\text{R}} \right) (^\circ\text{R}) \left(\frac{1}{\text{ } ^\circ\text{Hg}} \right) \left(\frac{\text{ } ^\circ\text{Hg}}{\text{lb}_f/\text{in}^2} \right) \left(\frac{\text{ft}^2}{\text{in}^2} \right) = \frac{\text{ft}^3}{\text{lb}_{da}}$$

Example 3

Moist air is at 72°F and has a relative humidity of 65%. What is the partial pressure of the water vapor in the air?

$$\phi = \left(\frac{P_w}{P_{w,s}} \right)_{t_{db}} \times 100$$

From the steam tables (Appendix 301-B):

$$P_{w,s} @ 72^\circ\text{F} = 0.38856 \text{ psia}$$

Then:

$$P_w = \phi P_{w,s}$$

$$= (0.65)(0.38856)$$

$$P_w = 0.2526 \text{ psia}$$

Note that in dealing with ratios such as this, you may use either psia or inches of mercury, whichever is more convenient.

Example 4

For the moist air of Example 3, what is the humidity ratio if the barometric pressure is 14.7 psia?

From Example 3, $P_w = 0.2526$ psia

The humidity ratio is given by:

$$W = 0.622 \frac{P_w}{P_b - P_w}$$
$$= \frac{(0.622)(0.2526)}{(14.7 - 0.2526)}$$

$$W = 0.0109 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Note that this calculation could have been made using "Hg pressure measurements instead of psia.

Example 5

For air at the conditions described in Examples 3 and 4, compute the degree of saturation.

From previous examples, we have:

$$P_{w,s} @ 72^\circ\text{F} = 0.38856 \text{ psia}$$

$$P_w = 0.2526 \text{ psia}$$

$$W = 0.0109 \frac{\text{lb}_w}{\text{lb}_{da}}$$

and:

$$\mu = \left(\frac{W}{W_s} \right)_{t_{db}} \times 100$$

So:

$$W_s = 0.622 \frac{P_{w,s}}{P_b - P_{w,s}}$$

$$= \frac{(0.622)(0.38856)}{(14.7 - 0.38856)}$$

$$W_s = 0.0169 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Then:

$$\mu = \frac{W}{W_s} = \left(\frac{0.0109}{0.0169} \right) (100)$$

$$\mu = 64.5\%$$

Example 6

For the air of Example 3 (72°F, 65% relative humidity), determine the dew point temperature.

Previously, we determined that:

$$p_w = 0.2526 \text{ psia}$$

Now, we want to find the temperature whose saturation pressure is equal to the partial pressure of the water vapor in the air. So from the steam tables (Appendix 301-B):

$$p_{w,s} @ 60^\circ\text{F} = 0.25618 \text{ psia}$$

$$p_{w,s} @ 59^\circ\text{F} = 0.24720 \text{ psia}$$

Interpolating, we find that a saturation pressure of 0.2526 psia corresponds to a temperature of 59.6°F.

Thus: $t_{dp} = 59.6^\circ\text{F}$

Example 7

It has been determined that certain moist air has a dry-bulb temperature of 68°F and a wet-bulb temperature of 56°F. What is the relative humidity of the air if the barometric pressure is 24.89"Hg?

From the steam tables (Appendix 301-B):

$$p_{w,s} @ 56^\circ\text{F} = 0.45176 \text{ "Hg}$$

$$p_{w,s} @ 68^\circ\text{F} = 0.69021 \text{ "Hg}$$

Using the Carrier Equation:

$$p_w = p_{w,s_{wbt}} - \frac{(p_b - p_{w,s_{wbt}})(t_{db} - t_{wb})}{2800 - 1.3t_{wb}}$$

$$= 0.45176 - \frac{(24.89 - 0.45176)(68 - 56)}{2800 - (1.3)(56)}$$

$$= 0.45176 - 0.10753$$

$$P_w = 0.3442 \text{ "Hg}$$

Then:

$$\phi = \left(\frac{P_w}{P_{w,s}} \right)_{t_{db}} \times 100$$

$$= \left(\frac{0.3442}{0.69021} \right) (100)$$

$$\phi = 49.9\%$$

Example 8

What is the enthalpy of moist air at 72°F dry-bulb temperature, 65% relative humidity, and 29.92"Hg barometric pressure?

Note that this air is at the same conditions as that of Examples 3 and 4. From that work we have:

$$t_{db} = 72^\circ\text{F}$$

$$\phi = 65\%$$

$$P_b = 29.92 \text{ "Hg}$$

$$W = 0.0109 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Now:

$$h = 0.24 t_{db} + W(1061 + 0.45 t_{db})$$

$$= (0.24)(72) + (0.0109)[1061 + (0.45)(72)]$$

$$= 17.28 + 11.92$$

$$h = 29.20 \frac{\text{Btu}}{\text{lb}_{da}}$$

Note that in the enthalpy equation, temperature has the units of degree Fahrenheit.

Example 9

Consider a device which humidifies air by spraying water into the air (an air washer). Air enters at 90°F dry-bulb temperature and with a humidity ratio of 0.0082 lb_w/lb_{da}. The exit air is saturated at 66°F and the barometric pressure is 14.7 psia. Determine the amount of water added to each pound of dry air flowing through the unit.

For the inlet and outlet air:

$$\begin{aligned} \textcircled{1} \quad t_{db} &= 90^\circ\text{F} & \textcircled{2} \quad t_{db} &= t_{wb} = t_{dp} = 66^\circ\text{F} \\ W &= 0.0082 \end{aligned}$$

From a mass balance on the dry air:

$$m_1 = m_2$$

From a mass balance on water (or water vapor):

$$m_3 = m_1(W_2 - W_1)$$

If we let $m_1 = 1 \text{ lb}_{da}$, then m_3 will represent the amount of water added to each pound of dry air.

The exit humidity ratio is found as:

$$P_{w,s} @ 66^\circ\text{F} = 0.64411 \text{ "Hg}$$

$$W_2 = W_{2,s} = .622 \frac{P_{w,2}}{P_b - P_{w,2}}$$

$$= \frac{(0.622)(0.64411)}{(29.92 - 0.64411)}$$

$$W_2 = 0.0137 \frac{\text{lb}_w}{\text{lb}_{da}}$$

So the water added is given by:

$$\begin{aligned}m_3 &= m_1(W_2 - W_1) \\&= 1(0.0137 - 0.0082)\end{aligned}$$

$$m_3 = 0.0055 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Example 10

Consider the air washer of Example 9. If the device has an efficiency of 80%, what is the exit humidity ratio and how much water is added to each pound of dry air under these conditions?

Note that the air washer of Example 9 has an efficiency of 100%. That is, the air is brought to saturation at the exit. In this case, the exit air is at a point below saturation.

From the definition of efficiency:

$$\eta_{\text{washer}} = \frac{W_2 - W_1}{W_{2,s} - W_1}$$

And from the previous example:

$$W_1 = 0.0082 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$W_{2,s} = 0.0137 \frac{\text{lb}_w}{\text{lb}_{da}}$$

So:

$$\begin{aligned}W_2 &= W_1 + \eta_w(W_{2,s} - W_1) \\&= 0.0082 + .8(.0137 - .0082) \\&= 0.0082 + 0.0044\end{aligned}$$

$$W_2 = 0.0126 \frac{\text{lb}_w}{\text{lb}_{da}}$$

The water added to each pound of dry air is now:

$$\begin{aligned} m_3 &= m_1(W_2 - W_1) \\ &= 1(0.0126 - 0.0082) \end{aligned}$$

$$m_3 = 0.0044 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Example 11

Air at 65°F dbt and carrying 0.005 pounds of water vapor per pound of dry air is mixed with a second quantity of air with a dry-bulb temperature of 85°F and a humidity ratio of 0.012 lb_w/lb_{da}.

Barometric pressure is 14.7 psia. The two streams are mixed in the ratio of 4 pounds of warmer air to 1 pound of cooler air. Determine the temperature, humidity ratio and enthalpy of the resulting mixture.

$$t_{db} = 65^\circ\text{F}$$

$$W = 0.005 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$m = 1 \text{ lb}_{da}$$

$$t_{db} = 85^\circ\text{F}$$

$$W = 0.012 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$m = 4 \text{ lb}_{da}$$

From a mass balance on dry air:

$$m_1 + m_2 = m_3$$

$$m_3 = 1 + 4 = 5 \text{ lb}_{da}$$

Then:

$$t_3 = \frac{m_1 t_1 + m_2 t_2}{m_3}$$
$$= \frac{(1)(65) + (4)(85)}{5}$$

$$t_3 = 81^\circ\text{F}$$

And:

$$w_3 = \frac{m_1 W_1 + m_2 W_2}{m_3}$$
$$= \frac{(1)(0.005) + (4)(0.012)}{5}$$

$$w_3 = 0.0106 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Recall that:

$$h = 0.24 t_{db} + W(1061 + 0.45 t_{db})$$

So:

$$h_1 = (0.24)(65) + (0.005)[1061 + (0.45)(65)]$$
$$= 21.05 \frac{\text{Btu}}{\text{lb}_{da}}$$

$$h_2 = (0.24)(85) + (0.012)[1061 + (0.45)(85)]$$
$$= 33.59 \frac{\text{Btu}}{\text{lb}_{da}}$$

And finally:

$$h_3 = \frac{m_1 h_1 + m_2 h_2}{m_3}$$

$$= \frac{(1)(21.05) + (4)(33.59)}{5}$$

$$h_3 = 31.08 \frac{\text{Btu}}{\text{lb}_{\text{da}}}$$

Example 12

Air at 72°F dry-bulb temperature has a relative humidity of 65%. Barometric pressure is 29.92"Hg. Using the psychrometric chart, determine

- humidity ratio
- degree of saturation
- enthalpy
- wet-bulb temperature
- specific volume

Locate the intersection of the two lines:

$$t_{\text{db}} = 72^\circ\text{F}$$

$$\phi = 65^\circ$$

Then:

$W = 0.0109 \frac{\text{lb}_w}{\text{lb}_{\text{da}}}$, which is the same as the value calculated in Example 4.

Continuing vertically along the 72° dbt-line to the saturation line ($\phi = 100\%$), we read:

$$W_s = 0.017 \frac{\text{lb}_w}{\text{lb}_{\text{da}}}$$

Then:

$$\begin{aligned}\mu &= \frac{W}{W_s} \times 100 \\ &= \frac{.0109}{.017} \times 100\end{aligned}$$

$\mu = 64.1\%$, which compares favorably to the value calculated in Example 5.

Again reading directly from the chart:

$$h = 29.2 \frac{\text{Btu}}{\text{lb}_{\text{da}}}, \text{ identical to the value calculated in Example 8.}$$

Note that the enthalpy and wet-bulb temperature lines are not parallel. Be careful!

$$t_{\text{wb}} = 64^\circ\text{F}$$

$$v = 13.7 \frac{\text{ft}^3}{\text{lb}_{\text{da}}}$$

Determine the dew point temperature of the air of Example 12, using the psychrometric chart.

After locating the intersection of the 72°F dbt and $\phi = 65\%$ lines, follow a horizontal line of constant humidity ratio to the saturation line. The temperature corresponding to this saturation point is the dew point temperature.

$$t_{\text{dp}} = 59.5^\circ\text{F}$$

which compares favorably to the 59.6° calculated in Example 6.

Example 14

Using the psychrometric chart, determine the relative humidity if the dry-bulb and wet-bulb temperatures are 68°F and 56°F, respectively. Barometric pressure is 24.89"Hg.

Using Chart #4, locate the intersection of the 68°F dbt line and the 56°F wbt line. Then read the relative humidity as:

$$\phi = 50\%$$

which is in agreement with the 49.9% value calculated in Example 7.

Example 15

Determine the amount of heat required to sensibly heat air from 70°F dbt, 0.006 lb_w/lb_{da} to 100°F dbt, if the flow rate is 1200 lb_{da}/hr.

The amount of heat required which must be added to the air is given by:

$$\begin{aligned} q_{\text{sens}} &= 0.244 \text{ m}_{\text{da}} (t_2 - t_1) \\ &= (0.244)(1200)(100-70) \\ &= 8784 \text{ Btu/hr} \end{aligned}$$

Reversing the procedure, if the air is sensibly cooled from 100°F dbt to 70°F dbt, the heat removed from the air is given by:

$$\begin{aligned}
 q &= 0.244 m_{da} (t_1 - t_2) \\
 &= (0.244)(1200)(100 - 70) \\
 &= 8784 \frac{\text{Btu}}{\text{hr}}
 \end{aligned}$$

Note that the quantity of heat is the same for both cases. The difference lies in the fact that it is a heat addition in the first case and a heat removal in the second.

Example 16

Determine the amount of energy (the latent heat) required to raise the humidity ratio of moist air at 100°F dbt from 0.006 to 0.013 lb_w/lb_{da}.

Flow rate is 1200 lb/hr of dry air.

$$\begin{aligned}
 q_{\text{lat}} &= m_{da} (W_2 - W_1) 1100 \\
 &= (1200)(0.013 - 0.006) 1100 \\
 &= 9240 \text{ Btu/hr}
 \end{aligned}$$

Conversely, the amount of latent heat that must be removed in order to lower the humidity ratio from 0.013 to 0.006 lb_w/lb_{da} is given by:

$$\begin{aligned}
 q_{lat} &= m_{da} (W_1 - W_2) 1100 \\
 &= (1200)(0.013 - 0.006) 1100 \\
 &= 9240 \text{ Btu/hr}
 \end{aligned}$$

Again note that the numerical values for both cases are the same, the difference being in whether the heat is added or removed.

Example 17

Consider the total process formed by combining the sensible and latent heating processes of Examples 15 and 16. Determine the sensible heat ratio for this total process.

The combined process is

Recalling that:

$$q_{sens} = 8784 \frac{\text{Btu}}{\text{hr}}$$

$$q_{lat} = 9240 \text{ Btu/hr}$$

Then:

$$SHR = \frac{q_{sens}}{q_{sens} + q_{lat}}$$

$$= \frac{8784}{8784 + 9240}$$

$$SHR = 0.487$$

Example 18

Consider again the mixing process of Example 11.

$$t_{db} = 65^\circ\text{F}$$

$$W = 0.005 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$t_{db} = 85^\circ\text{F}$$

$$W = 0.012 \frac{\text{lb}_w}{\text{lb}_{da}}$$

Again, determine the properties of the resulting mixture, but this time by use of the psychrometric chart.

On Chart #1:

The resultant mixture point (3) must be on the straight line connecting points (1) and (2). And we have:

$$\begin{aligned} m_3 &= m_1 + m_2 \\ &= 1 + 4 = 5 \text{ lb}_{da} \end{aligned}$$

So:

$$\frac{m_1}{m_3} = \frac{1}{5} = 0.2$$

$$\frac{m_2}{m_3} = \frac{4}{5} = 0.8$$

The ratios may then be used to locate point ③ as shown on the diagram. The properties at point ③ may then be read directly from the chart:

$$t_3 = 81^\circ\text{F}$$

$$w_3 = 0.0106 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$h_3 = 31.1 \frac{\text{Btu}}{\text{lb}_{da}}$$

In comparison, recall that our calculated values were:

$$t_3 = 81^\circ\text{F}$$

$$w_3 = 0.0106 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$h_3 = 31.08 \frac{\text{Btu}}{\text{lb}_{da}}$$

Example 19

A space has a sensible heat gain of 30,000 Btuh and a latent gain of 20,000 Btuh. Determine the flow rate and relative humidity of 60°F supply air if the space is to be maintained at 72°F and 50% relative humidity.

Assume $P_b = 14.7$ psia.

The sensible heat ratio is:

$$\text{SHR} = \frac{q_{\text{sens}}}{q_{\text{sens}} + q_{\text{lat}}}$$

$$= \frac{30,000}{30,000 + 20,000}$$

$$\text{SHR} = 0.60$$

The quantity of supply air required is given by:

$$q_{\text{sens}} = 0.244 m_{\text{da}} (t_d - t_s)$$

$$m_{\text{da}} = \frac{30,000}{(0.244)(72 - 60)}$$

$$m_{\text{da}} = 10,245 \frac{\text{lb}}{\text{hr}}$$

Now, using the psychrometric chart:

Locate point (d) on the chart and construct the SHR line through that point. This line must pass through both the supply and design points. Thus the intersection of the 60° dbt line and the SHR line will define point (s) and the relative humidity may be read as:

$$\phi_s = 60\%$$

Example 20

Saturated steam at 250 psia is injected into air at 75°F and 30% relative humidity. Determine the amount of steam added per pound of air if the final air temperature is 83°F.

it becomes saturated at 60°F. If the condensate is removed at 60°F, what quantity of heat is removed per pound of dry air?

Using the psychrometric chart, we can locate points ① and ② and determine the following properties:

$$W_1 = 0.0178 \text{ lb}_w/\text{lb}_{da} \quad W_2 = 0.0112 \text{ lb}_w/\text{lb}_{da}$$

$$h_1 = 42.4 \text{ Btu/lb}_{da} \quad h_2 = 26.5 \text{ Btu/lb}_{da}$$

And from III.B.4 we have:

$$q_{1-2} = m_{da}[(h_1 - h_2) - (W_1 - W_2)h_3]$$

From the steam tables:

$$h_3 = 28.1 \text{ Btu/lb}$$

So:

$$\begin{aligned} \frac{q_{1-2}}{m_{da}} &= (h_1 - h_2) - (W_1 - W_2)h_3 \\ &= (42.4 - 26.5) - (0.0178 - 0.0112)28.1 \\ &= 15.9 - .19 \end{aligned}$$

$$\frac{q_{1-2}}{m_{da}} = 15.71 \text{ Btu/lb}_{da}$$

Example 22

Evaluate the following conditions with regard to comfort.

a) $t_{db} = 74^{\circ}\text{F}$, $\phi = 50\%$

b) $t_{db} = 80^{\circ}\text{F}$, $\phi = 15\%$

Using the ASHRAE Comfort chart (Fig. IV.1) we find that:

a) $ET^* = 74$

This condition falls within the designated comfort zone and would be considered acceptable to a majority of people.

b) $ET^* = 78$

This condition is too warm and too dry to be considered comfortable.

Example 23

Determine the heat loss through a wall constructed of 8 inches of common brick and finished on the inside with 3/4 inch sand aggregate gypsum plaster on metal lath. The outdoor temperature is 10°F and the indoor temperature is 80°F .

	R
outside air film, $f = 6$	0.17
8" common brick, $8(0.20)$	1.60
inside air film, $f = 1.46$	<u>0.68</u>
	2.45

$$U = \frac{1}{R_t} = \frac{1}{2.45} = 0.408 \frac{\text{Btu}}{\text{hr-ft}^2 - ^\circ\text{F}}$$

Then:

$$\begin{aligned} \frac{q}{A} &= U(t_i - t_o) \\ &= 0.408(80 - 10) \\ &= 28.56 \text{ Btuh/ft}^2 \end{aligned}$$

Example 24

Calculate the heat loss through the ceiling of a room 30 x 36 feet, if the ceiling is constructed of 2 x 4 inch joists on 18-inch centers. The underside is 3/4 inch lightweight aggregate gypsum plaster on metal lath. The space between the joists is filled with 3-1/2 inches of expanded perlite and 1/2 inch plywood is laid over the joists. The room below the ceiling is at 72°F and the attic temperature is 25°F.

	R_f	R_{nf}
upper air film	0.68	0.60
1/2" plywood	0.62	0.62
3-1/2" softwood	4.35	—
3-1/2" perlite, 3.5(2.7)	—	9.45
3/4" lath and plaster	0.47	0.47
lower air film	<u>0.68</u>	<u>0.68</u>
	6.80	11.90

So:

$$U_f = \frac{1}{R_f} = \frac{1}{6.80} = 0.147 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

$$U_{nf} = \frac{1}{R_{nf}} = \frac{1}{11.90} = 0.084 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

And:

$$U_{avg} = \frac{A_{nf}U_{nf} + A_fU_f}{A_{nf} + A_f}$$

2 x 4's on 18" centers cover ~8% of area.

$$U_{avg} = (0.92)(0.084) + (0.08)(0.147)$$

$$= 0.077 + 0.012$$

$$U_{avg} = 0.089 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

Then:

$$q = UA (t_{\text{room}} - t_{\text{attic}})$$

$$= (0.089)(36)(30)(72 - 25)$$

$$q = 4518 \text{ Btuh}$$

Example 25

Determine the heat loss through an all-glass window 3 x 5 feet if it is of double insulating glass design with a 1/4 inch air space between glazings. It is winter and the temperature differential across the window is 40°F.

From Table V.5:

$$U = 0.65 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

Then:

$$\begin{aligned}q &= UA(t_i - t_o) \\&= (0.65)(3)(5)(40) \\q &= 390 \text{ Btuh}\end{aligned}$$

Example 26

Consider a basement area 20 feet square and 7 feet high with walls below grade. Compute the heat loss through the basement walls if the groundwater temperature is 50°F.

From Table V.3:

$$U\Delta t = 4.0 \frac{\text{Btuh}}{\text{ft}^2}$$

So:

$$\begin{aligned}q &= AU\Delta t \\&= 4(20)(7)(4) \\q &= 2240 \text{ Btuh}\end{aligned}$$

Example 27

For the basement of Example 26, calculate the heat loss through the floor if it is an unheated slab with no perimeter insulation.

From Table V.5: $F = 50$

$$\begin{aligned}q_{\text{slab}} &= FP \\&= (50)(4)(20) \\q_{\text{slab}} &= 4000 \text{ Btuh}\end{aligned}$$

Example 28

Calculate the infiltration heat loss through a single, poorly-fitted, double-hung, non-weatherstripped, wood-sash window. Outside conditions

are 0°F temperature with a 15 mph wind. Inside temperature is 70°F. The window is 4 x 7 feet.

From Table V.5:

$$B = 111 \text{ cfm/ft}$$

And:

$$L = 3(4) + 2(7)$$

$$= 12 + 14$$

$$= 26 \text{ ft.}$$

Then:

$$q_{inf} = 0.018 BL(t_i - t_o)$$

$$= (0.018)(111)(26)(70 - 0)$$

$$q_{inf} = 3636 \text{ Btuh}$$

Example 29

How many gallons of fuel oil are required during a winter season for an office building located in Chicago when the heat load of the building is 3,500,000 Btuh based on an inside temperature of 65°F and an outside temperature of -10°F? The heating unit has an overall efficiency of 75%. Use the degree-day method.

From Table V.5, there are 5855 degree-days in the Chicago winter season (Oct. 1 - May 1).

Then:

$$Q_D = \frac{Q_T}{t_i - t_o}$$

$$= \frac{3,500,000}{65 - (-10)}$$

$$Q_D = 46,667 \frac{\text{Btuh}}{^\circ\text{F}}$$

And:

$$\begin{aligned} FC &= \frac{(Q_D)(DD)(24)}{(HV)(\eta)} \\ &= \frac{(46,667)(5855)(24)}{(144,000)(0.75)} \\ FC &= 60,719 \text{ gals oil} \end{aligned}$$

Example 30

A 1/4-inch plate-glass window 5 x 7 feet is placed in the south wall of a building located near the 40° latitude line. The outside temperature is 93°F and the inside temperature is held at 80°F. Compute the total heat gain through the window at 11 a.m. on August 21.

Our basic equation (VI.B.4) is:

$$q = A[U(t_o - t_i) + (SC)(SHGF)]$$

$$U = 1.06 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}, \text{ Table VI.2}$$

$$SAGF = 140 \frac{\text{Btu}}{\text{hr-ft}^2}, \text{ Table VI.1}$$

$$\begin{aligned} SC &= 0.95, \text{ Table VI.3} \\ &(\text{h}_o = 4 \text{ for } 7\text{-}1/2 \text{ mph wind}) \end{aligned}$$

Then:

$$\begin{aligned} q &= (7)(5)[(1.06)(93 - 80) + (0.95)(140)] \\ &= 35 (13.78 + 133) \\ &= 5137 \text{ Btuh} \end{aligned}$$

Example 31

At 4 p.m. on a sunny afternoon in mid-July, what is the heat gain through the flat roof of a building 80 x 200 feet in size located at 40° north latitude? Assume the roof, which is approximately 4 inches thick and of medium construction, consists essentially of 2 inches of heavy-

weight concrete and 2 inches of insulation and is dark in color. Outside temperature is 97°F and the indoor temperature can be considered to be 75°F.

Using Table VI.6, we find that 97°F is within the outdoor temperature range of 93-102°F. Then:

$$TETD = 79^{\circ}\text{F}$$

$$U = \frac{0.122 \text{ Btu}}{\text{hr-ft}^2\text{-}^{\circ}\text{F}}$$

And:

$$\begin{aligned} q &= UA(TETD) \\ &= (0.122)(80)(200)(79) \end{aligned}$$

$$q = 154,208 \text{ Btuh}$$

Example 32

Calculate the sensible and latent infiltration through a double-hung, metal, unlocked, non-weatherstripped window, 3 x 5 feet in size. Outdoor conditions are 90°F, 70% relative humidity with a 10 mph wind. Inside conditions are 75°F, 40% relative humidity.

From the psychrometric chart:

$$t_o = 90^{\circ}\text{F}$$

$$t_i = 75^{\circ}\text{F}$$

$$\phi_o = 70\%$$

$$\phi_i = 40\%$$

$$w_o = 0.0216 \frac{\text{lb}_w}{\text{lb}_{da}}$$

$$w_i = 0.0074 \frac{\text{lb}_w}{\text{lb}_{da}}$$

From Table V.5:

$$B = 47 \text{ cfh/ft}$$

And:

$$\begin{aligned} L &= 3(3) + 2(5) \\ &= 19 \text{ ft.} \end{aligned}$$

The sensible gain is:

$$\begin{aligned}q_{inf} &= 0.018 \text{ BL}(t_o - t_i) \\&= (0.018)(47)(19)(90 - 75) \\&= 241 \text{ Btuh}\end{aligned}$$

The latent heat gain is:

$$\begin{aligned}q_{lat} &= 82.5 \text{ BL}(W_o - W_i) \\&= (82.5)(47)(19)(0.0216 - 0.0074) \\&= 1046 \text{ Btuh}\end{aligned}$$

Or:

$$\begin{aligned}m_w &= 0.075 \text{ BL}(W_o - W_i) \\&= (0.075)(47)(19)(0.0216 - 0.0074) \\&= 0.95 \text{ lb}_w/\text{hr}\end{aligned}$$

Example 33

A survey of a theater which is to be maintained at 82°F dbt and 68°F wbt shows that at 8:30 p.m. there is a transmission load (gain) of 20,000 Btuh and that an average of 1000 people are present. Determine the total load that occurs if light and equipment loads can be neglected.

From Table VI.8, the occupant heat gain is:

$$\begin{aligned}q_{sens} &= 245 \text{ Btuh/person} \\q_{lat} &= 105 \text{ Btuh/person}\end{aligned}$$

Then:

$$\begin{aligned}q_{sens} &= (245)(1000) + 20,000 \\&= 245,000 + 20,000 \\&= 265,000 \text{ Btuh}\end{aligned}$$

$$\begin{aligned} q_{lat} &= (105)(1000) \\ &= 105,000 \text{ Btuh} \end{aligned}$$

And:

$$\begin{aligned} q_{total} &= q_{sens} + q_{lat} \\ &= 265,000 + 105,000 \\ &= 370,000 \text{ Btuh} \end{aligned}$$

Example 34

Determine the friction loss resulting from the transport of 10,000 cfm of air at standard density through 75 feet of 24-inch diameter galvanized steel duct.

Using Fig. XII.2, locate the intersection of the 10,000 cfm and 24-inch diameter lines. Read the friction loss from the chart as:

$$\Delta p = 0.50 \text{ inches of water per 100 feet}$$

Then:

$$\Delta h = (0.50) \left(\frac{75}{100} \right) = 0.38 \text{ inches of water}$$

Example 35

Determine the friction loss in the duct of Example 34 if the temperature of the air is 200°F.

For air at 200°F, the density is 0.060 pounds per cubic foot. Thus the actual flow rate in the duct is:

$$Q = (10,000) \left(\frac{0.075}{0.060} \right) = 12,500 \text{ cfm}$$

From Fig. XII.2, locate the intersection of the 12,500 cfm and 24-inch diameter lines and read:

$$h_c = 0.77 \text{ inches of water}$$

From Fig. XII.3, locate the correction factor for 200°F:

$$k = 0.835$$

Then:

$$\begin{aligned} h_o &= kh_c \\ &= (0.835)(0.77) \left(\frac{75}{100} \right) \\ &= 0.48 \text{ inches of water.} \end{aligned}$$

Example 36

Determine the equivalent length of straight duct which has the same pressure drop as a 90° rectangular elbow with a height of 9 inches, a width of 18 inches, and a radius of curvature of 27 inches.

For the elbow we have:

$$\frac{R}{W} = \frac{27}{18} = 1.5$$

$$\frac{H}{W} = \frac{9}{18} = 0.5$$

From Fig. XII.5:

$$\frac{L}{W} = 3.8$$

So:

$$L_{eq} = (3.8) \left(\frac{18}{12} \right) = 5.7 \text{ feet}$$

Example 37

Calculate the pressure loss for standard air with an upstream velocity of 1200 fpm flowing through an abrupt expansion with an area ratio of $A_1/A_2 = 0.5$.

The velocity head is:

$$\begin{aligned}
 H_v &= \left(\frac{V}{4005} \right)^2 \\
 &= \left(\frac{1200}{4005} \right)^2 \\
 &= 0.090 \text{ inches of water}
 \end{aligned}$$

From Table XII.2:

$$C_1 = 0.25$$

The loss is then:

$$\begin{aligned}
 H_d &= C \left(\frac{V}{4005} \right)^2 \\
 &= 0.25(0.090) \\
 &= 0.0225 \text{ inches of water}
 \end{aligned}$$

Example 38

A fan supplies 6000 cfm to a duct system. The system consists of a duct run of 300 feet, at one end of which there is a hard bend through which 4000 cfm flow into a space. At 150 feet from the fan, a branch turns off the main duct at right angles and travels for 100 feet. This branch then turns at right angles again and delivers 2000 cfm of air. The duct has a maximum depth of 20 inches, which is used throughout the design. Size the main and branch using the Equal Friction Method. Assume that the air velocity in the main duct, shortly after the air leaves the fan, is 1200 fpm and then design the main run for the same friction drop throughout. Assume each bend has a radius ratio of 1.5 and that the outlet grilles on each branch have resistances equal to half the velocity head.

In the main duct leaving the fan:

$$A = \frac{Q}{V} = \frac{6000}{1200} = 5 \text{ ft}^2 = 720 \text{ in.}^2$$

$$A = WH = W(20) = 720 \text{ in.}^2$$

$$\therefore W = 36 \text{ in.}$$

From Table XII.1, $D_e = 29.0 \text{ in.}$ for A

From Fig. XII.2, $\Delta p = 0.07 \text{ in. H}_2\text{O}/100 \text{ ft.}$

Moving vertically along the 0.07 line in Fig. XII.2 we may find the equivalent diameters for sections B and C at the intersections with the 2000 and 4000 cfm lines. Then the rectangular equivalents may be determined from Table XII.1:

Section	cfm	Δp (in. H ₂ O/ 100 ft.)	D_e	Rectangular Size (inches)
A	6000	0.07	29.0	20 x 36
B	2000	0.07	19.2	20 x 16
C	4000	0.07	25.0	20 x 28

Now to check the pressure drop in each run:

$$V_B = \frac{Q}{A} = \frac{2000}{(20)(16)/144} = 900 \text{ fpm}$$

$$V_C = \frac{4000}{(20)(28)/144} = 1030 \text{ fpm}$$

So:

$$H_{vB} = \left(\frac{V_B}{4005} \right)^2 = \left(\frac{900}{4005} \right)^2 = 0.051 \text{ in. H}_2\text{O}$$

$$H_{vC} = \left(\frac{V_C}{4005} \right)^2 = \left(\frac{1030}{4005} \right)^2 = 0.067 \text{ in. H}_2\text{O}$$

And the grille losses are:

$$\Delta P_1 = \frac{1}{2} (0.051) = 0.0255 \text{ in. H}_2\text{O}$$

$$\Delta P_2 = \frac{1}{2} (0.067) = 0.0335 \text{ in. H}_2\text{O}$$

Calculate the equivalent length of the elbows from Fig. XII.5, with $R/W = 1.5$:

$$\text{run B: } \frac{H}{W} = \frac{20}{16} = 1.25$$

$$\frac{L_e}{W} = 4.6$$

$$L_e = (4.6) \frac{16}{12} = 6.13 \text{ ft.}$$

$$\text{run C: } \frac{H}{W} = \frac{20}{28} = 0.715$$

$$L_e = (4.2) \left(\frac{28}{12} \right) = 9.8 \text{ ft.}$$

The pressure drops in runs B and C, from fan to outlet, are:

$$L_B = 150 + 100 + 2(6.13) = 262.3 \text{ ft.}$$

$$L_C = 150 + 150 + 9.8 = 309.8 \text{ ft.}$$

$$\Delta P_B = \left(\frac{262.3}{100} \right) (0.07) + 0.0255$$

$$= 0.21" \text{ H}_2\text{O}$$

$$\Delta P_C = \left(\frac{309.8}{100} \right) (0.07) + 0.0335$$

$$= 0.25" \text{ H}_2\text{O}$$

Since Δp_B and Δp_C are within 0.05 inches of water of each other, this design is satisfactory.

APPENDIX B
ENERGY FUNDAMENTALS
STEAM TABLES
(ECT-301)

Fahr. Temp. (°F)	Absolute Pressure $p \times 10^3$		Specific Volume, cu ft per lb			Enthalpy, Btu per lb			Entropy, Btu per (lb) (°F)			Fahr. Temp. (°F)
	Lb/Sq In.	In. Hg	Sat. Solid v_f	Evap. $v_{fg} \times 10^{-3}$	Sat. Vapor $v_g \times 10^{-3}$	h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Solid s_f	Evap. s_{fg}	Sat. Vapor s_g	
-180	0.004949	0.01009	0.01722	36070	36070	-222.05	1212.43	990.38	-0.4907	4.8158	4.3251	-180
-150	0.009040	0.01840	0.01723	20050	20050	-220.44	1213.02	997.58	-0.4554	4.8112	4.3615	-150
-120	0.01620	0.03293	0.01723	11290	11290	-218.82	1213.63	994.80	-0.4501	4.8183	4.4387	-120
-100	0.02550	0.05000	0.01721	6577	6577	-217.17	1214.17	997.00	-0.4748	4.8382	4.5435	-100
-80	0.04022	0.1003	0.01724	3584	3584	-215.49	1214.70	999.21	-0.4938	4.7990	4.5201	-80
-60	0.05350	0.1706	0.01725	2205	2205	-213.60	1215.22	1001.62	-0.4843	4.7429	4.5745	-60
-40	0.1003	0.3350	0.01725	1400	1400	-212.08	1215.71	1003.63	-0.4590	4.6574	4.5254	-40
-20	0.2212	0.6703	0.01726	863.2	863.2	-210.34	1216.18	1005.54	-0.4538	4.6328	4.5800	-20
0	0.3787	0.7649	0.01728	538.6	538.6	-208.58	1216.63	1008.05	-0.4485	4.5815	4.6230	0
20	0.6019	1.228	0.01727	341.1	341.1	-206.79	1217.05	1010.26	-0.4433	4.5309	4.6375	20
40	0.9317	1.933	0.01728	218.9	218.9	-204.98	1217.45	1012.47	-0.4381	4.4813	4.6434	40
60	1.486	3.025	0.01728	143.2	143.2	-203.14	1217.82	1014.65	-0.4329	4.4325	4.6506	60
80	2.391	4.664	0.01729	92.53	92.53	-201.28	1218.17	1016.83	-0.4277	4.3838	4.6591	80
100	3.791	7.103	0.01729	62.23	62.23	-199.40	1218.50	1019.10	-0.4225	4.3412	4.6687	100
120	5.580	10.71	0.01730	41.56	41.56	-197.49	1218.80	1021.31	-0.4173	4.2959	4.6790	120
140	7.841	15.96	0.01730	28.45	28.45	-195.56	1219.05	1023.53	-0.4121	4.2526	4.6915	140
160	11.37	23.53	0.01731	19.53	19.53	-193.60	1219.23	1025.78	-0.4069	4.2114	4.7055	160
180	16.39	34.29	0.01732	12.66	12.66	-191.63	1219.38	1027.94	-0.4017	4.1702	4.7200	180
200	24.43	49.74	0.01733	9.501	9.501	-189.61	1219.50	1030.18	-0.3965	4.1301	4.7358	200
220	35.61	71.28	0.01733	6.715	6.715	-187.58	1219.59	1032.35	-0.3914	4.0910	4.7520	220
240	49.72	101.2	0.01734	4.788	4.788	-185.53	1220.10	1034.33	-0.3862	4.0528	4.7684	240
260	70.01	145.6	0.01734	3.443	3.443	-183.44	1220.32	1036.19	-0.3810	4.0153	4.7852	260
280	97.79	199.0	0.01735	2.490	2.490	-181.34	1220.34	1037.90	-0.3758	3.9780	4.8028	280
300	131.5	272.8	0.01736	1.843	1.843	-179.23	1220.27	1039.48	-0.3705	3.9413	4.8205	300
320	177.0	369.8	0.01736	1.341	1.341	-177.04	1220.40	1040.78	-0.3653	3.9051	4.8384	320
340	234.4	504.0	0.01736	1.018	1.018	-174.78	1220.43	1041.83	-0.3600	3.8699	4.8563	340
360	304.9	679.0	0.01737	0.791	0.791	-172.45	1220.45	1042.63	-0.3547	3.8352	4.8742	360
380	391.9	920.8	0.01738	0.6355	0.6355	-170.07	1220.46	1043.18	-0.3494	3.8010	4.8920	380
400	500.0	1190.0	0.01738	0.525	0.525	-167.63	1220.46	1043.53	-0.3441	3.7672	4.9098	400
420	634.1	1510.0	0.01738	0.443	0.443	-165.14	1220.45	1043.68	-0.3388	3.7338	4.9275	420
440	800.0	1900.0	0.01738	0.385	0.385	-162.60	1220.43	1043.73	-0.3335	3.7000	4.9450	440
460	1000.0	2380.0	0.01738	0.343	0.343	-160.00	1220.40	1043.78	-0.3282	3.6658	4.9625	460
480	1240.0	2960.0	0.01738	0.311	0.311	-157.35	1220.36	1043.83	-0.3229	3.6312	4.9798	480
500	1520.0	3650.0	0.01738	0.287	0.287	-154.65	1220.31	1043.88	-0.3176	3.5962	4.9969	500
520	1840.0	4460.0	0.01738	0.270	0.270	-151.90	1220.26	1043.93	-0.3123	3.5608	5.0138	520
540	2200.0	5400.0	0.01738	0.258	0.258	-149.10	1220.21	1043.98	-0.3070	3.5250	5.0305	540
560	2600.0	6480.0	0.01738	0.250	0.250	-146.25	1220.16	1044.03	-0.3017	3.4888	5.0470	560
580	3040.0	7700.0	0.01738	0.245	0.245	-143.35	1220.11	1044.08	-0.2964	3.4522	5.0634	580
600	3520.0	9060.0	0.01738	0.242	0.242	-140.40	1220.06	1044.13	-0.2911	3.4153	5.0797	600
620	4040.0	10560.0	0.01738	0.240	0.240	-137.40	1220.01	1044.18	-0.2858	3.3780	5.0958	620
640	4600.0	12200.0	0.01738	0.238	0.238	-134.35	1220.00	1044.23	-0.2805	3.3403	5.1117	640
660	5200.0	13980.0	0.01738	0.236	0.236	-131.25	1220.00	1044.28	-0.2752	3.3022	5.1274	660
680	5840.0	15900.0	0.01738	0.234	0.234	-128.10	1220.00	1044.33	-0.2699	3.2638	5.1428	680
700	6520.0	17960.0	0.01738	0.232	0.232	-124.90	1220.00	1044.38	-0.2646	3.2250	5.1580	700
720	7240.0	20160.0	0.01738	0.230	0.230	-121.65	1220.00	1044.43	-0.2593	3.1858	5.1730	720
740	8000.0	22500.0	0.01738	0.228	0.228	-118.35	1220.00	1044.48	-0.2540	3.1462	5.1878	740
760	8800.0	25000.0	0.01738	0.226	0.226	-115.00	1220.00	1044.53	-0.2487	3.1062	5.2024	760
780	9640.0	27660.0	0.01738	0.224	0.224	-111.60	1220.00	1044.58	-0.2434	3.0658	5.2168	780
800	10520.0	30480.0	0.01738	0.222	0.222	-108.15	1220.00	1044.63	-0.2381	3.0250	5.2310	800
820	11440.0	33460.0	0.01738	0.220	0.220	-104.65	1220.00	1044.68	-0.2328	2.9838	5.2450	820
840	12400.0	36600.0	0.01738	0.218	0.218	-101.10	1220.00	1044.73	-0.2275	2.9422	5.2588	840
860	13400.0	39900.0	0.01738	0.216	0.216	-97.50	1220.00	1044.78	-0.2222	2.9002	5.2724	860
880	14440.0	43360.0	0.01738	0.214	0.214	-93.85	1220.00	1044.83	-0.2169	2.8578	5.2858	880
900	15520.0	46980.0	0.01738	0.212	0.212	-90.15	1220.00	1044.88	-0.2116	2.8150	5.2990	900
920	16640.0	50760.0	0.01738	0.210	0.210	-86.40	1220.00	1044.93	-0.2063	2.7718	5.3120	920
940	17800.0	54700.0	0.01738	0.208	0.208	-82.60	1220.00	1044.98	-0.2010	2.7282	5.3248	940
960	19000.0	58800.0	0.01738	0.206	0.206	-78.75	1220.00	1045.03	-0.1957	2.6842	5.3374	960
980	20240.0	63060.0	0.01738	0.204	0.204	-74.85	1220.00	1045.08	-0.1904	2.6398	5.3498	980
1000	21520.0	67480.0	0.01738	0.202	0.202	-70.90	1220.00	1045.13	-0.1851	2.5950	5.3620	1000

* Compiled by John A. Goff and S. Gratch.

Table B.1 Thermodynamic Properties of Water at Saturation

Fahr. Temp. (°F)	Absolute Pressure P		Specific Volume, cu ft per lb			Enthalpy, Btu per lb			Entropy, Btu per (lb) (°F)			Fahr. Temp. (°F)
	Lb/Sq In.	In. Hg	Sat. Solid v_f	Evap. v_{fg}	Sat. Vapor v_g	Sat. Solid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Solid s_f	Evap. s_{fg}	Sat. Vapor s_g	
7	0.07033	0.05102	0.01743	10480	10480	-145.48	1210.84	1064.18	-0.3178	2.6128	2.2948	7
8	0.07191	0.05153	0.01743	9970	9970	-145.18	1210.80	1064.82	-0.3187	2.6081	2.2919	8
9	0.07338	0.05197	0.01744	9507	9507	-144.78	1210.76	1065.06	-0.3183	2.6025	2.2873	9
10	0.07487	0.05236	0.01744	9060	9060	-144.33	1210.72	1065.30	-0.3183	2.5969	2.2827	10
11	0.07648	0.05269	0.01744	8630	8630	-143.74	1210.68	1065.54	-0.3181	2.5913	2.2781	11
12	0.07812	0.05296	0.01744	8211	8211	-143.26	1210.64	1065.78	-0.3181	2.5857	2.2735	12
13	0.07983	0.05320	0.01744	7811	7811	-142.77	1210.60	1066.02	-0.3181	2.5801	2.2690	13
14	0.08167	0.05346	0.01744	7429	7429	-142.29	1210.55	1066.26	-0.3181	2.5746	2.2645	14
15	0.08357	0.05366	0.01744	7064	7064	-141.80	1210.50	1066.50	-0.3080	2.5690	2.2600	15
16	0.08553	0.05381	0.01745	6717	6717	-141.32	1210.46	1066.74	-0.3080	2.5635	2.2555	16
17	0.08757	0.05394	0.01745	6389	6389	-140.83	1210.41	1066.98	-0.3079	2.5581	2.2511	17
18	0.08968	0.05408	0.01745	6079	6079	-140.34	1210.36	1067.22	-0.3080	2.5526	2.2466	18
19	0.09187	0.05423	0.01745	5786	5786	-139.85	1210.31	1067.46	-0.3079	2.5471	2.2422	19
20	0.09413	0.05439	0.01745	5509	5509	-139.36	1210.26	1067.70	-0.3079	2.5417	2.2377	20
21	0.09647	0.05456	0.01745	5247	5247	-138.87	1210.21	1067.94	-0.3079	2.5363	2.2333	21
22	0.09889	0.05473	0.01745	5000	5000	-138.38	1210.16	1068.18	-0.3079	2.5310	2.2289	22
23	0.10139	0.05491	0.01745	4767	4767	-137.89	1210.11	1068.42	-0.3079	2.5256	2.2245	23
24	0.10397	0.05509	0.01745	4548	4548	-137.40	1210.06	1068.66	-0.3079	2.5203	2.2201	24
25	0.10663	0.05528	0.01745	4342	4342	-136.91	1210.01	1068.90	-0.3079	2.5150	2.2157	25
26	0.10937	0.05548	0.01745	4149	4149	-136.42	1210.00	1069.14	-0.3079	2.5097	2.2113	26
27	0.11219	0.05569	0.01745	3968	3968	-135.93	1210.00	1069.38	-0.3079	2.5044	2.2069	27
28	0.11509	0.05591	0.01745	3799	3799	-135.44	1210.00	1069.62	-0.3079	2.4991	2.2025	28
29	0.11807	0.05614	0.01745	3642	3642	-134.95	1210.00	1069.86	-0.3079	2.4938	2.1981	29
30	0.12113	0.05638	0.01745	3497	3497	-134.46	1210.00	1070.10	-0.3079	2.4885	2.1937	30
31	0.12427	0.05663	0.01745	3364	3364	-133.97	1210.00	1070.34	-0.3079	2.4832	2.1893	31
32	0.12749	0.05689	0.01745	3242	3242	-133.48	1210.00	1070.58	-0.3079	2.4779	2.1849	32
33	0.13079	0.05716	0.01745	3131	3131	-132.99	1210.00	1070.82	-0.3079	2.4726	2.1805	33
34	0.13417	0.05744	0.01745	3031	3031	-132.50	1210.00	1071.06	-0.3079	2.4673	2.1761	34
35	0.13763	0.05773	0.01745	2941	2941	-132.01	1210.00	1071.30	-0.3079	2.4620	2.1717	35
36	0.14117	0.05803	0.01745	2861	2861	-131.52	1210.00	1071.54	-0.3079	2.4567	2.1673	36
37	0.14479	0.05834	0.01745	2791	2791	-131.03	1210.00	1071.78	-0.3079	2.4514	2.1629	37
38	0.14849	0.05866	0.01745	2731	2731	-130.54	1210.00	1072.02	-0.3079	2.4461	2.1585	38
39	0.15227	0.05899	0.01745	2681	2681	-130.05	1210.00	1072.26	-0.3079	2.4408	2.1541	39
40	0.15613	0.05933	0.01745	2641	2641	-129.56	1210.00	1072.50	-0.3079	2.4355	2.1497	40
41	0.16007	0.05968	0.01745	2601	2601	-129.07	1210.00	1072.74	-0.3079	2.4302	2.1453	41
42	0.16409	0.06004	0.01745	2561	2561	-128.58	1210.00	1072.98	-0.3079	2.4249	2.1409	42
43	0.16819	0.06041	0.01745	2521	2521	-128.09	1210.00	1073.22	-0.3079	2.4196	2.1365	43
44	0.17237	0.06079	0.01745	2481	2481	-127.60	1210.00	1073.46	-0.3079	2.4143	2.1321	44
45	0.17663	0.06118	0.01745	2441	2441	-127.11	1210.00	1073.70	-0.3079	2.4090	2.1277	45
46	0.18097	0.06158	0.01745	2401	2401	-126.62	1210.00	1073.94	-0.3079	2.4037	2.1233	46
47	0.18539	0.06199	0.01745	2361	2361	-126.13	1210.00	1074.18	-0.3079	2.3984	2.1189	47
48	0.18989	0.06241	0.01745	2321	2321	-125.64	1210.00	1074.42	-0.3079	2.3931	2.1145	48
49	0.19447	0.06284	0.01745	2281	2281	-125.15	1210.00	1074.66	-0.3079	2.3878	2.1101	49
50	0.19913	0.06328	0.01745	2241	2241	-124.66	1210.00	1074.90	-0.3079	2.3825	2.1057	50
51	0.20387	0.06373	0.01745	2201	2201	-124.17	1210.00	1075.14	-0.3079	2.3772	2.1013	51
52	0.20869	0.06419	0.01745	2161	2161	-123.68	1210.00	1075.38	-0.3079	2.3719	2.0969	52
53	0.21359	0.06466	0.01745	2121	2121	-123.19	1210.00	1075.62	-0.3079	2.3666	2.0925	53
54	0.21857	0.06514	0.01745	2081	2081	-122.70	1210.00	1075.86	-0.3079	2.3613	2.0881	54
55	0.22363	0.06563	0.01745	2041	2041	-122.21	1210.00	1076.10	-0.3079	2.3560	2.0837	55
56	0.22877	0.06613	0.01745	2001	2001	-121.72	1210.00	1076.34	-0.3079	2.3507	2.0793	56
57	0.23400	0.06664	0.01745	1961	1961	-121.23	1210.00	1076.58	-0.3079	2.3454	2.0749	57
58	0.23931	0.06716	0.01745	1921	1921	-120.74	1210.00	1076.82	-0.3079	2.3401	2.0705	58
59	0.24471	0.06769	0.01745	1881	1881	-120.25	1210.00	1077.06	-0.3079	2.3348	2.0661	59
60	0.25019	0.06823	0.01745	1841	1841	-119.76	1210.00	1077.30	-0.3079	2.3295	2.0617	60
61	0.25575	0.06878	0.01745	1801	1801	-119.27	1210.00	1077.54	-0.3079	2.3242	2.0573	61
62	0.26139	0.06934	0.01745	1761	1761	-118.78	1210.00	1077.78	-0.3079	2.3189	2.0529	62
63	0.26711	0.06991	0.01745	1721	1721	-118.29	1210.00	1078.02	-0.3079	2.3136	2.0485	63
64	0.27291	0.07049	0.01745	1681	1681	-117.80	1210.00	1078.26	-0.3079	2.3083	2.0441	64
65	0.27879	0.07108	0.01745	1641	1641	-117.31	1210.00	1078.50	-0.3079	2.3030	2.0397	65
66	0.28475	0.07168	0.01745	1601	1601	-116.82	1210.00	1078.74	-0.3079	2.2977	2.0353	66
67	0.29079	0.07229	0.01745	1561	1561	-116.33	1210.00	1078.98	-0.3079	2.2924	2.0309	67
68	0.29691	0.07291	0.01745	1521	1521	-115.84	1210.00	1079.22	-0.3079	2.2871	2.0265	68
69	0.30311	0.07354	0.01745	1481	1481	-115.35	1210.00	1079.46	-0.3079	2.2818	2.0221	69
70	0.30939	0.07418	0.01745	1441	1441	-114.86	1210.00	1079.70	-0.3079	2.2765	2.0177	70
71	0.31575	0.07483	0.01745	1401	1401	-114.37	1210.00	1079.94	-0.3079	2.2712	2.0133	71

* Compiled by John A. Goff and B. Gratch.
 * Extrapolated to represent metastable equilibrium with undercooled liquid.

Table B.1 (continued)

Fehr. Temp. (°F)	Absolute Pressure p		Specific Volume, cu ft per lb			Enthalpy, Btu per lb			Entropy, Btu per (lb) (°F)			Fehr. Temp. (°F)
	Lb/Sq in.	in. Hg	Sat. Liquid v _f	Evap. v _{fg}	Sat. Vapor v _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Evap. s _{fg}	Sat. Vapor s _g	
72	0.38554	0.78112	0.01608	813.93	813.97	40.02	1032.84	1072.83	0.07834	1.9797	2.0580	72
73	0.40160	0.81629	0.01608	783.28	783.40	41.07	1032.01	1073.08	0.08022	1.9749	2.0531	73
74	0.41864	0.84626	0.01603	753.73	753.78	42.08	1031.44	1073.53	0.08207	1.9701	2.0472	74
75	0.43578	0.87506	0.01604	729.83	729.87	43.06	1030.89	1073.63	0.08396	1.9654	2.0414	75
76	0.44424	0.90473	0.01608	717.01	717.03	44.06	1030.22	1074.23	0.08572	1.9607	2.0355	76
77	0.45933	0.93321	0.01607	691.83	691.84	45.06	1029.78	1074.82	0.08759	1.9560	2.0297	77
78	0.47478	0.96066	0.01607	674.33	674.34	46.06	1029.19	1075.28	0.08945	1.9513	2.0239	78
79	0.49066	0.99500	0.01607	653.91	653.93	47.06	1028.63	1075.68	0.09140	1.9468	2.0180	79
80	0.50701	1.0323	0.01607	633.91	633.93	48.05	1028.07	1075.12	0.09325	1.9419	2.0122	80
81	0.52392	1.0683	0.01603	613.80	613.82	49.03	1027.50	1074.53	0.09510	1.9373	2.0064	81
82	0.54113	1.1017	0.01603	593.23	593.27	50.05	1026.93	1073.99	0.09694	1.9325	2.0007	82
83	0.55862	1.1360	0.01603	577.21	577.24	51.03	1026.37	1073.43	0.09878	1.9281	1.9949	83
84	0.57729	1.1722	0.01603	560.01	560.06	52.03	1025.80	1072.83	0.10062	1.9238	1.9891	84
85	0.59604	1.2102	0.01603	543.33	543.35	53.03	1025.23	1072.23	0.10246	1.9199	1.9833	85
86	0.61480	1.2500	0.01600	527.18	527.21	54.01	1024.67	1071.71	0.10429	1.9161	1.9775	86
87	0.63357	1.2933	0.01600	511.43	511.43	55.01	1024.10	1071.14	0.10611	1.9126	1.9717	87
88	0.65378	1.3391	0.01610	496.53	496.54	56.01	1023.51	1070.55	0.10794	1.9094	1.9659	88
89	0.67478	1.3779	0.01610	481.96	481.98	57.01	1022.92	1070.01	0.10978	1.9065	1.9601	89
90	0.69658	1.4191	0.01610	467.83	467.80	58.01	1022.33	1069.44	0.11155	1.9034	1.9543	90
91	0.72059	1.4631	0.01610	454.26	454.23	59.02	1021.74	1068.87	0.11332	1.9009	1.9485	91
92	0.74340	1.5134	0.01611	441.10	441.12	60.03	1021.17	1068.28	0.11509	1.8974	1.9427	92
93	0.76684	1.5613	0.01611	428.38	428.40	61.03	1020.70	1067.73	0.11687	1.8941	1.9369	93
94	0.79091	1.6103	0.01611	416.07	416.09	62.03	1020.13	1067.18	0.11861	1.8908	1.9311	94
95	0.81564	1.6607	0.01612	404.17	404.19	63.03	1019.56	1066.69	0.12031	1.8874	1.9253	95
96	0.84103	1.7124	0.01612	392.53	392.57	64.02	1019.00	1066.02	0.12201	1.8839	1.9195	96
97	0.86711	1.7653	0.01612	381.81	381.83	65.02	1018.43	1065.45	0.12372	1.8805	1.9137	97
98	0.89388	1.8200	0.01612	370.73	370.76	66.02	1017.87	1064.87	0.12542	1.8771	1.9079	98
99	0.92127	1.8768	0.01613	360.30	360.33	67.02	1017.30	1064.31	0.12712	1.8736	1.9021	99
100	0.94929	1.9354	0.01613	350.29	350.32	68.02	1016.73	1063.74	0.12882	1.8702	1.8963	100
101	0.97854	1.9952	0.01613	340.43	340.46	69.01	1016.16	1063.17	0.13052	1.8667	1.8905	101
102	1.00833	2.0570	0.01614	330.96	330.98	70.01	1015.58	1062.59	0.13222	1.8633	1.8847	102
103	1.03858	2.1219	0.01614	321.80	321.83	71.01	1015.01	1062.02	0.13392	1.8599	1.8789	103
104	1.07000	2.1896	0.01614	312.93	312.95	72.01	1014.44	1061.45	0.13562	1.8565	1.8731	104
105	1.10211	2.2600	0.01615	304.34	304.36	73.01	1013.87	1060.88	0.13732	1.8531	1.8673	105
106	1.13511	2.3310	0.01615	296.02	296.04	74.01	1013.30	1060.31	0.13902	1.8497	1.8615	106
107	1.16888	2.3758	0.01616	287.98	287.99	75.00	1012.73	1059.73	0.14072	1.8463	1.8557	107

Fehr. Temp. (°F)	Absolute Pressure p		Specific Volume, cu ft per lb			Enthalpy, Btu per lb			Entropy, Btu per (lb) (°F)			Fehr. Temp. (°F)
	Lb/Sq in.	in. Hg	Sat. Liquid v _f	Evap. v _{fg}	Sat. Vapor v _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Evap. s _{fg}	Sat. Vapor s _g	
108	1.2035	2.4503	0.01616	280.14	280.16	76.00	1012.16	1059.16	0.14242	1.8429	1.8499	108
109	1.2390	2.5228	0.01616	273.89	273.90	77.00	1011.58	1058.58	0.14412	1.8395	1.8441	109
110	1.2754	2.5968	0.01617	268.21	268.26	78.00	1011.01	1058.01	0.14582	1.8361	1.8387	110
111	1.3128	2.6728	0.01617	263.14	263.16	79.00	1010.44	1057.44	0.14752	1.8327	1.8329	111
112	1.3510	2.7507	0.01617	258.23	258.27	80.00	1009.88	1056.88	0.14922	1.8293	1.8285	112
113	1.3902	2.8306	0.01618	253.47	253.49	81.00	1009.33	1056.33	0.15092	1.8259	1.8241	113
114	1.4303	2.9125	0.01618	248.86	248.88	82.00	1008.78	1055.78	0.15262	1.8225	1.8197	114
115	1.4717	2.9963	0.01618	244.39	244.41	83.00	1008.23	1055.23	0.15432	1.8191	1.8153	115
116	1.5139	3.0822	0.01619	240.06	240.08	84.00	1007.68	1054.68	0.15602	1.8157	1.8115	116
117	1.5571	3.1703	0.01619	235.86	235.88	85.00	1007.13	1054.13	0.15772	1.8123	1.8077	117
118	1.6014	3.2606	0.01620	231.79	231.81	86.00	1006.58	1053.58	0.15942	1.8089	1.8039	118
119	1.6468	3.3530	0.01620	227.84	227.86	87.00	1006.03	1053.03	0.16112	1.8055	1.8005	119
120	1.6933	3.4477	0.01620	224.01	224.03	88.00	1005.48	1052.48	0.16282	1.8021	1.7961	120
121	1.7409	3.5446	0.01621	220.30	220.32	89.00	1004.93	1051.93	0.16452	1.7987	1.7917	121
122	1.7897	3.6438	0.01621	216.71	216.73	90.00	1004.38	1051.38	0.16622	1.7953	1.7873	122
123	1.8396	3.7453	0.01622	213.24	213.26	91.00	1003.83	1050.83	0.16792	1.7919	1.7829	123
124	1.8907	3.8490	0.01622	209.89	209.91	92.00	1003.28	1050.28	0.16962	1.7885	1.7785	124
125	1.9430	3.9548	0.01623	206.66	206.68	93.00	1002.73	1049.73	0.17132	1.7851	1.7751	125
126	1.9964	4.0631	0.01623	203.54	203.56	94.00	1002.18	1049.18	0.17302	1.7817	1.7717	126
127	2.0514	4.1748	0.01623	200.53	200.55	95.00	1001.63	1048.63	0.17472	1.7783	1.7673	127
128	2.1078	4.2910	0.01624	197.63	197.65	96.00	1001.08	1048.08	0.17642	1.7749	1.7629	128
129	2.1649	4.4027	0.01624	194.84	194.86	97.00	1000.53	1047.53	0.17812	1.7715	1.7585	129
130	2.2227	4.5190	0.01625	192.15	192.17	98.00	1000.00	1047.00	0.17982	1.7681	1.7551	130
131	2.2814	4.6403	0.01625	189.56	189.58	99.00	999.45	1046.45	0.18152	1.7647	1.7517	131
132	2.3413	4.7666	0.01626	187.07	187.09	100.00	998.90	1045.90	0.18322	1.7613	1.7483	132
133	2.4021	4.8980	0.01626	184.68	184.70	101.00	998.35	1045.35	0.18492	1.7579	1.7449	133
134	2.4638	5.0344	0.01627	182.39	182.41	102.00	997.80	1044.80	0.18662	1.7545	1.7415	134
135	2.5264	5.1758	0.01627	180.19	180.21	103.00	997.25	1044.25	0.18832	1.7511	1.7381	135
136	2.5908	5.3223	0.01628	178.08	178.10	104.00	996.70	1043.70	0.19002	1.7477	1.7347	136
137	2.6569	5.4740	0.01628	176.06	176.08	105.00	996.15	1043.15	0.19172	1.7443	1.7313	137
138	2.7248	5.6309	0.01629	174.13	174.15	106.00	995.60	1042.60	0.19342	1.7409	1.7279	138
139	2.7944	5.7930	0.01629	172.29	172.31	107.00	995.05	1042.05	0.19512	1.7375	1.7245	139
140	2.8658	5.9603	0.01630	170.54	170.56	108.00	994.50	1041.50	0.19682	1.7341	1.7211	140
141	2.9389	6.1328	0.01630	168.88	168.90	109.00	993.95	1040.95	0.19852	1.7307	1.7177	141
142	3.0137	6.3103	0.01631	167.31	167.33	110.00	993.40	1040.40	0.20022	1.7273	1.7143	142
143	3.0901	6.4928	0.01631	165.83	165.85	111.00	992.85	1039.85	0.20192	1.7239	1.7109	143

* Compiled by John A. Goff and S. Gratch.

Table B.1 (continued)

Fabr. Temp. (°F)	Absolute Pressure P		Specific Volume, cu ft per lb			Enthalpy, Btu per lb			Entropy, Btu per (lb) (°F)			Fabr. Temp. (°F)
	Lb/Sq In.	In. Hg	Sat. Liquid v _f	Evap. v _{fg}	Sat. Vapor v _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Evap. s _{fg}	Sat. Vapor s _g	
144	8.2004	6.5164	0.01631	111.70	111.72	111.86	1011.35	1193.21	0.20514	1.6783	1.8204	144
145	8.2124	6.5222	0.01631	109.09	109.11	111.86	1010.77	1192.73	0.20514	1.6783	1.8204	145
146	8.2244	6.5280	0.01632	106.48	106.50	111.86	1010.18	1192.14	0.20514	1.6783	1.8204	146
147	8.2364	6.5338	0.01632	103.87	103.89	111.86	1009.59	1191.55	0.20514	1.6783	1.8204	147
148	8.2484	6.5396	0.01633	101.26	101.28	111.86	1009.01	1190.97	0.20514	1.6783	1.8204	148
149	8.2604	6.5454	0.01633	98.65	98.67	111.86	1008.42	1190.38	0.20514	1.6783	1.8204	149
150	8.2724	6.5512	0.01633	96.04	96.06	111.86	1007.83	1189.80	0.20514	1.6783	1.8204	150
151	8.2844	6.5570	0.01633	93.43	93.45	111.86	1007.24	1189.21	0.20514	1.6783	1.8204	151
152	8.2964	6.5628	0.01633	90.82	90.84	111.86	1006.65	1188.62	0.20514	1.6783	1.8204	152
153	8.3084	6.5686	0.01633	88.21	88.23	111.86	1006.06	1188.03	0.20514	1.6783	1.8204	153
154	8.3204	6.5744	0.01633	85.60	85.62	111.86	1005.47	1187.44	0.20514	1.6783	1.8204	154
155	8.3324	6.5802	0.01633	82.99	83.01	111.86	1004.88	1186.85	0.20514	1.6783	1.8204	155
156	8.3444	6.5860	0.01633	80.38	80.40	111.86	1004.29	1186.26	0.20514	1.6783	1.8204	156
157	8.3564	6.5918	0.01633	77.77	77.79	111.86	1003.70	1185.67	0.20514	1.6783	1.8204	157
158	8.3684	6.5976	0.01633	75.16	75.18	111.86	1003.11	1185.08	0.20514	1.6783	1.8204	158
159	8.3804	6.6034	0.01633	72.55	72.57	111.86	1002.52	1184.49	0.20514	1.6783	1.8204	159
160	8.3924	6.6092	0.01633	69.94	69.96	111.86	1001.93	1183.90	0.20514	1.6783	1.8204	160
161	8.4044	6.6150	0.01633	67.33	67.35	111.86	1001.34	1183.31	0.20514	1.6783	1.8204	161
162	8.4164	6.6208	0.01633	64.72	64.74	111.86	1000.75	1182.72	0.20514	1.6783	1.8204	162
163	8.4284	6.6266	0.01633	62.11	62.13	111.86	1000.16	1182.13	0.20514	1.6783	1.8204	163
164	8.4404	6.6324	0.01633	59.50	59.52	111.86	999.57	1181.54	0.20514	1.6783	1.8204	164
165	8.4524	6.6382	0.01633	56.89	56.91	111.86	998.98	1180.95	0.20514	1.6783	1.8204	165
166	8.4644	6.6440	0.01633	54.28	54.30	111.86	998.39	1180.36	0.20514	1.6783	1.8204	166
167	8.4764	6.6498	0.01633	51.67	51.69	111.86	997.80	1179.77	0.20514	1.6783	1.8204	167
168	8.4884	6.6556	0.01633	49.06	49.08	111.86	997.21	1179.18	0.20514	1.6783	1.8204	168
169	8.5004	6.6614	0.01633	46.45	46.47	111.86	996.62	1178.59	0.20514	1.6783	1.8204	169
170	8.5124	6.6672	0.01633	43.84	43.86	111.86	996.03	1178.00	0.20514	1.6783	1.8204	170
171	8.5244	6.6730	0.01633	41.23	41.25	111.86	995.44	1177.41	0.20514	1.6783	1.8204	171
172	8.5364	6.6788	0.01633	38.62	38.64	111.86	994.85	1176.82	0.20514	1.6783	1.8204	172
173	8.5484	6.6846	0.01633	36.01	36.03	111.86	994.26	1176.23	0.20514	1.6783	1.8204	173
174	8.5604	6.6904	0.01633	33.40	33.42	111.86	993.67	1175.64	0.20514	1.6783	1.8204	174
175	8.5724	6.6962	0.01633	30.79	30.81	111.86	993.08	1175.05	0.20514	1.6783	1.8204	175
176	8.5844	6.7020	0.01633	28.18	28.20	111.86	992.49	1174.46	0.20514	1.6783	1.8204	176
177	8.5964	6.7078	0.01633	25.57	25.59	111.86	991.90	1173.87	0.20514	1.6783	1.8204	177
178	7.1849	14.829	0.01650	83.341	83.337	146.01	991.14	1137.16	0.25765	1.5313	1.8143	178
179	7.2469	14.959	0.01650	81.260	81.278	146.01	990.54	1137.45	0.25765	1.5313	1.8143	179
180	7.3119	15.095	0.01651	79.203	79.229	146.01	989.93	1137.71	0.25765	1.5313	1.8143	180
181	7.3801	15.237	0.01651	77.173	77.200	146.01	989.32	1137.97	0.25765	1.5313	1.8143	181
182	7.4514	15.386	0.01652	75.168	75.203	146.01	988.72	1138.24	0.25765	1.5313	1.8143	182
183	7.5268	15.541	0.01652	73.187	73.231	146.01	988.12	1138.51	0.25765	1.5313	1.8143	183
184	7.6063	15.703	0.01653	71.229	71.283	146.01	987.50	1138.78	0.25765	1.5313	1.8143	184
185	7.6901	15.871	0.01654	69.294	69.358	146.01	986.88	1139.05	0.25765	1.5313	1.8143	185
186	7.7783	16.046	0.01654	67.381	67.455	146.01	986.26	1139.32	0.25765	1.5313	1.8143	186
187	7.8719	16.228	0.01655	65.489	65.573	146.01	985.64	1139.59	0.25765	1.5313	1.8143	187
188	7.9710	16.417	0.01656	63.619	63.713	146.01	985.02	1139.86	0.25765	1.5313	1.8143	188
189	8.0756	16.614	0.01656	61.769	61.873	146.01	984.40	1140.13	0.25765	1.5313	1.8143	189
190	8.1857	16.819	0.01657	59.939	60.053	146.01	983.78	1140.40	0.25765	1.5313	1.8143	190
191	8.3014	17.032	0.01658	58.139	58.263	146.01	983.16	1140.67	0.25765	1.5313	1.8143	191
192	8.4227	17.253	0.01659	56.369	56.503	146.01	982.54	1140.94	0.25765	1.5313	1.8143	192
193	8.5496	17.482	0.01660	54.629	54.773	146.01	981.92	1141.21	0.25765	1.5313	1.8143	193
194	8.6821	17.719	0.01661	52.909	53.063	146.01	981.30	1141.48	0.25765	1.5313	1.8143	194
195	8.8203	17.964	0.01662	51.209	51.373	146.01	980.68	1141.75	0.25765	1.5313	1.8143	195
196	8.9643	18.217	0.01663	49.529	49.703	146.01	980.06	1142.02	0.25765	1.5313	1.8143	196
197	9.1143	18.478	0.01664	47.869	48.053	146.01	979.44	1142.29	0.25765	1.5313	1.8143	197
198	9.2703	18.747	0.01665	46.229	46.423	146.01	978.82	1142.56	0.25765	1.5313	1.8143	198
199	9.4323	19.024	0.01666	44.609	44.813	146.01	978.20	1142.83	0.25765	1.5313	1.8143	199
200	9.6003	19.309	0.01667	43.009	43.223	146.01	977.58	1143.10	0.25765	1.5313	1.8143	200
201	9.7743	19.594	0.01668	41.429	41.653	146.01	976.96	1143.37	0.25765	1.5313	1.8143	201
202	9.9543	19.889	0.01669	39.869	40.103	146.01	976.34	1143.64	0.25765	1.5313	1.8143	202
203	10.1403	20.194	0.01670	38.329	38.573	146.01	975.72	1143.91	0.25765	1.5313	1.8143	203
204	10.3323	20.509	0.01671	36.809	37.063	146.01	975.10	1144.18	0.25765	1.5313	1.8143	204
205	10.5303	20.834	0.01672	35.309	35.573	146.01	974.48	1144.45	0.25765	1.5313	1.8143	205
206	10.7343	21.169	0.01673	33.829	34.103	146.01	973.86	1144.72	0.25765	1.5313	1.8143	206
207	10.9443	21.514	0.01674	32.369	32.653	146.01	973.24	1144.99	0.25765	1.5313	1.8143	207
208	11.1603	21.869	0.01675	30.929	31.223	146.01	972.62	1145.26	0.25765	1.5313	1.8143	208
209	11.3823	22.234	0.01676	29.509	29.813	146.01	972.00	1145.53	0.25765	1.5313	1.8143	209
210	11.6103	22.609	0.01677	28.109	28.423	146.01	971.38	1145.80	0.25765	1.5313	1.8143	210
211	11.8443	23.004	0.01678	26.729	27.053	146.01	970.76	1146.07	0.25765	1.5313	1.8143	211
212	12.0843	23.419	0.01679	25.369	25.703	146.01	970.14	1146.34	0.25765	1.5313	1.8143	212

* Compiled by John A. Goff and B. Gratch.

Table B.1 (continued)

Fabr. Temp. (°F)	Abs. Press. lb./sq. in. p	Specific Volume		Enthalpy			Entropy			Fabr. Temp. (°F)
		Sat. Liquid v _f	Sat. Vapor v _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Evap. s _{fg}	Sat. Vapor s _g	
212	14.698	0.016716	26.80	180.16	970.3	1150.5	0.31213	1.4448	1.7567	212
214	15.291	.016729	25.83	182.17	969.1	1151.2	.31513	1.4384	1.7535	214
216	15.903	.016743	24.90	184.18	967.8	1152.0	.31811	1.4322	1.7504	216
218	16.535	.016758	24.00	186.20	966.5	1152.7	.32109	1.4261	1.7472	218
220	17.188	.016772	23.15	188.22	965.3	1153.5	.32406	1.4201	1.7441	220
222	17.861	.016788	22.33	190.24	964.0	1154.2	.32702	1.4140	1.7410	222
224	18.557	.016801	21.55	192.26	962.7	1154.9	.32998	1.4080	1.7380	224
226	19.275	.016816	20.80	194.28	961.4	1155.7	.33292	1.4020	1.7349	226
228	20.015	.016830	20.08	196.30	960.1	1156.4	.33586	1.3961	1.7319	228
230	20.78	.016845	19.386	198.32	958.8	1157.1	.33880	1.3901	1.7289	230
232	21.57	0.016860	18.723	200.34	957.5	1157.9	0.34172	1.3842	1.7260	232
234	22.38	.016875	18.087	202.37	956.2	1158.6	.34464	1.3784	1.7230	234
236	23.22	.016891	17.476	204.39	954.9	1159.3	.34755	1.3725	1.7201	236
238	24.09	.016906	16.890	206.42	953.6	1160.0	.35045	1.3667	1.7172	238
240	24.97	.016922	16.327	208.44	952.3	1160.7	.35335	1.3609	1.7143	240
242	25.88	.016937	15.788	210.47	950.9	1161.4	.35624	1.3552	1.7114	242
244	26.82	.016953	15.267	212.49	949.6	1162.1	.35912	1.3494	1.7085	244
246	27.79	.016969	14.767	214.52	948.3	1162.8	.36199	1.3437	1.7057	246
248	28.79	.016985	14.287	216.55	947.0	1163.5	.36486	1.3380	1.7029	248
250	29.82	.017001	13.826	218.59	945.6	1164.2	.36772	1.3324	1.7001	250
252	30.88	0.017017	13.382	220.62	944.3	1164.9	0.37058	1.3267	1.6973	252
254	31.97	.017034	12.955	222.65	942.9	1165.6	.37342	1.3211	1.6945	254
256	33.09	.017050	12.544	224.68	941.6	1166.2	.37626	1.3155	1.6918	256
258	34.24	.017067	12.149	226.72	940.2	1166.9	.37910	1.3100	1.6891	258
260	35.42	.017084	11.768	228.76	938.8	1167.6	.38193	1.3044	1.6864	260
262	36.64	.017101	11.402	230.79	937.5	1168.3	.38475	1.2989	1.6837	262
264	37.89	.017118	11.049	232.83	936.1	1168.9	.38756	1.2935	1.6810	264
266	39.17	.017135	10.709	234.87	934.7	1169.6	.39037	1.2880	1.6784	266
268	40.49	.017152	10.382	236.91	933.3	1170.2	.39317	1.2825	1.6757	268
270	41.85	.017170	10.066	238.95	932.0	1170.9	.39597	1.2771	1.6731	270
272	43.24	0.017187	9.762	241.00	930.6	1171.6	0.39876	1.2717	1.6705	272
274	44.67	.017205	9.469	243.04	929.2	1172.2	.40154	1.2664	1.6679	274
276	46.13	.017223	9.186	245.08	927.8	1172.8	.40432	1.2610	1.6653	276
278	47.64	.017241	8.913	247.13	926.3	1173.5	.40709	1.2557	1.6628	278
280	49.18	.017259	8.650	249.18	924.9	1174.1	.40986	1.2504	1.6602	280
282	50.77	.017277	8.397	251.23	923.5	1174.7	.41262	1.2451	1.6577	282
284	52.40	.017296	8.152	253.28	922.1	1175.4	.41537	1.2398	1.6552	284
286	54.07	.017314	7.915	255.33	920.6	1176.0	.41812	1.2346	1.6527	286
288	55.78	.017333	7.687	257.38	919.2	1176.6	.42086	1.2293	1.6502	288
290	57.53	.017352	7.467	259.44	917.8	1177.2	.42360	1.2241	1.6477	290
292	59.33	0.017371	7.254	261.50	916.3	1177.8	0.42633	1.2189	1.6453	292
294	61.17	.017390	7.048	263.55	914.9	1178.4	.42906	1.2138	1.6428	294
296	63.06	.017409	6.849	265.61	913.4	1179.0	.43178	1.2086	1.6404	296
298	65.00	.017429	6.657	267.67	911.9	1179.6	.43449	1.2035	1.6380	298
300	66.98	.017448	6.472	269.73	910.4	1180.2	.43720	1.1984	1.6356	300
310	77.64	.017548	5.632	280.06	903.0	1183.0	.45067	1.1731	1.6238	310
320	89.60	.017652	4.919	290.43	895.3	1185.8	.46400	1.1483	1.6123	320
330	103.00	.017760	4.312	300.84	887.5	1188.4	.47722	1.1238	1.6010	330
340	117.93	.017872	3.792	311.30	879.5	1190.8	.49031	1.0997	1.5901	340
350	134.53	.017988	3.346	321.80	871.3	1193.1	.50329	1.0760	1.5793	350
360	152.92	0.018108	2.961	332.35	862.9	1195.2	0.51617	1.0526	1.5685	360
370	173.23	.018233	2.628	342.96	854.2	1197.2	.52894	1.0295	1.5585	370
380	195.60	.018363	2.339	353.62	845.4	1199.0	.54163	1.0067	1.5483	380
390	220.2	.018498	2.087	364.34	836.2	1200.6	.55422	0.9841	1.5383	390
400	247.1	.018638	1.8661	375.12	826.8	1202.0	.56672	.9617	1.5284	400
410	276.5	.018784	1.6726	385.97	817.2	1203.1	.57916	.9395	1.5187	410
420	308.5	.018936	1.5024	396.89	807.2	1204.1	.59152	.9175	1.5091	420
430	343.3	.019094	1.3521	407.89	796.9	1204.8	.60381	.8957	1.4995	430
440	381.2	.019260	1.2192	418.98	786.3	1205.3	.61605	.8740	1.4900	440
450	422.1	.019433	1.1011	430.2	775.4	1205.6	.6282	.8523	1.4806	450
460	466.3	0.019614	0.9901	441.4	764.1	1205.5	0.6404	0.8308	1.4712	460
470	514.1	.019803	.9025	452.8	752.4	1205.2	.6525	.8093	1.4618	470
480	565.5	.020002	.8187	464.3	740.3	1204.6	.6646	.7878	1.4524	480
490	620.7	.020211	.7436	475.9	727.8	1203.7	.6767	.7663	1.4430	490
500	680.0	.02043	.6761	487.7	714.8	1202.5	.6888	.7448	1.4335	500

Temperatures in this table follow the Thermodynamic Fahrenheit Scale.

Table B.1 (continued)

Abs. Press. lb/Sq In. p	Fahr. Temp. (F)	Specific Volume		Enthalpy			Entropy			Abs. Press. lb/Sq In. p
		Sat. Liquid v _f	Sat. Vapor v _g	Sat. Liquid h _f	Evap. h _{fg}	Sat. Vapor h _g	Sat. Liquid s _f	Evap. s _{fg}	Sat. Vapor s _g	
14.696	211.99	0.016715	26.80	180.15	970.4	1150.5	0.31212	1.4446	1.7567	14.696
16	216.21	0.016746	24.75	184.50	967.6	1152.1	0.31858	1.4313	1.7499	16
18	222.40	0.016789	22.17	189.64	953.7	1154.4	0.32762	1.4128	1.7404	18
20	227.06	0.016830	20.09	196.26	960.1	1156.4	0.33580	1.3962	1.7320	20
22	233.08	0.016868	18.33	201.43	956.8	1158.2	0.34329	1.3811	1.7244	22
24	237.82	0.016905	16.94	206.23	953.7	1159.9	0.35019	1.3672	1.7174	24
26	242.26	0.016939	15.719	210.73	950.8	1161.5	0.35660	1.3544	1.7110	26
28	246.42	0.016972	14.665	214.95	948.0	1163.0	0.36259	1.3425	1.7051	28
30	250.34	0.017004	13.748	218.93	945.4	1164.3	0.36821	1.3314	1.6996	30
32	254.06	0.017034	12.942	222.71	942.9	1165.6	0.37351	1.3210	1.6945	32
34	257.59	0.017064	12.228	226.31	940.5	1166.8	0.37852	1.3111	1.6896	34
36	260.96	0.017092	11.591	229.73	938.2	1167.9	0.38328	1.3018	1.6851	36
38	264.18	0.017119	11.018	233.01	936.0	1169.0	0.38782	1.2930	1.6808	38
40	267.26	0.017146	10.501	236.16	933.8	1170.0	0.39214	1.2845	1.6767	40
42	270.22	0.017172	10.032	239.18	931.8	1171.0	0.39628	1.2765	1.6728	42
44	273.07	0.017197	9.603	242.09	929.8	1171.9	0.40026	1.2688	1.6691	44
46	275.82	0.017221	9.211	244.90	927.9	1172.8	0.40407	1.2615	1.6656	46
48	278.47	0.017245	8.851	247.61	926.0	1173.0	0.40775	1.2544	1.6622	48
50	281.03	0.017269	8.518	250.24	924.2	1174.4	0.41129	1.2476	1.6580	50
52	283.52	0.017291	8.210	252.78	922.4	1175.2	0.41471	1.2411	1.6558	52
54	285.92	0.017314	7.924	255.25	920.7	1176.0	0.41802	1.2348	1.6528	54
56	288.26	0.017336	7.658	257.65	919.0	1176.7	0.42122	1.2287	1.6499	56
58	290.53	0.017357	7.410	259.93	917.4	1177.4	0.42432	1.2228	1.6471	58
60	292.73	0.017378	7.177	262.25	915.8	1178.0	0.42733	1.2170	1.6444	60
62	294.88	0.017399	6.960	264.46	914.2	1178.7	0.43026	1.2115	1.6418	62
64	296.98	0.017419	6.755	266.61	912.7	1179.3	0.43310	1.2061	1.6392	64
66	299.02	0.017439	6.562	268.72	911.2	1179.9	0.43587	1.2009	1.6368	66
68	301.01	0.017458	6.380	270.77	909.7	1180.5	0.43857	1.1958	1.6344	68
70	302.96	0.017478	6.209	272.79	908.3	1181.0	0.44120	1.1909	1.6321	70
72	304.86	0.017496	6.046	274.75	906.8	1181.6	0.44376	1.1860	1.6298	72
74	306.72	0.017515	5.892	276.67	905.4	1182.1	0.44626	1.1814	1.6276	74
76	308.54	0.017534	5.746	278.55	904.1	1182.6	0.44871	1.1768	1.6255	76
78	310.32	0.017552	5.607	280.40	902.7	1183.1	0.45110	1.1723	1.6234	78
80	312.07	0.017570	5.474	282.21	901.4	1183.6	0.45344	1.1679	1.6214	80
82	313.78	0.017587	5.348	283.98	900.1	1184.1	0.45572	1.1637	1.6194	82
84	315.46	0.017605	5.228	285.72	898.8	1184.5	0.45798	1.1595	1.6175	84
86	317.11	0.017622	5.113	287.43	897.6	1185.0	0.46016	1.1554	1.6156	86
88	318.72	0.017639	5.004	289.11	896.3	1185.4	0.46231	1.1514	1.6137	88
90	320.31	0.017655	4.898	290.76	895.1	1185.9	0.46442	1.1475	1.6119	90
92	321.87	0.017672	4.798	292.38	893.9	1186.3	0.46649	1.1436	1.6101	92
94	323.41	0.017688	4.701	293.98	892.7	1186.7	0.46852	1.1399	1.6084	94
96	324.91	0.017705	4.609	295.55	891.5	1187.1	0.47051	1.1362	1.6067	96
98	326.40	0.017721	4.520	297.09	890.4	1187.4	0.47247	1.1326	1.6050	98
100	327.86	0.017736	4.434	298.61	889.2	1187.8	0.47439	1.1290	1.6034	100
110	334.82	0.017813	4.051	305.88	883.7	1189.6	0.48355	1.1122	1.5957	110
120	341.30	0.017886	3.730	312.67	878.5	1191.1	0.49201	1.0966	1.5886	120
130	347.37	0.017957	3.457	319.04	873.5	1192.5	0.49959	1.0822	1.5821	130
140	353.08	0.018024	3.221	325.05	868.7	1193.8	0.50727	1.0688	1.5761	140
150	358.48	0.018089	3.016	330.75	864.2	1194.9	0.51422	1.0562	1.5704	150
160	363.60	0.018152	2.836	336.16	859.8	1196.0	0.52078	1.0443	1.5651	160
170	368.47	0.018214	2.676	341.33	855.6	1196.9	0.52700	1.0330	1.5600	170
180	373.13	0.018273	2.533	346.29	851.5	1197.8	0.53292	1.0223	1.5553	180
190	377.59	0.018331	2.405	351.04	847.5	1198.6	0.53857	1.0122	1.5507	190
200	381.86	0.018387	2.289	355.6	843.7	1199.3	0.5440	1.0025	1.5464	200
250	401.04	0.018653	1.8418	370.2	825.8	1202.1	0.5680	0.9594	1.5274	250
300	417.43	0.018896	1.5442	394.1	809.8	1203.9	0.5883	0.9232	1.5115	300
350	431.82	0.019124	1.3267	409.9	795.0	1204.9	0.6060	0.8917	1.4978	350
400	444.70	0.019340	1.1620	424.2	781.2	1205.5	0.6218	0.8638	1.4856	400
450	456.39	0.019547	1.0326	437.4	768.2	1205.6	0.6360	0.8385	1.4746	450
500	467.13	0.019748	0.9283	449.5	755.8	1205.3	0.6490	0.8154	1.4645	500
550	477.07	0.019943	0.8423	460.9	743.0	1204.8	0.6611	0.7941	1.4551	550
600	486.33	0.02013	0.7702	471.7	732.4	1204.1	0.6723	0.7742	1.4464	600
700	503.23	0.02051	0.6558	491.5	710.5	1202.0	0.6927	0.7378	1.4305	700

Temperatures in this table follow the Thermodynamic Fahrenheit Scale.

Table B.2 Thermodynamic Properties of Water at Saturation Pressure Table

APPENDIX C
ENERGY FUNDAMENTALS
PSYCHROMETRIC CHART
(ECT - 301)

C.1 Psychrometric Chart

APPENDIX D
ENERGY FUNDAMENTALS
WEATHER DATA AND DESIGN CONDITIONS
MATERIAL THERMAL PROPERTIES
(ECT - 301)

CLIMATIC CONDITIONS FOR THE UNITED STATES^a

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^b	Col. 4 Elevation ^c Ft.	Winter ^d			Summer ^e			Col. 7 Mean Daily Range	Col. 8			
				Col. 5		Design Dry-Bulb 99%	Col. 6				Design Dry-Bulb and Mean Coincident Wet-Bulb 1% 2.5% 5%	Design Wet-Bulb 1% 2.5% 5%		
				Design Dry-Bulb 97.5%	Mean Coincident Wet-Bulb 1% 2.5% 5%		Mean Coincident Wet-Bulb 1% 2.5% 5%	Mean Coincident Wet-Bulb 1% 2.5% 5%	Mean Coincident Wet-Bulb 1% 2.5% 5%					
ALABAMA														
Alexander City	33	0	86	0	660	18	22	96/77	93/76	91/76	21	79	78	78
Anniston AP	33	4	85	3	599	18	22	97/77	94/76	92/76	21	79	78	78
Auburn	32	4	85	3	730	18	22	96/77	93/76	91/76	21	79	78	78
Birmingham AP	33	3	86	5	610	17	21	96/74	94/75	92/74	21	78	77	76
Decatur	34	4	87	0	580	11	16	95/75	93/74	91/74	22	78	77	76
Dothan AP	31	2	85	2	321	23	27	94/76	92/76	91/76	20	80	79	78
Florence AP	34	5	87	4	528	17	21	97/74	94/74	92/74	22	78	77	76
Gadsden	34	0	86	0	570	16	20	96/75	94/75	92/74	22	78	77	76
Huntsville AP	34	4	86	4	619	11	16	95/75	93/74	91/74	23	78	77	76
Mobile AP	30	4	88	2	211	25	29	95/77	93/77	91/76	18	80	79	78
Mobile CO	30	4	88	1	119	25	29	95/77	93/77	91/76	16	80	79	78
Montgomery AP	32	2	86	2	195	22	25	96/76	95/76	93/76	21	79	79	78
Selma-Craig AFB	32	2	87	0	207	22	26	97/78	95/77	93/77	21	81	80	79
Talladega	33	3	86	1	565	18	22	97/77	94/76	92/76	21	79	78	78
Tuscaloosa AP	33	1	87	4	170	20	23	98/75	96/76	94/76	22	79	78	77
ALASKA														
Anchorage AP	61	1	150	0	90	-23	-18	71/59	68/58	66/56	15	60	59	57
Barrow (S)	71	2	156	5	22	-45	-41	57/53	53/50	49/47	12	54	50	47
Fairbanks AP (S)	64	5	147	5	436	-51	-47	82/62	78/60	75/59	24	64	62	60
Juneau AP	58	2	134	4	17	-4	1	74/60	70/58	67/57	15	61	59	58
Kodiak	57	3	152	3	21	10	13	69/58	65/56	62/55	10	60	58	56
Nome AP	64	3	165	3	13	-31	-27	66/57	62/55	59/54	10	58	56	55
ARIZONA														
Douglas AP	31	3	109	3	4098	27	31	98/63	95/63	93/63	31	70	69	68
Flagstaff AP	35	1	111	4	6973	-2	4	84/55	82/55	80/54	31	61	60	59
Fort Huachuca AP (S)	31	3	110	2	4664	24	28	95/62	92/62	90/62	27	69	68	67
Kingman AP	35	2	114	0	3446	18	25	103/65	100/64	97/64	30	70	69	69
Nogales	31	2	111	0	3800	28	32	99/64	96/64	94/64	31	71	70	69
Phoenix AP(S)	33	3	112	0	1117	31	34	109/71	107/71	105/71	27	76	75	75
Prescott AP	34	4	112	3	5014	4	9	96/61	94/60	92/60	30	66	65	64
Tucson AP (S)	32	1	111	0	2584	28	32	104/66	102/66	100/66	26	72	71	71
Winslow AP	35	0	110	4	4880	5	10	97/61	95/60	93/60	32	66	65	64
Yuma AP	32	4	114	4	199	36	39	111/72	109/72	107/71	27	79	78	77
ARKANSAS														
Blytheville AFB	36	0	90	0	264	10	15	96/78	94/77	91/76	21	81	80	78
Camden	33	4	92	5	116	18	23	98/76	96/76	94/76	21	80	79	78
El Dorado AP	33	1	92	5	252	18	23	98/76	96/76	94/76	21	80	79	78
Fayetteville AP	36	0	94	1	1253	7	12	97/72	94/73	92/73	23	77	76	75
Fort Smith AP	35	2	94	2	449	12	17	101/75	98/76	95/76	24	80	79	78
Hot Springs	34	3	93	1	535	17	23	101/77	97/77	94/77	22	80	79	78
Jonesboro	35	5	90	4	345	10	15	96/78	94/77	91/76	21	81	80	78
Little Rock AP (S)	34	4	92	1	257	15	20	99/76	96/77	94/77	22	80	79	78
Pine Bluff AP	34	1	92	0	204	16	22	100/78	97/77	95/78	22	81	80	80
Tenarkana AP	33	3	94	0	361	18	23	98/76	96/77	93/76	21	80	79	78
CALIFORNIA														
Bakersfield AP	35	2	119	0	495	30	32	104/70	101/69	98/68	32	73	71	70
Barstow AP	34	5	116	5	2142	26	29	106/68	104/68	102/67	37	73	71	70
Blythe AP	33	4	114	3	390	30	33	112/71	110/71	108/70	28	75	73	74
Burbank AP	34	1	118	2	699	37	39	95/68	91/68	88/67	25	71	70	69
Chico	39	5	121	5	205	28	30	103/69	101/68	98/67	36	71	70	68

^a Table 1 was prepared by ASHRAE Technical Committee 4.2, Weather Data, from data compiled from official weather stations where hourly weather observations are made by trained observers. See also Ref. 1, 2, 3, 5 and 6.

^b Latitude, for use in calculating solar loads, and longitude are given in the nearest 10 minutes. For example, the latitude and longitude for Anniston, Alabama are given as 33 34 and 85 53 respectively, or 33° 40' and 85° 50'.

^c Elevations are ground elevations for each station. Temperature readings are generally made at an elevation of 5 ft above ground, except for locations marked r, indicating roof exposure of thermometers.

^d Percentages of winter design data shows the percent of the 3-month period, December through February.

^e Percentages of summer design data shows the percent of 4-month period, June through September.

Table D.1 Design Conditions for United States

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^b	Col. 4 Elevation ^c Ft.	Winter ^d		Summer ^d				Col. 7 Mean Daily Range	Col. 8			
				Col. 5		Col. 6					Col. 8			
				Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb					Design Wet-Bulb			
				99%	97.5%	1%	2.5%	5%	1%		2.5%	5%		
Concord	38	0	122	0	195	24	27	100/69	97/68	94/67	32	71	70	68
Covina	34	0	117	5	575	32	35	98/69	95/68	92/67	31	73	71	70
Crescent City AP	41	5	124	0	50	31	33	68/60	65/59	63/58	18	62	60	59
Downey	34	0	118	1	116	37	40	93/70	89/70	86/69	22	72	71	70
El Cajon	32	4	117	0	525	42	44	83/69	80/69	78/68	30	71	70	68
El Centro AP (S)	32	5	115	4	-30	35	38	112/74	110/74	108/74	34	81	80	78
Escondido	33	0	117	1	660	39	41	89/68	85/68	82/68	30	71	70	69
Eureka/ Arcata AP	41	0	124	1	217	31	33	68/60	65/59	63/58	11	62	60	59
Fairfield- Travis AFB	38	2	122	0	72	29	32	99/68	95/67	91/66	34	70	68	67
Fresno AP (S)	36	5	119	4	326	28	30	102/70	100/69	97/68	34	72	71	70
Hamilton AFB	38	0	122	3	3	30	32	89/68	84/66	80/65	28	72	69	67
Laguna Beach	33	3	117	5	35	41	43	83/68	80/68	77/67	18	70	69	68
Livermore	37	4	122	0	545	24	27	100/69	97/68	93/67	24	71	70	68
Lompoc- Vandenberg AFB	34	4	120	3	552	35	38	75/61	70/61	67/60	20	63	61	60
Long Beach AP	33	5	118	1	34	41	43	83/68	80/68	77/67	22	70	69	68
Los Angeles AP (S)	34	0	118	2	99	41	43	83/68	80/68	77/67	15	70	69	68
Los Angeles CO (S)	34	0	118	1	312	37	40	93/70	89/70	86/69	20	72	71	70
Merced-Castle AFB	37	2	120	3	178	29	31	102/70	99/69	96/68	36	72	71	70
Modesto	37	4	121	0	91	28	30	101/69	98/68	95/67	36	71	70	69
Monterey	36	4	121	5	38	35	38	75/63	71/61	68/61	20	64	62	61
Napa	38	2	122	2	16	30	32	100/69	96/68	92/67	30	71	69	68
Needles AP	34	5	114	4	913	30	33	112/71	110/71	108/70	27	75	75	74
Oakland AP	37	4	122	1	3	34	36	85/64	80/63	75/62	19	66	64	63
Oceanside	33	1	117	2	30	41	43	83/68	80/68	77/67	13	70	69	68
Ontario	34	0	117	36	995	31	33	102/70	99/69	96/67	36	74	72	71
Oxnard	34	1	119	1	43	34	36	83/66	80/64	77/63	19	70	68	67
Palmdale AP	34	4	118	1	2517	18	22	103/65	101/65	98/64	35	69	67	66
Palm Springs	33	5	116	4	411	33	35	112/71	110/70	108/70	35	76	74	73
Pasadena	34	1	118	1	864	32	35	98/69	95/68	92/67	29	73	71	70
Petaluma	38	1	122	4	27	26	29	94/68	90/66	87/65	31	72	70	68
Pomona CO	34	0	117	5	871	28	30	102/70	99/69	95/68	36	74	72	71
Redding AP	40	3	122	1	495	29	31	105/68	102/67	100/66	32	71	69	68
Redlands	34	0	117	1	1318	31	33	102/70	99/69	96/68	33	74	72	71
Richmond	38	0	122	2	55	34	36	85/64	80/63	75/62	17	66	64	63
Riverside- March AFB (S)	33	5	117	2	1511	29	32	100/68	98/68	95/67	37	72	71	70
Sacramento AP	38	3	121	3	17	30	32	101/70	98/70	94/69	36	72	71	70
Salinas AP	36	4	121	4	74	30	32	74/61	70/60	67/59	24	62	61	59
San Bernardino, Norton AFB	34	1	117	1	1125	31	33	102/70	99/69	96/68	38	74	72	71
San Diego AP	32	4	117	1	19	42	44	83/69	80/69	78/68	12	71	70	68
San Fernando	34	1	118	3	977	37	39	95/68	91/68	88/67	38	71	70	69
San Francisco AP	37	4	122	2	8	35	38	82/64	77/63	73/62	20	65	64	62
San Francisco CO	37	5	122	3	52	38	40	74/63	71/62	69/61	14	64	62	61
San Jose AP	37	2	122	0	70r	34	36	85/66	81/65	77/64	26	68	67	65
San Luis Obispo	35	2	120	4	315	33	35	92/69	88/70	84/69	26	73	71	70
Santa Ana AP	33	4	117	5	115r	37	39	89/69	85/68	82/68	28	71	70	69
Santa Barbara MAP	34	3	119	5	10	34	36	81/67	77/66	75/65	24	68	67	66
Santa Cruz	37	0	122	0	125	35	38	75/63	71/61	68/61	28	64	62	61
Santa Maria AP (S)	34	5	120	3	238	31	33	81/64	76/63	73/62	23	65	64	63
Santa Monica CO	34	0	118	3	57	41	43	83/68	80/68	77/67	16	70	69	68
Santa Paula	34	2	119	0	263	33	35	90/68	86/67	84/66	36	71	69	68
Santa Rosa	38	3	122	5	167	27	29	99/68	95/67	91/66	34	70	68	67
Stockton AP	37	5	121	2	28	28	30	100/69	97/68	94/67	37	71	70	68
Ukiah	39	1	122	4	620	27	29	99/69	95/68	91/67	40	70	68	67
Visalia	36	2	119	1	354	28	30	102/70	100/69	97/68	38	72	71	70
Yreka	41	4	122	4	2625	13	17	95/65	92/64	89/63	38	67	65	64
Yuba City	39	1	121	4	70	29	31	104/68	101/67	99/66	36	71	69	68
COLORADO														
Alamosa AP	37	3	105	5	7536	-11	-6	84/57	82/57	80/57	35	62	61	60
Boulder	40	0	105	2	5385	-6	0	93/59	91/59	89/59	27	64	63	62
Colorado														
Spring AP	38	5	104	4	6173	-3	2	91/58	88/57	86/57	30	63	62	61
Denver AP	39	5	104	5	5283	-3	1	93/59	91/59	89/59	28	64	63	62
Durango	37	1	107	5	6550	-6	-1	89/59	87/59	85/59	30	64	63	62

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

CLIMATIC CONDITIONS FOR THE UNITED STATES														
Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^b	Col. 4 Elevation ^c ft	Winter ^d		Summer ^e			Col. 7 Mean Daily Range	Col. 8				
				Col. 5		Col. 6				Col. 8				
				Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb				Design Wet-Bulb				
				92%	97.5%	1%	2.5%	5%		1%	2.5%	5%		
Fort Collins	40	4	105	0	5001	-5	1	93/59	91/59	89/59	28	64	63	62
Grand Junction AP (S)	39	1	108	3	4849	2	7	96/59	94/59	92/59	29	64	63	62
Greeley	40	3	104	4	4648	-2	4	96/60	94/60	92/60	29	65	64	63
La Junta AP	38	0	103	3	4188	-3	3	100/68	98/68	95/67	31	72	70	69
Leadville	39	2	106	2	10177	-18	-14	84/52	81/51	78/50	30	56	55	54
Pueblo AP	38	2	104	2	4639	-7	0	97/61	95/61	92/61	31	67	66	65
Sterling	40	4	103	1	3939	-7	-2	95/62	93/62	90/62	30	67	66	65
Trinidad AP	37	2	104	2	5746	-2	3	93/61	91/61	89/61	32	66	65	64
CONNECTICUT														
Bridgeport AP	41	1	73	1	7	6	9	86/73	84/71	81/70	18	75	74	73
Hartford														
Brainerd Field	41	5	72	4	15	3	7	91/74	88/73	85/72	22	77	75	74
New Haven AP	41	2	73	0	6	3	7	88/73	84/73	82/72	17	76	75	74
New London	41	2	72	1	60	5	9	88/73	85/72	83/71	16	76	75	74
Norwalk	41	1	73	3	37	6	9	86/73	84/71	81/70	19	75	74	73
Norwich	41	3	72	0	20	3	7	89/75	86/73	83/72	18	76	75	74
Waterbury	41	3	73	0	605	-4	2	88/73	85/71	82/70	21	75	74	72
Windsor Locks														
Bradley Field (S)	42	0	72	4	169	0	4	91/74	88/72	85/71	22	76	75	73
DELAWARE														
Dover AFB	39	0	75	3	38	11	15	92/75	90/75	87/74	18	79	77	76
Wilmington AP	39	4	75	3	78	10	14	92/74	89/74	87/73	20	77	76	75
DISTRICT OF COLUMBIA														
Andrews AFB	38	5	76	5	279	10	14	92/75	90/74	87/73	18	78	76	75
Washington														
National AP	38	5	77	0	14	14	17	93/75	91/74	89/74	18	78	77	76
FLORIDA														
Belle Glade	26	4	80	4	16	41	44	92/76	91/76	89/76	16	79	78	78
Cape Kennedy AP	28	3	80	3	16	35	38	90/78	88/78	87/78	15	80	79	79
Daytona Beach AP	29	1	81	0	31	32	35	92/78	90/77	88/77	15	80	79	78
Fort Lauderdale	26	0	80	1	13	42	46	92/78	91/78	90/78	15	80	79	79
Fort Myers AP	26	4	81	5	13	41	44	93/78	92/78	91/77	18	80	79	79
Fort Pierce	27	3	80	2	10	38	42	91/78	90/78	89/78	15	80	79	79
Gainesville AP (S)	29	4	82	2	155	28	31	95/77	93/77	92/77	18	80	79	78
Jacksonville AP	30	3	81	4	24	29	32	96/77	94/77	92/76	19	79	79	78
Key West AP	24	3	81	5	6	55	57	90/78	90/78	89/78	9	80	79	79
Lakeland CO (S)	28	0	82	0	214	39	41	93/76	91/76	89/76	17	79	78	78
Miami AP (S)	25	5	80	2	7	44	47	91/77	90/77	89/77	15	79	79	78
Miami Beach CO	25	5	80	1	9	45	48	90/77	89/77	88/77	10	79	79	78
Ocala	29	1	82	1	86	31	34	95/77	93/77	92/76	18	80	79	78
Orlando AP	28	3	81	2	106	35	38	94/76	93/76	91/76	17	79	78	78
Panama City														
Tyndall AFB	30	0	85	4	22	29	33	92/78	90/77	89/77	14	81	80	79
Pensacola CO	30	3	87	1	13	25	29	94/77	93/77	91/77	14	80	79	79
St. Augustine	29	5	81	2	15	31	35	92/78	89/78	87/78	16	80	79	79
St. Petersburg	28	0	82	4	35	36	40	92/77	91/77	90/76	16	79	79	78
Sanford	28	5	81	2	14	35	38	94/76	93/76	91/76	17	79	78	78
Sarasota	27	2	82	3	30	39	42	93/77	92/77	90/76	17	79	79	78
Tallahassee AP (S)	30	2	84	2	58	27	30	94/77	92/76	90/76	19	79	78	78
Tampa AP (S)	28	0	82	3	19	36	40	92/77	91/77	90/76	17	79	79	78
West Palm Beach AP	26	4	80	1	15	41	45	92/78	91/78	90/78	16	80	79	79
GEORGIA														
Albany, Turner AFB	31	3	84	1	224	25	29	91/77	95/76	93/76	20	80	79	78
Americus	32	0	84	2	476	21	25	91/77	94/76	92/75	20	79	78	77
Athens	34	0	83	2	700	18	22	94/74	92/74	90/74	21	78	77	76
Atlanta AP (S)	33	4	84	3	1005	17	22	94/74	92/74	90/73	19	77	76	75
Augusta AP	33	2	82	0	143	20	23	91/77	95/76	93/76	19	80	79	78
Brunswick	31	1	81	3	14	29	32	92/78	89/78	87/78	18	80	79	79
Columbus														
Lawson AFB	32	3	85	0	242	21	24	95/76	93/76	91/75	21	79	78	77
Dalton	34	5	85	0	720	17	22	94/76	93/76	91/76	22	79	78	77
Dublin	32	3	83	0	215	21	25	96/77	93/76	91/75	20	79	78	77
Gainesville	34	2	83	5	1254	16	21	93/74	91/74	89/73	21	77	76	75
Griffin (S)	33	1	84	2	980	18	22	93/76	90/75	88/74	21	78	77	76

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^a	Col. 3 Longitude ^b	Col. 4 Elevation ^c ft	Winter ^d			Summer ^e									
				Design Dry-Bulb	Mean Coincident Wet-Bulb	Col. 6	Col. 7 Mean Daily Range	Col. 8	Design Wet-Bulb	1%	2.5%	5%				
													Col. 5	Col. 6	Col. 7	Col. 8
													99%	97.5%	1%	2.5%	5%	1%	2.5%	5%
La Grange	33	0	85	0	715	19	23	94/76	91/73	89/74	21	78	77	76		
Macon AP	32	4	83	4	356	21	25	96/77	93/76	91/73	22	79	78	77		
Marietta,																
Dobbins AFB	34	0	84	3	1016	17	21	94/74	92/74	90/74	21	78	77	76		
Moultrie	31	1	83	4	340	27	30	97/77	95/77	92/76	20	80	79	78		
Rome AP	34	2	85	1	637	17	22	94/76	93/76	91/76	23	79	78	77		
Savannah-Travis AP	32	1	81	1	52	24	27	96/77	93/77	91/77	20	80	79	78		
Valdosta-Moody AFB	31	0	83	1	239	28	31	96/77	94/77	92/76	20	80	79	78		
Waycross	31	2	82	2	140	26	29	96/77	94/77	91/76	20	80	79	78		
HAWAII																
Hilo AP (S)	19	4	155	1	31	61	62	84/73	83/72	82/72	15	75	74	74		
Honolulu AP	21	2	158	0	7	62	63	87/73	86/73	85/72	12	76	75	74		
Kaneohe Bay MCAS	21	2	157	5	18	65	66	85/75	84/74	83/74	12	76	76	75		
Wahiawa	21	3	158	0	900	58	59	86/73	85/72	84/72	14	75	74	73		
IDAHO																
Boise AP(S)	43	3	116	1	2842	3	10	96/65	94/64	91/64	31	68	66	65		
Burley	42	3	113	5	4180	-3	2	99/62	95/61	92/66	35	64	63	61		
Coeur d'Alene AP	47	5	116	5	2973	-8	-1	89/62	86/61	83/60	31	64	63	61		
Idaho Falls AP	43	3	112	0	4730	-11	-6	89/61	87/61	84/59	38	63	63	61		
Lewiston AP	46	2	117	0	1413	-1	6	96/65	93/64	90/63	32	67	66	64		
Moscow	46	4	117	0	2660	-7	0	90/63	87/62	84/61	32	65	64	62		
Mountain Home AFB	43	0	115	5	2992	6	12	99/64	97/63	94/62	36	66	65	63		
Pocatello AP	43	0	112	4	4444	-8	-1	94/61	91/60	89/59	35	64	63	61		
Twin Falls (AP) (S)	42	3	114	3	4148	-3	2	99/62	95/61	92/60	34	64	63	61		
ILLINOIS																
Aurora	41	5	88	2	744	-6	-1	93/76	91/76	88/75	20	79	78	76		
Belleville, Scott AFB	38	3	89	5	447	1	6	94/76	92/76	89/75	21	79	78	76		
Bloomington	40	3	89	0	775	-6	-2	92/75	90/74	88/73	21	78	76	75		
Carbondale	37	5	89	1	380	2	7	95/77	93/77	90/76	21	80	79	77		
Champaign/Urbana	40	0	88	2	743	-3	2	95/75	92/74	90/73	21	78	77	75		
Chicago, Midway AP	41	5	87	5	610	-5	0	94/74	91/73	88/72	20	77	75	74		
Chicago, O'Hare AP	42	0	87	5	658	-8	-4	91/74	89/74	86/72	20	77	76	74		
Chicago CO	41	5	87	4	594	-3	2	94/75	91/74	88/73	15	79	77	75		
Danville	40	1	87	4	558	-4	1	93/75	90/74	88/73	21	78	77	75		
Decatur	39	5	88	5	670	-3	2	94/75	91/74	88/73	21	78	77	75		
Elgin	41	5	89	3	694	-7	-7	91/75	90/74	88/73	23	78	77	75		
Freeport	42	0	88	2	820	-7	-2	91/75	88/74	86/73	21	78	77	75		
Galesburg	41	0	90	3	771	-7	-2	93/75	91/75	88/74	22	78	77	75		
Greenville	39	0	89	2	563	-1	4	94/76	92/75	89/74	21	79	78	76		
Joliet	41	3	88	1	588	-5	0	93/75	90/74	88/73	20	78	77	75		
Kankakee	41	1	87	5	625	-4	1	93/75	90/74	88/73	21	78	77	75		
La Salle/Peru	41	2	89	1	520	-7	-2	93/75	91/75	88/74	22	78	77	75		
Macomb	40	3	90	4	702	-5	0	95/76	92/76	89/75	22	79	78	76		
Moline AP	41	3	90	3	582	-9	-4	93/75	91/75	88/74	23	78	77	75		
Mt Vernon	38	2	88	5	500	0	5	95/76	92/75	89/74	21	79	78	76		
Peoria AP	40	4	89	4	652	-8	-4	91/75	89/74	87/73	22	78	76	75		
Quincy AP	40	0	91	1	762	-2	3	96/76	93/76	90/76	22	80	78	77		
Rantoul,																
Chanute AFB	40	2	88	1	740	-4	1	94/75	91/74	89/73	21	78	77	75		
Rockford	42	1	89	0	724	-9	-4	91/74	89/73	87/72	24	77	76	74		
Springfield AP	39	5	89	4	587	-3	2	94/75	92/74	89/74	21	79	77	76		
Waukegan	42	2	87	5	680	-6	-3	92/76	89/74	87/73	21	78	76	75		
INDIANA																
Anderson	40	0	85	4	847	0	6	95/76	92/75	89/74	22	79	78	76		
Bedford	38	5	86	3	670	0	5	95/76	92/75	89/74	22	79	78	76		
Bloomington	39	1	86	4	820	0	5	95/76	92/75	89/74	22	79	78	76		
Columbus,																
Bakalar AFB	39	2	85	5	661	3	7	95/76	92/75	90/74	22	79	78	76		
Crawfordsville	40	0	86	5	752	-2	3	94/75	91/74	88/73	22	79	77	76		
Evansville AP	38	0	87	3	381	4	9	95/76	93/75	91/75	22	79	78	77		
Fort Wayne AP	41	0	85	1	791	-4	1	92/73	89/72	87/72	24	77	75	74		
Goshen AP	41	3	85	5	823	-3	1	91/73	89/73	86/72	23	77	75	74		
Hobart	41	3	87	2	600	-4	2	91/73	88/73	85/72	21	77	75	74		
Huntington	40	4	85	3	802	-4	1	92/73	89/72	87/72	23	77	75	74		
Indianapolis AP (S)	39	4	86	2	793	-2	2	92/74	90/74	87/73	22	78	76	75		
Jeffersonville	38	2	85	5	455	5	10	95/74	93/74	90/74	23	79	77	76		
Kokomo	40	3	86	1	790	-4	0	91/74	90/73	88/73	22	77	75	74		
Lafayette	40	2	86	5	600	-3	3	94/74	91/73	88/73	22	78	76	75		

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

CLIMATIC CONDITIONS FOR THE UNITED STATES														
Col. 1 State and Station	Col. 2 Lat- tude ^b	Col. 3 Longi- tude ^c	Col. 4 Eleva- tion ^e ft	Winter ^d			Summer ^d			Col. 7 Mean Daily Range	Col. 8			
				Design	Dry-Bulb		Design	Dry-Bulb and Coincident Wet-Bulb			Design	Wet-Bulb		
					99%	97.5%		1%	2.5%			5%	1%	2.5%
La Porte	41	3	86	4	810	-3	3	93/74	90/74	87/73	22	78	76	75
Marion	40	3	85	4	791	-4	0	91/74	90/73	88/73	23	77	75	74
Muncie	40	1	85	2	955	-3	2	92/74	90/73	87/73	22	76	76	75
Peru														
Bunker Hill AFB	40	4	86	1	804	-6	-1	90/74	88/73	86/73	22	77	75	74
Richmond AP	39	5	84	5	1138	-2	2	92/74	90/74	87/73	22	78	76	75
Shelbyville	39	3	85	5	765	-1	3	93/74	91/74	88/73	22	78	76	75
South Bend AP	41	4	86	2	773	-3	1	91/73	89/73	86/72	22	77	75	74
Terre Haute AP	39	3	87	2	601	-2	4	95/75	92/74	89/73	22	79	77	76
Valparaiso	41	2	87	0	801	-3	3	93/74	90/74	87/73	22	78	76	75
Vincennes	38	4	87	3	420	1	6	95/75	92/74	90/73	22	79	77	76
IOWA														
Ames (S)	42	0	93	4	1004	-11	-6	93/75	90/74	87/73	23	78	76	75
Burlington AP	40	5	91	1	694	-7	-3	94/74	91/75	88/73	22	78	77	75
Cedar Rapids AP	41	5	91	4	863	-10	-5	91/76	88/75	86/74	23	78	77	75
Clinton	41	5	90	1	595	-8	-3	92/75	90/75	87/74	23	78	77	75
Council Bluffs	41	2	95	5	1210	-8	-3	94/76	91/75	88/74	22	78	77	75
Des Moines AP	41	3	93	4	948r	-10	-5	94/75	91/74	88/73	23	78	77	75
Dubuque	42	2	90	4	1065	-12	-7	90/74	88/73	86/72	22	77	75	74
Fort Dodge	42	3	94	1	1111	-12	-7	91/74	88/74	86/72	23	77	75	74
Iowa City	41	4	91	3	645	-11	-6	92/76	89/76	87/74	22	80	78	76
Keokuk	40	2	91	2	526	-5	0	95/75	92/75	89/74	22	79	77	76
Marshalltown	42	0	92	5	898	-12	-7	92/76	90/75	88/74	23	78	77	75
Mason City AP	43	1	93	2	1194	-15	-11	90/74	88/74	85/72	24	77	75	74
Newton	41	4	93	0	946	-10	-5	94/75	91/74	88/73	23	78	77	75
Ottumwa AP	41	1	92	2	842	-8	-4	94/75	91/74	88/73	22	78	77	75
Sioux City AP	42	2	96	2	1095	-11	-7	95/74	92/74	89/73	24	78	77	75
Waterloo	42	3	92	2	868	-15	-10	91/76	89/75	86/74	23	78	77	75
KANSAS														
Atchison	39	3	95	1	945	-2	2	96/77	93/76	91/76	23	81	79	77
Chanute AP	34	4	95	3	977	3	7	100/74	97/74	94/74	23	78	77	76
Dodge City AP (S)	37	5	100	0	2594	0	5	100/69	97/69	95/69	25	74	73	71
El Dorado	37	5	96	5	1282	3	7	101/72	98/73	96/73	24	77	76	75
Emporia	38	2	96	1	1209	1	5	100/74	97/74	94/73	25	78	77	76
Garden City AP	38	0	101	0	2882	-1	4	99/69	96/69	94/69	28	74	73	71
Goodland AP	39	2	101	4	3645	-5	0	99/66	96/65	93/66	31	71	70	68
Great Bend	38	2	98	5	1940	0	4	101/73	98/73	95/73	28	76	76	75
Hutchinson AP	38	0	97	5	1524	4	8	102/72	99/72	97/72	28	77	75	74
Liberal	37	0	101	0	2838	2	7	99/68	96/68	94/68	28	73	72	71
Manhattan,														
Fort Riley (S)	39	0	96	5	1076	-1	3	99/75	95/75	92/74	24	78	77	76
Parsons	37	2	95	3	908	5	9	100/74	97/74	94/74	23	79	77	76
Russell AP	38	5	98	5	1864	0	4	101/73	98/73	95/73	29	78	76	75
Salina	38	5	97	4	1271	0	5	103/74	100/74	97/73	26	78	77	75
Topeka AP	39	0	95	4	877	0	4	99/75	96/75	93/74	24	79	78	76
Wichita AP	37	4	97	3	1321	3	7	101/72	98/73	96/73	23	77	76	75
KENTUCKY														
Ashland	38	3	82	4	551	5	10	94/76	91/74	89/73	22	78	77	75
Bowling Green AP	37	0	86	3	535	4	10	94/77	92/75	89/74	21	79	77	76
Corbin AP	37	0	84	1	1175	4	9	94/73	92/73	89/72	23	77	76	75
Covington AP	39	0	84	4	869	1	6	92/73	90/72	88/72	22	77	75	74
Hopkinsville														
Campbell AFB	36	4	87	3	540	4	10	94/77	92/75	89/74	21	79	77	76
Lexington AP (S)	38	0	84	4	979	3	8	93/73	91/73	88/72	22	77	76	75
Louisville AP	38	1	85	4	474	5	10	95/74	93/74	90/74	23	79	77	76
Madisonville	37	2	87	3	439	5	10	96/76	93/75	90/75	22	79	78	77
Owensboro	37	5	87	1	420	5	10	97/76	94/75	91/75	23	79	78	77
Paducah AP	37	0	88	4	398	7	12	98/76	95/75	92/75	20	79	78	77
LOUISIANA														
Alexandria AP	31	2	92	2	92	23	27	95/77	94/77	92/77	20	80	79	78
Baton Rouge AP	30	3	91	1	64	25	29	95/77	93/77	92/77	19	80	80	79
Bogalusa	30	5	89	5	103	24	28	95/77	93/77	92/77	19	80	80	79
Houma	29	3	90	4	13	31	35	95/78	93/78	92/77	15	81	80	79
Lafayette AP	30	1	92	0	38	26	30	95/78	94/78	92/78	18	81	80	79
Lake Charles AP (S)	30	1	93	1	14	77	21	95/77	93/77	92/77	17	80	79	79
Minden	32	4	93	2	250	20	25	99/77	96/76	94/76	20	79	79	78
Mossroe AP	32	3	92	0	78	20	25	99/77	96/76	94/76	20	79	79	78
Natchitoches	31	5	93	0	120	22	26	97/77	95/77	93/77	20	80	79	78

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^c	Col. 4 Elevation ^d Ft.	Winter ^d				Summer ^e				Col. 8		
				Col. 5		Col. 6		Col. 7		Col. 8		Col. 8		
				Design Dry-Bulb		Mean Coincident Wet-Bulb		Mean Daily Range		Design Wet-Bulb		Col. 8		
				99%	97.5%	1%	2.5%	5%	Range	1%	2.5%	5%		
New Orleans AP	30	0	90	2	3	29	33	93/78	92/78	90/77	16	81	80	79
Shreveport AP(S)	32	3	93	5	252	20	25	99/77	96/76	94/76	20	79	79	78
MAINE														
Augusta AP	44	2	69	5	350	-7	-3	88/73	85/70	82/68	22	74	72	70
Bangor, Dow AFB	44	5	68	5	162	-11	-6	86/70	83/68	80/67	22	73	71	69
Caribou AP (S)	46	5	68	0	624	-18	-13	84/69	81/67	78/66	21	71	69	67
Lewiston	44	0	70	1	182	-7	-2	88/73	85/70	82/68	22	74	72	70
Millinocket AP	45	4	68	4	405	-13	-9	87/69	83/68	80/66	22	72	70	68
Portland (S)	43	4	70	2	61	-6	-1	87/72	84/71	81/69	22	74	72	70
Waterville	44	3	69	4	89	-8	-4	87/72	84/69	81/68	22	74	72	70
MARYLAND														
Baltimore AP	39	1	76	4	146	10	13	94/75	91/75	89/74	21	78	77	76
Baltimore CO	39	2	76	3	14	14	17	92/77	89/76	87/75	17	80	78	76
Cumberland	39	4	78	5	945	6	10	92/75	89/74	87/74	22	77	76	75
Frederick AP	39	3	77	3	294	8	12	94/76	91/75	88/74	22	78	77	76
Hagerstown	39	4	77	4	660	8	12	94/75	91/74	89/74	22	77	76	75
Salisbury (S)	38	2	75	3	52	12	16	93/75	91/75	88/74	18	79	77	76
MASSACHUSETTS														
Boston AP (S)	42	2	71	0	15	6	9	91/73	88/71	85/70	16	75	74	72
Clinton	42	2	71	4	398	-2	2	90/72	87/71	84/69	17	75	73	72
Fall River	41	4	71	1	190	5	9	87/72	84/71	81/69	18	74	73	72
Framingham	42	2	71	3	170	3	6	89/72	86/71	83/69	17	74	73	71
Gloucester	42	3	70	4	10	2	5	89/73	86/71	83/70	15	75	74	72
Greenfield	42	3	72	4	205	-7	-2	88/72	85/71	82/69	23	74	73	71
Lawrence	42	4	71	1	57	-6	0	90/73	87/72	84/70	22	76	74	73
Lowell	42	3	71	2	90	-4	1	91/73	88/72	85/70	21	76	74	73
New Bedford	41	4	71	0	70	5	9	85/72	82/71	80/69	19	74	73	72
Pittsfield AP	42	3	73	2	1170	-8	-3	87/71	84/70	81/68	23	73	72	70
Springfield,														
Westover AFB	42	1	72	3	247	-5	0	90/72	87/71	84/69	19	75	73	72
Taunton	41	5	71	1	20	5	9	89/73	86/72	83/70	18	75	74	73
Worcester AP	42	2	71	5	986	0	4	87/71	84/70	81/68	18	73	72	70
MICHIGAN														
Adrian	41	5	84	0	754	-1	3	91/73	88/72	85/71	23	76	75	73
Alpena AP	45	0	83	2	699	-11	-6	89/70	85/70	83/69	27	73	72	70
Battle Creek AP	42	2	85	2	939	1	5	92/74	88/72	85/70	25	76	74	73
Benton Harbor AP	42	1	86	3	649	1	5	91/72	88/72	85/70	20	75	74	72
Detroit	42	2	83	0	633	3	6	91/73	88/72	86/71	20	76	74	73
Escanaba	45	4	87	0	594	-11	-7	87/70	83/69	80/68	17	73	71	69
Flint AP	42	0	83	4	766	-4	1	90/73	87/72	85/71	25	76	74	72
Grand Rapids AP	42	5	85	3	681	1	5	91/72	88/72	85/70	24	75	74	72
Holland	42	5	86	1	612	2	6	88/72	86/71	83/70	22	75	73	72
Jackson AP	42	2	84	2	1003	1	5	92/74	88/72	85/70	23	76	74	73
Kalamazoo	42	1	85	3	930	1	5	92/74	88/72	85/70	23	76	74	73
Lansing AP	42	5	84	4	852	-3	1	90/73	87/72	84/70	24	75	74	72
Marquette CO	46	3	87	3	677	-12	-8	84/70	81/69	77/66	18	72	70	68
Mt Pleasant	43	4	84	5	796	0	4	91/73	87/72	84/71	24	76	74	72
Muskegon AP	43	1	86	1	627	2	6	86/72	84/70	82/70	21	75	73	72
Pontiac	42	4	83	2	974	0	4	90/73	87/72	85/71	21	76	74	73
Port Huron	43	0	82	3	586	0	4	90/73	87/72	83/71	21	76	74	73
Saginaw AP	43	3	84	1	662	0	4	91/73	87/72	84/71	23	76	74	72
Sault														
St. Marie AP (S)	46	3	84	2	721	-12	-8	84/70	81/69	77/66	23	72	70	68
Traverse City AP	44	4	85	4	618	-3	1	89/72	86/71	83/69	22	75	73	71
Ypsilanti	42	1	83	3	777	1	5	92/72	89/71	86/70	22	75	74	72
MINNESOTA														
Albert Lea	43	4	93	2	1235	-17	-12	90/74	87/72	84/71	24	77	75	73
Alexandria AP	45	5	95	2	1421	-22	-16	91/72	88/72	85/70	24	76	74	72
Bemidji AP	47	3	95	0	1392	-31	-26	88/69	85/69	81/67	24	73	71	69
Brainerd	46	2	94	2	1214	-20	-15	90/73	87/71	84/69	24	75	73	71
Duluth AP	46	5	92	1	1426	-21	-16	85/70	82/68	79/66	22	72	70	68
Fairbault	44	2	93	2	1190	-17	-12	91/74	88/72	85/71	24	77	75	73
Fergus Falls	46	1	96	0	1210	-21	-17	91/72	88/72	85/70	24	76	74	72
International Falls AP	48	3	93	2	1179	-29	-25	85/68	83/68	80/66	26	71	70	68

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Lat- tude ^b	Col. 3 Long- tude ^c	Col. 4 Eleva- tion ^e Ft	Winter ^d		Summer ^d								
				Col. 5		Col. 6			Col. 7					Col. 8
				Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range		Design Wet-Bulb			
				99%	97.5%	1%	2.5%	5%	1%	2.5%	5%			
Mankato	44	1	94	0	785	-17	-12	91/72	88/72	85/70	24	77	75	73
Minneapolis/ St Paul AP	44	5	93	1	822	-16	-12	92/75	89/73	86/71	22	77	75	73
Rochester AP	44	0	92	3	1297	-17	-12	90/74	87/72	84/71	24	77	75	73
St Cloud AP (S)	45	4	94	1	1034	-15	-11	91/74	88/72	85/70	24	76	74	72
Virginia	47	3	92	3	1435	-25	-21	85/69	83/68	80/66	23	71	70	68
Willmar	45	1	95	0	1133	-15	-11	91/74	88/72	85/71	24	76	74	72
Winona	44	1	91	4	652	-14	-10	91/75	88/73	85/72	24	77	75	74
MISSISSIPPI														
Biloxi,														
Keesler AFB	30	2	89	0	25	28	31	94/79	92/79	90/78	16	82	81	80
Clarksdale	34	1	90	3	178	14	19	96/77	94/77	92/76	21	80	79	78
Columbus AFB	33	4	88	3	224	15	20	95/77	93/77	91/76	22	80	79	78
Greenville AFB	33	3	91	1	139	15	20	95/77	93/77	91/76	21	80	79	78
Greenwood	33	3	90	1	128	15	20	95/77	93/77	91/76	21	80	79	78
Hattiesburg	31	2	89	2	200	24	27	96/78	94/77	92/77	21	81	80	79
Jackson AP	32	2	90	1	330	21	25	97/76	95/76	93/76	21	79	78	78
Laurel	31	4	89	1	264	24	27	96/78	94/77	92/77	21	81	80	79
McComb AP	31	2	90	3	458	21	26	96/77	94/76	92/76	18	80	79	78
Meridian AP	32	2	88	5	294	19	23	97/77	95/76	93/76	22	80	79	78
Natchez	31	4	91	3	168	23	27	96/78	94/78	92/77	21	81	80	79
Tupelo	34	2	88	4	289	14	19	96/77	94/77	92/76	22	80	79	78
Vicksburg CO	32	2	91	0	234	22	26	97/78	95/78	93/77	21	81	80	79
MISSOURI														
Cape Girardeau	37	1	89	3	330	8	13	98/76	95/75	92/75	21	79	78	77
Columbia AP (S)	39	0	92	2	778	-1	4	97/74	94/74	91/73	22	78	77	76
Farmington AP	37	5	90	3	928	3	8	96/76	93/75	90/74	22	78	77	75
Hannibal	39	4	91	2	489	-2	3	96/76	93/76	90/76	22	80	78	77
Jefferson City	38	4	92	1	640	2	7	98/75	95/74	92/74	23	78	77	76
Joplin AP	37	1	94	3	982	6	10	100/73	97/73	94/73	24	78	77	76
Kansas City AP	39	1	94	4	742	2	6	99/75	96/74	93/74	20	78	77	76
Kirkville AP	40	1	92	4	966	-5	0	96/74	93/74	90/73	24	78	77	76
Mexico	39	1	92	0	775	-1	4	97/74	94/74	91/73	22	78	77	76
Moberly	39	3	92	3	850	-2	3	97/74	94/74	91/73	23	78	77	76
Poplar Bluff	36	5	90	3	322	11	16	98/78	95/76	92/76	22	81	79	78
Rolla	38	0	91	5	1202	3	9	94/77	91/75	89/74	22	78	77	76
St Joseph AP	39	5	95	0	809	-3	2	96/77	93/76	91/76	23	81	79	77
St Louis AP	38	5	90	2	535	2	6	97/75	94/75	91/74	21	78	77	76
St Louis CO														
Sedalia,	38	4	90	2	465	3	8	98/75	94/75	91/74	18	78	77	76
Whiteman AFB	38	4	93	3	838	-1	4	95/76	92/76	90/75	22	79	78	76
Sikeston	36	5	89	3	318	9	15	98/77	95/76	92/75	21	80	78	77
Springfield AP	37	1	93	2	1265	3	9	96/73	93/74	91/74	23	78	77	75
MONTANA														
Billings AP	45	5	108	3	3567	-15	-10	94/64	91/64	88/63	31	67	66	64
Bozeman	45	5	111	0	4856	-20	-14	90/61	87/60	84/59	32	63	62	60
Butte AP	46	0	112	3	5526	-24	-17	86/58	83/56	80/56	35	60	58	57
Cut Bank AP	48	4	112	2	3838	-25	-20	88/61	85/61	82/60	35	64	62	61
Glasgow AP (S)	48	1	108	4	2277	-22	-18	92/64	89/63	85/62	29	68	66	64
Glendive	47	1	104	4	2076	-18	-13	95/66	92/64	89/62	29	69	67	65
Great Falls AP (S)	47	3	111	2	3664	-21	-15	91/60	88/60	85/59	28	64	62	60
Havre	48	3	109	4	2488	-18	-11	94/65	90/64	87/63	33	68	66	65
Helena AP	46	4	112	0	3893	-21	-16	91/60	88/60	85/59	32	64	62	61
Kalispell AP	48	2	114	2	2965	-14	-7	91/62	87/61	84/60	34	65	63	62
Lewiston AP	47	0	109	3	4132	-22	-16	90/62	87/61	83/60	30	65	63	62
Livingston AP	45	4	110	3	4653	-20	-14	90/61	87/60	84/59	32	63	62	60
Miles City AP	46	3	105	5	2629	-20	-15	98/66	95/66	92/65	30	70	68	67
Missoula AP	46	5	114	1	3200	-13	-6	92/62	88/61	85/60	36	65	63	62
NEBRASKA														
Beatrice	40	2	96	5	1235	-5	-2	99/75	95/74	92/74	24	78	77	76
Chadron AP	42	5	103	0	3300	-8	-3	97/66	94/65	91/65	30	71	69	68
Columbus	41	3	97	2	1442	-6	-2	98/74	95/73	92/73	25	77	76	75
Fremont	41	3	96	3	1203	-6	-2	98/75	95/74	92/74	22	78	77	76

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

CLIMATIC CONDITIONS FOR THE UNITED STATES														
Col. 1 State and Station	Col. 2 Latitude ^a	Col. 3 Longitude ^a	Col. 4 Elevation ^a ft	Winter ^d		Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb			Summer ^d		Col. 8 Design Wet-Bulb			
				Col. 5					Col. 7					
				Design	Dry-Bulb	1%	2.5%	5%	Mean Daily Range	1%	2.5%	5%		
Grand Island AP	41	0	98	2	1841	-8	-3	97/72	94/71	91/71	28	75	74	73
Hastings	40	4	98	3	1932	-7	-3	97/72	94/71	91/71	27	75	74	73
Kearney	40	4	99	1	2146	-9	-4	96/71	93/70	90/70	28	74	73	72
Lincoln CO (S)	40	5	96	5	1150	-5	-2	99/75	95/74	92/74	24	78	77	76
McCook	40	1	100	4	2565	-6	-2	98/69	95/69	91/69	28	74	72	71
Norfolk	42	0	97	3	1532	-8	-4	97/74	93/74	90/73	30	78	77	75
North Platte AP (S)	41	1	100	4	2779	-8	-4	97/69	94/69	90/69	28	74	72	71
Omaha AP	41	2	95	5	978	-8	-3	94/76	91/75	88/74	22	78	77	75
Scottsbluff AP	41	5	103	4	3950	-8	-3	95/65	92/65	90/64	31	70	68	67
Sidney AP	41	1	103	0	4292	-8	-3	95/65	92/65	90/64	31	70	68	67
NEVADA														
Carson City	39	1	119	5	4675	4	9	94/60	91/59	89/58	42	63	61	60
Elko AP	40	5	115	5	5075	-8	-2	94/59	92/59	90/58	42	63	62	60
Ely AP (S)	39	1	114	5	6257	-10	-4	89/57	87/56	85/55	39	60	59	58
Las Vegas AP (S)	36	1	115	1	2162	25	28	108/66	106/65	104/65	30	71	70	69
Lovelock AP	40	0	118	3	3900	8	12	98/63	96/63	93/62	42	66	65	64
Reno AP (S)	39	3	119	5	4404	5	10	95/61	92/60	90/59	45	64	62	61
Reno CO	39	3	119	5	4490	6	11	96/61	93/60	91/59	45	64	62	61
Tonopah AP	38	0	117	1	5426	5	10	94/60	92/59	90/58	40	64	62	61
Winnemucca AP	40	5	117	5	4299	-1	3	96/60	94/60	92/60	42	64	62	61
NEW HAMPSHIRE														
Berlin	44	3	71	1	1110	-14	-9	87/71	84/69	81/68	22	73	71	70
Claremont	43	2	72	2	420	-9	-4	89/72	86/70	83/69	24	74	73	71
Concord AP	43	1	71	3	339	-8	-3	90/72	87/70	84/69	26	74	73	71
Keene	43	0	72	2	490	-12	-7	90/72	87/70	83/69	24	74	73	71
Laconia	43	3	71	3	505	-10	-5	89/72	86/70	83/69	25	74	73	71
Manchester,														
Grenier AFB	43	0	71	3	253	-8	-3	91/72	88/71	85/70	24	75	74	72
Portsmouth,														
Pease AFB	43	1	70	5	127	-2	2	89/73	85/71	83/70	22	75	74	72
NEW JERSEY														
Atlantic City CO	39	3	74	3	11	10	13	92/74	89/74	86/72	18	78	77	75
Long Branch	40	2	74	0	20	10	13	93/74	90/73	87/72	18	78	77	75
Newark AP	40	4	74	1	11	10	14	94/74	91/73	88/72	20	77	76	75
New Brunswick	40	3	74	3	86	6	10	92/74	89/73	86/72	19	77	76	75
Paterson	40	5	74	1	100	6	10	94/74	91/73	88/72	21	77	76	75
Phillipsburg	40	4	75	1	180	1	6	92/73	89/72	86/71	21	76	75	74
Trenton CO	40	1	74	5	144	11	14	91/75	88/74	85/73	19	78	76	75
Vineland	39	3	75	0	95	8	11	91/75	89/74	86/73	19	78	76	75
NEW MEXICO														
Alamogordo,														
Holloman AFB	32	5	106	1	4070	14	19	98/64	96/64	94/64	30	69	68	67
Albuquerque AP (S)	35	0	106	4	5310	12	16	96/61	94/61	92/61	27	66	65	64
Artesia	32	5	104	2	3375	13	19	103/67	100/67	97/67	30	72	71	70
Carlsbad AP	32	2	104	2	3234	13	19	103/67	100/67	97/67	28	72	71	70
Clovis AP	34	3	103	1	4279	8	13	95/65	93/65	91/65	28	69	68	67
Farmington AP	36	5	108	1	5495	1	6	95/63	93/62	91/61	30	67	65	64
Gallup	35	3	108	5	6465	0	5	90/59	89/58	86/58	32	64	62	61
Grants	35	1	107	5	6520	-1	4	89/59	88/58	85/57	32	64	62	61
Hobbs AP	32	4	103	1	3664	13	18	101/66	99/66	97/66	29	71	70	69
Las Cruces	32	2	107	0	3900	15	20	99/64	96/64	94/64	30	69	68	67
Los Alamos	35	5	106	2	7410	5	9	89/60	87/60	85/60	32	62	61	60
Raton AP	36	5	104	3	6379	-4	1	91/60	89/60	87/60	34	65	64	63
Roswell,														
Walker AFB	33	2	104	3	3643	13	18	100/66	98/66	96/66	33	71	70	69
Santa Fe CO	35	4	106	0	7045	6	10	90/61	88/61	86/61	28	63	62	61
Silver City AP	32	4	108	2	5373	5	10	95/61	94/60	91/60	30	66	64	63
Socorro AP	34	0	106	5	4617	13	17	97/62	95/62	93/62	30	67	66	65
Tucuman AP	35	1	103	4	4053	8	13	99/66	97/66	95/65	28	70	69	68
NEW YORK														
Albany AP (S)	42	5	73	5	277	-6	-1	91/73	88/72	85/70	23	75	74	72
Albany CO	42	5	73	5	19	-4	1	91/73	88/72	85/70	20	75	74	72
Auburn	43	0	76	3	715	-3	2	90/73	87/71	84/70	22	75	73	72
Batavia	43	0	78	1	900	1	5	90/72	87/71	84/70	22	75	73	72
Binghamton AP	42	1	76	0	1590	-2	1	86/71	83/69	81/68	20	73	72	70
Buffalo AP	43	0	78	4	705r	2	6	88/71	85/70	83/69	21	74	73	72
Cortland	42	4	76	1	1129	-5	0	88/71	85/71	82/70	23	74	73	71
Dunkirk	42	3	79	2	590	4	9	88/73	85/72	83/71	18	75	74	72
Elmira AP	42	1	76	5	860	-4	1	89/71	86/71	83/70	24	74	73	71
Geneva (S)	42	5	77	0	590	-3	2	90/73	87/71	84/70	22	75	73	72

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^c	Col. 4 Elevation ^d - Ft	Winter ^a			Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb			Summer ^a		Col. 8		
				Col. 5						Col. 7				
				Design Dry-Bulb						Mean Daily Range				
				99%	97.5%		1%	2.5%	5%			1%	2.5%	5%
Glen Falls	42	2	73	4	321	-11	-5	88/72	85/71	82/69	23	74	73	71
Gloversville	43	1	74	2	790	-8	-2	89/72	86/71	83/69	23	75	74	72
Hornell	42	2	77	4	1325	-4	0	88/71	85/70	82/69	24	74	73	72
Ithaca (S)	42	3	76	3	950	-5	0	88/71	85/71	82/70	24	74	73	71
Jamestown	42	1	79	2	1390	-1	3	88/70	86/70	83/69	20	74	72	71
Kingston	42	0	74	0	279	-3	2	91/73	88/72	85/70	22	76	74	73
Lockport	43	1	78	4	520	4	7	89/74	86/72	84/71	21	76	74	73
Massena AP	43	0	75	0	202r	-13	-8	86/70	83/69	80/68	20	73	72	70
Newburg														
Stewart AFB	41	3	74	1	460	-1	4	90/73	88/72	85/70	21	76	74	73
NYC-Central Park (S)	40	5	74	0	132	11	15	92/74	89/73	87/72	17	76	75	74
NYC-														
Kennedy AP	40	4	73	5	16	12	15	90/73	87/72	84/71	16	76	75	74
NYC-														
La Guardia AP	40	5	73	5	19	11	15	92/74	89/73	87/72	16	76	75	74
Niagra Falls AP	43	1	79	0	596	4	7	89/74	86/72	84/71	20	76	74	73
Olean	42	1	78	3	1420	-2	2	87/71	84/71	81/70	23	74	73	71
Oneonta	42	3	75	0	1150	-7	-4	86/71	83/69	80/68	24	73	72	70
Orwego CO	43	3	76	3	300	1	7	86/73	83/71	80/70	20	75	73	72
Pittsburg AFB	44	4	73	3	165	-13	-8	86/70	83/69	80/68	22	73	72	70
Poughkeepsie	41	4	73	5	103	0	6	92/74	89/74	86/72	21	77	75	74
Rochester AP	43	1	77	4	543	1	5	91/73	88/71	85/70	22	75	73	72
Rome														
Griffiss AFB	43	1	75	3	515	-11	-5	88/71	85/70	83/69	22	75	73	71
Schenectady (S)	42	5	74	0	217	-4	1	90/73	87/72	84/70	22	75	74	72
Suffolk County AFB	40	5			57	7	10	86/72	83/71	80/70	16	76	74	73
Syracuse AP	43	1	76	1	424	-3	2	90/73	87/71	84/70	20	75	73	72
Utica	43	1	75	2	714	-12	-6	88/73	85/71	82/70	22	75	73	71
Watertown	44	0	76	0	497	-11	-6	86/73	83/71	81/70	20	75	73	72
NORTH CAROLINA														
Asheville AP	35	3	82	3	217r	10	14	89/73	87/72	85/71	21	75	74	72
Charlotte AP	35	0	81	0	735	18	22	95/74	93/74	91/74	20	77	76	76
Durham	36	0	78	5	406	16	20	94/75	92/75	90/75	20	78	77	76
Elizabeth City AP	36	2	76	1	10	12	19	93/78	91/77	89/76	18	80	78	78
Fayetteville														
Pope AFB	35	1	79	0	95	17	20	95/76	92/76	90/75	20	79	78	77
Goldisboro, Seymour-														
Johnson AFB	35	2	78	0	88	18	21	94/77	91/76	89/75	18	79	78	77
Greensboro AP (S)	36	1	80	0	887	14	18	93/74	91/73	89/73	21	77	76	75
Greenville	35	4	77	2	25	18	21	93/77	91/76	89/75	19	79	78	77
Henderson	36	2	78	2	510	12	15	95/77	92/76	90/76	20	79	78	77
Hickory	35	4	81	2	1165	14	18	92/73	90/72	88/72	21	75	74	73
Jacksonville	34	5	77	3	24	20	24	92/78	90/78	88/77	18	80	79	78
Lumberton	34	4	79	0	132	18	21	95/76	92/76	90/75	20	79	78	77
New Bern AP	35	1	77	0	17	20	24	92/78	90/78	88/77	18	80	79	78
Raleigh/														
Durham AP (S)	35	5	78	5	433	16	20	94/75	92/75	90/75	20	78	77	76
Rocky Mount	36	0	77	5	81	18	21	94/77	91/76	89/75	19	79	78	77
Wilmington AP	34	2	78	0	30	23	26	93/79	91/78	89/77	18	81	80	79
Winston-Salem AP	36	1	80	1	967	16	20	94/74	91/73	89/73	20	76	75	74
NORTH DAKOTA														
Bismark AP (S)	46	5	100	5	1647	-23	-19	95/68	91/68	88/67	27	73	71	70
Devil's Lake	48	1	98	5	1471	-25	-21	91/69	88/68	85/66	25	73	71	69
Dickinson AP	46	5	102	5	2595	-21	-17	94/68	90/66	87/65	25	71	69	68
Fargo AP	46	5	96	5	900	-22	-18	92/73	89/71	85/69	25	76	74	72
Grands Forks AP	48	0	97	2	832	-26	-22	91/70	87/70	84/68	25	74	72	70
Jamestown AP	47	0	98	4	4492	-22	-18	94/70	90/69	87/68	26	74	74	71
Minot AP	48	2	101	2	1713	-24	-20	92/68	89/67	86/65	25	72	70	68
Williston	48	1	103	4	1877	-25	-21	91/68	88/67	85/65	25	72	70	68
OHIO														
Akron-Canton AP	41	0	81	3	1210	1	6	89/72	86/71	84/70	21	75	73	72
Ashtabula	42	0	80	5	690	4	9	88/73	85/72	83/71	18	75	74	72
Athens	39	2	82	1	700	0	6	95/75	92/74	90/73	22	78	76	74
Bowling Green	41	3	83	4	675	-2	2	92/73	89/73	86/71	23	76	75	73
Cambridge	40	0	81	4	800	1	7	93/75	90/74	87/73	23	78	76	75

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Lat- tude ^b	Col. 3 Long- tude ^c	Col. 4 Eleva- tion ^c ft	Winter ^d			Summer ^d				Col. 8			
				Col. 5		Design Dry-Bulb	Col. 6			Mean Daily Range	Col. 7			
				99%	97.5%		Design Dry-Bulb and Mean Coincident Wet-Bulb	1%	2.5%	5%	1%	2.5%	5%	5%
Chillicothe	39	2	83	0	638	0	95/73	92/74	90/73	22	78	76	74	74
Cincinnati CO	39	1	84	4	761	1	92/73	90/72	88/72	21	77	75	74	74
Cleveland AP (S)	41	2	81	5	777	1	91/73	88/72	86/71	22	76	74	73	73
Columbus AP (S)	40	0	82	5	812	0	92/73	90/73	87/72	24	77	75	74	74
Dayton AP	39	5	84	1	997	-1	91/73	89/72	86/71	20	76	75	73	73
Defiance	41	2	84	2	700	-1	94/74	91/73	88/72	24	77	76	74	74
Findlay AP	41	0	83	4	797	2	92/74	90/73	87/72	24	77	76	74	74
Fremont	41	2	83	1	600	-3	90/73	88/73	85/71	24	76	75	73	73
Hamilton	39	2	84	3	650	0	92/73	90/72	87/71	22	76	75	73	73
Lancaster	39	4	82	4	920	0	93/74	91/73	88/72	23	77	75	74	74
Lima	40	4	84	0	860	-1	94/74	91/73	88/72	24	77	76	74	74
Mansfield AP	40	5	82	3	1297	0	90/73	87/72	85/72	22	76	74	73	73
Marion	40	4	83	1	920	0	93/74	91/73	88/72	23	77	76	74	74
Middletown	39	3	84	3	635	0	92/73	90/72	87/71	22	76	75	73	73
Newark	40	1	82	3	825	-1	94/73	92/73	89/72	23	77	75	74	74
Norwalk	41	1	82	4	720	-3	90/73	88/73	85/71	22	76	75	73	73
Portsmouth	38	5	83	0	530	5	95/76	92/74	89/73	22	78	77	75	75
Sandusky CO	41	3	82	4	606	1	93/73	91/72	88/71	21	76	74	73	73
Springfield	40	0	83	5	1020	-1	91/74	89/73	87/72	21	77	76	74	74
Steubenville	40	2	80	4	992	1	89/72	86/71	84/70	22	74	73	72	72
Toledo AP	41	4	83	5	676	-3	90/73	88/73	85/71	25	76	75	73	73
Warren	41	2	80	5	900	0	89/71	87/71	85/70	23	74	73	71	71
Wooster	40	5	82	0	1030	1	89/72	86/71	84/70	22	75	73	72	72
Youngstown AP	41	2	80	4	1178	-1	88/71	86/71	84/70	23	74	73	71	71
Zanesville AP	40	0	81	5	881	1	93/75	90/74	87/73	23	78	76	75	75
OKLAHOMA														
Ada	34	5	96	4	1015	10	100/74	97/74	95/74	23	77	76	75	75
Altus AFB	34	4	99	2	1390	11	102/73	100/73	98/73	25	77	76	75	75
Ardmore	34	2	97	1	880	13	100/74	98/74	95/74	23	77	77	76	76
Bartlesville	36	5	96	0	715	6	101/73	98/74	95/74	23	77	77	76	76
Chickasha	35	0	98	0	1085	10	101/74	98/74	95/74	24	78	77	76	76
Enid-Vance AFB	36	2	98	0	1287	9	103/74	100/74	97/74	24	79	77	76	76
Lawton AP	34	3	98	2	1108	12	101/74	99/74	96/74	24	78	77	76	76
McAlester	34	5	95	5	760	14	99/74	96/74	93/74	23	77	76	75	75
Muskogee AP	35	4	95	2	610	10	101/74	98/75	95/75	23	79	78	77	77
Norman	35	1	97	3	1109	9	99/74	96/74	94/74	24	77	76	75	75
Oklahoma City AP (S)	35	2	97	4	1280	9	100/74	97/74	95/73	23	78	77	76	76
Ponca City	36	4	97	0	996	5	100/74	97/74	94/74	24	77	76	75	75
Seminole	35	2	96	4	865	11	99/74	96/74	94/73	23	77	76	75	75
Stillwater (S)	36	1	97	1	884	8	100/74	96/74	93/74	24	77	76	75	75
Tulsa AP	36	1	95	5	650	8	101/74	98/75	95/75	22	79	78	77	77
Woodward	36	3	99	3	1900	6	100/73	97/73	94/73	26	78	76	75	75
OREGON														
Albany	44	4	123	1	224	18	92/67	89/66	86/65	31	69	67	66	66
Astoria AP (S)	46	1	123	5	8	25	75/65	71/62	68/61	16	65	63	62	62
Baker AP	44	5	117	5	3368	-1	92/63	89/61	86/60	30	65	63	61	61
Bend	44	0	121	2	3599	-3	90/62	87/60	84/59	33	64	62	60	60
Corvallis (S)	44	3	123	2	221	18	92/67	89/66	86/65	31	69	67	66	66
Eugene AP	44	1	123	1	364	17	92/67	89/66	86/65	31	69	67	66	66
Grants Pass	42	3	123	2	925	20	99/69	96/68	93/67	33	71	69	68	68
Klamath Falls AP	42	1	121	4	4091	4	90/61	87/60	84/59	36	63	61	60	60
Medford AP (S)	42	2	122	5	1298	19	98/68	94/67	91/66	35	70	68	67	67
Pendleton AP	45	4	118	5	1492	-2	97/65	93/64	90/62	29	66	65	63	63
Portland AP	45	4	122	4	21	17	89/68	85/67	81/65	23	69	67	66	66
Portland CO	45	3	122	4	57	18	90/68	86/67	82/65	21	69	67	66	66
Roseburg AP	43	1	123	2	505	18	93/67	90/66	87/65	30	69	67	66	66
Salem AP	45	0	123	0	195	18	92/68	88/66	84/65	31	69	68	66	66
The Dalles	45	4	121	1	102	13	93/69	89/68	85/66	28	70	68	67	67
PENNSYLVANIA														
Allentown AP	40	4	75	3	376	4	92/73	88/72	86/72	22	76	75	73	73
Altoona CO	40	2	78	2	1468	0	90/72	87/71	84/70	23	74	73	72	72
Butler	40	4	80	0	1100	1	90/73	87/72	85/71	22	75	74	73	73
Chambersburg	40	0	77	4	640	4	93/75	90/74	87/73	23	77	76	75	75
Erie AP	42	1	80	1	732	4	88/73	85/72	83/71	18	75	74	72	72
Harrisburg AP	40	1	76	5	335	7	94/75	91/74	88/73	21	77	76	75	75
Johnstown	40	2	78	5	1214	-3	86/70	83/70	80/68	23	72	71	70	70
Lancaster	40	1	76	2	255	4	93/75	90/74	87/73	22	77	76	75	75
Meadville	41	4	80	1	1065	0	88/71	85/70	83/69	21	73	72	71	71
New Castle	41	0	80	2	825	2	91/73	88/72	86/71	23	75	74	73	73

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES^a

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^c	Col. 4 Elevation ^d Ft	Winter ^e		Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb			Summer ^e		Col. 8 Design Wet-Bulb			
				Desire Dry-Bulb 99%	97.5%	1%	2.5%	5%	Mean Daily Range	1%	2.5%	5%		
Philadelphia AP	39	5	75	2	7	10	14	93/73	90/74	87/72	21	77	76	75
Pittsburgh AP	40	3	80	1	1137	1	5	89/72	86/71	84/70	22	74	73	72
Pittsburgh CO	40	3	80	0	749	3	7	91/72	88/71	86/70	19	74	73	72
Reading CO	40	2	76	0	226	9	13	92/73	89/72	86/72	19	76	75	73
Scranton/ Wilkes-Barre	41	2	75	4	940	1	5	90/72	87/71	84/70	19	74	73	72
State College (S)	40	5	77	5	1175	3	7	90/72	87/71	84/70	23	74	73	72
Sunbury	40	5	76	5	480	2	7	92/73	89/72	86/70	22	75	74	73
Uniontown	39	5	79	4	1040	5	9	91/74	88/73	85/72	22	76	75	74
Warren	41	5	79	1	1280	-2	4	89/71	86/71	83/70	24	74	73	72
West Chester	40	0	75	4	440	9	13	92/75	89/74	86/72	20	77	76	75
Williamsport AP	41	1	77	0	527	2	7	92/73	89/72	86/70	23	75	74	73
York	40	0	76	4	390	8	12	94/75	91/74	88/73	22	77	76	75
RHODE ISLAND														
Newport (S)	41	3	71	2	20	5	9	88/73	85/72	82/70	16	76	75	73
Providence AP	41	4	71	3	55	5	9	89/73	86/72	83/70	19	75	74	73
SOUTH CAROLINA														
Anderson	34	3	82	4	764	19	23	94/74	92/74	90/74	21	77	76	75
Charleston AFB (S)	32	5	80	0	41	24	27	93/78	91/78	89/77	18	81	80	79
Charleston CO	32	5	80	0	9	25	28	94/78	92/78	90/77	13	81	80	79
Columbia AP	34	0	81	1	217	20	24	97/76	95/75	93/75	22	79	78	77
Florence AP	34	1	79	4	146	22	25	94/77	92/77	90/76	21	80	79	78
Georgetown	33	2	79	2	14	23	26	92/79	90/78	88/77	18	81	80	79
Greenville AP	34	5	82	1	957	18	22	93/74	91/74	89/74	21	77	76	75
Greenwood	34	1	82	1	671	18	22	95/75	93/74	91/74	21	78	77	76
Orangeburg	33	3	80	5	244	20	24	97/76	95/75	93/75	20	79	78	77
Rock Hill	35	0	81	0	470	19	23	96/75	94/74	92/74	20	78	77	76
Spartanburg AP	35	0	82	0	816	18	22	93/74	91/74	89/74	20	77	76	75
Sumter-Shaw AFB	34	0	80	3	291	22	25	95/77	92/76	90/75	21	79	78	77
SOUTH DAKOTA														
Aberdeen AP	45	3	98	3	1296	-19	-15	94/73	91/72	88/70	27	77	75	73
Brookings	44	2	96	5	1642	-17	-13	95/73	92/72	89/71	25	77	75	73
Huron AP	44	3	98	1	1282	-18	-14	96/73	93/72	90/71	28	77	75	73
Mitchel	43	5	98	0	1346	-15	-10	96/72	93/71	90/70	28	76	75	73
Pierre AP	44	2	100	2	1718	-15	-10	99/71	95/71	92/69	29	75	74	72
Rapid City AP (S)	44	0	103	0	3165	-11	-7	95/66	92/65	89/63	28	71	69	67
Sioux Falls AP	43	4	96	4	1420	-15	-11	94/73	91/72	88/71	24	76	75	73
Watertown AP	45	0	97	0	1746	-19	-15	94/73	91/72	88/71	26	76	75	73
Yankton	43	0	97	2	1280	-13	-7	94/73	91/72	88/71	25	77	76	74
TENNESSEE														
Athens	33	3	84	4	940	13	18	95/74	92/73	90/73	22	77	76	75
Bristol														
Tri City AP	36	3	82	2	1519	9	14	91/72	89/72	87/71	22	75	75	73
Chattanooga AP	35	0	85	1	670	13	18	96/75	93/74	91/74	22	78	77	76
Clarksville	36	4	87	2	470	6	12	95/76	93/74	90/74	21	78	77	76
Columbia	35	4	87	0	690	10	15	97/75	94/74	91/74	21	78	77	76
Dyersburg	36	0	89	3	334	10	15	96/78	94/77	91/76	21	81	80	78
Greenville	35	5	82	5	1320	11	16	92/73	90/72	88/72	22	76	75	74
Jackson AP	35	4	88	5	413	11	16	98/76	95/75	92/75	21	79	78	77
Knoxville AP	35	5	84	0	980	13	19	94/74	92/73	90/73	21	77	76	75
Memphis AP	35	0	90	0	263	13	18	98/77	95/76	93/76	21	80	79	78
Murfreesboro	35	5	86	2	608	9	14	97/75	94/74	91/74	22	78	77	76
Nashville AP (S)	36	1	86	4	577	9	14	97/75	94/74	91/74	21	78	77	76
Tullahoma	35	2	86	1	1075	8	13	96/74	93/73	91/73	22	77	76	75
TEXAS														
Abilene AP	32	3	99	4	1759	15	20	101/71	99/71	97/71	22	75	74	74
Alice AP	27	4	98	0	180	31	34	100/78	98/77	95/77	20	82	81	79
Amarillo AP	35	1	101	4	3607	6	11	98/67	95/67	93/67	26	71	70	70
Austin AP	30	2	97	4	597	24	28	100/74	98/74	97/74	22	78	77	77
Bay City	29	0	96	0	52	29	33	96/77	94/77	92/77	16	80	79	78
Beaumont	30	0	94	0	18	27	31	95/79	93/78	91/78	19	81	80	80
Beeville	28	2	97	4	225	30	33	99/78	97/77	95/77	18	82	81	79
Big Springs AP (S)	32	2	101	3	2337	16	20	100/69	97/69	95/69	26	74	73	72
Brownsville AP (S)	25	5	97	3	16	35	39	94/77	93/77	92/77	18	80	79	78
Brownwood	31	5	99	0	1435	18	22	101/73	99/73	96/73	22	77	76	75
Bryan AP	30	4	96	2	275	24	29	98/76	96/76	94/76	20	79	78	77

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^c	Col. 4 Elevation ^d ft	Winter ^e		Summer ^e			Col. 8					
				Design Dry-Bulb	Mean Coincident Wet-Bulb	Mean Daily Range	Design Wet-Bulb							
							99%	97.5%	1%	2.5%	5%			
Corpus Christi AP	27	5	97	3	43	31	35	95/78	94/78	92/78	19	80	80	79
Corsicana	32	0	96	3	425	20	25	100/75	98/75	96/75	21	79	78	77
Dallas AP	32	5	96	3	481	18	22	102/75	100/75	97/75	20	78	78	77
Del Rio														
Laughlin AFB	29	2	101	0	1072	26	31	100/73	98/73	97/73	24	79	77	76
Denton	33	1	97	1	655	17	22	101/74	99/74	97/74	22	78	77	76
Eagle Pass	28	5	100	3	743	27	32	101/73	99/73	98/73	24	78	78	77
El Paso AP (S)	31	5	106	2	3918	20	24	100/64	98/64	96/64	27	69	68	68
Fort Worth AP (S)	32	5	97	0	544	17	22	101/74	99/74	97/74	22	78	77	76
Galveston AP	29	2	94	5	5	31	36	90/79	89/79	88/78	10	81	80	80
Greenville	33	0	96	1	575	17	22	101/74	99/74	97/74	21	78	77	76
Hartlingen	26	1	97	4	37	35	39	96/77	94/77	93/77	19	80	79	79
Houston AP	29	4	95	2	50	27	32	96/77	94/77	92/77	18	80	79	79
Houston CO	29	5	95	2	158	28	33	97/77	95/77	93/77	18	80	79	79
Huntsville	30	4	95	3	494	22	27	100/75	98/75	96/75	20	78	78	77
Killeen-Gray AFB	31	0	97	4	1021	20	25	99/73	97/73	95/73	22	77	76	75
Lamesa	32	5	102	0	2965	13	17	99/69	96/69	94/69	26	73	72	71
Laredo AFB	27	3	99	3	503	32	36	102/73	101/73	99/74	23	78	78	77
Longview	32	2	94	4	345	19	24	99/76	97/76	95/76	20	80	79	78
Lubbock AP	33	4	101	5	3243	10	15	98/69	96/69	94/69	26	73	72	71
Lufkin AP	31	1	94	5	286	25	29	99/76	97/76	94/76	20	80	79	78
Mc Allen	26	1	98	1	122	35	39	97/77	95/77	94/77	21	80	79	79
Midland AP (S)	32	0	102	1	2815	16	21	100/69	98/69	96/69	26	73	72	71
Mineral Wells AP	32	5	98	0	934	17	22	101/74	99/74	97/74	22	78	77	76
Palestine CO	31	5	95	4	580	23	27	100/76	98/76	96/76	20	79	79	78
Pampa	35	3	101	0	3230	7	12	99/67	96/67	94/67	26	71	70	70
Pecos	31	2	103	3	2580	16	21	100/69	98/69	96/69	27	73	72	71
Plainview	34	1	101	4	3400	8	13	98/68	96/68	94/68	26	72	71	70
Port Arthur AP	30	0	94	0	16	27	31	95/79	93/78	91/78	19	81	80	80
San Angelo														
Goodfellow AFB	31	2	100	2	1878	18	22	101/71	99/71	97/70	24	75	74	73
San Antonio AP (S)	29	3	98	3	792	25	30	99/72	97/73	96/73	19	77	76	76
Sherman														
Perrin AFB	33	4	96	4	763	15	20	100/75	98/75	95/74	22	78	77	76
Snyder	32	4	101	0	2325	13	18	100/70	98/70	96/70	26	74	73	72
Temple	31	1	97	2	675	22	27	100/74	99/74	97/74	22	78	77	77
Tyler AP	32	2	95	2	527	19	24	99/76	97/76	95/76	21	80	79	78
Vernon	34	1	99	2	1225	13	17	102/73	100/73	97/73	24	77	76	75
Victoria AP	28	5	97	0	104	29	32	98/78	96/77	94/77	18	82	81	79
Waco AP	31	4	97	0	500	21	26	101/75	99/75	97/75	22	78	78	77
Wichita Falls AP	34	0	98	3	994	14	18	103/73	101/73	98/73	24	77	76	75
UTAH														
Cedar City AP	37	4	113	1	5613	-2	5	93/60	91/60	89/59	32	65	63	62
Logan	41	4	111	5	4775	-3	2	93/62	91/61	88/60	33	65	64	63
Moab	38	5	109	3	3965	6	11	100/60	98/60	96/60	30	65	64	63
Ogden AP	41	1	112	0	4455	1	5	93/63	91/61	88/61	33	66	65	64
Price	39	4	110	5	5580	-2	5	93/60	91/60	89/59	33	65	63	62
Provo	40	1	111	4	4470	1	6	98/62	96/62	94/61	32	66	65	64
Richfield	38	5	112	0	5300	-2	5	93/60	91/60	89/59	34	65	63	62
St George CO	37	1	113	4	2899	14	21	103/65	101/65	99/64	33	70	68	67
Salt Lake City AP (S)	40	5	112	0	4220	3	8	97/62	95/62	92/61	32	66	65	64
Vernal AP	40	3	109	3	5280	-5	0	91/61	89/60	86/59	32	64	63	62
VERMONT														
Barre	44	1	72	3	1120	-16	-11	84/71	81/69	78/68	23	73	71	70
Burlington AP (S)	44	3	73	1	331	-12	-7	88/72	85/70	82/69	23	74	72	71
Rutland	43	3	73	0	620	-13	-8	87/72	84/70	81/69	23	74	72	71
VIRGINIA														
Charlottesville	38	1	78	3	870	14	18	94/74	91/74	88/73	23	77	76	75
Danville AP	36	3	79	2	590	14	16	94/74	92/73	90/73	21	77	76	75
Fredericksburg	38	2	77	3	50	10	14	96/76	93/75	90/74	21	78	77	76
Harrisonburg	38	3	78	5	1340	12	16	93/72	91/72	88/71	23	75	74	73
Lynchburg AP	37	2	79	1	947	12	16	93/74	90/74	88/73	21	77	76	75
Norfolk AP	36	5	76	1	26	20	22	93/77	91/76	89/76	18	79	78	77
Petersburg	37	1	77	3	194	14	17	95/76	92/76	90/75	20	79	78	77

Table D.1 (continued)

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^c	Col. 4 Elevation ^d Ft	Winter ^d		Summer ^d			Col. 7 Mean Daily Range	Col. 8				
				Col. 5		Col. 6				Col. 8				
				Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb				Design Wet-Bulb				
				99%	97.5%	1%	2.5%	5%		1%	2.5%	5%		
Richmond AP	37	3	77	2	162	14	17	95/76	92/76	90/75	21	79	78	77
Roanoke AP	37	2	80	0	1174r	12	16	93/72	91/72	88/71	23	75	74	73
Staunton	38	2	78	5	1480	12	16	93/72	91/72	88/71	23	75	74	73
Winchester	39	1	78	1	750	6	10	93/75	90/74	88/74	21	77	76	75
WASHINGTON														
Aberdeen	47	0	123	5	12	25	28	80/65	77/62	73/61	16	65	63	62
Bellingham AP	48	5	122	3	150	10	15	81/67	77/65	74/63	19	68	65	63
Bremerton	47	3	122	4	162	21	25	82/65	78/64	75/62	20	66	64	63
Ellensburg AP	47	0	120	3	1729	2	6	94/65	91/64	87/62	34	66	63	63
Everett- Paine AFB	47	5	122	1	598	21	25	80/65	76/64	73/62	20	67	64	63
Kennewick	46	0	119	1	392	5	11	99/68	96/67	92/66	30	70	68	67
Longview	46	1	123	0	12	19	24	88/68	85/67	81/65	30	69	67	66
Moses Lake														
Larson AFB	47	1	119	2	1183	1	7	97/66	94/65	90/63	32	67	66	64
Olympia AP	47	0	122	5	190	16	22	87/66	83/65	79/64	32	67	66	64
Port Angeles	48	1	123	3	99	24	27	72/62	69/61	67/60	18	64	62	61
Seattle-														
Boeing Fld	47	3	122	2	14	21	26	84/68	81/66	77/65	24	69	67	65
Seattle CO (S)	47	4	122	2	14	22	27	85/68	82/66	78/65	19	69	67	65
Seattle-														
Tacoma AP (S)	47	3	122	2	386	21	26	84/65	80/64	76/62	22	66	64	63
Spokane AP (S)	47	4	117	3	2357	-6	2	93/64	90/63	87/62	28	65	64	62
Tacoma-														
Mc Chord AFB	47	1	122	3	350	19	24	86/66	82/65	79/63	22	68	66	64
Walla Walla AP	46	1	118	2	1185	0	7	97/67	94/66	90/65	27	69	67	66
Wenatchee	47	2	120	2	634	7	11	99/67	96/66	92/64	32	68	67	65
Yakima AP	46	3	120	3	1061	-2	5	96/65	93/65	89/63	36	68	66	65
WEST VIRGINIA														
Beckley	37	5	81	1	2330	-2	4	83/71	81/69	79/69	22	73	71	70
Bluefield AP	37	2	81	2	2850	-2	4	83/71	81/69	79/69	22	73	71	70
Charleston AP	38	2	81	4	939	7	11	92/74	90/73	87/72	20	76	75	74
Clarksburg	39	2	80	2	977	6	10	92/74	90/73	87/72	21	76	75	74
Elkins AP	38	5	79	5	1970	1	6	86/72	84/70	82/70	22	74	72	71
Huntington CO	38	2	82	3	565r	5	10	94/76	91/74	89/73	22	78	77	75
Martinsburg AP	39	2	78	0	537	6	10	93/75	90/74	88/74	21	77	76	75
Morgantown AP	39	4	80	0	1245	4	8	90/74	87/73	85/73	22	76	75	74
Parkersburg CO	39	2	81	3	615r	7	11	93/75	90/74	88/73	21	77	76	75
Wheeling	40	1	80	4	659	1	5	89/72	86/71	84/70	21	74	73	72
WISCONSIN														
Appleton	44	2	88	2	742	-14	-9	89/74	86/72	83/71	23	76	74	72
Ashland	46	3	90	5	650	-21	-16	85/70	82/68	79/66	23	72	70	68
Beloit	42	3	89	0	780	-7	-3	92/75	90/75	88/74	24	78	77	75
Eau Claire AP	44	5	91	3	888	-15	-11	92/75	89/73	86/71	23	77	75	73
Fond du Lac	43	5	88	3	760	-12	-8	89/74	86/72	84/71	23	76	74	72
Green Bay AP	44	3	88	1	683	-13	-9	88/74	85/72	83/71	23	76	74	72
La Crosse AP	43	5	91	2	652	-13	-9	91/75	88/73	85/72	22	77	75	74
Madison AP (S)	43	1	89	2	858	-11	-7	91/74	88/73	85/71	22	77	75	73
Manitowoc	44	1	87	4	660	-11	-7	89/74	86/72	83/71	21	76	74	72
Marinette	45	0			605	-15	-11	87/73	84/71	82/70	20	75	73	71
Milwaukee AP	43	0	87	5	672	-8	-4	90/74	87/73	84/71	21	76	74	73
Racine	42	4	87	4	640	-6	-2	91/75	88/73	85/72	21	77	75	74
Sheboygan	43	4	87	4	648	-10	-6	89/75	86/73	83/72	20	77	75	74
Stevens Point	43	0	89	3	1079	-15	-11	92/75	89/73	86/71	23	77	75	73
Waukesha	43	0	88	1	860	-9	-5	90/74	87/73	84/71	23	76	74	73
Wausau AP	44	6	89	4	1196	-16	-12	91/74	88/72	85/70	23	76	74	72
WYOMING														
Casper AP	42	5	106	3	3319	-11	-5	92/58	90/57	87/57	31	63	61	60
Cheyenne AP	41	1	104	5	6126	-9	-1	89/58	86/58	84/57	30	63	62	60
Cody AP	44	3	109	0	3090	-19	-13	89/60	86/60	83/59	32	64	63	61
Evanston	41	2	111	0	6860	-9	-3	86/55	84/55	82/54	32	59	58	57
Lander AP (S)	42	5	108	4	5563	-16	-11	91/61	88/61	85/60	32	64	63	61
Laramie AP (S)	41	2	105	3	7266	-14	-6	84/56	81/56	79/55	28	61	60	59
Newcastle	43	5	104	1	4480	-17	-12	91/64	87/63	84/63	30	69	68	66
Rawlins	41	5	107	1	6736	-12	-4	86/57	83/57	81/56	40	62	61	60
Rock Springs AP	41	4	109	0	6741	-9	-3	86/55	84/55	82/54	32	59	58	57
Sheridan AP	44	5	107	0	3942	-14	-8	94/62	91/62	88/61	32	66	65	63
Torrington	4	0	104	1	4098	-14	-8	94/62	91/62	88/61	30	66	65	63

Table D.1 (continued)

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*
 (For Industrial Insulation Design Values, see Table 3B). These constants are expressed in Btu per (hour) (square foot) (degree Fahrenheit temperature difference). Conductivities (*k*) are per inch thickness, and conductances (*C*) are for thickness or construction stated, not per inch thickness. All values are for a mean temperature of 75 F, except as noted by an asterisk (*) which have been reported at 45 F. The SI units for Resistance (last two columns) were calculated by taking the values from the two Resistance columns under Customary Unit, and multiplying by the factor 1/*k* (r/in.) and 1/*C* (R) for the appropriate conversion factor in Table 18.

Description	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Customary Unit		Specific Heat, Btu/(lb (deg F)	SI Unit	
				Resistance ^b (R)			Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m · K) W	(m ² · K) W
BUILDING BOARD								
Boards, Panels, Subflooring, Sheathing Woodboard Panel Products								
Asbestos-cement board	120	4.0	—	0.25	—	0.24	1.73	0.003
Asbestos-cement board	120	—	33.00	—	0.03	—	—	0.01
Asbestos-cement board	120	—	16.50	—	0.06	—	—	0.06
Gypsum or plaster board	50	—	3.10	—	0.32	0.26	—	0.08
Gypsum or plaster board	50	—	2.22	—	0.45	—	—	0.10
Gypsum or plaster board	50	—	1.78	—	0.56	—	—	—
Plywood (Douglas Fir)	34	0.80	—	1.25	—	0.29	8.66	0.05
Plywood (Douglas Fir)	34	—	3.20	—	0.31	—	—	0.08
Plywood (Douglas Fir)	34	—	2.13	—	0.47	—	—	0.11
Plywood (Douglas Fir)	34	—	1.60	—	0.62	—	—	0.19
Plywood (Douglas Fir)	34	—	1.29	—	0.77	—	—	—

Table D.2 Thermal Properties of Building and Insulating Materials

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*

Description	Customary Unit						SI Unit	
	Density (lb/ft ³)	Conduc- tivity (B)	Conduc- tance (C)	Resistance ^b (R)		Specific Heat, Btu/(lb (deg F)	Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K) W	(m ² ·K) W
Plywood or wood panels..... 0.75 in.	34	—	1.07	—	0.93	0.29		0.16
Vegetable Fiber Board								
Sheathing, regular density..... 0.5 in.	18	—	0.76	—	1.32	0.31		0.23
..... 0.75 in.	18	—	0.49	—	2.06			0.36
Sheathing intermediate density..... 0.5 in.	22	—	0.82	—	1.22	0.31		0.21
Nail-base sheathing..... 0.5 in.	25	—	0.88	—	1.14	0.31		0.20
Shingle backer..... 0.375 in.	18	—	1.06	—	0.94	0.31		0.17
Shingle backer..... 0.3125 in.	18	—	1.28	—	0.78			0.14
Sound deadening board..... 0.5 in.	15	—	0.74	—	1.35	0.30		0.24
Tile and lay-in panels, plain or acoustic..... 0.5 in.	18	0.40	—	2.50	—	0.14	17.33	
..... 0.75 in.	18	—	0.80	—	1.25			0.22
Laminated paperboard..... 0.75 in.	18	—	0.53	—	1.89			0.33
Homogeneous board from recycled paper..... 0.75 in.	30	0.50	—	2.00	—	0.33	13.86	
Hardboard..... 0.75 in.	30	0.50	—	2.00	—	0.28	13.86	
Medium density..... 0.75 in.	50	0.73	—	1.37	—	0.31	9.49	
High density, service temp. service underlay..... 0.75 in.	55	0.82	—	1.22	—	0.32	8.46	
High density, std. tempered..... 0.75 in.	63	1.00	—	1.00	—	0.32	6.93	
Particleboard..... 0.75 in.	37	0.54	—	1.85	—	0.31	12.82	
Low density..... 0.75 in.	50	0.94	—	1.06	—	0.31	7.35	
Medium density..... 0.75 in.	62.5	1.18	—	0.85	—	0.31	5.89	
High density..... 0.75 in.	40	—	1.22	—	0.82	0.29		0.14
Underlayment..... 0.625 in.	—	—	1.06	—	0.94	0.33		0.17
Wood subfloor..... 0.75 in.								
BUILDING MEMBRANE								
Vapor—permeable felt..... 0.75 in.	—	—	16.70	—	0.06			0.01
Vapor—seal, 2 layers of mopped 15-lb felt..... 0.75 in.	—	—	8.35	—	0.12			0.02
Vapor—seal, plastic film..... 0.75 in.	—	—	—	—	Negl.			
FINISH FLOORING MATERIALS								
Carpet and fibrous pad..... 0.75 in.	—	—	0.48	—	2.08	0.34		0.37
Carpet and rubber pad..... 0.75 in.	—	—	0.81	—	1.23	0.33		0.22
Cork tile..... 0.125 in.	—	—	3.60	—	0.28	0.48		0.05
Terrazzo..... 1 in.	—	—	12.50	—	0.08	0.19		0.01
Tile—asphalt, linoleum, vinyl, rubber vinyl asbestos..... 0.75 in.	—	—	20.00	—	0.05	0.30		0.01
ceramic..... 0.75 in.	—	—	—	—	—	0.24		
Wood, hardwood finish..... 0.75 in.	—	—	1.47	—	0.68	0.19		0.12
INSULATING MATERIALS								
BLANKET AND BATT								
Mineral Fiber, fibrous form processed from rock, slag, or glass..... 0.3-2.0 in.	0.3-2.0	—	0.143	—	7 ^a	0.17-0.23		1.23
approx. # 2-3.75 in..... 0.3-2.0 in.	0.3-2.0	—	0.091	—	11 ^a			1.94
approx. # 3-3.5 in..... 0.3-2.0 in.	0.3-2.0	—	0.053	—	19 ^a			3.35
approx. # 3.50-6.5 in..... 0.3-2.0 in.	0.3-2.0	—	0.045	—	22 ^a			3.67
approx. # 6-7 in..... 0.3-2.0 in.	0.3-2.0	—	0.033	—	30 ^a			5.28
BOARD AND SLABS								
Cellular glass..... 8.5	8.5	0.38	—	2.63	—	0.24	18.23	
Glass fiber, organic bonded..... 4-9	4-9	0.25	—	4.00	—	0.23	27.72	
Expanded rubber (rigid)..... 4.5	4.5	0.22	—	4.55	—	0.40	31.53	
Expanded polystyrene extruded Cut cell surface..... 1.8	1.8	0.25	—	4.00	—	0.29	27.72	
Expanded polystyrene extruded Smooth skin surface..... 2.2	2.2	0.20	—	5.00	—	0.29	34.65	
Expanded polystyrene extruded Smooth skin surface..... 3.5	3.5	0.19	—	5.26	—		36.45	
Expanded polystyrene, molded beads..... 1.0	1.0	0.28	—	3.57	—	0.29	24.74	
Expanded polyurethane ^c (R-11 exp.)..... 1.5	1.5	0.16	—	6.25	—	0.38	43.82	
(Thickness 1 in. or greater)..... 2.5	2.5							

Table D.2 (continued)

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*

Description	Customary Unit						SI Unit	
	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Resistance ^b (R)		Specific Heat, Btu/(lb (deg F)	Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K) W	(m ² ·K) W
Mineral fiber with resin binder	15	0.29	—	3.45	—	0.17	23.91	
Mineral fiberboard, wet felted								
Core or roof insulation	16-17	0.34	—	2.94	—		20.38	
Acoustical tile	18	0.35	—	2.86	—	0.19	19.82	
Acoustical tile	21	0.37	—	2.70	—		18.71	
Mineral fiberboard, wet molded								
Acoustical tiles	23	0.42	—	2.38	—	0.14	16.49	
Wood or cane fiberboard								
Acoustical tiles	0.5 in.	—	0.80	—	1.25	0.31		0.22
Acoustical tiles	0.75 in.	—	0.53	—	1.89			0.33
Interior finish (plank, tile)	15	0.35	—	2.86	—	0.32	19.82	
Wood shredded (cemented in preformed slabs)	22	0.60	—	1.67	—	0.31	11.57	
LOOSE FILL								
Cellulosic insulation (milled paper or wood pulp)	2.3-3.2	0.27-0.32	—	3.13-3.70	—	0.33	21.69-25.64	
Sawdust or shavings	8.0-15.0	0.45	—	2.22	—	0.33	15.39	
Wood fiber, softwoods	2.0-3.5	0.30	—	3.33	—	0.33	23.08	
Perlite, expanded	5.0-8.0	0.37	—	2.70	—	0.26	18.71	
Mineral fiber (rock, slag or glass)								
approx. * 3.75-5 in.	0.6-2.0	—	—	—	11	0.17		1.94
approx. * 6.5-8.75 in.	0.6-2.0	—	—	—	19			3.35
approx. * 7.5-10 in.	0.6-2.0	—	—	—	22			3.87
approx. * 10.25-13.75 in.	0.6-2.0	—	—	—	30			5.28
Vermiculite, exfoliated	7.0-8.2	0.47	—	2.13	—	3.20	14.76	
	4.0-6.0	0.44	—	3.27	—		15.73	
ROOF INSULATION*								
Preformed, for use above deck								
Different roof insulations are available in different thicknesses to provide the design C values listed.* Consult individual manufacturers for actual thickness of their material.			0.72 to 0.12		1.39 to 8.33			0.24 to 1.47
MASONRY MATERIALS								
CONCRETES								
Cement mortar	116	5.0	—	0.20	—		1.39	
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips	51	1.66	—	0.60	—	0.21	4.16	
Lightweight aggregates including ex- panded shale, clay or slate; expanded slags; cinders; pumice; vermiculite; also cellular concretes	120	5.2	—	0.19	—		1.32	
	100	3.6	—	0.28	—		1.94	
	80	2.5	—	0.40	—		2.77	
	60	1.7	—	0.59	—		4.09	
	40	1.15	—	0.86	—		5.96	
	30	0.90	—	1.11	—		7.69	
	20	0.70	—	1.43	—		9.91	
Perlite, expanded	40	0.93	—	1.08	—		7.48	
	30	0.71	—	1.41	—		9.77	
	20	0.50	—	2.00	—	0.32	13.86	
Sand and gravel or stone aggregate (oven dried)	140	9.0	—	0.11	—	0.22	0.76	
Sand and gravel or stone aggregate (not dried)	140	12.0	—	0.08	—		0.55	
Stucco	116	5.0	—	0.20	—		1.39	
MASONRY UNITS								
Brick, common	120	5.0	—	0.20	—	0.19	1.39	
Brick, face	130	9.0	—	0.11	—		0.76	
Clay tile, hollow:								
1 cell deep	3 in.	—	1.25	—	0.80	0.21		0.14
1 cell deep	4 in.	—	0.90	—	1.11			0.20
2 cells deep	6 in.	—	0.66	—	1.52			0.27
2 cells deep	8 in.	—	0.54	—	1.85			0.33
2 cells deep	10 in.	—	0.45	—	2.22			0.39
3 cells deep	12 in.	—	0.40	—	2.50			0.44

Table D.2 (continued)

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*

Description	Density (lb./ft. ³)	Conduc- tivity (k)	Conduc- tance (C)	Customary Unit		Specific Heat, Btu/(lb.) (deg F)	SI Unit	
				Resistance ^b (R)			Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K)	(m ² ·K) W
Concrete blocks, three oval core: Sand and gravel aggregate	4 in.	—	1.40	—	0.71	0.22		0.13
	8 in.	—	0.90	—	1.11			0.20
	12 in.	—	0.78	—	1.28			0.23
Cinder aggregate	3 in.	—	1.16	—	0.86	0.21		0.15
	4 in.	—	0.90	—	1.11			0.20
	8 in.	—	0.58	—	1.72			0.30
	12 in.	—	0.53	—	1.89			0.33
Lightweight aggregate (expanded shale, clay, slate or slag; pumice)	3 in.	—	0.79	—	1.27	0.21		0.22
	4 in.	—	0.67	—	1.50			0.26
	8 in.	—	0.50	—	2.00			0.35
	12 in.	—	0.44	—	2.27			0.40
Concrete blocks, rectangular core, ^a Sand and gravel aggregate								
2 core, 8 in. 36 lb. k ^a	—	—	0.96	—	1.04	0.22		0.18
Same with filled cores ^j	—	—	0.52	—	1.93	0.22		0.34
Lightweight aggregate (expanded shale, clay, slate or slag, pumice):								
3 core, 6 in. 19 lb. k ^a	—	—	0.61	—	1.63	0.21		0.29
Same with filled cores ^j	—	—	0.33	—	2.99			0.53
2 core, 8 in. 24 lb. k ^a	—	—	0.46	—	2.18			0.38
Same with filled cores ^j	—	—	0.20	—	5.03			0.89
3 core, 12 in. 38 lb. k ^a	—	—	0.40	—	2.48			0.44
Same with filled cores ^j	—	—	0.17	—	5.82			1.02
Stone, lime or sand.	—	12.50	—	0.08	—	0.19	0.55	
Gypsum partition tile:								
3 × 12 × 30 in. solid	—	—	0.79	—	1.26	0.19		0.22
3 × 12 × 30 in. 4-cell	—	—	0.74	—	1.35			0.24
4 × 12 × 30 in. 3-cell	—	—	0.60	—	1.67			0.29
METALS (See Chapter 37, Table 3)								
PLASTERING MATERIALS								
Cement plaster, sand aggregate	116	5.0	—	0.20	—	0.20	1.39	
Sand aggregate	0.375 in.	—	13.3	—	0.08	0.20		0.01
Sand aggregate	0.75 in.	—	6.66	—	0.15	0.20		0.03
Gypsum plaster:								
Lightweight aggregate	0.5 in.	45	3.12	—	0.32			0.06
Lightweight aggregate	0.625 in.	45	2.67	—	0.39			0.07
Lightweight agg. on metal lath	0.75 in.	—	2.13	—	0.47			0.08
Perlite aggregate	45	1.5	—	0.67	—	0.32	4.64	
Sand aggregate	105	5.6	—	0.18	—	0.20	1.25	
Sand aggregate	0.5 in.	105	11.10	—	0.09			0.02
Sand aggregate	0.625 in.	105	9.10	—	0.11			0.02
Sand aggregate on metal lath	0.75 in.	—	7.70	—	0.13			0.02
Vermiculite aggregate	45	1.7	—	0.59	—		4.09	
ROOFING								
Asbestos-cement shingles	120	—	4.76	—	0.21	0.24		0.04
Asphalt roll roofing	70	—	6.50	—	0.15	0.36		0.03
Asphalt shingles	70	—	2.27	—	0.44	0.30		0.08
Built-up roofing	0.375 in.	70	3.00	—	0.33	0.35		0.06
Slate	0.5 in.	—	20.00	—	0.05	0.30		0.01
Wood shingles, plain and plastic film faced	—	—	1.06	—	0.94	0.31		0.17
SIMING MATERIALS (ON FLAT SURFACE)								
Shingles								
Asbestos-cement	120	—	4.75	—	0.21			0.04
Wood, 16 in., 7.5 exposure	—	—	1.15	—	0.87	0.31		0.15
Wood, double, 16-in., 12-in. exposure	—	—	0.84	—	1.19	0.28		0.21
Wood, plus insul. backer board, 0.3125 in.	—	—	0.71	—	1.40	0.31		0.25
Siding								
Asbestos-cement, 0.25 in., lapped	—	—	4.76	—	0.21	0.24		0.04
Asphalt roll siding	—	—	6.50	—	0.15	0.39		0.03
Asphalt insulating siding (0.5 in. bed.)	—	—	0.69	—	1.46	0.35		0.26
Wood, drop, 1 × 8 in.	—	—	1.27	—	0.79	0.28		0.14
Wood, bevel, 0.5 × 8 in., lapped	—	—	1.23	—	0.81	0.28		0.14
Wood, bevel, 0.75 × 10 in., lapped	—	—	0.95	—	1.05	0.28		0.18
Wood, plywood, 0.375 in., lapped	—	—	1.59	—	0.59	0.29		0.10
Wood, medium density siding, 0.4375 in.	40	1.49	—	0.67	—	0.28	4.63	

Table D.2 (continued)

Thermal Properties of Typical Building and Insulating Materials—(Design Values) ^a								
Description	Customary Unit						SI Unit	
	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Resistance ^b (R)		Specific Heat, Btu/(lb (deg F)	Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K) W	(m ² ·K) W
Aluminum or Steel ^c , over sheathing								
Hollow-backed	—	—	1.61	—	0.61	0.29		0.11
Insulating-board backed nominal 0.375 in.	—	—	0.55	—	1.82	0.32		0.32
Insulating-board backed nominal 0.375 in., foil backed	—	—	0.34	—	2.96			0.52
Architectural glass	—	—	10.00	—	0.10	0.20		0.02
WOODS ^d								
Maple, oak, and similar hardwoods	45	1.10	—	0.91	—	0.30	6.31	
Fir, pine, and similar softwoods	32	0.80	—	1.25	—	0.33	8.66	
Fir, pine, and similar softwoods	32	—	1.06	—	0.94	0.33		0.17
1.5 in.	—	—	0.53	—	1.89			0.33
2.5 in.	—	—	0.32	—	3.12			0.60
3.5 in.	—	—	0.23	—	4.35			0.75

Notes for Table 3A

^aRepresentative values for dry materials were selected by ASHRAE TC4.4, Insulation and Moisture Barriers. They are intended as design (not specification) values for materials in normal use. For properties of a particular product, use the value supplied by the manufacturer or by unbiased tests.

^bResistance values are the reciprocals of C before rounding off C to two decimal places.

^cAlso see Insulating Materials, Board.

^dDoes not include paper backing and facing, if any. Where insulation forms a boundary (reflective or otherwise) of an air space, see Tables 1 and 2 for the insulating value of air space for the appropriate effective emittance and temperature conditions of the space.

^eConductivity varies with fiber diameter. (See Chapter 20, Thermal Conductivity section, and Fig. 1.) Insulation is produced by different densities; therefore, there is a wide variation in thickness for the same R-value among manufacturers. No effort should be made to relate any specific R-value to any specific thickness. Commercial thicknesses generally available range from 2 to 8.5.

^fValues are for aged board stock. For change in conductivity with age of expanded urethane, see Chapter 19, Factors Affecting Thermal Conductivity.

^gInsulating values of acoustical tile vary, depending on density of the board and on type, size, and depth of perforations.

^hThe U. S. Department of Commerce, *Simplified Practice Recommendation for Thermal Conductance Factors for Preformed Above-Deck Roof Insulation*, No. R 257-55, recognizes the specification of roof insulation on the basis of the C-values shown. Roof insulation is made in thicknesses to meet these values.

ⁱFace brick and common brick do not always have these specific densities. When density is different from that shown, there will be a change in thermal conductivity.

^jData on rectangular core concrete blocks differ from the above data on oval core blocks, due to core configuration, different mean temperatures, and possibly differences in unit weights. Weight data on the oval core blocks tested are not available.

^kWeights of units approximately 7.625 in. high and 15.75 in. long. These weights are given as a means of describing the blocks tested, but conductance values are all for 1 ft² of area.

^lVermiculite, perlite, or mineral wool insulation. Where insulation is used, vapor barriers or other precautions must be considered to keep insulation dry.

^mValues for metal siding applied over flat surfaces vary widely, depending on amount of ventilation of air space beneath the siding; whether air space is reflective or nonreflective; and on thickness, type, and application of insulating backing-board used. Values given are averages for use as design guides, and were obtained from several guarded hotbox tests (ASTM C236) or calibrated hotbox (BSS 77) on hollow-backed types and types made using backing-boards of wood fiber, foamed plastic, and glass fiber. Departures of 50% or more from the values given may occur.

Table D.2 (continued)

WALL ASSEMBLIES

Table D-2

U_w SELECTED SHALL NOT EXCEED THE U_o DETERMINED BY SECTION 602.2(a) FOR ANY WALL SECTION.

NOTE: DETAILS SHOWN ARE FOR INSULATION AND ARE NOT COMPLETE CONSTRUCTION DETAILS.

WALL DETAILS		R VALUE OF INSULATION	U _w
SCHEDULES			
TYP. INTERIOR FINISH 1.GYPSUM WALLBOARD 2.LATH & PLASTER 3.3/8"MIN.WD.PANELING	TYP. EXTERIOR FINISH 1.STUCCO 2.WD. OR PLYWD.SDG. 3.BRICK VENEER		
WOOD STUD CONSTRUCTION INTERIOR FINISH — — EXTERIOR FINISH INSULATION — — SECTION		7	.12
		11	.09
		14	.07
		19	.05
AIR SPACE — — EXTERIOR FINISH INTERIOR FINISH — — RIGID INSULATION PLAN		4	.15
		6	.11
		8	.09
		10	.08
		12	.06
STEEL STUD CONSTRUCTION INTERIOR FINISH — — EXTERIOR FINISH INSULATION — — SECTION		7	.12
		11	.08
		14	.06
		19	.05
AIR SPACE OR INSULATION — — EXTERIOR FINISH INTERIOR FINISH — — INSULATION PLAN		4	.15
		6	.11
		8	.09
		10	.08
		12	.06

WALL ASSEMBLIES

Table D-2

U_w SELECTED SHALL NOT EXCEED THE U_0 DETERMINED BY SECTION 602.2(a) FOR ANY WALL SECTION.

NOTE: DETAILS SHOWN ARE FOR INSULATION AND ARE NOT COMPLETE CONSTRUCTION DETAILS.

MASONRY CONSTRUCTION

WALL DETAILS		R VALUE OF INSULATION	U_w
INT. FINISH - 1/2" GYPSUM BOARD ON FURRING STRIPS
	6" BLOCK	NO INSUL.	.37
	INSULATION 8" BLK.	LOOSE FILL IN CORES	.18
		NO INSUL.	.34
	LOOSE FILL IN CORES	.14
	4" BLOCK	NO INSUL. (NO INT. FINISH)	.25
	INSULATION	LOOSE FILL IN CAVITY	.14
		NO INSUL. WITH INT. FIN.	.19
	LOOSE FILL IN CAVITY WITH INT. FINISH	.11
	INSULATION	NO INSUL. INT. FINISH	.23
	RIGID INSUL.	LOOSE FILL IN CORES WITH INT. FINISH	.12
		1" RIGID GLASS FIBER INSUL. & INT. FINISH	.14
	INSULATION	R-7 INSUL. WITH INT. FINISH	.10

WALL ASSEMBLIES

Table D-2

U_w SELECTED SHALL NOT EXCEED THE U_0 DETERMINED BY SECTION 602.2(a) FOR ANY WALL SECTION.

NOTE: DETAILS SHOWN ARE FOR INSULATION AND ARE NOT COMPLETE CONSTRUCTION DETAILS.

WALL DETAILS		R VALUE OF INSULATION	U_w
INT. FINISH - 1/2" GYPSUM BOARD APPLIED ON FURRING STRIPS			
BRICK MASONRY CONSTRUCTION		SOLID GROUT IN SPACE	.38
		2" SPACE W/ LOOSE FILL R=4	.16
		4" SPACE W/ LOOSE FILL R=8	.10
CONCRETE CONSTRUCTION		4	.12
		6	.09
		7	.09
		11	.07
		4	.18
		6	.13
		7	.12
		11	.08
		4	.17
		6	.12
		7	.11
		11	.08

ROOF/CEILING ASSEMBLIES

Table D-2

U_r SELECTED SHALL NOT EXCEED THE
VALUE SPECIFIED IN 602.2(b).

NOTE: DETAILS SHOWN ARE FOR INSULATION AND ARE NOT COMPLETE CONSTRUCTION DETAILS.

ROOF DETAILS	R VALUE OF INSULATION	U_r
TYPICAL INTERIOR FINISH SCHEDULE 1.GYPSUM WALLBOARD 2.LATH & PLASTER
RAFTERS CLG. JOIST INSULATION CEILING FINISH SEE SCHEDULE	11 14 19 22 30	.09 .07 .05 .04 .03
AIR SPACE & VENTILATION DESIRABLE BUILT-UP ROOF SHEATHING INSULATION CLG. JSTS. OR RAFTERS CLG. FIN. SEE SCH'L.	11 14 19 22 30	.08 .06 .05 .04 .03
CATHEDRAL TYPE CEILING BUILT-UP ROOF RIGID INSULATION WD. OR PLYWD. SHT'G. BEAM	wood decking 9 plywood 10	.08 .08

1. SKYLITES NOT EXCEEDING ONE PERCENT OF THE ROOF AREA ARE PERMITTED.

FLOOR ASSEMBLIES

Table D-2

U_f SELECTED SHALL NOT EXCEED THE U_o SPECIFIED IN SECTION 602.2(c).

FLOOR DETAILS	R VALUE OF INSULATION	U_f
<p>The diagram illustrates a cross-section of a floor assembly. At the top, a layer of insulation is shown with a wavy pattern, labeled 'INSULATION'. Below it is a solid horizontal line representing the 'SUB-FLOOR'. The entire assembly is supported by vertical structural members labeled 'FLR. JOIST' and 'FLR. GIRDER'. The joists are shown as vertical lines with diagonal bracing, and the girder is a horizontal beam at the bottom with several small circles representing rivets or bolts.</p>	NO INSULATION	.32
	4	.15
	6	.12
	7	.11
	11	.08

CHAPTER 3
INTRODUCTION TO ENERGY CONSERVATION
MODEL ENERGY CONSERVATION CODE
(ECT-302)

PART 1. INTRODUCTION

I. ENERGY CONSERVATION

This section is designed to be used in conjunction with the code document itself. It provides information concerning the code, its intent, and some problems which may arise from its provisions; however, the code document itself should be the primary focus for the student.

The Code is based on the ASHRAE Standard 90-75. However, it restructures Standard 90-75, and adds accepted practice provisions for certain buildings. These will be discussed in more detail. The intent of the Code is to provide a means of implementing the provisions of ASHRAE Standard 90-75.

The following differences will be found when compared to ASHRAE 90-75:

- (a) Metric Equivalents Deleted: The S.I. equivalent formulas and units have been deleted from the Code. This is in accordance with the current code format. It is anticipated that the S.I. units will be added when the national building codes includes S.I. units throughout.
- (b) COP Improvement Targets: The improved COP target levels for HVAC equipment have been deleted since it is not possible to adopt a building code containing future enforcement provisions. The Code will be amended to include the 1980 COP levels at the time they are effective.
- (c) Code Restructured: The Code has been restructured into a three-path approach. Compliance with any of these paths produces a code complying building.

Path 1 (Section 4 of the Code) is the systems analysis design approach. This section also includes nondepletable energy source utilization, Std. 90-75, Chapters 10-11.

This section established design criteria in terms of total energy use by a building including all of its systems. Compliance with this section will require an annual energy analysis.

A building designed in accordance with this section will be deemed as complying with this Code if the annual energy consumption is not greater than a similar building whose enclosure elements and energy consuming systems are designed in accordance with Section 5.

A building of similar design would be a building utilizing the same energy source(s) for the same functions and having equal floor area, environmental requirements, occupancy, climate data and usage operational schedule.

The comparison is expressed as BTU input per square foot of gross floor area per year. If the proposed alternative design results in an increase in another energy source (even though similar sources are used for similar purposes) the difference in each energy source is converted to equivalent energy units for purposes of comparing the total energy used.

According to this method, any type of trade-off may be made in the design of a building, provided that the total amount of energy consumed is no greater than that in a building of conventional design. This path permits full utilization for code credit of any future developments in energy conservation equipment.

Path 2 (Section 5 of the Code) is the component performance design, ASHRAE 90-75, Chapters 4,5,6,7,8 and 9.

This path involves analysis of the heat loss and/or heat gain characteristics of the exterior building envelope. Thermal performance of individual components may be adjusted, but the entire assembly is required to meet specific standards. If a building utilizes both heating and cooling, it must meet the more stringent of the heating or cooling requirements. Requirements for mechanical, domestic hot water and electrical systems are contained in this section.

Path 3 (Section 6 of the Code) contains acceptable practice provisions for conventional residential buildings of three stories or less, or small commercial buildings of stud or masonry-wall construction of less than 5,000 square feet. This section of acceptable practice permits structures to be constructed in accordance with designated provisions in lieu of performing a thermal analysis. There are a number of limiting conditions

where these special provisions may not be applicable.

- (d) Charts and Graphs: The various graphs relative to envelope design have been relocated to the Reference Standards and replaced by a matrix providing spaces for the appropriate values. The reason for this is that the Code, when adopted by a local regulatory agency, becomes site-specific, and after adoption of the Code and identification of the appropriate U_o , OTTV, etc., values, there is no further need for the graphs.

One additional change involves creating a chapter entitled "Design Conditions", containing the basic design criteria. This follows the traditional building code approach of a chapter design loads followed by chapters regulating specific material design.

The Code is divided into Sections as follows:

SECTION 1 ADMINISTRATIVE AND ENFORCEMENT

SECTION 2 DEFINITIONS

SECTION 3 DESIGN CONDITIOINS

SECTION 4 BUILDING DESIGN BY SYSTEMS ANALYSIS AND BUILDINGS USING
NON-DEPLETABLE ENERGY RESOURCES

SECTION 5 COMPONENT DESIGN

SECTION 6 BUILDING DESIGN BY ACCEPTABLE PRACTICE

Refer to the Code for details of the various sections.

PART 2 BUILDING DESIGN AND SYSTEMS ANALYSIS

I. GENERAL

Section 4 of the Model Energy Conservation Code establishes a design criteria in terms of total energy by a building including all of its systems. An annual energy analysis is required for buildings not in compliance with established criteria for different building energy consuming and enclosure elements (Sections 5 and 6). When an annual energy analysis is required it must be of sufficient detail to permit evaluation of the effect of system design, climatic factors, operational characteristics and mechanical equipment of annual energy usage. The calculation procedure must be based upon 8,760 hours of operation of the building and its service systems and shall utilize accepted

engineering practice. Proposed alternative designs from the standard design criteria for single-family dwellings and for commercial industrial structures having an area of 5,000 square feet or less having the indoor temperature controlled from a single point may be exempted from the full-year energy analysis.

The annual energy analysis requirements virtually restrict the analysis to use of high speed digital computer programs. A variety of load and energy programs exist and their availability varies. These programs are generally:

- a) not proprietary and available by direct purchase.
- b) proprietary but available on time-sharing systems.
- c) proprietary and available only by submittal of inputs to the owner/developer.

Two main categories of programs are heating and/or cooling load programs and energy analysis programs. Heating and/or cooling load programs are used specifically to determine heating and/or cooling loads on building for varying weather conditions and indoor schedules of occupation and internal heat gains. Often these programs are utilized in determining peak load conditions for design and selection of HVAC equipment. Energy analysis programs generally have a load calculation section and an equipment simulation section. The equipment simulation allows calculation of energy consumption of depletable and non-depletable energy sources. Many of these programs include a complete economic analysis of alternative systems based on life cycle costs. Life cycle costing accounts for variables such as initial capital invested, equipment life, depreciation expense, operating expense and maintenance expense in comparing competing types of systems. The following section will review some of the more commonly known computer programs developed with specific emphasis on availability, description of the programs and input/output requirements.

II. SYSTEMS ANALYSIS PROCEDURE

A. Computer Programs

1. TRACE - Trane Air Conditioning

Economics

- a. Developer - The Trane Company, LaCrosse, Wisconsin.

- b. Availability - Proprietary, available solely through local Trane representatives or through time sharing systems.
- c. Description - Peak and hourly zone loads are calculated based on coincident hourly climatic data. Hourly climatic data consists of one statistical typical day per month. Supply air quantities and temperatures required for each zone.

Annual energy consumption is determined based on part-load equipment performance data for competing systems. Equipment is restricted to Trane manufactured equipment. An economic comparison of competing systems based on life cycle costs is supplied.

- d. Inputs - Inputs to the program consist of building descriptions, equipment descriptions, and economic factors.
- e. Outputs - Outputs include peak building loads, monthly and yearly equipment energy consumptions, and economic comparison of up to four (4) alternative systems based on life cycle cost analysis.

2. APEC (HCC) - Heating/Cooling

Calculations

- a. Developer - Automated Procedures for Engineering Consultants (APEC).
- b. Availability - Proprietary, subject to approval or to an APEC member firm.
- c. Description - HCC determines design heating and cooling loads based on ASHRAE methodology.
- d. Inputs - Inputs consist of physical descriptions of the building, weather data, solar radiation data, zone-room designations and system descriptions.
- e. Outputs - Outputs include room and zone loads and air quantity requirements, system analysis results and building peak heating and cooling loads.

3. AXCESS - Alternate Choice Comparison for Energy Systems Selection

- a. Developer - Edison Electric Institute.
- b. Availability - The program is classified not proprietary and may be utilized through participating utilities, time sharing

systems, direct purchase or service from participating consulting firms.

- c. Inputs - Inputs consist of weather data, base load profiles, design heating and cooling loads, space and zone data, HVAC system description and desired output.
 - d. Output - Output consists of energy consumption and demand for primary systems and alternative systems. Other optional forms of output are available.
4. E-CUBE - Energy Conservation Utilizing Better Engineering
- a. Developer - American Gas Association.
 - b. Availability - Program can be utilized via Control Data Corporation's Cybernet timing sharing network or via leasing agreement.
 - c. Description - E-CUBE is a series of programs which utilize design point calculations of peak thermal and electrical loads to make hourly, monthly, and annual estimates of the energy requirements of a building. An economic analysis of various types of systems is used to compare total owning and operation costs of competing systems.
 - d. Input - Maximum value and hourly percentage profiles for internal heat gain, electrical and process loads. Transmission and air infiltration loads as a function of ambient temperature. Maximum solar load on building. Hourly weather data. Part-load equipment performance characteristics and economic variables.
 - e. Output - Peak, monthly and annual energy requirements for the primary system. Annual energy requirements for alternative systems. Cash flow and discounted rate of return on alternative investments.
5. NBSLD - National Bureau of Standards Load Determination
- a. Developer - Tom Kusuda, National Bureau of Standards.
 - b. Availability - Program not proprietary and may be purchased directly.
 - c. Description - NBSLD calculates hour by hour heating and/or cooling loads using a transient thermal analysis called response

factors. Response factors are described in the following section.

- d. Inputs - Inputs consist of a detailed physical description of the building, occupancy and internal heat gain schedules and hourly weather data.
- e. Outputs - Hourly heating and/or cooling loads and conditioned space temperatures for each zone are outputted for entire year.

6. Other programs

Other load and energy programs are available. Some of the more familiar program code names include ESOP, BUILDSIM, NECAP and SCOUT. Descriptions of these and other programs are contained in reference 302-5-1.

B. ASHRAE Algorithms¹ for Building Heat Transfer Subroutines

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. has over the years supported development of algorithms for calculating heating and cooling loads and energy requirements for buildings. In 1972 ASHRAE first published procedures for determining heating and cooling loads for computerized energy calculations. The procedures were primarily a result of work done by the General American Research Division of General American Transportation Corporation (GARD-GATX) for the United States Postal Service. In 1975 ASHRAE published an updated version of the procedures incorporating work done by the National Bureau of Standards. These new procedures had the advantage over the 1972 procedures of indoor floating temperature capabilities. Previously the procedures required a fixed indoor zone or room temperature. The procedures were not capable of accurately simulating regular indoor temperature variations such as night setback during unoccupied periods.

The ASHRAE algorithms for determining heating and/or cooling loads are based on a transient thermal analysis of heat flow through multi-layered envelope slabs using the response factor technique.

1. Response Factor Technique

Response factors are a technique for accounting for transient heat flow through multi-layer building envelope slabs. The transient heat flow analysis accounts for thermal storage in building envelope elements. The importance of a transient analysis over a steady-state analysis is that it can account for thermal lag in

massive building envelope elements. This thermal lag may cause peak loads on a building HVAC system to occur several hours after the maximum load on the building envelope exterior surface occurs. Peak summer loads on the refrigeration systems of many massive buildings occur late in the evening after occupancy hours and peak outdoor thermal conditions.

Masonry Mass Effect²

An important factor in design for energy conservation is the mass, or heat storage effect, on both heat loss and heat gain in buildings. The principle of this mass effect is that a heavier wall or roof takes much longer to transfer heat to interior spaces. This results in more uniform and moderate interior temperatures because heat is stored during the warmest part of the day and slowly dissipated during cool hours.

The development of response factors is well beyond the scope of this session.

2. Floating Temperatures

The floating indoor temperature capabilities of the ASHRAE procedures have several advantages over fixed indoor temperature routines. First, as discussed above, the effects of thermostat setback schedules on energy requirements may be modeled accurately. Secondly, spaces which are not temperature controlled may be modeled accurately. For residential structures these spaces may consist of attics, basements and crawl spaces. Thirdly, thermal overloading of HVAC equipment may be accurately modeled. And finally, total shutdown of the HVAC equipment may be simulated. In this final case the zones or spaces air temperatures simply float. Figure 302-2-1 illustrates comparisons of simulated zone air temperature using the ASHRAE methodology and the measured zone air temperature for a test residence under HVAC equipment shutdown. Figure 302-2-2 illustrates simulated versus measured attic space air temperature for the same test house during a clear summer day. The outdoor air temperature and solar radiation intensity are shown at the top of the graph.

3. Weather Effects on Building Loads

The ASHRAE procedures require hourly weather data input. This input is comprised of: outdoor dry bulb and wet bulb temperatures, wind speed and direction, and solar radiation data. Hourly weather parameters for past years are available from the National Climatic Center for various cities of the United States.

Figure 302-2-1 Floating Temperature Illustration

Figure 302-2-2 Attic Space Air Temperatures

Solar radiation data is available at relatively few weather stations. Table 302-2-1 lists weather stations which report solar radiation data. Table 302-2-2 lists all weather stations reporting data. For localities with no solar radiation data available, methods of simulating solar radiation data exist.

a. Temperature Effects

Outdoor hourly temperature variations influence both conduction loads through the building envelope and air infiltration loads. Conduction loads through the building envelope occur as a result of temperature gradients across envelope elements. The magnitude of the loads depends on the size of thermal gradient and the resistance of envelope elements to heat transfer. Conditioned spaces or zones with outdoor exposures are generally referred to as perimeter zones. Residential and small commercial buildings are often considered a single zone and have time varying loads influenced by conduction loads. Large commercial buildings generally have an interior core with no direct exposures to outdoors and perimeter zones. The influences of outdoor hourly temperature variations on some large commercial buildings may be small depending on the zone configurations. Sections 502.3 and 502.4 of the Model Energy Conservation Code set design criteria for overall thermal resistance of building envelopes for mechanically heated or cooled buildings in various geographic areas of the United States. Temperature gradients across openings in building envelopes cause air to flow into and out of the structure. Openings in building are exterior joints around windows and door frames, openings between walls and foundations, between walls and roof and between wall panels, and openings at penetrations of utility services through walls, floors, and roofs. When the temperature in a building or zone is different from that outside, pressure differences between inside and outside occur as a result of differences in air densities, that is chimney or "stack effect". When the inside temperature is higher than outside, this "stack effect" produces a negative inside pressure and inward flow of air at lower levels and a positive inside pressure and outflow at higher levels. The reverse occurs when the inside temperature is lower than outside. A "neutral" zone is the zone where inside and outside pressures are equalized. Section 502.4 of the Model Energy Conservation Code sets criteria for sealing openings in the building envelope and reducing loads due to an infiltration.

b. Wind Effects

Air flow due to wind around and over a building creates regions

Table 302-2-1 Solar Radiation Data

Albuquerque, New Mexico
 Apalachicola, Florida
 Barrow, Alaska
 Bethel, Alaska

Lake Charles, Louisiana
 Lake Charles, Louisiana
 Lincoln, Nebraska
 Lincoln, Nebraska

Bismark, North Dakota
 Blue Hill/Milton, Massachusetts
 Boston, Massachusetts
 Brownsville, Texas

Los Angeles, California
 Madison, Wisconsin
 Matanuska, Alaska
 Medford, Oregon

Canton Island
 Cape Hatteras, North Carolina
 Caribou, Maine
 Charleston, South Carolina

Miami, Florida
 Nashville, Tennessee
 New York, New York
 Oak Ridge, Tennessee

Cleveland, Ohio
 Columbia, Missouri
 Dodge City, Kansas
 El Paso, Texas

Omaha, Nebraska (North Omaha)
 Phoenix, Arizona
 Riverside, California
 Santa Maria, California

Ely, Nevada
 Fairbanks, Alaska
 Fort Worth, Texas
 Fort Worth, Texas

Santa Maria, California
 Sault Ste. Marie, Michigan
 Seattle, Washington
 Sterling, Virginia

Fresno, California
 Grand Lake/Granby, Colorado
 Great Falls, Montana
 Hatteras, North Carolina
 Inyokern, California

Tucson, Arizona
 Upton, New York
 Wake Island
 Washington, D.C.

Stations for which Local Climatological Data are issued, as of January 1, 1972

a. Monthly summary issued. b. Monthly summary includes available 3-hourly observations,
Published if 3 or more available per day. c. Annual Summary issued.

210

in which the static pressure is either above or below the static pressure in the undisturbed air stream. In general, pressures are positive on the windward side, resulting in inflow of air, and negative on the leeward side, resulting in outflow of air. Wind velocity and direction are used exclusively by the ASHRAE program for determination of air infiltration and exfiltration of the buildings.

c. Solar Radiation Effect

Solar radiation on exterior building elements may be partially absorbed by opaque elements or transmitted directly into the building conditioned space. The ASHRAE program has the capability of determining the amount of solar radiation incident on building elements relative to their position with the sun. Two components of incident solar radiation are:

- direct (beam)
- indirect (diffuse).

Direct radiation is the actual radiation flux along a line connecting the exterior element surface and the sun. Diffuse radiation, or sky radiation is background radiation resulting from partial scattering of incoming beam radiation by the earth's atmosphere.

Measured solar radiation data is not generally available for many areas of the country and must be generated from observed data. The ASHRAE program has an internal routine CLIMAT which is capable of generating beam and diffuse radiation normal to earth's surface based on local cloud cover observations.

Solar radiation incident on building elements provides a cooling load effect on the building space. This cooling load effect affects energy requirements for space cooling. Internal shading devices for glazed areas, such as draperies or blinds, are an effective way to reduce energy requirements for a building under net cooling loads. External shading louvers are another effective way to reduce the energy requirements.

C. The ASHRAE Load Verification Program - Field Test Data On Energy Conservation at the Legal Aids Center,

ASHRAE sponsored a two-phase program to validate the proposed simulation procedures. In Phase I, four buildings were chosen for extensive study. One of the buildings, the Ohio Legal Center, is located on The Ohio State University campus. A study was made of the buildings and their installed environmental control systems to

determine the instrumentation that would be required to measure all data necessary to calculate building and system load and energy requirements. Also the loads and energy consumption were predicted by using the proposed procedures for load calculation and system simulation. Simulation of the system's components over the entire range of operating conditions, instead of at the design point, allows the design engineer to select components that make the total system more energy efficient. Three guidelines were set forth for the system simulation: it was to be a steady state simulation over a given time period, manufacturer's data was to be used for modeling component performance wherever possible, and the simulation was to be kept as simple as possible without sacrificing accuracy.

In Phase II the Ohio Legal Center and its environmental control system was instrumented in accordance with the guidelines of Phase I.

Data was then collected at 15-minute intervals for a period of more than one year. The measurements consisted of temperatures, flow rates, gas consumption, electrical power usage of the major components, and solar radiation. The collected data was reduced to average hourly engineering units and was used as either input data to the computer programs or as comparison values for validation of the simulations. The validation was done by comparing these measurements to those operating parameters predicted by the simulations.

The simulation was done in two steps. In step one the building load simulation uses weather data, building geometry, schedules for lighting and people, and the space set point temperature as input to predict the hourly sensible and latent space loads. In step two the system simulation uses the building loads, as predicted in step one, weather data and control set points as input to calculate the energy consumption required by the environmental control system to maintain the space conditions. The results were used to further develop the load calculation and system simulation procedures to improve their accuracy and reliability.

The HVAC equipment system at Legal Aids consists of a constant volume, high efficiency, dual duct reheat system which is supplemented in winter by a radiant panel heating system. Hot water for the hot deck, radiant panels and domestic hot water supply are supplied from a gas fired hot-water generator. The refrigeration system employs a vapor compression cycle utilizing refrigerant-22 as the working fluid.

D. Comparison of Simulated Versus Measured Energy Consumption

A summary of results of the validation test are listed in Table 302-2-3. Total yearly percentage difference in gas consumption for year 1972 was -2.6% and the total yearly percentage difference electrical usage was -0.8%.

III. BUILDINGS USING NONDEPLETABLE ENERGY SOURCES

A. General

Any proposed building utilizing solar, geothermal, wind or other nondepletable energy sources for all or part of its energy source shall meet the requirements of Section 401 of the Model Energy Conservation Code, except such nondepletable energy may be excluded from the total annual energy consumption allowed for the building.

To qualify for this exclusion, such energy must be derived from a specific collection, storage and distribution system. The solar energy passing through windows shall also be considered as qualifying if such windows are provided with (1) operable insulating shutters or other devices which, when drawn or closed, shall cause the window area to reduce maximum outward heat flows to those in accordance with Section 502.3 (a) and Section 502.4 (a) of the Model Energy Conservation Code and (2) the window areas are shaded or otherwise protected from the direct rays of the sun during periods when cooling is required.

1. Provisions also apply to nocturnal cooling processes in lieu of energy consuming refrigeration processes.
2. All other criteria covered in Sections 401 and 402 of the Model Energy Conservation Code shall apply to the proposed alternative designs utilizing nondepletable sources of energy.

B. Documentation

Proposed alternative designs, submitted as requests for exception to the standard design criteria shall be accompanied by an energy analysis, as specified in Section 402. The report shall provide sufficient technical detail on the alternative building and system designs and on the data employed in and resulting from the comparative analyses as to verify that both the analyses and the designs meet the criteria of Section 5. The energy derived from nondepletable sources and the reduction in conventional energy requirements derived from nocturnal cooling, shall be separately identified from the overall building energy use. Supporting documentation, on the basis of the performance estimates for the aforementioned nondepletable energy sources or nocturnal cooling means, must be submitted. Energy usage must be calculated in

TABLE 302-2-3

Monthly Summaries of

Natural Gas and Electrical Energy

Measured vs Simulated Systems with Measured load

Month 1972	Natural Gas Btu x 10 ⁶			Electricity KWH		
	Measured	Simulated	%Diff.	Measured	Simulated	%Diff.
January	527.4	505.8	-4.1	25389	25506	+0.46
February	502.6	488.7	-2.8	23154	24048	+3.9
March	508.9	460.6	-9.5	25095	25860	+3.0
April	347.9	376.1	+8.1	32309	34686	+7.4
May	273.4	280.6	+2.6	48260	47518	-1.5
June	252.5	251.0	-0.6	51646	50382	-2.4
July	222.2	227.5	+2.4	55875	56414	+1.0
August	214.8	203.7	-5.2	56433	58417	+3.5
September	233.4	192.3	-17.6	48889	49760	+1.8
October	324.6	316.5	-2.5	37034	35604	-3.9
November	390.6	396.5	+1.5	25139	25792	+2.5
December	472.1	460.0	-2.6	25695	24655	-4.0
Year Total	4270.4	4159.3	-2.6	454918.0	458642.2	+0.8

accordance with the design conditions and methods specified in this Code.

EXCEPTIONS: Proposed alternative designs for residential and commercial structures of less than 20,000 ft. that derive a minimum of 30 percent of their total annual energy usage from nondepletable sources or from nocturnal cooling, shall be exempt from the requirement of a full year energy system analysis, providing that the annual input of such nondepletable sources, or the extent of such nocturnal cooling can reasonably be expected to meet the demands imposed by the proposed alternative design. Other commercial, institutional and industrial structures that derive over 50 percent of their annual thermal requirements (heating, cooling, service water heating) or over 30 percent of their annual total energy requirements from nondepletable sources shall be exempted from the necessity of comparing the proposed design to a standard design which follows the provisions of Section 401.1. Documentation, verifying the percentage of annual energy use derived from such nondepletable sources shall be required as provided in Section 403.1.

References

For

ECT-302

- 1 302-2-1 Procedure For Determining Heating and Cooling Loads For Computerizing Energy Calculations - Algorithms, For Building Heat Transfer Subroutines, ASHRAE, New York City, New York, 1975.
- 2 302-2-2 ASHRAE Handbook of Fundamentals, Published By ASHRAE, New York City, New York, 1977, p. 22.9-22.10.

CHAPTER 4

MODEL ENERGY CONSERVATION CODE APPLICATION

(ECT-303)

PART 1 MODEL CODE TESTING

I. IMPACT ON BUILDING ENERGY USAGE AND ECONOMICS

Concurrent with ASHRAE's effort to devise a standard promoting the energy-efficient design of new buildings¹, the Federal Energy Administration (FEA) - through its mandate from Congress - commissioned a study to identify the potential energy, economic, and institutional implications which could be brought about by the widespread adoption of ASHRAE Standard 90-75.

The study was undertaken by Arthur D. Little, Inc. (ADL) Cambridge, Massachusetts. In turn, Kling/Lindquist Engineering, Inc., Philadelphia, Pennsylvania, was retained by ADL to do the actual interpretation and application of ASHRAE 90, and the subsequent engineering analysis.

A. Methodology, Assumptions

The analysis of ASHRAE 90's impact on the energy consumption, initial investment, and operating costs of new buildings was based upon the application of the standard to several building types and locations.

Five building types in each of the four geographical locations were selected for investigation, or a total of 20 separate cases. The building types were chosen on the basis of their annual contribution to the nation's energy demand, and consisted of:

- a detached single-family dwelling,
- a low-rise apartment building,
- an office building,
- a retail store, and
- a school building.

The four locations - one from each major Census region - were selected based upon a weighted, average analysis of annual heating requirements (degree days) and the geographical dispersion of new construction. The locations were New York City (Northeast), Omaha (North Central), Atlanta (South), and Albuquerque (West).

The application of ASHRAE 90 to each of the 20 cases focused upon

the standard "prescriptive/performance" approach.

For each of the 20 cases, two sets of energy calculations were made using the prescriptive/performance approach: One for the "conventional" building and one for the "ASHRAE 90 modified" building. Annual energy consumption for the detached single-family residence was estimated using ASHRAE-approved manual methods, such as the degree-day method for calculating heating requirements. For all other building types, computer simulation techniques were employed using the programs developed by Ross F. Meriwether and Associates, San Antonio, Texas.

Given the above methodology, and the fact that ASHRAE 90 had to be interpreted for the first time in a design situation, several critical assumptions had to be made. These were as follows:

- Interpretation of the Standard:

For the purposes of the analysis, a "strict" interpretation of ASHRAE 90 was adopted; i.e., where the document only recommends rather than requires certain measures be taken, the recommendation was interpreted to be a requirement.

- "Conventional" Buildings:

The size, configuration, physical characteristics, and HVAC systems selected for the "conventional" buildings represent that which was considered typical in new construction. Selections were based upon various public and in-house statistics, and as such, the buildings should be considered "prototypical", since there is no such thing as an "average" building.

- "ASHRAE 90 Modified" Buildings:

In modifying the conventional buildings to meet the requirements of ASHRAE 90, the principal criterion for deciding among design alternatives was initial cost. That alternative which offered the minimum effect on initial building cost, while at the same time maintained the aesthetic appearance of the building, was selected. In certain cases when confronted with a trade-off, changes to the composition of the opaque wall were made rather than to undertake any further reduction in fenestration.

A second consideration in modifying the conventional buildings concerned the amount of change needed in component performance. The philosophy was to meet - but not purposely exceed - the standard since building owners and members of the design community would most probably not choose to adopt major modifications in building appearance.

- Operating Conditions:

The operating conditions of the buildings were assumed to reflect the conditions prevalent within the construction industry prior to the oil embargo of 1973. Inasmuch as ASHRAE 90 does not dictate how buildings should be operated, identical operating conditions were retained for both the "conventional" and the "ASHRAE 90 modified" buildings.

Based on a comparison of the two building designs, and their estimated energy consumption, the effect of ASHRAE 90 was determined on the physical characteristics of the building, HVAC system size and configuration, annual energy consumption, and initial capital cost of the building. This then formed the data base for the analysis.

Impact on Consumption

Under a strict interpretation of the standard, ASHRAE 90 appears to be very effective in reducing annual energy consumption in buildings. Of the 20 cases evaluated, all showed a reduction in energy usage. Figures 303-1-1 through 303-1-5 illustrate the impact on each building type and location by end use. As opposed to actual unit energy consumption, the percentage reduction in consumption is perhaps the best indicator of the effectiveness of the study. The unweighted average reduction in annual energy consumption of the ASHRAE 90 modified buildings relative to 1973 construction were as follows:

	<u>% Reduction</u>
Single-Family Residence	11.3%
Low-Rise Apartment Building	42.7%
Office Building	59.7%
Retail Store	40.1%
School Building	48.1%

ASHRAE 90 appears to be less effective in reducing annual energy demand in the detached single-family residence than in the remaining nonresidential buildings. This lower effectiveness may be largely accounted for by the lower overall U-values (combination of opaque walls and windows) obtainable in single-family frame wall construction (0.21 to 0.24) versus nonresidential construction (0.28 to 0.58). Another consideration is the use of manual versus computer simulation estimating techniques, although this should not greatly influence the results.

Chart 303-1-1

*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission and distribution.

COMPARATIVE ANNUAL ENERGY CONSUMPTION, *CONVENTIONAL VERSUS
ASHRAE 90 MODIFIED PROTOTYPICAL SINGLE FAMILY RESIDENCES

Chart 303-1-2

*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission and distribution.

COMPARATIVE ANNUAL ENERGY CONSUMPTION,*CONVENTIONAL VERSUS
ASHRAE 90 MODIFIED PROTOTYPICAL LOW-RISE MULTI-FAMILY APARTMENT BUILDINGS

*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission and distribution.

COMPARATIVE ANNUAL ENERGY CONSUMPTION,*CONVENTIONAL VERSUS
ASHRAE 90 MODIFIED PROTOTYPICAL OFFICE BUILDINGS

Chart 303-1-3

*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission and distribution.

COMPARATIVE ANNUAL ENERGY CONSUMPTION, *CONVENTIONAL VERSUS
ASHRAE 90 MODIFIED PROTOTYPICAL RETAIL STORES

Chart 303-1-4

Chart 303-1-5

*Electrical energy useage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission and distribution.

COMPARATIVE ANNUAL ENERGY CONSUMPTION, *SCHOOL BUILDINGS CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL SCHOOL BUILDINGS

It is also of interest that ASHRAE 90 modified residences in both the Northeast (New York City), and North Central (Omaha) locations met the standard using single glazing and a minimum reduction in glass area. The Omaha house showed the minimum allowable glass area of about 14.4%, which is very close to the average fenestration for new residential construction in that region.

In the case of the low-rise apartment and nonresidential buildings, the effect of ASHRAE 90 in reducing overall energy usage is more pronounced. Unlike single-family residences, significant savings in domestic hot water and space heating were generally matched by savings in other end uses, specifically auxiliary HVAC equipment, supply air fans, and lighting.

Regarding geographical location, ASHRAE 90 appears to be more effective in the colder climates. This is mainly due to the large percentage of annual energy demand accounted for by space heating and the inherent effectiveness of ASHRAE 90 in reducing annual heating requirements. In general, the decrease in space heating requirements accounted for 60 to 75% of the total reduction in actual energy consumption, with the exception of the retail store.

Certain sections of ASHRAE 90 appear to be more critical than others in terms of reducing energy. If measured in terms of energy reduction potential, the most "effective" sections in the document were found to vary by type of building. With few exceptions, all of the sections have some influence on the reduction in annual energy consumption.

Referring to Table 303-1-1, changes in winter design conditions and supplied domestic hot water temperatures appear to be the most effective parameters for the single-family residence, while those chapters dealing with HVAC equipment, systems, and control appear to be most effective in nonresidential construction. The estimates given are based upon Kling-Lindquist's educated judgment, and the reader is reminded that further analysis is required to determine a more accurate contribution by the various parameters.

C. Physical Characteristics

Application of ASHRAE 90 brought about changes in the physical characteristics of virtually all the buildings. Glass area was reduced in approximately two-thirds of the buildings. Reductions were as much as 30%, but most were less than 20%. Only one region - the North Central - required reductions in glass area for

all building types. Similarly, decreases in glass area were balanced by increases in net wall area, and virtually all increases were less than 8%.

Double glazing was found to be necessary in only the office building as all other commercial buildings could be brought into compliance with ASHRAE 90 by modifying the opaque wall.

Additional insulation requirements for residential construction varied from 80 to 300 pounds of batt insulation per unit, with most of this being applied to the roof. Increased requirements for insulation - particularly rigid board - in commercial construction were even greater than those in residential construction. This is mainly due to the historic absence of insulation in commercial construction as compared to residential construction.

Reductions in lamps and lamp fixtures varied by building type, and average 24% and 22%, respectively, for nonresidential construction. Additional switching was also required for more individual area control of lights.

Reductions in installed heating system capacities were significant, averaging 42%, while reductions in installed cooling systems were generally less, averaging 31%. The greatest reductions were found to be in the school building. Auxiliary HVAC equipment, including pumps, cooling tower fans, supply fans, etc., also showed a significant reduction, averaging 44% in rated kilowatt (or horsepower) capacity.

D. Building Economics

Based on mid-1975 energy costs compiled during the study, annual savings in operating costs ranged between \$0.05 and \$1.05 per square foot, but were generally within the range between \$0.20 and \$0.70 per square foot (Table 303-1-2). Savings in single-family residences were generally lower than those for commercial buildings. Again, inasmuch as the buildings were "prototypical", a better indicator of savings may be the percent reduction, in which case savings in annual energy costs ranged from 9-15% in the single-family as compared to 30-45% for commercial buildings.

Regarding initial construction costs, estimates were made for both conventional and ASHRAE 90 modified buildings on an element-by-element basis. ASHRAE 90 generally increases the cost of the exterior wall, floors, roof, and domestic hot water system. In turn, glazing costs may be higher or lower depending upon building type, location, acceptable window area and the need for double glazing. Unit costs for lighting, and particularly HVAC equipment

PARAMETERS ATTRIBUTABLE TO ENERGY REDUCTION

Parameter (Applicable Sections from ASHRAE 90)	(Percent)				
	Single-Family Residence	Low-Rise Apartment	Office Building	Retail Store	School
• Summer Design Conditions (4.2.5 & 5.3.2)	1.8	4.6	3.4	3.4	2.5
• Winter Design Conditions (4.2.5 & 5.3.2)	3.9	8.8	12.4	7.3	7.6
• Overall Thermal Requirements - U _t (4.3)	0.9	8.0	8.0	4.0	4.0
• Lighting (9.3.1)	0	1.8	6.3	8.6	4.4
• Ventilation (5.3.2.3)	0	2.3	7.0	5.5	13.0
• Infiltration (4.5.3 & 5.3.2.4)	1.3	0.8	1.5	1.0	2.5
• Domestic Hot Water (7.3)	2.5	5.0	1.0	0.5	3.0
• HVAC Equipment, Systems, and Control (6.3, 6.4 & 6.6)	0.9	11.4	20.0	9.5	11.1
Total Reduction	11.3	42.7	59.6	40.1	48.1

Source: Kling-Lindquist, Inc. Estimates

Table 303-1-1

ANNUAL SAVINGS IN ENERGY COST (DOLLARS PER SQ. FT. AND PERCENT REDUCTION IN ANNUAL COST)

	Northeast	North Central	South	West
Single Family Residence	0.136 (15%)	0.048 (13%)	0.049 (10%)	0.061 (9%)
Low-Rise Apartment	0.626 (43%)	0.178 (39%)	0.228 (48%)	0.189 (45%)
Office Building	0.718 (47%)	0.349 (44%)	0.291 (39%)	0.242 (38%)
Retail Store	1.048 (35%)	0.673 (39%)	0.578 (34%)	0.414 (30%)
School	0.299 (36%)	0.143 (34%)	0.138 (34%)	0.116 (33%)

Source: Arthur D. Little, Inc., estimates

Table 303-1-2

ment and distribution systems, were significantly lower and tended to offset the increase in other costs. As an example, consider the Omaha-office building:

	Change in Cost (Dollars per Square Foot Floor Area)
Exterior Walls	+0.33
Exterior Glass	+0.24
Roof	+0.15
HVAC Equipment	-0.39
HVAC Distribution	-0.48
HVAC Controls	+0.12
Lighting	-0.04
Electrical Distribution	-0.28
Domestic Water Heating	+0.02
Hot Water Distribution	+0.04
Net Change	-0.29

The estimated changes in unit costs for all 20 cases are shown in Table 303-1-3. It is particularly interesting to note that those buildings modified under the standard prescriptive/performance approach were actually found to cost less than their conventional counterparts in most cases. Unit savings range from \$0.04 to \$0.94 per square foot, with the greatest savings experienced in office buildings. In only three cases does initial project cost increase, and then only marginally. However, the results of Table 303-1-3 should be carefully qualified. Those in the building profession know that estimating building costs during present conditions of high inflation is highly uncertain, and perhaps it would be more appropriate to say that the application of ASHRAE 90 need not necessarily increase initial construction costs.

ESTIMATED CHANGE IN UNIT COST* OF CONVENTIONAL
vs. ASHRAE 90 MODIFIED BUILDINGS
(DOLLARS PER SQ. FT. OF FLOOR SPACE)

	Northeast	North Central	South	West	Unweighted Average
Single-Family Residence	+0.01	-0.04	-0.04	+0.01	-0.02
Multi-Family, Low Rise	-0.45	-0.54	-0.28	-0.36	-0.41
Office Building	-0.35	-0.29	-0.94	-0.93	-0.63
Retail Stores	-0.11	+0.04	-0.32	-0.33	-0.18
School	-0.56	-0.39	-0.46	-0.33	-0.44

* Cost to the owner; regionally adjusted.
Source: Arthur D. Little, Inc.

TABLE 303-1-3

In addition to construction costs, the application of ASHRAE 90 will probably result in additional design costs. While the potential impact on the design profession will be discussed at length in subsequent articles, the investigation indicated that additional design services would be on the order of \$0.24 per square foot for the single-family residence, and \$0.09 to \$0.16 per square foot for the other building types. With the exception of the residence, the straight payback of design services due to energy cost savings was found to be less than one year, and less than six months in most cases.

II. POTENTIAL IMPACT ON NATIONAL ENERGY DEMAND²

The ultimate test of the value of ASHRAE Standard 90, "Energy Conservation in New Building Design", is the extent to which it will curtail future energy consumption in new residential and commercial buildings. Of course, this can only be determined after the Standard has been implemented on a widespread basis; however, it is possible to estimate the maximum savings that might result based upon ASHRAE 90's effect on the five prototypical buildings and four geographical locations investigated previously.

The purpose here is to quantify the potential savings in the nation's energy demand ASHRAE 90 could claim over the coming 15 years, recognizing that the Standard is applicable only to new construction. A second purpose will be to investigate the status of state regulatory efforts in moving to regulate energy consumption in buildings, and - assuming that each state must act for itself on adopting ASHRAE 90 - to relate this to the total potential energy savings possible.

A. Annual Energy Demand

Initially, the amount of energy consumed annually in residential and commercial buildings can be estimated based on a previous report by Arthur D. Little, Inc. It was estimated that the U.S. consumed approximately 17.4 quads (quad = 10^{15} Btu) of energy in the residential and commercial building sectors in 1975 when measured at the building boundary (Table 303-1-4). This represents slightly less than one-quarter of the nation's total energy requirements. Residential demand is far more dominant with 12.6 quads of the total being consumed in the residential sector versus only 4.2 quads in the commercial sector. Total demand for the commercial sector excludes 0.6 quads which was classified as "unallocated commercial", and which ASHRAE 90 does not affect.

An alternate method of expressing building energy demand is to include losses in efficiency due to the generation, transmission,

and distribution of electricity. In this case, electricity is converted at 10,000 Btu/kWh, rather than 3,412 Btu/kWh, to allow for inefficiency. Figure 303-1-6 shows 1970 energy demand in residential and commercial buildings by end use under each method. While this graph clearly shows the extent to which demand is understood under the building boundary method, this assumption is appropriate for a demand analysis because it does not raise the issue of power plant efficiency, which more properly belongs in a supply analysis.

ANNUAL ENERGY DEMAND BY BUILDING TYPE
1975 AND 1990
(quadrillion Btu)

	1975	1990
Residential		
Mobile Homes	0.4	0.8
Single-Family Detached	9.4	11.6
Low Density	1.8	2.1
Multi-Family, Low Rise	0.6	.8
Multi-Family, High Rise	0.4	.5
Total	12.6	15.8
Commercial		
Office Buildings	0.8	1.6
Retail Establishments	0.9	2.0
Schools	0.9	1.2
Hospitals	0.5	.8
Other	1.1	1.7
Total	4.2	7.3
Unallocated Commercial	0.6	1.1
Grand Total	17.4	24.2

SOURCE: Arthur D. Little, Inc.

	1950	1960	1970	1980	1990
Energy Usage (quads)	6.6	10.2	15.3	19.5	24.2
Average Annual Growth Rates		4.6%	4.1%	2.4%	2.2%

SOURCES: Bureau of Mines and Arthur D. Little, Inc., estimates.

TABLE 303-1-4

Two significant conclusions can be drawn from Table 303-1-4 and Figure 303-1-6. First, the residential sector, with over 70% of the energy demand, is the major end user. Second, space heating requirements - dominant in both sectors - account for approximately 70% of the total energy used. It follows that any standard which significantly reduces both space heating requirements and does so effectively in residential construction will be effective in

conserving the nation's energy supplies. The fact that different geographical regions have grossly different fuel consumption patterns also emphasizes the problem of finding universal solutions to the energy conservation puzzle.

1970 ENERGY DEMAND BY END USE

FIGURE 303-1-6

B. Impact of ASHRAE 90

The reduction in energy demand attributable to the implementation of ASHRAE 90 would increase over time as the annual energy consumed by those buildings built after 1975 increases as a percent of the total energy consumed in existing buildings. The annual energy demand by buildings constructed after 1975 would increase to 10.6 quads by 1990 or 44% of total demand. Thus, the earlier ASHRAE 90 - or some similar standard - is adopted by the industry, the greater the potential annual savings achievable in any future year.

Likewise, maximum potential energy savings could only be realized if the Standard were adopted and enforced by all code authorities.

Depending upon how many states adopt ASHRAE 90 or some similar standard, a somewhat lesser reduction is more probable.

The maximum percentage energy reduction available if ASHRAE 90 were to be adopted by all states beginning in 1976, was estimated based upon the computer simulation done for the prototypical buildings. The five building types selected represent approximately 85% of annual residential consumption and 66% of annual commercial consumption. For those building types not analyzed, assumptions were made as to the likely reduction possible under ASHRAE 90, which were arrived at subjectively by an interpretation of their construction and usage characteristics. Low-density residential construction (two to four units) were assumed to have the same reduction as the single-family residence. Reductions in the low-rise apartment buildings were also assumed to apply to high-rise multi-family buildings. Hospitals, which were classified as institutional buildings and thought to have an energy requirement which is probably less susceptible to ASHRAE 90 due to medical and life support considerations, were assumed to have potential reductions on the order of 75% of those possible for school buildings. Reductions in "other" nonresidential buildings were assumed to be the unweighted average of the office, retail store, and school buildings.

Based on the above, the maximum annual energy savings possible by the implementation of ASHRAE 90 are estimated to be 0.8 quads by 1980. This would increase to approximately 1.8 quads by 1985, and to 2.9 quads by 1990. Figure 303-1-7 shows that the potential energy which could be saved by the year 1990 due to the adoption of ASHRAE 90 is about 27% of the energy consumed by those buildings constructed beginning in 1976. A more significant fact is that even with complete adoption (and enforcement) of ASHRAE 90 by all states, annual energy demand in the construction sector will continue to increase over the period 1975 to 1990, although at a lesser rate (1.4% per year versus 2.3% per year).

What is not shown by Figure 303-1-7 is that the reduction in annual energy usage is considerably greater in the commercial sector. In relation to estimates on energy consumption by end use, this indicates that while the residential sector will account for most of the actual demand, the major savings under ASHRAE 90 would be realized in commercial construction. If the standard were more effective in residential construction, the total potential annual energy savings would be considerably greater.

Perhaps the most appropriate way in which to evaluate the potential savings of ASHRAE 90 is by percent reduction. Table 303-1-5 shows that the potential energy saved by adoption of ASHRAE 90 by all

POTENTIAL IMPACT OF ASHRAE 90 ON ANNUAL ENERGY CONSUMPTION
1975 - 1990

FIGURE 303-1-7

ANNUAL SAVINGS POSSIBLE BY ADOPTION OF ASHRAE 90

	1980	1985	1990
Total Annual Energy Consumed in Construction (Quads)	19.5 (100%)	21.6 (100%)	24.2 (100%)
Annual Energy Consumed by Buildings Built After 1975			
Residential	11.9	20.5	26.7
Commercial	5.5	11.1	17.2
Total	17.4%	32.6%	43.9%
Potential Energy Saved by Adoption of ASHRAE 90			
Residential	1.6	2.8	3.7
Commercial	2.6	5.3	8.2
Total	4.2%	8.1%	11.9%

SOURCE: Arthur D. Little, Inc., estimates.

TABLE 303-1-5

states approximates 4%, 8% and 12% of total annual energy consumption for the years 1980, 1985 and 1990 respectively.

Further investigation showed that the North Central region accounts for the largest energy demand although the amount of annual demand in 1990 which is attributable to buildings built after 1975 is greater in both the South and West. The potential energy saved

by adoption of ASHRAE 90 will be greater in the North Central Region when expressed as a percent of total energy consumed. The major cause for this is in the region's higher per unit space heating load, an area where ASHRAE 90 is very effective.

PART 2 BUILDING DESIGN BY SYSTEMS ANALYSIS APPROACH

I. REVIEW OF CODE REQUIREMENTS

A major aspect of the Model Energy Conservation Code is the provision for building designs which do not meet the design criteria set forth in Sections 5 and 6 of the Code. A building design will comply with the Code if:

"the annual energy consumption is not greater than a similar building (defined as a "standard design") whose enclosure elements and energy consuming systems are designed in accordance with Section 5".

Building heating/cooling load calculation used for the annual energy analysis must be of sufficient detail to account for:

- environmental requirements (Section 3)
- climatic data
- building data
- operational characteristics
- mechanical equipment
- internal heat generation

Documentation must be provided to demonstrate that the analysis used is consistent with accepted techniques and procedures.

II. ENERGY ESTIMATING METHODS³

A. General Considerations

Although the procedures used for estimating energy requirements vary considerably in degree of sophistication, they all have three common elements, the calculation of: (1) space load (heat gain or loss); (2) equipment load, and; (3) equipment energy requirements.

The space load calculations determine the amounts of energy which must be added to or extracted from a space to maintain thermal comfort. The space load includes the effects of outdoor conditions and is often based upon no more than the calculated peak design heating and/or cooling load. The simplest procedures assume that the energy required to maintain comfort is a function of a single parameter, the outdoor dry bulb temperature. The more reliable methods include consideration of solar effects, internal gains,

heat storage in the walls and interiors, coincident wet bulb temperatures, and the effects of wind on both the building envelope heat transfer and infiltration. The most sophisticated procedures are based on hourly profiles for climatic conditions and operational characteristics for a number of "typical" days of the year, or, better still, a full 8760 hr. of operation.

The second step translates the space load into a load on the equipment. This can be a simple estimate of duct or piping losses or gains, or a complex hour-by-hour simulation of an air system such as variable air volume with outdoor air cooling.

The third step calculates the fuel and energy required to meet these loads. It gives consideration to efficiencies and part-load characteristics of the equipment.

The sophistication of the calculation procedure used can often be inferred from the number of separate ambient conditions and/or time increments used in the calculations. Thus, a simple procedure may use only one measure, such as annual degree days and will be appropriate only for simple systems and applications. A detailed computer program may consider ambient conditions for each hour of the year and thus provide more realistic estimates for many types of buildings.

B. The Degree Day Method

The traditional degree day procedure for estimating heating energy requirements is based on the assumption that, on a long-term average, solar and internal gains will offset heat loss when the mean daily outdoor temperature is 65°F, and that fuel consumption will be proportional to the difference between the mean daily temperature and 65°F. In other words, on a day when the mean temperature is 20 F deg below 65 F, twice as much fuel is consumed as on days when the mean temperature is 10 F deg below 65 F.

Table 303-2-1 lists the average number of degree days that have occurred over a long period of years, by months, and the yearly totals for various cities in the United States and Canada. The number of degree days for U.S. cities were calculated by taking the difference between 65 F and the daily mean temperature computed as half the total of the daily maximum and the daily minimum temperatures.

Studies made by the American Gas Association⁴ up to 1932, and by the National District Heating Association⁵ in 1932, indicated the 65 F base. However, residential insulation practices have improved over the past 40 years from virtually none in 1930 to R-11 in walls and R-19 in ceilings today.⁶

Average Monthly and Yearly Degree Days for Cities in the United States and Canada^{1,2,3} (Base 65 F)

State	Station		Avg. Winter Temp ⁴	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Ala.	Birmingham	A	54.2	0	0	6	93	363	555	592	462	363	108	9	0	2551
	Huntsville	A	51.3	0	0	12	127	426	663	694	557	434	138	19	0	3070
	Mobile	A	59.9	0	0	0	22	213	357	415	300	211	42	0	0	1560
	Montgomery	A	55.4	0	0	0	68	330	527	543	417	316	90	0	0	2291
Alaska	Anchorage	A	23.0	245	291	516	930	1284	1572	1631	1316	1293	879	592	315	10864
	Fairbanks	A	6.7	171	332	642	1203	1833	2254	2359	1901	1739	1068	555	222	14279
	Juneau	A	32.1	301	338	483	725	921	1135	1237	1070	1073	810	601	381	9070
	Nome	A	13.1	481	496	693	1094	1455	1820	1879	1666	1770	1314	930	573	14171
Ariz.	Flagstaff	A	35.6	46	68	201	558	867	1073	1169	991	911	651	437	180	7152
	Phoenix	A	58.5	0	0	0	22	234	415	474	328	217	75	0	0	1765
	Tucson	A	58.1	0	0	0	25	231	406	471	344	242	75	6	0	1800
	Winslow	A	43.0	0	0	6	245	711	1008	1054	770	601	291	96	0	4782
Ark.	Yuma	A	64.2	0	0	0	0	108	264	307	190	90	15	0	0	974
	Fort Smith	A	50.3	0	0	12	127	450	704	781	596	456	144	22	0	3292
	Little Rock	A	50.5	0	0	9	127	465	716	756	577	434	126	9	0	3219
	Texarkana	A	54.2	0	0	0	78	345	561	626	468	350	105	0	0	2533
Calif.	Bakersfield	A	55.4	0	0	0	37	282	502	546	364	267	105	19	0	2122
	Bishop	A	46.0	0	0	48	260	576	797	874	680	555	306	143	36	4275
	Blue Canyon	A	42.2	28	37	108	347	594	781	896	795	806	597	412	195	5596
	Burbank	A	58.6	0	0	6	43	177	301	366	277	239	138	81	18	1646
	Eureka	C	49.9	270	257	258	329	414	499	546	470	505	438	372	285	4643
	Fresno	A	53.3	0	0	0	84	354	577	605	426	335	162	62	6	2611
	Long Beach	A	57.8	0	0	9	47	171	316	397	311	264	171	93	24	1803
	Los Angeles	A	57.4	28	28	42	78	180	291	372	302	288	219	158	81	2061
	Los Angeles	C	60.3	0	0	6	31	132	229	310	230	202	123	68	18	1349
	Mt. Shasta	C	41.2	25	34	123	406	696	902	983	784	738	525	347	159	5722
	Oakland	A	53.5	53	50	45	127	309	481	527	400	353	255	180	90	2870
	Red Bluff	A	53.8	0	0	0	53	318	555	605	428	341	168	47	0	2515
	Sacramento	A	53.9	0	0	0	56	321	546	583	414	332	178	72	0	2502
	Sacramento	C	54.4	0	0	0	62	312	533	561	392	310	173	76	0	2419
	Sandberg	C	46.8	0	0	30	202	480	691	778	661	620	426	264	57	4209
	San Diego	A	59.5	9	0	21	43	135	236	298	235	214	135	90	42	1458
San Francisco	A	53.4	81	78	60	143	306	462	508	395	363	279	214	126	3015	
San Francisco	C	55.1	192	174	102	118	231	388	443	356	319	279	239	180	3001	
Santa Maria	A	54.3	99	93	96	146	270	391	459	370	363	282	233	165	2967	
Colo.	Alamosa	A	29.7	65	99	279	639	1065	1420	1476	1162	1020	696	440	168	8529
	Colorado Springs	A	37.3	9	25	132	456	825	1032	1128	938	893	582	319	84	6423
	Denver	A	37.6	6	9	117	428	819	1035	1132	938	887	558	288	66	6283
	Denver	C	40.8	0	0	90	366	714	905	1004	851	800	492	254	48	5524
	Grand Junction	A	39.3	0	0	30	313	786	1113	1209	907	729	387	146	21	5641
	Pueblo	A	40.4	0	0	54	326	750	986	1085	871	772	429	174	15	5462
	Bridgeport	A	39.9	0	0	66	307	615	986	1079	966	853	510	208	27	5617
	Hartford	A	37.3	0	12	117	394	714	1101	1190	1042	908	519	205	33	6235
Conn.	New Haven	A	39.0	0	12	87	347	648	1011	1097	991	871	543	245	45	5897
	Wilmington	A	42.5	0	0	51	270	588	927	980	874	735	387	112	6	4930
	Washington	A	45.7	0	0	33	217	519	834	871	762	626	288	74	0	4224
	Apalachicola	C	61.2	0	0	0	16	153	319	347	260	180	33	0	0	1308
Fla.	Daytona Beach	A	64.5	0	0	0	0	75	211	248	190	140	15	0	0	879
	Fort Myers	A	68.6	0	0	0	0	24	109	146	101	62	0	0	0	442
	Jacksonville	A	61.9	0	0	0	12	144	310	332	246	174	21	0	0	1239
	Key West	A	73.1	0	0	0	0	0	28	40	31	9	0	0	0	108
	Lakeland	C	66.7	0	0	0	0	57	164	195	146	99	0	0	0	661
	Miami	A	71.1	0	0	0	0	0	65	74	56	19	0	0	0	214

¹Data for United States cities from a publication of the United States Weather Bureau, *Monthly Normals of Temperature, Precipitation and Heating Degree Days*, 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 revisions to this publication, where available.

²Data for airport stations, A, and city stations, C, are both given where available.

³Data for Canadian cities were computed by the Climatology Division, Department of Transport from normal monthly mean temperatures, and the monthly values of heating degree days data were obtained using the National Research Council computer and a method devised by H. C. S. Thom of the United States Weather Bureau. The heating degree days are based on the period from 1931 to 1960.

⁴For period October to April, inclusive.

Table 303-2-1

Average Monthly and Yearly Degree-Days for Cities in the United States and Canada (Base 65 F)
(Continued)

State	Station	Avg. Winter Temp ¹	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Fla. (Cont'd)	Miami Beach.....	C 72.5	0	0	0	0	0	40	56	36	9	0	0	0	141
	Orlando.....	A 63.7	0	0	0	0	0	72	198	220	163	105	6	0	766
	Pensacola.....	A 60.4	0	0	0	19	195	353	400	277	183	36	0	0	1463
	Tallahassee.....	A 60.1	0	0	0	28	198	360	375	286	202	36	0	0	1485
	Tampa.....	A 66.4	0	0	0	0	60	171	202	148	102	0	0	0	683
	West Palm Beach.....	A 68.4	0	0	0	0	6	65	87	64	31	0	0	0	253
Ga.	Athens.....	A 51.8	0	0	12	115	405	632	642	529	431	141	22	0	2929
	Atlanta.....	A 51.7	0	0	18	124	417	648	636	518	428	147	25	0	2961
	Augusta.....	A 54.5	0	0	0	78	333	552	549	445	350	90	0	0	2397
	Columbus.....	A 54.8	0	0	0	87	333	543	552	434	338	96	0	0	2383
	Macon.....	A 56.2	0	0	0	71	297	502	505	403	295	63	0	0	2136
	Rome.....	A 49.9	0	0	24	161	474	701	710	577	468	177	34	0	3326
	Savannah.....	A 57.8	0	0	0	47	246	437	437	353	254	45	0	0	1819
	Thomasville.....	C 60.0	0	0	0	25	198	366	394	305	208	33	0	0	1529
Hawaii	Lihue.....	A 72.7	0	0	0	0	0	0	0	0	0	0	0	0	0
	Honolulu.....	A 74.2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hilo.....	A 71.9	0	0	0	0	0	0	0	0	0	0	0	0	0
Idaho	Boise.....	A 39.7	0	0	132	415	792	1017	1113	854	722	438	245	81	5809
	Lewiston.....	A 41.0	0	0	123	403	756	933	1063	815	694	426	239	90	5542
	Pocatello.....	A 34.8	0	0	172	493	900	1166	1324	1058	905	555	319	141	7033
Ill.	Cairo.....	C 47.9	0	0	36	164	513	791	856	680	539	195	47	0	3821
	Chicago (O'Hare).....	A 35.8	0	12	117	381	807	1166	1265	1086	939	534	260	72	6639
	Chicago (Midway).....	A 37.5	0	0	81	326	753	1113	1209	1044	890	480	211	48	6155
	Chicago.....	C 38.9	0	0	66	279	705	1051	1150	1000	868	489	226	48	5882
	Moline.....	A 36.4	0	9	99	335	774	1181	1314	1100	918	450	189	39	6408
	Peoria.....	A 38.1	0	6	87	326	759	1113	1218	1025	849	426	183	33	6025
	Rockford.....	A 34.8	6	9	114	400	837	1221	1333	1137	961	516	236	60	6830
	Springfield.....	A 40.6	0	0	72	291	696	1023	1135	935	769	354	136	18	5429
Ind.	Evansville.....	A 45.0	0	0	66	220	606	896	955	767	620	237	68	0	4435
	Fort Wayne.....	A 37.3	0	9	105	378	783	1135	1178	1028	890	471	189	39	6205
	Indianapolis.....	A 39.6	0	0	90	316	723	1051	1113	949	809	432	177	39	5699
	South Bend.....	A 36.6	0	6	111	372	777	1125	1221	1070	933	525	239	60	6439
Iowa	Burlington.....	A 37.6	0	0	93	322	768	1135	1259	1042	859	426	177	33	6114
	Des Moines.....	A 35.5	0	6	96	363	828	1225	1370	1137	915	438	180	30	5588
	Dubuque.....	A 32.7	12	31	156	450	906	1287	1420	1204	1026	546	260	78	7376
	Sioux City.....	A 34.0	0	9	108	369	867	1240	1435	1198	989	483	214	39	6951
	Waterloo.....	A 32.6	12	19	138	428	909	1296	1460	1221	1023	531	229	54	7320
Kans.	Concordia.....	A 40.4	0	0	57	276	705	1023	1163	935	781	372	149	18	5479
	Dodge City.....	A 42.5	0	0	33	251	666	939	1051	840	719	354	124	9	4986
	Goodland.....	A 37.8	0	6	81	381	810	1073	1166	955	884	507	236	42	6141
	Topeka.....	A 41.7	0	0	57	270	672	980	1122	893	722	330	124	12	5182
	Wichita.....	A 44.2	0	0	33	229	618	905	1023	804	645	270	87	6	4620
Ky.	Covington.....	A 41.4	0	0	75	291	669	983	1035	893	756	390	149	24	5265
	Lexington.....	A 43.8	0	0	54	239	609	902	946	818	685	325	105	0	4683
	Louisville.....	A 44.0	0	0	54	248	609	890	930	818	682	315	105	9	4660
La.	Alexandria.....	A 57.5	0	0	0	56	273	431	471	361	260	69	0	0	1921
	Baton Rouge.....	A 59.8	0	0	0	31	216	369	409	294	208	33	0	0	1560
	Lake Charles.....	A 60.5	0	0	0	19	210	341	381	274	195	39	0	0	1459
	New Orleans.....	A 61.0	0	0	0	19	192	322	363	258	192	39	0	0	1385
	New Orleans.....	C 61.8	0	0	0	12	165	291	344	241	177	24	0	0	1254
	Shreveport.....	A 56.2	0	0	0	47	297	477	552	426	304	81	0	0	2184
Me.	Caribou.....	A 24.4	78	115	336	682	1044	1535	1690	1470	1308	858	468	183	9767
	Portland.....	A 33.0	12	53	195	508	807	1215	1339	1182	1042	675	372	111	7511
Md.	Baltimore.....	A 43.7	0	0	48	264	585	905	936	820	679	327	90	0	4654
	Baltimore.....	C 46.2	0	0	27	189	486	806	859	762	629	288	65	0	4111
	Frederick.....	A 42.0	0	0	66	307	624	955	995	876	741	384	127	12	5087
Mass.	Boston.....	A 40.0	0	9	60	316	603	983	1088	972	846	513	208	36	5634
	Nantucket.....	A 40.2	12	22	93	332	573	896	992	941	896	621	384	129	5891
	Pittsfield.....	A 32.6	25	59	219	524	831	1231	1339	1196	1063	660	326	105	7578
	Worcester.....	A 34.7	6	34	147	450	774	1172	1271	1123	998	612	304	78	6969

Table 303-2-1 (continued)

Average Monthly and Yearly Degree Days for Cities in the United States and Canada (Base 65 F)
(Continued)

State	Station		Avg. Winter Temp	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Mich.	Alpena.....	A	29.7	68	105	273	580	912	1268	1404	1299	1218	777	446	156	8506
	Detroit (City).....	A	37.2	0	0	87	360	738	1088	1181	1058	936	522	220	42	6232
	Detroit (Wayne).....	A	37.1	0	0	96	353	738	1088	1194	1061	933	534	239	57	6293
	Detroit (Willow Run).....	A	37.2	0	0	90	357	750	1104	1190	1053	921	519	229	45	6258
	Escanaba.....	C	29.6	59	87	243	539	924	1293	1445	1296	1203	777	456	159	8481
	Flint.....	A	33.1	16	40	159	465	843	1212	1330	1198	1066	639	319	90	7377
	Grand Rapids.....	A	34.9	9	28	135	434	804	1147	1259	1134	1011	579	279	75	6894
	Lansing.....	A	34.8	6	22	138	431	813	1163	1262	1142	1011	579	273	69	6909
	Marquette.....	C	30.2	59	81	240	527	936	1268	1411	1268	1187	771	468	177	8393
	Muskegon.....	A	36.0	12	28	120	400	762	1088	1209	1100	995	594	310	78	6696
	Sault Ste. Marie.....	A	27.7	96	105	279	580	951	1367	1525	1380	1277	810	477	201	9048
Minn.	Duluth.....	A	23.4	71	109	330	632	1131	1581	1745	1518	1355	840	490	198	10000
	Minneapolis.....	A	28.3	22	31	189	505	1014	1454	1631	1380	1166	621	288	81	8382
	Rochester.....	A	28.8	25	34	186	474	1005	1438	1593	1366	1150	630	301	93	8295
Miss.	Jackson.....	A	55.7	0	0	0	65	315	502	546	414	310	87	0	0	2239
	Meridian.....	A	55.4	0	0	0	81	339	518	543	417	310	81	0	0	2289
	Vicksburg.....	C	56.9	0	0	0	53	279	462	512	384	282	69	0	0	2041
Mo.	Columbia.....	A	42.3	0	0	54	251	651	967	1076	874	716	324	121	12	5046
	Kansas City.....	A	43.9	0	0	39	220	612	905	1032	818	682	294	109	0	4711
	St. Joseph.....	A	40.3	0	6	60	285	708	1039	1172	949	769	348	133	15	5484
	St. Louis.....	A	43.1	0	0	60	251	627	936	1026	848	704	312	121	15	4900
	St. Louis.....	C	44.8	0	0	36	202	576	884	977	801	651	270	87	0	4484
	Springfield.....	A	44.5	0	0	45	223	600	877	973	781	660	291	105	6	4900
Mont.	Billings.....	A	34.5	6	15	186	487	897	1135	1296	1100	970	570	285	102	7049
	Glasgow.....	A	26.4	31	47	270	608	1104	1466	1711	1439	1187	648	335	150	8996
	Great Falls.....	A	32.8	28	53	258	543	921	1169	1349	1154	1063	642	384	186	7750
	Havre.....	A	28.1	28	53	306	595	1065	1367	1584	1364	1181	657	338	162	8700
	Havre.....	C	29.8	19	37	252	539	1014	1321	1528	1305	1116	612	304	135	8182
	Helena.....	A	31.1	31	59	294	601	1002	1265	1438	1170	1042	651	381	195	8129
	Kalispell.....	A	31.4	50	99	321	654	1020	1240	1401	1134	1029	639	397	207	8191
	Miles City.....	A	31.2	6	6	174	502	972	1296	1504	1252	1057	579	276	99	7723
	Missoula.....	A	31.5	34	74	303	651	1035	1287	1420	1120	970	621	391	219	8125
	Grand Island.....	A	36.0	0	6	108	381	834	1172	1314	1089	908	462	211	45	6530
	Lincoln.....	C	38.8	0	6	75	301	726	1066	1237	1016	834	402	171	30	5864
	Norfolk.....	A	34.0	9	0	111	397	873	1234	1414	1179	983	498	233	48	6979
	North Platte.....	A	35.5	0	6	123	440	885	1166	1271	1039	930	519	248	57	6684
Omaha.....	A	35.6	0	12	105	357	828	1175	1355	1126	939	465	208	42	6612	
Scottsbluff.....	A	35.9	0	0	138	459	876	1128	1231	1008	921	552	285	75	6673	
Valentine.....	A	32.6	9	12	165	493	942	1237	1395	1176	1045	579	288	84	7425	
Nev.	Elko.....	A	34.0	9	34	225	561	924	1197	1314	1036	911	621	409	192	7433
	Ely.....	A	33.1	28	43	234	592	939	1184	1308	1075	977	672	456	225	7733
	Las Vegas.....	A	53.5	0	0	0	78	387	617	688	487	335	111	6	0	2709
	Reno.....	A	39.3	43	87	204	490	801	1026	1073	823	729	510	357	189	6332
	Winnemucca.....	A	36.7	0	34	210	536	876	1091	1172	916	837	573	363	153	6761
N.H.	Concord.....	A	33.0	6	50	177	505	822	1240	1358	1184	1032	636	298	75	7383
	Mt. Washington Obsv.....		15.2	493	536	720	1057	1341	1742	1820	1663	1652	1260	930	603	13817
N.J.	Atlantic City.....	A	43.2	0	0	39	251	549	880	936	848	741	420	133	15	4812
	Newark.....	A	42.8	0	0	30	248	573	921	983	876	729	381	118	0	4589
	Trenton.....	C	42.4	0	0	57	264	576	924	989	885	753	399	121	12	4980
N. M.	Albuquerque.....	A	45.0	0	0	12	229	642	868	930	703	595	288	81	0	4348
	Clayton.....	A	42.0	0	6	66	310	699	899	986	812	747	429	183	21	5158
	Raton.....	A	38.1	9	28	126	431	825	1048	1116	904	834	543	301	63	6228
	Roswell.....	A	47.5	0	0	18	202	573	806	840	641	481	201	31	0	3793
	Silver City.....	A	48.0	0	0	6	183	525	729	791	605	518	261	87	0	3705
N.Y.	Albany.....	A	34.6	0	19	138	440	777	1194	1311	1156	992	564	239	45	6875
	Albany.....	C	37.2	0	9	102	375	699	1104	1218	1072	908	498	186	30	6201
	Binghamton.....	A	33.9	22	65	201	471	810	1184	1277	1154	1045	645	313	99	7286
	Binghamton.....	C	36.6	0	28	141	406	732	1107	1190	1081	949	543	229	45	6451
	Buffalo.....	A	34.5	19	37	141	440	777	1156	1256	1145	1039	645	329	28	7062
	New York (Cent. Park).....	C	42.8	0	0	30	233	540	902	986	885	760	408	118	9	4871
New York (La Guardia).....	A	43.1	0	0	27	223	528	887	973	879	750	414	124	6	4811	

Table 303-2-1 (continued)

Average Monthly and Yearly Degree Days for Cities in the United States and Canada (Base 65 F)
(Continued)

State	Station	Avg. Winter Temp	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
N. C.	New York (Kennedy)	A	41.4	0	0	36	248	564	933	1029	935	815	480	167	5219
	Rochester	A	35.4	9	31	126	415	747	1125	1234	1123	1014	597	279	6748
	Schenectady	C	35.4	0	22	123	422	756	1159	1283	1131	970	543	211	6650
	Syracuse	A	35.2	6	28	132	415	744	1153	1271	1140	1004	570	248	6756
	Asheville	C	46.7	0	0	48	245	555	775	784	683	592	273	87	4042
	Cape Hatteras		53.3	0	0	0	78	273	521	580	518	440	177	25	2612
	Charlotte	A	50.4	0	0	6	124	438	691	691	582	481	156	22	3191
	Greensboro	A	47.5	0	0	33	192	513	778	784	672	552	234	47	3805
	Raleigh	A	49.4	0	0	21	164	450	716	725	616	487	180	34	3393
	Wilmington	A	54.6	0	0	0	74	291	521	546	462	357	96	0	2347
N. D.	Winston-Salem	A	48.4	0	0	21	171	483	747	753	652	524	207	37	3595
	Bismarck	A	26.6	34	28	222	577	1083	1463	1708	1442	1203	645	329	8851
	Devils Lake	A	22.4	40	53	273	642	1191	1634	1872	1579	1345	753	381	9901
	Fargo	A	24.8	28	37	219	574	1107	1569	1789	1520	1262	690	332	9226
Ohio	Williston	A	25.2	31	43	261	601	1122	1513	1758	1473	1262	681	357	9243
	Akron-Canton	A	38.1	0	9	96	381	726	1070	1138	1016	871	489	202	6037
	Cincinnati	C	45.1	0	0	39	208	558	862	915	790	642	294	96	4410
	Cleveland	A	37.2	9	25	105	384	738	1088	1159	1047	918	552	260	6351
	Columbus	A	39.7	0	6	84	347	714	1039	1088	949	809	426	171	5660
	Columbus	C	41.5	0	0	57	285	651	977	1032	902	760	396	136	5211
	Dayton	A	39.8	0	6	78	310	696	1045	1097	955	809	429	167	5622
	Mansfield	A	36.9	9	22	114	397	768	1110	1169	1042	924	543	245	6403
	Sandusky	C	39.1	0	6	66	313	684	1032	1107	991	868	495	198	5796
	Toledo	A	36.4	0	16	117	406	792	1138	1200	1056	924	543	242	6494
Okla.	Youngstown	A	36.8	6	19	120	412	771	1104	1169	1047	921	540	248	6417
	Oklahoma City	A	48.3	0	0	15	164	498	766	868	664	527	189	34	3725
Ore.	Tulsa	A	47.7	0	0	18	158	522	787	893	683	539	213	47	3860
	Astoria	A	45.6	146	130	210	375	561	679	753	622	636	480	363	5186
	Burns	C	35.9	12	37	210	515	867	1113	1246	988	856	570	366	6957
	Eugene	A	45.6	34	34	129	366	585	719	803	627	589	426	279	4726
	Medford	A	34.2	84	124	288	580	918	1091	1209	1005	983	726	527	7874
	Medford	A	43.2	0	0	78	372	678	871	918	697	642	432	242	5008
	Pendleton	A	42.6	0	0	111	350	711	884	1017	773	617	396	205	5127
	Portland	A	45.6	25	28	114	335	597	735	825	644	586	396	245	4635
	Portland	C	47.4	12	16	75	267	534	679	769	594	536	351	198	4109
	Roseburg	A	44.3	22	16	105	329	567	713	766	608	570	403	267	4491
Pa.	Salem	A	45.4	37	31	111	338	594	729	822	647	611	417	273	4754
	Allentown	A	38.9	0	0	90	353	693	1045	1116	1002	849	471	167	5810
	Erie	A	36.8	0	25	102	391	714	1063	1169	1081	973	585	288	6451
	Harrisburg	A	41.2	0	0	63	298	648	992	1045	907	766	396	124	5251
	Philadelphia	A	41.8	0	0	60	297	620	965	1016	889	747	392	118	5144
	Philadelphia	C	44.5	0	0	30	205	513	856	924	823	691	351	93	4486
	Pittsburgh	A	38.4	0	9	105	375	726	1063	1119	1002	874	480	195	5987
	Pittsburgh	C	42.2	0	0	60	291	615	930	983	885	763	390	124	5053
	Reading	C	42.4	0	0	34	257	597	939	1001	885	735	372	105	4945
	Scranton	A	37.2	0	19	132	434	762	1104	1156	1028	893	498	195	6254
R. I.	Williamsport	A	38.5	0	9	111	375	717	1073	1122	1002	856	468	177	5934
	Block Island	A	40.1	0	16	78	307	594	902	1020	955	877	612	344	5804
	Providence	A	38.8	0	16	96	372	660	1023	1110	988	868	534	236	5954
	Charleston	A	56.4	0	0	0	59	282	471	487	389	291	54	0	2033
	Charleston	C	57.9	0	0	0	34	210	425	443	367	273	42	0	1794
	Columbia	A	54.0	0	0	0	84	345	577	570	470	357	81	0	2484
	Florence	A	54.5	0	0	0	78	315	552	552	459	347	84	0	2387
	Greenville-Spartanburg	A	51.6	0	0	6	121	399	651	660	546	446	132	19	2980
	Huron	A	28.8	9	12	165	508	1014	1432	1628	1355	1125	600	288	8223
	Rapid City	A	33.4	22	12	165	481	897	1172	1333	1145	1051	615	326	7345
S. D.	Sioux Falls	A	30.6	19	25	168	462	972	1361	1544	1285	1082	573	270	7839
	Bristol	A	46.2	0	0	51	236	573	828	828	700	598	261	68	4143
	Chattanooga	A	50.3	0	0	18	143	468	698	722	577	453	150	25	3254
	Knoxville	A	49.2	0	0	30	171	489	725	732	613	493	198	43	3494
Tenn.	Memphis	A	50.5	0	0	18	130	447	698	729	585	456	147	22	3232

Table 303-2-1 (continued)

Average Monthly and Yearly Degree Days for Cities in the United States and Canada (Base 65 F)
(Continued)

State or Prov.	Station	Avg. Winter Temp ^a	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total
Tex.	Memphis.....	C 51.6	0	0	12	102	396	648	710	568	434	129	16	0	3015
	Nashville.....	A 48.9	0	0	30	158	495	732	778	644	512	189	40	0	3578
	Oak Ridge.....	C 47.7	0	0	39	192	531	772	778	669	552	228	56	0	3817
	Abilene.....	A 53.9	0	0	0	99	366	586	642	470	347	114	0	0	2624
	Amarillo.....	A 47.0	0	0	18	205	570	797	877	664	546	252	56	0	3983
	Austin.....	A 59.1	0	0	0	31	225	388	468	325	223	51	0	0	1711
	Brownsville.....	A 67.7	0	0	0	0	66	149	205	106	74	0	0	0	600
	Corpus Christi.....	A 64.6	0	0	0	0	120	220	291	174	109	0	0	0	914
	Dallas.....	A 55.3	0	0	0	62	321	524	601	440	319	90	6	0	2363
	El Paso.....	A 52.9	0	0	0	84	414	648	685	445	319	105	0	0	2700
	Fort Worth.....	A 55.1	0	0	0	65	324	536	614	448	319	99	0	0	2405
	Galveston.....	A 62.2	0	0	0	6	147	276	360	263	189	-33	0	0	1274
	Galveston.....	C 62.0	0	0	0	0	138	270	350	258	189	30	0	0	1235
	Houston.....	A 61.0	0	0	0	6	183	307	384	288	192	36	0	0	1396
	Houston.....	C 62.0	0	0	0	0	165	288	363	258	174	30	0	0	1278
	Laredo.....	A 66.0	0	0	0	0	105	217	267	134	74	0	0	0	797
	Lubbock.....	A 48.8	0	0	18	174	513	744	800	613	484	201	31	0	3578
	Midland.....	A 53.8	0	0	0	87	381	592	651	468	322	90	0	0	2591
	Port Arthur.....	A 60.5	0	0	0	22	207	329	384	274	192	39	0	0	1447
	San Angelo.....	A 56.0	0	0	0	68	318	536	567	412	288	66	0	0	2255
	San Antonio.....	A 60.1	0	0	0	31	204	363	428	286	195	39	0	0	1546
	Victoria.....	A 62.7	0	0	0	6	150	270	344	230	152	21	0	0	1173
	Waco.....	A 57.2	0	0	0	43	270	456	536	389	270	66	0	0	2030
	Wichita Falls.....	A 53.0	0	0	0	99	381	632	698	518	378	120	6	0	2832
Utah	Milford.....	A 36.5	0	0	99	443	867	1141	1252	988	822	519	279	87	6497
	Salt Lake City.....	A 38.4	0	0	81	419	849	1082	1172	910	763	459	233	84	6052
	Wendover.....	A 39.1	0	0	48	372	822	1091	1178	902	729	408	177	51	5778
Vt.	Burlington.....	A 29.4	28	65	207	539	891	1349	1513	1333	1187	714	353	90	8269
Va.	Cape Henry.....	C 50.0	0	0	0	112	360	645	694	633	536	246	53	0	3279
	Lynchburg.....	A 46.0	0	0	51	223	540	822	849	731	605	267	78	0	4166
	Norfolk.....	A 49.2	0	0	0	136	408	698	738	655	533	216	37	0	3421
	Richmond.....	A 47.3	0	0	36	214	495	784	815	703	546	219	53	0	3865
	Roanoke.....	A 46.1	0	0	51	229	549	825	834	722	614	261	65	0	4150
Wash.	Olympia.....	A 44.2	68	71	198	422	636	753	834	675	645	450	307	177	5236
	Seattle-Tacoma.....	A 44.2	56	62	162	391	633	750	828	678	657	474	295	159	5145
	Seattle.....	C 46.5	50	47	129	329	543	657	738	599	571	396	242	117	4424
	Spokane.....	A 36.5	9	25	168	493	879	1082	1231	980	834	531	288	135	6655
	Walla Walla.....	C 43.8	0	0	87	310	681	843	986	745	589	342	177	45	4805
	Yakima.....	A 39.1	0	12	144	450	828	1039	1163	868	713	435	220	69	5941
W. Va.	Charleston.....	A 44.8	0	0	63	254	591	865	880	770	648	300	96	9	4476
	Elkins.....	A 40.1	9	25	135	400	729	992	1008	896	791	444	198	48	5675
	Huntington.....	A 45.0	0	0	63	257	585	856	880	764	636	294	99	12	4446
	Parkersburg.....	C 43.5	0	0	60	264	606	905	942	826	691	339	115	6	4754
Wisc.	Green Bay.....	A 30.3	28	50	174	484	924	1333	1494	1313	1141	634	335	99	8029
	La Crosse.....	A 31.5	12	19	153	437	924	1339	1504	1277	1070	540	245	69	7589
	Madison.....	A 30.9	25	40	174	474	930	1330	1473	1274	1113	618	310	102	7863
	Milwaukee.....	A 32.6	43	47	174	471	876	1252	1376	1193	1054	642	372	135	7635
Wyo.	Casper.....	A 33.4	6	16	192	524	942	1169	1290	1084	1020	657	381	129	7410
	Cheyenne.....	A 34.2	28	37	219	543	909	1085	1212	1042	1026	702	428	150	7381
	Lander.....	A 31.4	6	19	204	555	1020	1299	1417	1145	1017	634	381	153	7870
	Sheridan.....	A 32.5	25	31	219	539	948	1200	1355	1154	1051	642	366	150	7680
Alta.	Banff.....	C —	220	295	498	797	1185	1485	1624	1364	1237	855	589	402	10551
	Calgary.....	A —	109	186	402	719	1110	1389	1575	1379	1268	798	477	291	9703
	Edmonton.....	A —	74	180	411	738	1215	1603	1810	1520	1330	765	400	222	10268
	Lethbridge.....	A —	56	112	318	611	1011	1277	1497	1291	1159	696	403	213	8644
B. C.	Kamloops.....	A —	22	40	189	546	894	1138	1314	1057	818	462	217	102	6799
	Prince George.....	A —	236	251	444	747	1110	1420	1612	1319	1122	747	468	279	9755
	Prince Rupert.....	C —	273	248	339	539	708	868	936	808	812	648	493	357	7029
	Vancouver.....	A —	81	87	219	456	657	787	862	723	676	501	310	156	5515
	Victoria.....	A —	136	140	225	462	663	775	840	718	691	504	341	204	5699
	Victoria.....	C —	172	184	243	426	607	723	805	668	660	487	354	250	5579

Table 303-2-1 (continued)

Average Monthly and Yearly Degree Days for Cities in the United States and Canada (Base 65 F)
(Concluded)

State or Prov.	Station	Avg. Winter Temp.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Yearly Total	
Man.	Brandon*	A	—	47	90	357	747	1290	1792	2034	1737	1476	837	431	198	11036
	Churchill	A	—	160	375	681	1082	1620	2248	2558	2277	2130	1569	1153	675	16728
	The Pas	C	—	59	127	429	831	1440	1981	2232	1853	1624	969	508	228	12281
	Winnipeg	A	—	38	71	322	683	1251	1757	2008	1719	1465	813	405	147	10679
N. B.	Fredericton*	A	—	78	68	234	592	915	1392	1541	1379	1172	753	406	141	8671
	Moncton	C	—	62	105	276	611	891	1342	1482	1336	1194	789	468	171	8727
	St. John	C	—	109	102	246	527	807	1194	1370	1229	1097	756	490	249	8219
Nfld.	Argentia	A	—	260	167	294	564	750	1001	1159	1085	1091	879	707	483	8440
	Corner Brook	C	—	102	133	324	642	873	1194	1358	1283	1212	885	639	333	8978
	Gander	A	—	121	152	330	670	909	1231	1370	1266	1243	939	657	366	9254
	Goose*	A	—	130	205	444	843	1227	1745	1947	1689	1494	1074	741	348	11887
	St. John's*	A	—	186	180	342	651	831	1113	1262	1170	1187	927	710	432	8991
N. W. T.	Aklavik	C	—	273	459	807	1414	2064	2530	2632	2336	2282	1674	1063	483	18017
	Fort Norman	C	—	164	341	666	1234	1959	2474	2592	2209	2058	1386	732	294	16109
	Resolution Island	C	—	843	831	900	1113	1311	1724	2021	1850	1817	1488	1181	942	16021
N. S.	Halifax	C	—	58	51	180	457	710	1074	1213	1122	1030	742	487	237	7361
	Sydney	A	—	62	71	219	518	765	1113	1262	1206	1150	840	567	276	8049
	Yarmouth	A	—	102	115	225	471	696	1029	1156	1065	1004	726	493	258	7340
Ont.	Cochrane	C	—	96	180	405	760	1233	1776	1978	1701	1528	963	570	222	11412
	Fort William	A	—	90	133	366	694	1140	1597	1792	1557	1380	876	543	237	10405
	Kapuskasing	C	—	74	171	405	756	1245	1807	2037	1735	1562	978	580	222	11572
	Kitchener	C	—	16	59	177	505	855	1234	1342	1226	1101	663	322	66	7566
	London	A	—	12	43	159	477	837	1206	1305	1198	1066	648	332	66	7349
	North Bay	C	—	37	90	267	608	990	1507	1680	1463	1277	780	400	120	9219
	Ottawa	C	—	25	81	222	567	936	1469	1624	1441	1231	708	341	90	8735
	Toronto	C	—	7	18	151	439	760	1111	1233	1119	1013	616	298	62	6827
P.E.I.	Charlottetown	C	—	40	53	198	518	804	1215	1380	1274	1169	813	496	204	8164
	Summerside	C	—	47	84	216	546	840	1246	1438	1291	1206	841	518	216	8488
Que.	Arvida	C	—	102	136	327	682	1074	1659	1879	1619	1407	891	521	231	10528
	Montreal*	A	—	9	43	165	521	882	1392	1566	1381	1175	684	316	69	8203
	Montreal	C	—	16	28	165	496	864	1355	1510	1328	1138	657	288	54	7899
	Quebec*	A	—	56	84	273	636	996	1516	1665	1477	1296	819	428	126	9372
	Quebec	C	—	40	68	243	592	972	1473	1612	1418	1228	780	400	111	8937
Sask.	Prince Albert	A	—	81	136	414	797	1368	1872	2108	1763	1559	867	446	219	11630
	Regina	A	—	78	93	360	741	1284	1711	1965	1687	1473	804	409	201	10806
	Saskatoon	C	—	56	87	372	750	1302	1758	2006	1689	1463	798	403	186	10870
Y. T.	Dawson	C	—	164	326	645	1197	1875	2415	2561	2150	1838	1068	570	258	15067
	Mayo Landing	C	—	208	366	648	1135	1794	2325	2427	1992	1665	1020	580	294	14454

*The data for these normals were from the full ten-year period 1951-1960, adjusted to the standard normal period 1931-1960.

Table 303-2-1 (continued)

Internal gains have also increased dramatically. Edison Electric Institute⁷ reports show average residential electric usage of 675 kwh per month in 1973 versus 46 kwh in 1930. Recent research indicates that monthly average internal and solar gains are sufficient to offset a home's heat loss at mean daily temperatures below 65 F. Thus, the use of the 65 F base degree day would require the use of "seasonal utilization efficiencies" in excess of 100% to match measured fuel consumption for newer residences. A modified degree day procedure has been developed for newer residences.⁸

C. Modified Degree Day Procedure

The general equation for calculating the probable energy consumption by the modified degree day method is:

$$E = \left(\frac{H_L \times D \times 24}{\Delta t \times \eta \times V} \right) (C_D)(C_F)$$

where:

E = fuel or energy consumption for the estimate period.

H_L = design heat loss, including infiltration, Btu per hour.

D = number of 65 F degree days for the estimate period.

Δt = design temperature difference, Fahrenheit.

η = rated full load efficiency, decimal.

V = heating value of fuel, consistent with H_L and E.

C_D = interim correction factor for heating effect vs degree days.

C_F = interim part-load correction factor for fueled systems only; equals 1.0 for electric resistance heating.

Values of heating load, H_L, must be determined for the particular residence for which the estimate is being made. It must account for size, building materials, architectural features, use and climatic conditions. Generally, the peak design heating load is used. Rated full-load efficiencies of fuel-fired equipment are usually in the range of 70 to 80% and may be obtained from the manufacturer. Tables 303-2-2 and 303-2-3 give values for C_D and C_F.

Table 303-2-2 Heat Loss vs. Degree Days
Interim Factor C_D *

Outdoor Design Temp, F	-20	-10	0	+10	+20
Factor C_D	0.57	0.64	0.71	0.79	0.89

*The multipliers in Table 2 which are high for mild climates and low for cold regions, are not in error as might appear. For equivalent buildings, those in warm climates have a greater portion of their heating requirements on days when the mean temperature is close to 65 F, and thus the actual heat loss is not reflected.

Table 303-2-3 Part-Load Correction
Factor for Fuel-Fired Equipment*

Percent oversizing	0	20	40	60	80
Factor C_F	1.36	1.56	1.79	2.04	2.32

*Because equipment performance at extremely low loads is highly variable, it is strongly recommended that the values in Table 303-2-3 be extrapolated.

D. Equivalent Full-Load Hours

This procedure simply consists of using an estimate, based on local experience, of the ratio of annual cooling energy requirements to rated energy input of the cooling equipment.

The energy budget of cooling equipment during a particular summer depends on variables such as the amounts of sunshine and rain, the number of abnormally hot or cool days, and the efficiency of the equipment. It is also influenced by human factors, such as operation of equipment only during the hottest weather, opening windows at night, and difference in preferred indoor temperatures. Nevertheless, it is important that lending agencies and prospective buyers of equipment be given a reasonably accurate estimate of the operating cost during normal summer weather and under usual operating conditions. Adjustments can then be made for any special conditions anticipated. The approximate electrical power inputs for the various motorized components in mechanical cycle air conditioners are shown in Table 303-2-4.

Energy consumption per hour can be estimated by multiplying the estimated power per ton, and the cooling capacity in tons. Thus, the estimated consumption per hour for a central 3-ton air conditioner with an air-cooled condenser will be $1.63 \text{ kw} \times 3 \text{ tons}$. It is essential to use the correct step of the utility residential rate structure to get a good estimate. The basis of the method used requires the use of a table of the estimated annual hours of operation for properly sized equipment in typical cities. (See Table 303-2-5.)

E. Bin Method Procedure

The bin method consists of performing an instantaneous energy calculation at many different outdoor dry-bulb temperature conditions, and multiplying the result by the number of hours of occurrence of each calculation. The "bins" are usually 5 F in size and further divided into three daily eight-hour shifts. For example, a calculation is performed for 42 F outdoor (representing all occurrences of 40-44 F) and with building operation during the midnight-to-eight a.m. shift. Since there are 23 bins between -10 F and 105 F, and three shifts, 69 separate operating points would be calculated. For many applications, the number of calculations can be reduced. A residential heat pump (heating portion), for example, could be calculated for just the bins below 65 F, and without the "three shifts" breakdown. The bin method may be used with or without refinements such as coincident wet-bulb conditions, depending on the anticipated impact of the additional parameters. Weather data for use with the bin method is available in Air Force Manual 88-8, Chapter 6, Engineering Weather Data.

The three energy estimating methods presented thus far do not satisfy the energy analysis criteria set forth in Section 4 of the Code without modification. A recently developed procedure utilizing the bin method concept has been adopted by ASHRAE to meet the criteria of ASHRAE 90-75. The procedure represents a manual method for estimating energy requirements for buildings by inclusion of variables such as mass orientation, and internal loading previously restricted to computer analysis. The procedure is discussed further in Section IV.

F. Hour-By-Hour Calculations

The wide-ranging and constantly changing internal and external factors which determine the thermal loads on commercial and industrial buildings suggest the need for frequent evaluation of those factors to obtain reasonable accuracy in estimating annual

TABLE 303-2-4

APPROXIMATE POWER INPUTS

	Compressor Kw/Design Ton	Auxiliaries Kw/Design Ton
Window Units	1.46	0.32
Through-Wall Units	1.64	0.30
Dwelling Unit, Central Air-Cooled	1.49	0.14
Central, Group, or Bldg. Cooling Plants		
(3 to 25 tons) Air-Cooled	1.20	0.20
(25 to 100 tons) Air-Cooled	1.18	0.21
(25 to 100 tons) Water-Cooled	0.94	0.17
(Over 100 tons) Water-Cooled	0.79	0.20

TABLE 303-2-5

ESTIMATED EQUIVALENT RATED FULL-LOAD HOURS OF OPERATION FOR
PROPERLY SIZED EQUIPMENT DURING NORMAL COOLING SEASON

Albuquerque, NM	800-2200	Indianapolis, In	600-1600
Atlantic City, NJ	500-800	Little Rock, AR	1400-2400
Birmingham, AL	1200-2200	Minneapolis, MN	400-800
Boston, MA	400-1200	New Orleans, LA	1400-2800
Burlington, VT	200-600	New York, NY	500-1000
Charlotte, NC	700-1100	Newark, NJ	400-900
Chicago, IL	500-1000	Oklahoma City, OK	1100-2000
Cleveland, OH	400-800	Pittsburgh, PA	900-1200
Cincinnati, OH	1000-1500	Rapid City, SD	800-1000
Columbia, SC	1200-1400	St. Joseph, MO	1000-1600
Corpus Christi, TX	2000-2500	St. Petersburg, FL	1500-2700
Dallas, TX	1200-1600	San Diego, CA	800-1700
Denver, CO	400-800	Savannah, GA	1200-1400
Des Moines, IA	600-1000	Seattle, WA	400-1200
Detroit, MI	700-1000	Syracuse, NY	200-1000
Duluth, MN	300-500	Trenton, NJ	800-1000
El Paso, TX	1000-1400	Tulsa, OK	1500-2000
Honolulu, HI	1500-3500	Washington, DC	700-1200

energy consumption. The high peak internal heat loads in many commercial modern buildings make it necessary to look at these load patterns at every hour of the day and for each different type of day during the year, to evaluate the changing relationship between internal and external loads. The diversity and sophistication of modern energy distribution and control systems further contribute to energy consumption differences which can only be found by an hourly calculation of the loads on the system and response of the system to those loads.

Hourly calculations do not necessarily imply that 8760 sequential computations be made. A full 8760-hr series of load and system performance calculations could be expected to give more reliable energy estimates, but such procedures require a very large computer and often considerable time for the preparation of input data. On the other hand, simpler methods such as the degree day method or the conventional bin method may not include consideration of the elements of energy analysis which may be essential. Therefore, a variety of computer programs have been developed which attempt to preserve the general characteristics of 8760 hourly calculations, but are somewhat more economical to operate. Some programs use bin-type temperature data but include coincident wet-bulb temperature, solar gain, internal heat gain, and operational data. Others perform the sequential hourly calculations, but for a number of typical days for each month or season rather than for a full year. Program users are well advised to examine various programs to determine their capabilities and limitations prior to any extensive use.

An energy analysis program should have the capability of considering the following essential elements:

1. The physical characteristics of the building; orientation, size, shape, mass and the air moisture and heat transfer characteristics.
2. The changing external environment (climatic data); coincident values for temperature, humidity, solar radiation, and wind data sufficient to evaluate daily and seasonal energy consumption profiles.
3. The variation in internal conditions and operating characteristics; occupancy, lighting and equipment operating schedules, control set points, temperature, humidity, and ventilation schedules.

4. Special features, computer installations, kitchens and special use facilities.
5. Air/water distribution system design and controls.
6. Equipment performance, full- and part-load operating characteristics.

III. COMPUTERIZED LOAD AND ENERGY ANALYSIS

Computerized load and energy programs provide a means by which alternative building designs may be analyzed in accordance with Section 4 of the Code.

The annual energy analysis requirements virtually restrict the analysis to use of high speed digital computer programs. A variety of load and energy programs exist and their availability varies. Two main categories of programs are heating and/or cooling load programs, and energy analysis programs. Heating and/or cooling load programs are used specifically to determine heating and/or cooling loads on buildings for varying weather conditions and indoor schedules of occupation and internal heat gains. Often these programs are utilized in determining peak load conditions for design and selection of HVAC equipment. Energy analysis programs generally have a load calculation section and an equipment simulation section. The equipment simulation allows calculation of energy consumption of depletable and nondepletable energy sources. Many of these programs include a complete economic analysis of alternative systems based on life cycle costs. Life cycle costing accounts for variables such as initial capital invested, equipment life, depreciation expense, operating expense, and maintenance expense in comparing competing types of systems. The following section will review some of the more commonly known computer programs developed with specific emphasis on availability, description of the programs, and input/output requirements.

A. Computer Programs⁹

1. TRACE - Trane Air Conditioning Economics

- a. Developer - The Trane Company, La Crosse, Wisconsin.
- b. Availability - Proprietary, available solely through local Trane representatives or through time sharing systems.

- c. Description - Peak and hourly zone loads are calculated based on coincident hourly climatic data. Hourly climatic data consists of one statistical typical day per month. Supply air quantities and temperatures required for each zone.

Annual energy consumption is determined based on part-load equipment performance data for competing systems. Equipment is restricted to Trane manufactured equipment. An economic comparison of competing systems based on life cycle costs is supplied.

- d. Inputs - Inputs to the program consist of building descriptions, equipment descriptions and economic factors.
- e. Outputs - Outputs include peak building loads, monthly and yearly equipment energy consumptions, and economic comparison of up to four (4) alternative systems based on life cycle cost analysis.

2. APEC (HCC) - Heating/Cooling Calculations

- a. Developer - Automated Procedures for Engineering Consultants (APEC).
- b. Availability - Proprietary, subject to approval or to an APEC member firm.
- c. Description - HCC determines design heating and cooling loads based on ASHRAE methodology.
- d. Inputs - Inputs consist of physical descriptions of the building, weather data, solar radiation data, zone-room designations and system descriptions.
- e. Outputs - Outputs include room and zone loads and air quantity requirements, system analysis results and building peak heating and cooling loads.

3. ACCESS - Alternate Choice Comparison for Energy Systems Selection

- a. Developer - Edison Electric Institute.

- b. Availability - The program is classified not proprietary and may be utilized through participating utilities, time sharing systems, direct purchase or service from participating consulting firms.
 - c. Inputs - Inputs consist of weather data, base load profiles, design heating and cooling loads, space and zone data, HVAC system description, and desired output.
 - d. Output - Output consists of energy consumption and demand for primary systems and alternative systems. Other optional forms of output are available.
4. E-CUBE - Energy Conservation Utilizing Better Engineering
- a. Developer - American Gas Association
 - b. Availability - Program can be utilized via Control Data Corporation's Cybernet timing sharing network or via leasing agreement.
 - c. Description - E-CUBE is a series of programs which utilize design point calculations of peak thermal and electrical loads to make hourly, monthly, and annual estimates of the energy requirements of a building. An economic analysis of various types of systems is used to compare total owning and operation costs of competing systems.
 - d. Input - Maximum value and hourly percentage profiles for internal heat gain, electrical and process loads. Transmission and air infiltration loads as a function of ambient temperature. Maximum solar load on building. Hourly weather data. Part-load equipment performance characteristics, and economic variables.
 - e. Output - Peak, monthly and annual energy requirements for the primary system. Annual energy requirements for alternative systems. Cash flow and discounted rate of return on alternative investments.
5. NBSLD - National Bureau of Standards Load Determination
- a. Developer - Tom Kusuda, National Bureau of Standards
 - b. Availability - Program not proprietary and may be purchased directly.

- c. Description - NBSLD calculates hour by hour heating and/or cooling loads using a transient thermal analysis called response factors. Response factors are described in a following section.
- d. Inputs - Inputs consist of a detailed physical description of the building, occupancy and internal heat gain schedules, and hourly weather data.
- e. Outputs - Hourly heating and/or cooling loads and conditioned space temperatures for each zone are outputted for entire year.

6. Other Programs

Other load and energy programs are available. Some of the more familiar program code names include ESOP, BUILDSIM, NECAP and SCOUT.

The procedures utilized by the individual programs vary in type and sophistication. Some programs calculate hourly data while others may use "typical" days of the month. Since a more detailed description of the individual program procedures would be prohibitive, one program will be described - the ASHRAE adopted algorithms.

B. ASHRAE Algorithms for Building Heat Transfer Subroutines¹⁰

The American Society of Heating, Refrigerating and Air-Conditioning Engineers has over the years supported development of algorithms for calculating heating and cooling loads and energy requirements for buildings. In 1972 ASHRAE first published procedures for determining heating and cooling loads for computerized energy calculations. The procedures were primarily a result of work done by the General American Research Division of General American Transportation Corporation (GARD-GATX) for the United States Postal Service. In 1975 ASHRAE published an updated version of the procedures incorporating work done by the National Bureau of Standards. These new procedures had the advantage over the 1972 procedures of indoor floating temperature capabilities. Previously the procedures required a fixed indoor zone or room temperature. The procedures were not capable of accurately simulating regular indoor temperature variations such as night setback during unoccupied periods.

Figure 302-2-1 illustrates the type of data required for the ASHRAE load algorithms by a user. Data is categorized as:

- space physical data
- space operational data
- environmental data

Space physical data describes the physical construction of a building envelope and interior. Space operational data describes people, lights, and equipment schedules by hour, by day of week, space thermal condition specifications for various operating schedules such as occupied and unoccupied periods, and designation of schedules to be used by calendar day. Environmental data includes hourly outdoor weather variables, design point weather data, ground and atmospheric cleanness data, and building location.

Figure 303-2-2 illustrates the hourly calculation sequence of the program. Output consists of hourly heating/cooling loads.

The ASHRAE algorithms for determining heating and/or cooling loads are based on a transient thermal analysis of heat flow through multi-layered envelope slabs using the response factor technique.

1. Response Factor Technique

Response factors are a technique for accounting for transient heat flow through multi-layer building envelope slabs. The transient heat flow analysis accounts for thermal storage in building envelope elements. The importance of a transient analysis over a steady-state analysis is that it can account for thermal lag in massive building envelope elements. This thermal lag may cause peak loads on a building HVAC system to occur several hours after the maximum load on the building envelope exterior surface occurs. Peak summer loads on the refrigeration systems of many massive buildings occur late in the evening after occupancy hours and peak outdoor thermal conditions.

The development of response factors is well beyond the scope of this session.¹¹ An illustration of the thermal response of a building envelope element is provided in Figure 303-2-3. Shown is a built-up roof structure subjected to summer radiation and temperature disturbances. Note the time lag in heat passing through the roof structure and into the room where it must be removed by the HVAC system.

**SPACE
PHYSICAL
INPUT DATA**

**SPACE
OPERATIONAL
INPUT DATA**

**ENVIRONMENTAL
INPUT DATA**

**CALCULATION OF HOURLY HEATING/COOLING
LOAD WITH ASHRAE ALGORITHMS**

PROGRAM OUTPUT DATA

<p>Required outputs</p> <ol style="list-style-type: none"> Hourly sensible Btu Hourly latent Btu 	<p>Optional outputs</p> <ol style="list-style-type: none"> Summation (monthly & annually) of <ol style="list-style-type: none"> Sensible cooling Btu Latent cooling Btu Sensible heating Btu Latent heating Btu Peak values (monthly & annually) of <ol style="list-style-type: none"> Sensible cooling Btu/h Latent cooling Btu/h Sensible heating Btu/h Latent heating Btu/h
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Data to be Supplied by User for ASHRAE Heating-Cooling Load Calculations Procedure

FIGURE 303-2-1

FIGURE 303-2-2

INSULATED ROOF (SUMMER)

FIGURE 303-2-3

2. Floating Temperatures

The floating indoor temperature capabilities of the ASHRAE procedures have several advantages over fixed indoor temperature routines. First, as discussed above, the effects of thermostat setback schedules on energy requirements may be modelled accurately. Secondly, spaces which are not temperature controlled may be modelled accurately. For residential structures these spaces may consist of attics, basements, and crawl spaces. Thirdly, thermal overloading of HVAC equipment may be accurately modelled. And finally, total shutdown of the HVAC equipment may be simulated. In this final case the zone or spaces air temperatures simply float.

C. The ASHRAE Load Verification Program - Field Test Data on Energy Conservation at the Legal Aids Center

ASHRAE sponsored a two-phase program to validate the proposed simulation procedures. In Phase I, four buildings were chosen for extensive study. One of the buildings, the Ohio Legal Center, is located on The Ohio State University campus. A study was made of the buildings and their installed environmental control systems to determine the instrumentation that would be required to measure all data necessary to calculate building and system loads and energy requirements. Also, the loads and energy consumptions were predicted by using the proposed procedures for load calculation and system simulation. Simulation of the system's components over the entire range of operating conditions, instead of at the design point, allows the design engineer to select components that make the total system more energy efficient. Three guidelines were set forth for the system simulation: it was to be a steady state simulation over a given time period, manufacturer's data was to be used for modeling component performance wherever possible, and the simulation was to be kept as simple as possible without sacrificing accuracy.

In Phase II the Ohio Legal Center and its environmental control system was instrumented in accordance with the guidelines of Phase I. Data was then collected at 15-minute intervals for a period of more than one year. The measurements consisted of temperatures, flow rates, gas consumption, electrical power usage of the major components, and solar radiation. The collected data was reduced to average hourly engineering units and was used as either input data to the computer programs or as comparison values for validation of the simulations. The validation was done by comparing these measurements to those operating parameters predicted by the simulations.

The simulation was done in two steps. In step one the building load simulation uses weather data, building geometry, schedules for lighting and people, and the space set point temperature as input to predict the hourly sensible and latent space loads. In step two the system simulation uses the building loads, as predicted in step one, weather data and control set points as input to calculate the energy consumption required by the environmental control system to maintain the space conditions. The results were used to further develop the load calculation and system simulation procedures to improve their accuracy and reliability.

The HVAC equipment system at Legal Aids consists of a constant volume, high efficiency, dual duct reheat system which is supplemented in winter by a radiant panel heating system. Hot water for the hot deck, radiant panels, and domestic hot water supply are supplied from a gas fired hot water generator. The refrigeration system employs a vapor compression cycle utilizing refrigerant-22 as the working fluid.

D. Comparison of Simulated Versus Measured Energy Consumption

A summary of results of the validation test are listed in Table 303-2-6. Total yearly percentage difference in gas consumption for year 1972 was -2.6% and the total yearly percentage difference electrical usage was -0.8%.

IV. PRINCIPALS FOR A SIMPLIFIED ENERGY CALCULATION PROCEDURE FOR USE IN ENERGY CONSERVATION STANDARD ACTIVITIES

A simplified energy calculation procedure has recently been developed by ASHRAE.

The simplified procedure is based upon conventional engineering calculation practices. It is concise and so logically clear that each step of the calculations can be verified by manual operations. This requirement was mandated for the implementation of ASHRAE Standard 90-75, "Energy Conservation in New Building Design".

The standard requires energy consumption evaluation by many practicing engineers who feel comfortable with the conventional calculation procedures without resorting to the advanced computer analysis. As compared to the sophisticated and computerized calculation procedures which are based upon 8760 hour-by-hour simulations of dynamic interplay among building heat gain/loss, performance of air-side systems and mechanical equipment, the

TABLE 303-2-6

Monthly Summaries of
Natural Gas and Electrical Energy
Measured vs Simulated Systems with Measured load

Month 1972	Natural Gas Btux10 ⁶			Electricity KWH		
	Measured	Simulated	%Diff.	Measured	Simulated	%Diff.
January	527.4	505.8	-4.1	25389	25506	+0.46
February	502.6	488.7	-2.8	23154	24048	+3.9
March	508.9	460.6	-9.5	25095	25860	+3.0
April	347.9	376.1	+8.1	32309	34686	+7.4
May	273.4	280.6	+2.6	48260	47518	-1.5
June	252.5	251.0	-0.6	51646	50382	-2.4
July	222.2	227.5	+2.4	55875	56414	+1.0
August	214.8	203.7	-5.2	56433	58417	+3.5
September	233.4	192.3	-17.6	48889	49760	+1.8
October	324.6	316.5	-2.5	37034	35604	-3.9
November	390.6	396.5	+1.5	25139	25792	+2.5
December	472.1	460.0	-2.6	25695	24655	-4.0
Year Total	4270.4	4159.3	-2.6	454918.0	458642.2	+0.8

simplified procedure would obviously be a compromise in accuracy for the sake of its simplicity. Recognizing the limitations inherent in the traditional methods represented by the degree-day procedures and the conventional bin method, the Carrier REAP procedure "Rational Energy Analysis Procedure" was chosen as a starting point for the recommended procedure.

This particular method was chosen because:

- It is well developed and has been already used with some success by many practicing engineers.
- Its logic has been presented in a very clear and concise manner.
- At least for a limited number of preliminary calculations, it has predicted an annual energy consumption close to those determined by the comprehensive computer calculations.
- Weather data in the bin form are available in the Air Force Manual 88-8 for most U.S. cities.

A. Brief Description Of The Analysis Procedure

The Air Force Manual AFM 88-8 shows monthly temperatures, in bin form, at three daily periods, 02 to 09, 10 to 17 and 18 to 01 hours, such as shown in Tables 1 and 2 for Seattle, Washington. Since most energy data will be required for two periods, "ON" 7:00 a.m. to 7:00 p.m. and "OFF" 7:00 p.m. to 7:00 a.m., it would be necessary to take a percentage out of the 02 to 09 period and also the 18 to 01 period and add this to the 10 to 17 period. A rule of thumb would be 25% out of each period.

To be able to interpret the bin data and make it more meaningful, a histogram is made, as shown in Figure 303-2-4.

The purpose of the histogram is to visualize the hourly temperature variations with reference to the standard ASHRAE equipment design temperatures for both the occupied and unoccupied periods.

The figure clearly shows the importance of intermediate temperature during the off-design condition as far as the energy calculation is concerned, because the majority of energy-consuming hours are in the intermediate temperature range.

The bin method is based upon a classic design-type calculation performed at at least four temperature points, A, B, C, and D, as

FIGURE 303-2-4

indicated in Figure 303-2-4, instead of the traditional two points, A & B, calculation (heating design point and cooling design point). The intermediate points, C & D, may represent two peaks in the bin histogram, which are off-peak and off-design conditions to include consideration of the part-load performance of the systems and equipment.

Instead of the simple heat-loss and heat-gain calculation, a relatively comprehensive load calculation, air-side system simulation, and equipment-load estimation are performed at these selected temperature points, and the energy consumption at any other points is derived by the linear interior extrapolations. The important and significant improvement for the method developed herein is that the rigorous energy calculations including detailed HVAC system simulations will have to be performed for the occupied-hour condition as well as for the non-occupied conditions. Having available the average annual bin data for the hourly outdoor temperature for both the occupied and non-occupied hours, the hourly energy consumption would be interpolated at every temperature level and be multiplied by the bin temperature frequencies and summed to yield the annual energy consumption.

Although the attractive feature of the improved bin method is its use of conventional calculation procedures which are familiar to practicing engineers not accustomed to the advanced computer simulation technique, it should be recognized that this new method still requires a relatively comprehensive set of input data.

The procedures for performing the manual load and energy analysis will be available in ASHRAE's 1977 Guide And Data Handbook Of Fundamentals.

PART 3 ENERGY CONSERVATION IN BUILDINGS BY UTILIZING NONDEPLETING ENERGY SOURCES

The Energy Research and Development Administration (ERDA) has recognized solar energy for heating and cooling as making a significant contribution to supplying our energy needs both near term (now to 1985) and mid-term (1985-2000). ERDA is currently funding programs to demonstrate solar heating and cooling to make possible an initial contribution by 1985 and a substantial annual contribution of 4.5-9 quads by 2000.

1 Quad = 180 million barrels of petroleum
42 million tons of bituminous coal
0.98 trillion cubic feet of natural gas
293 billion kilowatt-hours of electricity

I. SOLAR ENERGY COLLECTORS

A. Flat Plate Collector

Components of a typical flat plate collector (see Figure 303-3-1) consist of:

- absorber plate
- cover system
- back and edge insulation
- collector casing

Solar radiation is transmitted through the cover system and is mostly absorbed by the absorber plate, raising the plate temperature. A fluid such as air or water flowing in contact with the absorber plate picks up a portion of the energy absorbed by the plate and carries it away from the collector. Flat plate collectors are normally designed to operate in a temperature range to 300°F (150°C) above ambient. A variety of flat plate configurations exists. The optimum azimuth of a fixed flat plate collector array is true south, the optimal tilt from horizontal being 10 to 15 degrees below north latitude for cooling and 10 to 15 degrees above north latitude for heating.

B. Concentrating Collectors

A concentrating collector may be viewed as a special case of flat plate collector, modified to increase the radiation flux on the absorber surface (target). Figure 303-3-2 illustrates the basic components of a concentrating collector.

The ratio of solar flux on the absorber surface of a concentrating collector compared to that on a flat plate collector ranges from 1.5 to 10,000 depending on the application. Concentrating collectors are generally used to generate higher working fluid temperatures than flat plate collectors.

Concentration of solar flux on the absorber surface is accomplished by incorporating optical systems to focus incoming direct solar radiation on an absorber target. Concentrating collectors require diurnal tracking of the sun to properly align the optical system.

PPG ALUMINUM SOLAR COLLECTOR (FULL SIZE)

FIGURE 303-3-1

SOLAR SYSTEMS SALES
PPG INDUSTRIES
ONE GATEWAY CENTER
PITTSBURGH, PA. 15222 11/75

Figure 303-3-2 Concentrating Collector Components

II. ENERGY STORAGE

Thermal energy storage can be accomplished through sensible heat or through latent heat. Latent heat storage is accomplished by a physical change of state of the storage material, usually the solid to liquid transition.

A. Liquids

Liquids are classified as sensible heat storage materials. The two most commonly used liquid storage materials are:

- water
- water/ethylene glycol solution

Table 303-3-1 lists heat storage properties of sensible heat materials.

B. Solids

Solids, like liquids, are also classified as sensible storage materials. Solid storage materials such as concrete and gravel are typically used in our active collector systems and passive collector systems.

C. Phase Change Storage

Phase change materials (PCM's) or latent storage materials have

Heat Storage Properties of Sensible Heat Materials

Storage Medium	Density lb/ft ³	Specific Heat	
		Btu/lb°F	Btu/ft ³ °F
Water	62.4	1.0	62.4
Water/Ethylene Glycol (50:50)	65.5	0.83	54.4
Concrete	140	0.156	21.8
Gravel	96*	0.18	17.3*

* Bulk density

TABLE 303-3-1

higher thermal storage capacities than corresponding sensible materials per unit volume. The temperature range of solar systems for heating and cooling of buildings limits the phase change materials which may be used for storage. Phase change materials used in systems today are generally either salt solutions or waxes. Some PCM's are:

- Sodium thiosulfate pentahydrate (STP)(119°F)
- Calcium dinitrate tetrahydrate (117°F)
- P-116 paraffin wax (116°F)

Table 303-3-2 lists heat storage properties of common phase change materials.

Heat Storage Properties of Phase Change Materials

Storage Medium	Melting Temperature °F	Density lb/ft ³	Heat of Fusion	
			Btu/lb	Btu/ft ³
Na ₃ PO ₄ · 12H ₂ O	150	89	82	7,300
NaOH · H ₂ O	148	105	117	12,200
NaC ₂ H ₃ O ₂ · 3H ₂ O	136	81	114	9,200
Na ₂ S ₂ O ₃ · 5H ₂ O	119	103	90	9,300
Ca(NO ₃) ₂ · 4H ₂ O	117	116	66	7,650
P116 Paraffin Wax	116	49	90	4,400
FeCl ₃ · 6H ₂ O	97	101	96	9,700
Na ₂ CO ₃ · 12H ₂ O	97	95	114	10,800
Na ₂ CO ₃ · 10H ₂ O	93	90	108	9,750
Na ₂ SO ₄ · 10H ₂ O	89	91	108	9,850

TABLE 303-3-2

III. ENERGY CONSERVATION IN WATER HEATING SYSTEMS UTILIZING SOLAR ENERGY

A. Domestic Hot Water Heaters

One application of solar energy is an energy source for domestic hot water heating. Domestic hot water for residential and small commercial buildings may be a significant component of the overall energy budget.

Domestic hot water temperatures in the range of 120 to 150°F are well within the application range of flat plate collector systems. Solar systems for domestic hot water heating usually require an auxiliary thermal energy storage system to provide energy during noncollection periods.

B. Industrial Hot Water Heaters

Solar energy application extends to industrial thermal processes where water is in the temperature range of 120 to 200°F. The collector designs for industrial process heating applications are generally simple and vary depending on the process requirements.

IV. ENERGY CONSERVATION BY UTILIZING SOLAR ASSISTED HEATING SYSTEMS

Solar energy may assist conventional heating systems to improve operating performance. One such system consists of solar assisted heat pump heating. This system utilizes solar energy to increase the heat transfer potential at the evaporator coil and thereby increase the capacity and coefficient of performance of the heat pump. Air-to-air, air-to-water, and water-to-water heat pumps are adaptable to solar assistance. Solar assisted heat pump heating is economically attractive by reducing the necessary installed capacity of the heat pump unit and increasing the operating efficiency of the unit.

An example of a solar assisted heat pump application is a new elementary school planned for Goldsboro School, North Carolina. Carolina.¹² Figure 303-3-3 illustrates the system. Zone water-to-air heat pumps provide combinations of heating and cooling simultaneously to building zones. A solar panel array is utilized to provide heat to the primary water loop when heat pumps in heating mode cause water temperature to drop below prescribed limit. If solar energy is available and heating of primary water loop is not required, then heat is directed to a 400 gallon domestic water heater. The total HVAC system is expected to cost \$5 per square foot.

V. AVAILABILITY OF SOLAR ENERGY

Solar availability for space heating and/or cooling is a factor of location and local weather conditions. Figures 303-3-4 and 303-3-5 illustrate solar availability for the continental U.S. for heating and cooling, respectively.¹³

Note:

$$1 \text{ LY (Langly)} = 3.687 \frac{\text{Btu}}{\text{ft}^2}$$

Figure 303-3-3 Example Solar Assisted Heat Pump System

VI. SOLAR SYSTEMS^{14,15,16,17,18}

Schematics of various types of solar systems are illustrated in Figures 303-3-6 through 303-3-9. Systems include:

- Decade 80 House, Tucson, Arizona - space heat, space cooling, swimming pool heating, Figure 303-3-6.
- Solar House, Colorado State University - space heating, space cooling, DHW heating, Figure 303-3-7.
- Quechee Lake House - space heating, DHW heating, Figure 303-3-8.
- George A. Towns Elementary School, Atlanta, Georgia - space heating, space cooling, DHW heating, Figure 303-3-9.

VII. ECONOMICS OF SOLAR HEATING AND COOLING

The economics of solar heating and cooling varies with type of system used, initial capital costs, conventional utility costs, and maintenance costs. Generally, solar systems are more economical when compared to conventional electric systems versus other types of systems - gas, oil, and combination oil/electric. Payoff periods for solar systems are expected to decrease as fossil fuel costs increase and collector capital investment costs (\$/sq. ft.) decrease. Table 303-3-3 compares payback periods for various types of systems, types of alternative energy and fuel costs.¹⁹

VIII. FINANCING SOLAR SYSTEMS

Financing practices in the residential field make solar systems easier to obtain economic justification than for commercial applications. Generally, "Shelter Costs" are set at 25% of a family's gross income by lending institutions. Monthly shelter cost usually consists of monthly mortgage payment, taxes, insurance costs, utility costs, fuel costs and prorated maintenance costs. HVAC equipment, including solar, is considered as part of the mortgage - normally 20 to 40 years. Solar monthly shelter costs may be comparable to conventional oil system shelter costs, thus justifying the added initial capital cost of the solar system to the lender. Shelter costs for solar systems, when compared with electric resistance systems, may be significantly lower, again warranting justification by the lender.

Figure 303-3-4 Solar Availability For Space Heating

Figure 303-3-5 Solar Availability For Space Cooling

Figure 303-3-6 Decade 80 House - Tucson, Arizona

Figure 303-3-7 Solar House - Colorado State University

Quechee Lake House-Heating & Domestic HW System

Figure 303-3-8 Quechee Lake House

Figure 303-3-9 George A. Towns Elementary School - Atlanta, Georgia

Solar vs. electric

	Solar system cost	Conventional energy alternative	Time to pay off solar cost: Conventional energy escalates at 5% per year, starting from:		
Southwest, single family residence, hot water only	\$ 1,000	electric	\$.03/KWH 7.8 Yrs.	\$.035/KWH 8.9 Yrs.	\$.04/KWH 6.1 Yrs.
Northeast, single family residence, hot water only	1,600	electric	\$.04/KWH 8.3 Yrs.	\$.045/KWH 7.5 Yrs.	\$.05/KWH 6.9 Yrs.
Southwest, single family residence, heating & hot water	3,400	electric	\$.03/KWH 8.0 Yrs.	\$.035/KWH 8.0 Yrs.	\$.04/KWH 7.1 Yrs.
Midwest, single family residence, heating & hot water	4,400	electric	\$.03/KWH 8.1 Yrs.	\$.035/KWH 8.0 Yrs.	\$.04/KWH 7.2 Yrs.
Northeast, single family residence, heating & hot water	4,400	electric	\$.04/KWH 8.5 Yrs.	\$.045/KWH 7.7 Yrs.	\$.05/KWH 7.1 Yrs.
Southwest, multi-family low rise, hot water only	18,000	electric	\$.03/KWH 6.8 Yrs.	\$.035/KWH 4.9 Yrs.	\$.04/KWH 4.3 Yrs.
Northeast, multi-family low rise, hot water only	18,000	electric	\$.04/KWH 8.5 Yrs.	\$.045/KWH 4.9 Yrs.	\$.05/KWH 4.5 Yrs.

Solar vs. gas, oil or oil and electricity in combination

	Solar system cost	Conventional energy alternative	Time to pay off solar cost: oil & gas escalate 8% per year; electricity escalates 5% per year; starting from:		
Southwest, single family residence, hot water only	\$ 1,000	gas	\$1.50/MCF 16.9 Yrs.	\$2.00/MCF 14.2 Yrs.	\$2.50/MCF 12.4 Yrs.
Northeast, single family residence, hot water only	1,600	gas	\$2.00/MCF 17.5 Yrs.	\$2.50/MCF 15.4 Yrs.	\$3.00/MCF 13.8 Yrs.
Southwest, single family residence, heat + hot water	3,400	HW-gas heat-gas	\$1.50/MCF 20.1 Yrs.	\$2.00/MCF 17.2 Yrs.	\$2.50/MCF 15.2 Yrs.
		HW-electric heat-oil	\$.03/KWH \$.35/Gal. 11.7 Yrs.	\$.035/KWH \$.40/Gal. 10.5 Yrs.	\$.04/KWH \$.45/Gal. 9.9 Yrs.
Midwest, single family residence, heat + hot water	4,400	HW-gas heat-gas	\$1.50/MCF 20.2 Yrs.	\$2.00/MCF 17.4 Yrs.	\$2.50/MCF 15.3 Yrs.
		HW-electric heat-oil	\$.03/KWH \$.35/Gal. 12.3 Yrs.	\$.035/KWH \$.40/Gal. 11.2 Yrs.	\$.04/KWH \$.45/Gal. 10.2 Yrs.
Northeast, single family residence, heat + hot water	4,400	HW-gas heat-gas	\$2.00/MCF 19.4 Yrs.	\$2.50/MCF 17.2 Yrs.	\$3.00/MCF 15.5 Yrs.
		HW-electric heat-oil	\$.04/KWH \$.35/Gal. 13.2 Yrs.	\$.045/KWH \$.40/Gal. 12.1 Yrs.	\$.05/KWH \$.45/Gal. 11.2 Yrs.
Southwest, multi-family low rise, hot water only	18,000	gas	\$1.50/MCF 14.7 Yrs.	\$2.00/MCF 12.2 Yrs.	\$2.50/MCF 10.6 Yrs.
		oil	\$.35/Gal. 10.5 Yrs.	\$.40/Gal. 8.8 Yrs.	\$.45/Gal. 8.8 Yrs.
Northeast, multi-family low rise, hot water only	\$18,000	gas	\$2.00/MCF 14.4 Yrs.	\$2.50/MCF 12.6 Yrs.	\$3.00/MCF 11.1 Yrs.
		oil	\$.35/Gal. 12.5 Yrs.	\$.40/Gal. 11.5 Yrs.	\$.45/Gal. 10.6 Yrs.

Table 303-3-3

IX. ARCHITECTURAL CONSIDERATIONS

Architectural considerations have a significant impact on size of collectors required (sq. ft.), economics of operation, and aesthetics. Building exterior design may be used to optimize use of existing solar radiation and minimize heat loss. Solar systems may be designed which utilize building thermal storage and nocturnal cooling to minimize the size of the system and system operating costs.

PART 4 ACCEPTED PRACTICES

I. GENERAL

This part details many accepted practices used to conserve energy in both new and existing buildings. The three basic areas to which energy conservation techniques can be applied are the building envelope, distribution losses, automatic controls and the HVAC system.

II. BUILDING ENCLOSURE, ELEMENTS

A. Orientation and Shape

The heat loss or gain from a building for a given temperature difference is in part a function of its total exposed area. Obviously the first way to minimize energy consumption is to minimize the exposed area. This can be done by taking advantage of more underground area and by eliminating designs with long thin wings. Theoretically a cubic shape offers the least exposed area for a given volume.

A more subtle exposed area effect comes to light when building orientation is considered. Buildings oriented along an east-west axis will have large summer peak cooling loads on the south side and large winter heating loads on the north side. Likewise, buildings with a north-south orientation will experience large solar loads on the east side in the morning and on the west side in the evening. The added factor of wind condition compounds the design to the point where it is often necessary to use computer programs to select the best orientation compromise.

B. Building Thermal Envelope

The building thermal envelope consists of walls, roof/ceilings, floors, windows and doors. The heat loss or gain from the

envelope consists of conduction, radiation and infiltration losses. For a complete discussion on Building Insulation see Appendix 303-A.

1. Building thermal envelope U values - The acceptable practice for residential buildings is given in Section 6 of Ref. 303-4-1.²¹ In general, wall construction must be designed based on an overall coefficient of transmission as discussed in Section 5 of the Model Energy Conservation Code. Therefore, the proportionate areas of each type of construction must be considered to determine the overall U value.

A detailed description on the methodology and accepted practice of calculating the heat transfer through building walls, ceilings, and floors is presented in Appendix 303-B.

The reference tables refer to the "Model Code for Energy Conservation in New Building Construction". Four very detailed examples are presented for the reader who is not familiar with calculating overall heat transfer coefficients.

- a. Checking wall, roof/ceiling, floors over unheated space, and slab on grade construction for envelope requirements.

The maximum allowed coefficient of transmission value required for each component of the building envelope is dependent upon four factors:

1. Building Type: Residential or Commercial
2. Type of HVAC system: Heating or Cooling or Both
3. Average weather conditions in the area where the building is constructed.
4. If mechanical cooling is provided in a commercial building, then the location in degrees north latitude is required.

Once these factors have been determined, the maximum allowed coefficient of transmission value can be determined as discussed in Section 5 of Ref. 303-4-1.

Next the combined thermal transmittance value (U_o) or the overall thermal transfer value (OTTV) must be calculated from the equations presented in Section 5 of Ref. 303-4-1. The two equations are:

EQUATION 1

$$U_o = \frac{U_w A_w + U_g A_g + U_d A_d}{A}$$

where:

U_o = the average or combined transmittance of the gross exterior wall, floor or roof/ceiling assembly area. (Except slabs on grade.)

A = the gross exterior wall, floor or roof/ceiling assembly area.

U_w = the thermal transmittance of the components of the opaque wall, floor or roof/ceiling assembly area.

A_w = opaque wall, floor or roof/ceiling assembly area.

U_g = the thermal transmittance of the glazing (window or skylight area).

A_g = glazing area.

U_d = the thermal transmittance of the door, or similar opening.

A_d = door area.

NOTE: Where more than one type of wall, window, roof/ceiling, door and skylight is used, the U and A terms for those items shall be expanded into subelements as:

$$U_{w1} A_{w1} + U_{w2} A_{w2} + U_{w3} A_{w3} +, \text{ etc.}$$

A detailed description on the methodology and accepted practices of calculating the heating and cooling requirements of a building are presented in Appendix 303-C.

Detailed calculations are presented for four different geographical locations in the United States.

EQUATION 2

$$OTTV = \frac{(U_w A_w T_{DEQ}) + (A_f S_f S_c) + (U_f A_f \Delta t)}{A}$$

where:

OTTV = average or combined thermal transfer value

A = gross exterior wall

U_w = U value of opaque wall (all elements)

A_w = opaque wall area

U_f = U value of the fenestration area

A_f = fenestration area

TD_{EQ} = temperature difference value (from table below)

SC = shading coefficient of the fenestration

Δt = temperature difference between exterior and interior design condition °F

SF = solar factor value

NOTE: Where more than one type of wall is used, the respective terms for those elements shall be expanded into subelements, as:

$$(U_{w1}A_{w1}TD_{EQ1}) + (U_{w2}A_{w2}TD_{EQ2}) + \text{etc.}$$

TEMPERATURE DIFFERENCES FOR USE WITH EQUATION 2

Walls

Wt. of Construction Lbs./Ft. ²	TD_{EQ} Factor
0-25	44
26-40	37
41-70	30
71 and above	23

LSF = Solar Factor shall be determined from Ref. 303-4-2.

The U values which are used in the equations for each component of construction in the building envelope are determined by the procedure presented in Chapter 20 of Ref. 303-4-2.²²

The areas, A values, are taken directly from the construction drawings. It should be noted that the values of solar factor, SF, and temperature difference, TD, are designed to account for the effect of solar radiation on the heat gain to the structure in various parts of the country and for various types of construction.

For residential buildings the process of determining U_o & OTTV has been simplified if certain types of standard construction are employed. This simplified procedure is discussed in Section 6 of Ref. 303-4-1.

Two examples follow. The first using the procedure outlined in Section 6 and the second using equations 1 and 2 for a commercial building.

b. Example 1

GIVEN:

Type A1 detached one- and two-family residential dwelling.

- Annual heating degree days, 6000.
- Structure is provided with heating and cooling.

NOTE: Location in degrees north latitude is not required for residential structures.

- Wall construction is wood siding with R-11 insulation and interior gypsum wall board.
- Roof/Ceiling construction is pitched roof with R-19 insulation over ceiling of 1/2" gypsum wall board.
- Floor is slab on grade w/2" of expanded polystyrene, molded beads.
- 15% of the wall is single glazed glass.

SOLUTION:

Referring to Figure 303-4-1 for Type A1 buildings at 6000 degree days, U_o for walls must be no greater than 0.22. Figure 303-4-2 shows that the R value for the insulation on a heated slab cannot be less than 7.0. The roof/ceiling construction cannot exceed a U_o of 0.05 where the

U_o WALLS—GROUP R BUILDINGS

TYPE R BUILDINGS SHALL INCLUDE:

A 1 DETACHED ONE AND TWO FAMILY DWELLINGS

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

MULTI-FAMILY DWELLINGS
HOTELS AND MOTELS

Figure 303-4-1

R VALUES—SLAB ON GRADE

Figure 303-4-2

Figure 303-4-3

Glass, percent of wall surface¹
 Combinations of Wall and Single Glazed Openings for Use with Section 602.2(a)

CHART 6-A

¹One-half the opaque door area shall be included in the total glazed openings area.

Figure 303-4-4

combinations of Wall and Double Glazed Openings for Use with Section 602.2(a)

CHART 6-B

¹The total area of opaque doors shall be included in the glazed opening area.

Thermal Properties of Typical Building and Insulating Materials—(Design Values)^a

Description	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Customary Unit		Specific Heat, Btu/(lb (deg F)	SI Unit	
				Resistance ^b (R)			Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K) W	(m ² ·K) W
Plywood or wood panels 0.75 in.	34	—	1.07	—	0.93	0.29		0.16
Vegetable Fiber Board								
Sheathing, regular density 0.5 in.	18	—	0.76	—	1.32	0.31		0.23
. 0.78125 in.	18	—	0.49	—	2.06			0.36
Sheathing intermediate density 0.5 in.	22	—	0.82	—	1.22	0.31		0.21
Nail-base sheathing 0.5 in.	25	—	0.88	—	1.14	0.31		0.20
Shingle backer 0.375 in.	18	—	1.06	—	0.94	0.31		0.17
Shingle backer 0.3125 in.	18	—	1.28	—	0.78			0.14
Sound deadening board 0.5 in.	15	—	0.74	—	1.35	0.30		0.24
Tile and lay-in panels, plain or								
acoustic 18	18	0.40	—	2.50	—	0.14	17.33	
. 0.5 in.	18	—	0.80	—	1.25			0.22
. 0.75 in.	18	—	0.53	—	1.89			0.33
Laminated paperboard 30	30	0.50	—	2.00	—	0.33	13.86	
Homogeneous board from								
recycled paper 30	30	0.50	—	2.00	—	0.28	13.86	
Hardboard								
Medium density 50	50	0.73	—	1.37	—	0.31	9.49	
High density, service temp. service								
underlay 55	55	0.82	—	1.22	—	0.32	8.46	
High density, std. tempered 63	63	1.00	—	1.00	—	0.32	6.93	
Particleboard								
Low density 37	37	0.54	—	1.85	—	0.31	12.82	
Medium density 50	50	0.94	—	1.06	—	0.31	7.35	
High density 62.5	62.5	1.18	—	0.85	—	0.31	5.89	
Underlayment 0.625 in.	40	—	1.22	—	0.82	0.29		0.14
Wood subfloor 0.75 in.	—	—	1.06	—	0.94	0.33		0.17
BUILDING MEMBRANE								
Vapor—permeable felt	—	—	16.70	—	0.06			0.01
Vapor—seal, 2 layers of mopped								
15-lb felt	—	—	8.35	—	0.12			0.02
Vapor—seal, plastic film	—	—	—	—	Negl.			
FINISH FLOORING MATERIALS								
Carpet and fibrous pad	—	—	0.48	—	2.08	0.34		0.37
Carpet and rubber pad	—	—	0.81	—	1.23	0.33		0.22
Cork tile 0.125 in.	—	—	3.60	—	0.28	0.48		0.05
Terrazzo 1 in.	—	—	12.50	—	0.08	0.19		0.01
Tile—asphalt, linoleum, vinyl, rubber								
vinyl asbestos	—	—	20.00	—	0.05	0.30		0.01
ceramic	—	—	—	—	—	0.24		
.	—	—	—	—	—	0.19		
Wood, hardwood finish 0.75 in.	—	—	1.47	—	0.68			0.12
INSULATING MATERIALS								
BLANKET AND BATT								
Mineral Fiber, fibrous form processed								
from rock, slag, or glass								
approx. * 2–2.75 in.	0.3–2.0	—	0.143	—	7 ^a	0.17–0.23		1.23
approx. * 3–3.5 in.	0.3–2.0	—	0.091	—	11 ^a			1.94
approx. * 3.50–6.5	0.3–2.0	—	0.053	—	19 ^a			3.35
approx. * 6–7 in.	0.3–2.0	—	0.045	—	22 ^a			3.87
approx. * 8.5 in.	0.3–2.0	—	0.033	—	30 ^a			5.28
BOARD AND SLABS								
Cellular glass	8.5	0.38	—	2.63	—	0.24	18.23	
Glass fiber, organic bonded	4–9	0.25	—	4.00	—	0.23	27.72	
Expanded rubber (rigid)	4.5	0.22	—	4.55	—	0.40	31.53	
Expanded polystyrene extruded								
Cut cell surface	1.8	0.25	—	4.00	—	0.29	27.72	
Expanded polystyrene extruded								
Smooth skin surface	2.2	0.20	—	5.00	—	0.29	34.65	
Expanded polystyrene extruded								
Smooth skin surface	3.5	0.19	—	5.26	—			36.45
Expanded polystyrene, molded beads	1.0	0.28	—	3.57	—	0.29	24.74	
Expanded polyurethane ^c (R-11 exp.)	1.5	0.16	—	6.25	—	0.38	43.82	
(Thickness 1 in. or greater)	2.5	—	—	—	—			

Figure 303-4-5

Surface Conductances and Resistances for Air

All conductance values expressed in $\text{Btu}/(\text{hr} \cdot \text{ft}^2 \cdot \text{F})$.

A surface cannot take credit for both an air space resistance value and a surface resistance value. No credit for an air space value can be taken for any surface facing an air space of less than 0.5 in.

SECTION A. Surface Conductances and Resistances ^{a,b,c}								SECTION B. Reflectivity and Emittance Values of Various Surfaces ^a and Effective Emittances of Air Spaces				
Position of Surface	Direction of Heat Flow	Surface Emittance						Surface	Reflectivity in Percent	Average Emittance ϵ	Effective Emittance E of Air Space	
		Non-reflective $\epsilon = 0.90$	Reflective $\epsilon = 0.20$		Reflective $\epsilon = 0.05$		One surface emittance ϵ ; the other 0.90				Both surfaces emittances ϵ	
			b_1	R	b_1	R						b_1	$R$
STILL AIR												
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32	Aluminum foil, bright	92 to 97	0.05	0.05	0.03
Sloping—45 deg	Upward	1.60	0.62	0.88	1.14	0.73	1.37	Aluminum sheet	80 to 95	0.12	0.12	0.06
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70	Aluminum coated paper, polished	75 to 84	0.20	0.20	0.11
Sloping—45 deg	Downward	1.32	0.76	0.60	1.67	0.45	2.22	Steel, galvanized, bright	70 to 80	0.25	0.24	0.15
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55	Aluminum paint	30 to 70	0.50	0.47	0.35
MOVING AIR												
(Any Position)		b_a	R	b_a	R	b_a	R	Building materials: wood, paper, masonry, nonmetallic paints	5 to 15	0.90	0.82	0.82
15-mph Wind	Any	6.00	0.17					Regular glass	5 to 15	0.84	0.77	0.72
(for winter)												
7.5-mph Wind	Any	4.00	0.25									
(for summer)												

^aFor ventilated attics or spaces above ceilings under summer conditions (heat flow down) see Table 6.

^bConductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10 deg F and for surface temperature of 70 F.

^cSee also Chapter 2, Table 4.

^dSee Fig. 1 for additional data.

Figure 303-4-6

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*
 (*For Industrial Insulation Design Values, see Table 3B). These constants are expressed in Btu per (hour) (square foot) (degree Fahrenheit temperature difference). Conductivities (*k*) are per inch thickness, and conductances (*C*) are for thickness or construction stated, not per inch thickness. All values are for a mean temperature of 75 F, except as noted by an asterisk (*) which have been reported at 45 F. The SI units for Resistance (last two columns) were calculated by taking the values from the two Resistance columns under Customary Unit, and multiplying by the factor 1/*k* (r/in.) and 1/*C* (R) for the appropriate conversion factor in Table 18.

Description	Density (lb/ft ³)	Conduc- tivity (<i>k</i>)	Conduc- tance (<i>C</i>)	Customary Unit		Specific Heat, Btu/(lb (deg F)	SI Unit	
				Resistance ^b (<i>R</i>)			Resistance ^b (<i>R</i>)	
				Per inch thickness (1/ <i>k</i>)	For thick- ness listed (1/ <i>C</i>)		(m · K) W	(m ² · K) W
BUILDING BOARD								
Boards, Panels, Subflooring, Sheathing								
Woodboard Panel Products								
Asbestos-cement board	120	4.0	—	0.25	—	0.24	1.73	0.005
Asbestos-cement board 0.125 in.	120	—	33.00	—	0.03			0.01
Asbestos-cement board 0.25 in.	120	—	16.50	—	0.06			0.06
Gypsum or plaster board 0.375 in.	50	—	3.10	—	0.32	0.26		0.08
Gypsum or plaster board 0.5 in.	50	—	2.22	—	0.45			0.10
Gypsum or plaster board 0.625 in.	50	—	1.78	—	0.56			
Plywood (Douglas Fir) 3/4	34	0.80	—	1.25	—	0.29	8.66	0.05
Plywood (Douglas Fir) 0.25 in.	34	—	3.20	—	0.31			0.08
Plywood (Douglas Fir) 0.375 in.	34	—	2.13	—	0.47			0.11
Plywood (Douglas Fir) 0.5 in.	34	—	1.60	—	0.62			0.19
Plywood (Douglas Fir) 0.625 in.	34	—	1.29	—	0.77			

Figure 303-4-7

heating degree days are less than 8000 per paragraph 4.3.2.2 of ASHRAE 90-75.

First the wall construction for this building is shown in Table 6-1 as having a U value of 0.08. Turning to chart 6-1A (Figure 303-4-3) for a required U_o of 0.22 and a wall construction U of 0.08, the maximum percent glass is 13.5%. This house has 15% glazing, therefore, the wall U value must be decreased to 0.06 or the glazing area must be reduced. If double glazing were used with the 0.08 wall construction, the glass area could be about 24% as shown in Chart 6-1B (Figure 303-4-4).

In Chapter 20 Table 3A (Figure 303-4-5) of Ref. 303-4-2, the resistance of expanded polystyrene molded beads is given as 3.57 per inch of thickness. Since this structure has 2" thick insulation under the floor slab $R = 2 \times 3.57 = 7.14$ which is greater than 7.0 required by 90-75.

The roof/ceiling R value is also determined by obtaining values from Table 1 (Figure 303-4-6) and Table 3A (Figure 303-4-7). The following values are found:

	R
Inside surface, still air	0.61
1/2" gypsum	0.45
Insulation (given)	19.00
Outside surface, still air (Top of insulation in attic)	0.61
TOTAL	20.67

$$U = 1/R = 1/20.67 = 0.0484$$

ASHRAE 90-75 requires the maximum U_o to be 0.05:

This construction meets that requirement. Note that if the ceiling were of the wooden cathedral type, the U_o value would only have to be 0.08 Btu/Hr-Ft²-°F.

Example 2

GIVEN:

- Commercial type building, 4 stories.
- Annual heating degree days, 6000.
- Structure provided with heating and cooling.

- Location 40 degrees north latitude.
- Wall construction: brick and block with 1/2" gypsum boards 60 lb/sq.ft. (18,000 sq.ft.).
- Roof construction: built-up roof over a 2" concrete slab on a metal deck with no insulation.
- Ceiling construction: metal lath and 3/4" plaster.
- Floor: 2" concrete (80 lb/cu.ft.) slab over unheated basement with a carpet and rubber pad.
- Door: $U = 1.0$ and area is 63 sq. ft.
- Glass: double glazed with 1/4" air space (2,000 sq. ft.).

SOLUTION:

Figure 303-4-8 shows the maximum allowable $U_O = 0.33$ at 6000 degree days for buildings over 3 stories.

Figure 303-4-9 shows a maximum $U_O = 0.076$ for roof/ceiling construction at 6000 degree days.

Figure 303-4-10 shows a maximum $U_O = 0.08$ for floors over unheated space at 6000 degree days.

Figure 303-4-11 shows a maximum OTTV of 33.4 for walls of buildings with cooling at 40° north latitude.

Paragraph 4.4.3.2 of ASHRAE 90-75 requires that the roof/ceiling U_O value not exceed 0.05 for a building with cooling.

To determine the U_O of the wall, equation 1 must be utilized. The U of double glazed glass is 0.65 per Figure 303-4-12, and the U of the wall is 0.16 per Figure 303-4-13.

From equation 1:

$$\begin{aligned}
 U_O &= \frac{U_w A_w + U_g A_g + U_d A_d}{A} \\
 &= \frac{(0.16 \times 18,000) + (0.65 \times 2,000) + (1.0 \times 63)}{20,063} \\
 &= 0.212 \text{ Btu/Hr-sq.ft.}-^\circ\text{F}
 \end{aligned}$$

U_o WALLS—HEATING

FOR ALL BUILDINGS NOT REGULATED BY SECTION 502.2

Figure 303-4-8

U_o —ROOFS AND CEILINGS

FOR ALL
BUILDINGS NOT REGULATED BY SECTION
502.2

Figure 303-4-9

U_o VALUES—FLOORS OVER UNHEATED SPACES

Figure 303-4-10

OVERALL THERMAL TRANSFER VALUE
WALLS COOLING
FOR ALL
BUILDINGS NOT REGULATED BY SECTION
502.2

Figure 303-4-11

which is less than the 0.33 requirement and, therefore, complies with 90-75 in that respect.

The roof/ceiling construction would only have to have a $U_o = 0.076$ per Figure 303-4-9 if the building were only heated. Since the building is cooled as well, the roof/ceiling construction must comply with paragraph 4.4.3.2 of ASHRAE 90-75 which requires a $U_o = 0.05$ Btu/h-sq.ft.-°F.

The U of the roof is 0.22 per Figure 303-4-14 which is too high. The resistance of this construction is 4.65 and the required resistance is $1/U_o = 1/0.05 = 20$. Therefore:

Required Resistance	20.00
Less Resistance of existing construction	<u>- 4.65</u>
Resistance required to be added by insulation or other means.	15.35

The floor slab resistance is calculated as follows from values in Tables 1 and 3A of Ref. 303-4-2.

Top surface, still air	$\frac{R}{0.61}$
Carpet & rubber pad	1.23 (Fig.303-4-15)
2" conc. slab	.80 (Fig.303-4-16)
Bottom surface, still air	<u>.61</u>
R	3.25

$$U = 1/R = 1/3.25 = 0.308$$

The maximum allowable $U_o = 0.08$; therefore:

$$\text{Minimum } R = 1/U_o = 1/0.08 = 12.5$$

Less Floor	<u>3.25</u>
Resistance required to be added by insulation or other means	9.25

Last, the OTTV for the wall construction must be checked since the building is provided with mechanical cooling.

**Overall Coefficients of Heat Transmission
(U-Values) for Fenestration under Summer Conditions
(7.5 mph Wind Outdoors, Still Air Indoors)**

Type of Glass	U-Value	
	No Shading	Internal Shading ^a
Any Uncoated Single Glass ^c	1.06	0.81
▷ Insulating Glass : $\frac{1}{8}$ in. Air Space uncoated ▷ $\frac{1}{4}$ in. Air Space $\frac{3}{4}$ in. Air Space $\frac{1}{2}$ in. Air Space	0.66	0.54
	0.65	0.52
	0.61	0.50
	0.59	0.48
Prime Window Plus Storm Window, Air Space 1 in. or more	0.54 ^b	0.47 ^b
	No Supplementary Shading	
Double Glazing with Between-Glass Shading		
Louvered Sun Screen Separated by Air Space	0.63	
Venetian Blinds, Closed, in Air Space	0.44	
Glass Block Panels ^d		
Types I and II	0.56	
Types II, III, and IIIA	0.48	

^a Values apply to tightly closed Venetian and vertical blinds, draperies, and roller shades.

^b Values apply to storm sash with a tight air space. Air leakage present in virtually all storm windows will, in effect, increase this value.

^c U-values can be substantially reduced by low-emittance coatings applied to the inner surface of single or double glazing and to an air-space surface of insulating glass. Consult manufacturers for applicable U-values.

^d Values listed are for $7\frac{1}{2} \times 7\frac{1}{2} \times 3\frac{1}{2}$ in. block. For $11\frac{1}{2} \times 11\frac{1}{2} \times 3\frac{1}{2}$ in. block, reduce the listed value by 0.04, and for $5\frac{1}{2} \times 5\frac{1}{2} \times 3\frac{1}{2}$ in. block, increase the listed value by 0.04. See Table 24 for definition of types.

Figure 303-4-12

Coefficients of Transmission (U) of Masonry Walls^a

Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based on an outside wind velocity of 15 mph

Example		Example of Substitution	
Resistances used are given below in this table or in Table 8 or 9A		Resistances used are given below in this table or in Table 8 or 9A	
Construction	Resistance (R)	Replace item 4 with 6 in. block with filled cores	
1. Outside surface (15 mph wind).....	0.17	Total resistance.....	6.36
2. Face brick (4 in.).....	0.44	Deduct: 4. 8 in. cinder block.....	1.78
3. Cement mortar (½ in.).....	0.10	Difference.....	4.64
4. Concrete block (cinder agg.) (8 in.).....	1.78	Add: 4. 6 in. LWA block, filled cores.....	2.99
5. Air space ^b (reflective).....	2.80	Total resistance.....	7.63
6. Gypsum wallboard, Foil back (½ in.).....	0.45	$U_i = 1/R = 1/7.63 =$	0.13
7. Inside surface (still air).....	0.68	Adjustment for furring (1 × 2 in. @ 16 in. o.c.)	
Total resistance.....	6.36	$= U_i \times 1.03 = 0.13 \times 1.03 = 0.13$	
$U = 1/R = 1/6.36 =$	0.16		
Adjustment for furring (1 × 2 in. @ 16 in. o.c.)			
$= U_i \times 1.04 = 0.16 \times 1.04 = 0.17$			

^a See text section Calculating Overall Coefficients for basis of calculations.
^b To adjust U values for the effect of added insulation between framing members, see Table 5A.

Figure 303-4-13

^a See text Calculating Overall Coefficients for basis of calculations.
^b To adjust U values for the effect of added insulation between framing members, see Table 5A.

Coefficients of Transmission (U) of Flat Masonry Roofs with Built-up Roofing, with and without Suspended Ceilings^{a, b} (Winter Conditions, Upward Flow)

These Coefficients are expressed in Btu per (hour) (square foot) (Fahrenheit degree difference in temperature between the air on the two sides), and are based upon an outside wind velocity of 15 mph.

Example		Example of Substitution	
Resistances used are given below in this table or in Table 8 or 9A		For addition of roof insulation, see Table 5B.	
Construction (heat flow up)	Resistance (R)		
1. Outside surface (15 mph wind).....	0.17		
2. Built-up roofing—½ in.....	0.33		
3. Roof insulation (none).....	—		
4. Concrete slab (lt. wt. agg.) (2 in.).....	2.28		
5. Corrugated metal.....	0		
6. Air space ^b	0.86		
7. Metal lath and ½ in. plas. (lt. wt. agg.).....	0.47		
8. Inside surface (still air).....	0.61		
Total resistance.....	4.65		
$U = 1/R = 1/4.65 =$	0.22		

^a See text section Calculating Overall Coefficients for basis of calculations.
^b To adjust U values for the effect of added insulation between framing members, see Table 5 or 6.

Figure 303-4-14

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*

Description	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Customary Unit		Specific Heat, Btu/(lb (deg F)	SI Unit	
				Resistance ^b (R)			Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K) W	(m ² ·K) W
Plywood or wood panels 0.75 in.	34	—	1.07	—	0.93	0.29		0.16
Vegetable Fiber Board								
Sheathing, regular density 0.5 in.	18	—	0.76	—	1.32	0.31		0.23
. 0.78125 in.	18	—	0.49	—	2.06			0.36
Sheathing intermediate density 0.5 in.	22	—	0.82	—	1.22	0.31		0.21
Nail-base sheathing 0.5 in.	25	—	0.88	—	1.14	0.31		0.20
Shingle backer 0.375 in.	18	—	1.06	—	0.94	0.31		0.17
Shingle backer 0.3125 in.	18	—	1.28	—	0.78			0.14
Sound deadening board 0.5 in.	15	—	0.74	—	1.35	0.30		0.24
Tile and lay-in panels, plain or acoustic 0.5 in.	18	0.40	—	2.50	—	0.14	17.33	
. 0.75 in.	18	—	0.80	—	1.25			0.22
. 0.75 in.	18	—	0.53	—	1.89			0.33
Laminated paperboard	30	0.50	—	2.00	—	0.33	13.86	
Homogeneous board from recycled paper	30	0.50	—	2.00	—	0.28	13.86	
Hardboard								
Medium density	50	0.73	—	1.37	—	0.31	9.49	
High density, service temp. service underlay	55	0.82	—	1.22	—	0.32	8.46	
High density, std. tempered	63	1.00	—	1.00	—	0.32	6.93	
Particleboard								
Low density	37	0.54	—	1.85	—	0.31	12.82	
Medium density	50	0.94	—	1.06	—	0.31	7.35	
High density	62.5	1.18	—	0.85	—	0.31	5.89	
Underlayment 0.625 in.	40	—	1.22	—	0.82	0.29		0.14
Wood subfloor 0.75 in.			1.06	—	0.94	0.33		0.17
BUILDING MEMBRANE								
Vapor—permeable felt	—	—	16.70	—	0.06			0.01
Vapor—seal, 2 layers of mopped 15-lb felt	—	—	8.35	—	0.12			0.02
Vapor—seal, plastic film	—	—	—	—	Negl.			
FINISH FLOORING MATERIALS								
Carpet and fibrous pad	—	—	0.48	—	2.08	0.34		0.37
Carpet and rubber pad	—	—	0.81	—	1.23	0.33		0.22
Cork tile 0.125 in.	—	—	3.60	—	0.28	0.48		0.05
Terrazzo 1 in.	—	—	12.50	—	0.08	0.19		0.01
Tile—asphalt, linoleum, vinyl, rubber vinyl asbestos	—	—	20.00	—	0.05	0.30		0.01
ceramic						0.24		
.						0.19		
Wood, hardwood finish 0.75 in.			1.47		0.68			0.12
INSULATING MATERIALS								
BLANKET AND BATT								
Mineral Fiber, fibrous form processed from rock, slag, or glass								
approx. 2–2.75 in.	0.3–2.0	—	0.143	—	7 ^d	0.17–0.23		1.23
approx. 3–3.5 in.	0.3–2.0	—	0.091	—	11 ^d			1.94
approx. 3.50–6.5	0.3–2.0	—	0.053	—	19 ^d			3.35
approx. 6–7 in.	0.3–2.0	—	0.045	—	22 ^d			3.87
approx. 8.5 in.	0.3–2.0	—	0.033	—	30 ^d			5.28
BOARD AND SLABS								
Cellular glass	8.5	0.38	—	2.63	—	0.24	18.23	
Glass fiber, organic bonded	4–9	0.25	—	4.00	—	0.23	27.72	
Expanded rubber (rigid)	4.5	0.22	—	4.55	—	0.40	31.53	
Expanded polystyrene extruded Cut cell surface	1.8	0.25	—	4.00	—	0.29	27.72	
Expanded polystyrene extruded Smooth skin surface	2.2	0.20	—	5.00	—	0.29	34.65	
Expanded polystyrene extruded Smooth skin surface	3.5	0.19	—	5.26	—		36.45	
Expanded polystyrene, molded beads	1.0	0.28	—	3.57	—	0.29	24.74	
Expanded polyurethane ^c (R-11-exp.)	1.5	0.16	—	6.25	—	0.38	43.82	
(Thickness 1 in. or greater)	2.5							

Figure 303-4-15

Thermal Properties of Typical Building and Insulating Materials—(Design Values)*

Description	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Customary Unit		Specific Heat, Btu/(lb (deg F)	SI Unit	
				Resistance ^b (R)			Resistance ^b (R)	
				Per inch thickness (1/k)	For thick- ness listed (1/C)		(m·K) W	(m ² ·K) W
Mineral fiber with resin binder	15	0.29	—	3.45	—	0.17	23.91	
Mineral fiberboard, wet felted								
Core or roof insulation	16-17	0.34	—	2.94	—		20.38	
Acoustical tile	18	0.35	—	2.86	—	0.19	19.82	
Acoustical tile	21	0.37	—	2.70	—		18.71	
Mineral fiberboard, wet molded								
Acoustical tiles	23	0.42	—	2.38	—	0.14	16.49	
Wood or cane fiberboard								
Acoustical tiles 0.5 in.	—	—	0.80	—	1.25	0.31		0.22
Acoustical tiles 0.75 in.	—	—	0.53	—	1.89			0.33
Interior finish (plank, tile)	15	0.35	—	2.86	—	0.32	19.82	
Wood shredded (cemented in preformed slabs)	22	0.60	—	1.67	—	0.31	11.57	
LOOSE FILL								
Cellulosic insulation (milled paper or wood pulp)	2.3-3.2	0.27-0.32	—	3.13-3.70	—	0.33	21.69-25.64	
Sawdust or shavings	8.0-15.0	0.45	—	2.22	—	0.33	15.39	
Wood fiber, softwoods	2.0-3.5	0.30	—	3.33	—	0.33	23.08	
Perlite, expanded	5.0-8.0	0.37	—	2.70	—	0.26	18.71	
Mineral fiber (rock, slag or glass)								
approx. 3.75-5 in.	0.6-2.0	—	—		11	0.17		1.94
approx. 6.5-8.75 in.	0.6-2.0	—	—		19			3.35
approx. 7.5-10 in.	0.6-2.0	—	—		22			3.87
approx. 10.25-13.75 in.	0.6-2.0	—	—		30			5.28
Vermiculite, exfoliated	7.0-8.2	0.47	—	2.13	—	3.20	14.76	
	4.0-6.0	0.44	—	2.27	—		15.73	
ROOF INSULATION^b								
Preformed, for use above deck								
Different roof insulations are available in different thicknesses to provide the design C values listed. ^b			0.72		1.39			0.24
Consult individual manufacturers for actual thickness of their material.			0.12		8.33			1.47
MASONRY MATERIALS								
CONCRETES								
Cement mortar	116	5.0	—	0.20	—		1.39	
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips	51	1.66	—	0.60	—	0.21	4.16	
Lightweight aggregates including ex- panded shale, clay or slate; expanded	120	5.2	—	0.19	—		1.32	
slags; cinders; pumice; vermiculite; also cellular concretes.	100	3.6	—	0.28	—		1.94	
	80	2.5	—	0.40	—		2.77	
	60	1.7	—	0.59	—		4.09	
	40	1.15	—	0.86	—		5.96	
	30	0.90	—	1.11	—		7.69	
	20	0.70	—	1.43	—		9.91	
Perlite, expanded	40	0.93	—	1.08	—		7.48	
	30	0.71	—	1.41	—		9.77	
	20	0.50	—	2.00	—	0.32	13.86	
Sand and gravel or stone aggregate (oven dried)	140	9.0	—	0.11	—	0.22	0.76	
Sand and gravel or stone aggregate (not dried)	140	12.0	—	0.08	—		0.55	
Stucco	116	5.0	—	0.20	—		1.39	
MASONRY UNITS								
Brick, common ¹	120	5.0	—	0.20	—	0.19	1.39	
Brick, face ¹	130	9.0	—	0.11	—		0.76	
Clay tile, hollow:								
1 cell deep 3 in.	—	—	1.25	—	0.80	0.21		0.14
1 cell deep 4 in.	—	—	0.90	—	1.11			0.20
2 cells deep 6 in.	—	—	0.66	—	1.52			0.27
2 cells deep 8 in.	—	—	0.54	—	1.85			0.33
2 cells deep 10 in.	—	—	0.45	—	2.22			0.39
3 cells deep 12 in.	—	—	0.40	—	2.50			0.44

Figure 303-4-16

SOLAR FACTOR (SF) VALUES

Figure 303-4-17

Shading Coefficients for Single Glass and Insulating Glass ^a				
A. Single Glass				
Type of Glass	Nominal Thickness ^b	Solar Trans. ^b	Shading Coefficient	
			$h_g=4.0$	$h_g=3.0$
Clear	1/8 in.	0.84	1.00	1.00
	1/4 in.	0.78	0.94	0.95
	3/8 in.	0.72	0.90	0.92
	1/2 in.	0.67	0.87	0.88
Heat Absorbing	1/8 in.	0.64	0.83	0.85
	1/4 in.	0.46	0.69	0.73
	3/8 in.	0.33	0.60	0.64
	1/2 in.	0.24	0.53	0.58
B. Insulating Glass				
Clear Out, Clear In	1/8 in. ^c	0.71 ^e	0.88	0.88
Clear Out, Clear In	1/4 in.	0.61	0.81	0.82
Heat Absorbing ^d Out, Clear In	1/4 in.	0.36	0.55	0.58

^aRefers to factory-fabricated units with 3/16, 1/4, or 1/2-in. air space or to prime windows plus storm sash.
^bRefer to manufacturer's literature for values.
^cThickness of each pane of glass, not thickness of assembled unit.
^dRefers to gray, bronze, and green tinted heat-absorbing float glass.
^eCombined transmittance for assembled unit.

Figure 303-4-18

The value for SF in Equation 2 was found by use of Figure 303-4-17. At 40° north latitude the required solar factor, SF = 127.

The shading coefficient, SC, was found in Figure 303-4-18 and Δt was assumed to be 20° for this building.

Using Equation 2:

$$\begin{aligned} \text{OTTV} &= \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f \Delta t)}{A} \\ &= \frac{(0.16 \times 18,000 \times 30) + (2000 \times 127 \times 0.88) + (0.65 \times 2000 \times 20)}{20,000} \\ &= \frac{86,400 + 223,520 + 26,000}{20,000} = 16.80 \end{aligned}$$

which is less than the 33.4 required; thus, the wall construction complies with Code requirements.

C. Infiltration - Air leakage through cracks and spaces, around windows and doors, and through floors and walls is called infiltration. Its magnitude is a function of construction type, workmanship, condition of the building, entrance design and traffic, by the pressure in the building and by the pressure difference across a surface. The pressure difference may be caused by wind pressures, by mechanical ventilation and exhaust systems, or by the indoor-outdoor temperature difference in tall buildings.

1. Windows - Air leakage occurs between the frame and surrounding construction and between sash and frame. The latter is usually more predominant. Leakage is minimized by caulking between the frame and surrounding construction and by using tight fits and seals around the sash. Leakage should not exceed 0.5 ft³/min. per foot of sash crack at a pressure differential of 1.567 lb/ft².
2. Walls - Data on air leakage through walls is given in Table 3, Chapter 19, Ref. 304-4-2. In general, two infiltration barriers are needed to ensure minimal air leakage because materials generally used in construction of walls are porous.
3. Doors - Leakage through doors occurs both as a result of cracks and by opening and closing.

- a. Cracks - Positive seals are generally used to reduce infiltration through cracks. These may be felt, rubber or a magnetic gasket.
- b. Entrance - Reducing entrance infiltration can be accomplished by reducing pressure differential across the entrance or by using some type of air lock. The pressure differential can be reduced by eliminating air leakage through other parts of the building and by eliminating any pressure difference caused by excessive exhaust.

A revolving door is an effective air lock; vestibule entrances are somewhat less effective.

- c. Air infiltration at doors cannot exceed 0.5 cfm/sq.ft. of door area for residential glass sliding doors or 1.25 cfm/sq.ft. of door area for residential entrance doors.
- d. Commercial building doors cannot exceed 11 cfm/linear foot of crack for swinging, sliding or revolving doors.
- e. Manufacturer's data on air leakage for windows and doors as established by ASTM E283-73, Standard Method Of Test for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors; is the best method to check to see that the building meets the air infiltration requirements of this Code. Even with this information and even though data supports the adequate construction of the doors and windows, the installation must be properly performed to ensure minimum leakage.
- f. Windows constructed at the job site cannot be tested but good visual inspection and careful installation will ensure minimum leakage.

D. General Discussion of Lighting Design

- 1. Lighting Design - In the design of a lighting system it is first necessary to select lighting equipment that will provide the highest visual comfort and the highest visual performance. Because of practical considerations, the area to be lighted may limit the choice of equipment. Economics is always a factor and may require the use of a combination of lighting systems, such as general lighting and localized lighting. The Code requires the use of task lighting for design and determination of the lighting power budget. After the luminaires to be used and the illumination needed have

been determined, it is possible to calculate the number of luminaires required to produce that illumination. In the case of local lighting and localized general lighting, it is necessary to calculate the illumination at the point where the actual task is located rather than the average illumination throughout the room. The Illumination Engineering Society (IES) specifies that the illumination levels recommended for various specific tasks are needed on the task itself. This would require that point by point methods be utilized. However, because of the ease of application of the Lumen Method, which yields the average illumination in a room, this system is usually employed for larger areas where the illumination is basically uniform.

2. Lumen Method - The Lumen Method is based on the definition of a footcandle equaling one lumen per square foot.

$$\text{Footcandle} = \frac{\text{Lumens in Area}}{\text{Square feet of Area}}$$

By knowing the initial lumen output of each lamp (published by lamp manufacturer), the number of lamps installed in the area, and the square feet of area, one can calculate the lumens per square foot initially generated in the area.

However, the maintained footcandle load in an area differs. This difference occurs because some lumens are absorbed in the luminaire and also because of other factors such as dirt on the luminaire, gradual depreciation of the lumen output of the lamps, ballast performance, and operating voltage. Taking these factors in consideration, the following lumen method formula is derived.

$$\text{Footcandles} = \frac{\text{Lamps/Luminaire} \times \text{Lumens/Lamp} \times \text{Coefficient of Utilization} \times \text{Light Loss Factor}}{\text{Area per Luminaire}}$$

In using the Lumen Method, the following steps should be taken:

- a. Determine the required level of illumination. Recommended levels of illumination listed in Figure 9-80 (IES Lighting Handbook) are the required design values for the tasks in various types of interiors.
- b. Determine the coefficient of utilization. The coefficient of utilization is the ratio of the lumens reaching the

working plane (usually 30 inches above the floor) to the lumens generated by the lamps. It is a factor that takes into account the efficiency and distribution of the luminaire, its mounting height, the room dimensions and the reflectances of the ceiling, wall and floor. This coefficient is specified in the Code for various conditions.

In general, the higher and narrower the room, the larger the percentage of light absorbed by the walls, and the lower the coefficient of utilization.

The Cavity Ratio may be calculated as follows:

$$\text{Room Cavity Ratio (RCR)} = \frac{5H (\text{Room Length} + \text{Room Width})}{\text{Room Length} \times \text{Room Width}}$$

when H is the height of the cavity. Cavity is the distance from the bottom of the fixture to the working plane.

The Cavity Ratio may also be determined using the Figure 9-10 Cavity Ratios (IES Lighting Handbook). The technical data showing the coefficient of utilization for a number of fixtures is listed on pages 9-12 to 9-30 of the IES Lighting Handbook. When working with a luminaire for which the data is not listed on these pages, the coefficient of utilization should be selected from a table for a luminaire that has a similar efficiency and distribution.

- c. Determine the light loss factor. From the moment the new lighting installation is energized, the illumination is in a process of constant change as the lamp ages, the luminaire accumulates dirt, and the effect of other contributing loss factors are felt.

There are four contributing loss factors that require consideration.

- Ballast Performance: The Certified Ballast Manufacturer Association specifications for fluorescent lamps require the ballast to operate a fluorescent lamp at 95% of the output of the lamp when operating on a reference ballast. For ballasts bearing the CBM label, use 0.95 — for ballasts not bearing the CBM label, the lumen output is usually lower. Specification standards are not available for mercury vapor ballasts. Consult

with ballast manufacturer for this light loss factor.

- Voltage to Luminaires: In service voltage is difficult to predict. For filament lamps a 1% voltage deviation will cause a 3% lumen output change. For regulated output ballasts the lamp lumen output is independent from the primary voltage. Fluorescent lamp lumens change approximately 1% for every 2-1/2% change in primary voltage.
- Lamp Lumen Depreciation: The gradual reduction in lumen output of the lamp as it burns through life is more rapid for some lamps than for others. The contribution loss factor for fluorescent is usually expressed as a ratio of the lumen output at 70% of the rated life to the initial (100 hours) value. The lamp lumen depreciation factors for fluorescent, filament and mercury lamps are listed on pages 8-57 to 8-107 of the IES Lighting Handbook.
- Luminaire Dirt Depreciation: This factor varies with the type of luminaire and the atmosphere in which it is operated. Luminaires are divided into six categories (see Figure 9-6, page 9-5). After determining the category, the atmosphere in which the luminaire is operating should be established from Figure 9-2 or 9-3. Once that has been established, the luminaire dirt depreciation factor can be read from one of the five curves for each category on page 9-6, Figure 9-7. The Code specifies the design light loss factor.

- d. Calculate the number of lamps and luminaires required. The number of luminaires and lamps can be calculated from the following formulas:

$$\text{Number of Lamps} = \frac{\text{Footcandles} \times \text{Area}}{\text{Lumens/Lamp} \times \text{Coefficient of Utilization} \times \text{Light Loss Factor}}$$

$$\begin{array}{lcl} \text{Number of Luminaires} & \text{Number of Lamps} & \\ \text{(or fixtures)} & = & \text{Lamps/Luminaire (or fixtures)} \end{array}$$

From Figure 9-12, page 9-22, item 20:

The coefficient of utilization for ceiling reflectance of 70% to wall reflectance of 50% and RCR of 3 is .45.

3. Example: Small service store 48' x 32' with a 12' ceiling height -- assume the mounting height of the fixtures is 9'.

The design lighting level is 100 footcandles, the minimum recommended by IES becomes the maximum allowed. From the Code the following factors are determined:

Reflection Factors:	Ceiling	89%
	Walls	50%
	Floor	20%

Coefficient of Utilization	0.63
Light Loss Factor	0.70
Room Cavity Ratio	2.34

From the manufacturer's literature--

4-40 lamps/fixtures
 200 watts/fixture (4 @ 40 + 10 watt Ballast Loss)
 Large type F40T12 Lumens/Lamp 3100

See example problem for remainder of solution.

LIGHTING POWER BUDGET

ROOM NAME Service Store FT.C. REQ. 100

LENGTH 48 x WIDTH 32 = AREA 1500 SQ.FT.

CEILING HT. 12 MOUNTING HT. 9 RCR 2.34

REFLECTION FACTORS: CEILING 80 % WALLS 50 %
 FLOOR 20 %

COEF. OF UTILIZATION .63 LIGHT LOSS FACTOR .70

FIXTURE TYPE A LAMPS/FIXTURE 4 WATTS/FIXTURE 200

LAMP TYPE F40T12 LUMENS/LAMP 3100

TOTAL LUMENS	$\frac{\text{FT.C.} \times \text{A}}{\text{CU. MF}}$	$\frac{100 \times 1500}{.63 \times .70}$	<u>340140</u>
--------------	--	--	---------------

NO. FIXT. = $\frac{\text{TOTAL LUMENS}}{\text{LUMENS/LAMP} \times \text{LAMPS/FIXTURE}} = \frac{340140}{3100 \times 4} = \frac{27.4}{\text{call } 28}$

LIGHTING POWER BUDGET - NO. FIXT. 28 x WATTS/FIXT. 200 = 5600 WATTS

III. BUILDING MECHANICAL SYSTEMS

A. Application of Energy Reduction Techniques for HVAC Systems

1. Introduction

The basic philosophy for energy conservation is to meet but never exceed the environmental requirements of each building area and to meet those requirements only when they are needed and to supply these services in the most efficient, practical manner.

2. Design Calculations

Accurate calculations of heating and cooling loads are important because they are necessary in order to properly size heating and cooling equipment. Equipment which is undersized cannot meet the environmental requirements of the space and oversized equipment cycles frequently which reduces its efficiency. Therefore, an efficient building design begins with careful and detailed load calculations and equipment sizing.

3. Simultaneous Heating and Cooling

The best way to approach the problem of simultaneous heating and cooling is to examine HVAC systems which require the use of both warm and cool energy to maintain space conditions.

First, it should be noted that residential type heating and cooling systems do not fall into the category of systems which heat and cool simultaneously. The fuel fired or electric furnace in a home provides heat only when the space requires it to maintain the desired temperature inside. In the same manner, the mechanical refrigeration unit in a home provides cooling only when it is required to remove heat from the space. The residential type units never provide heat to the space at the same time the cooling system is in operation.

The primary reason for this is that the normal residence can be treated as a single temperature control zone and still provide a satisfactory environment within the space. In a large commercial building, this is not the case. Frequently, there are situations within large commercial buildings which require the building to provide heat to a zone located on the north side of the building exterior and cooling to an

interior zone or a zone on the south exposure, particularly if the zone has a large glass area. Thus, systems were developed which are capable of providing either heating or cooling to any zone within the building at any given time. Most of these systems operate inefficiently due to this capability of simultaneously heating and cooling.

The most inefficient type of HVAC system which utilizes the simultaneous heating and cooling principle is the terminal reheat system. While being very inefficient, the terminal reheat system does have one advantage over other systems. With this system, precise control of space humidity can be obtained.

Therefore, this system is commonly used in computer rooms, hospital surgeries and other areas where humidity control is very important. A schematic drawing of this type of system is shown in Figure 304-4-19. This system is designed to circulate a fixed volume of air at a fixed temperature, usually 50° to 55°F, through the building. The volume of air that is supplied to each zone is determined by the heat gain to the space. That is, the appropriate amount of air required to remove the maximum heat gain is introduced into each zone at a given temperature, say 55°F. Therefore, when the zone is receiving its maximum solar load and is fully occupied with people and equipment, all the 55°F air supplied to the zone is required to remove the heat in the space. However, if the heat gain is reduced by decreasing the solar load or turning off lights or equipment or by people leaving, the continued supply of a constant volume of 55°F air would subcool the room. Thus, to maintain the space temperature a reheat coil is activated to raise the supply air temperature an appropriate amount. If there were no heat gain in the space, the reheat coil would have to increase the supply air temperature from 55° to the zone thermostat set point, say 75°F. This means that over 20 Btu's would be added to each cfm of 55°F air supplied to the zone.

This may sound like a wasteful and inefficient way to control space temperature, and it is; but what compounds the waste is that during the summer cooling season, all the air circulated in the system is mechanically cooled to 55°F. Then every zone that is not experiencing its maximum cooling load has some degree of heat added back into the air stream in order to maintain space temperatures. Energy is expended to cool all of the air to 55°F and then energy is expended to reheat part of the air to some temperature above 55°F. This is

Figure 303-4-19 Terminal Reheat System

simultaneous heating and cooling and the new energy code attempts to limit the practice of such wasteful design.

Other common systems which utilize the mixing of warm and cool energy to maintain space comfort conditions are the dual duct system, Fig. 303-4-20; the multizone system, Fig. 303-4-21; and the induction system, Fig. 303-4-22. Simultaneous heating and cooling occurs in all of these systems, but if properly designed, they are not as inefficient as the terminal reheat system.

The Model Energy Code restricts the use of these systems. The mixing of warm and cool energy cannot be used except as follows:

- a. "Recovered energy, provided the new energy expended in the recovery process is less than the amount recovered, may be used for control of temperature and humidity."
- b. "New energy may be used, when necessary, to prevent relative humidity from rising above 60 percent for comfort control or to prevent condensation on terminal units or outlets."
- c. New energy may be used for temperature control in reheat systems serving multiple zones if they are provided with automatic controls that reset the cold air supply to the highest level possible to be able to satisfy the zone requiring the coolest air.

This means that the control system must be capable of sensing the supply air temperature required in each zone and resetting the cold air supply from the central unit so that no reheat energy is expended in at least one zone, the zone requiring the coolest air.

Thus, the energy expended to cool and dehumidify the air is minimized as well as reducing the amount of energy consumed to reheat air.

For dual duct systems the control system must not only reset cold air supply to the highest possible temperature but also must reset hot air supply to the lowest possible temperature. In this case there would be at least one zone which would require no hot air for space temperature control and at least one zone which would require no cold air for space temperature control. That is, the zone

Figure 303-4-20 Dual Duct System

Figure 303-4-21 Multizone System

Figure 303-4-22 Induction System

requiring the coolest air would receive all its air at the cold deck temperature and the zone requiring the warmest would receive all its air at the hot deck temperature. Thus, at least two zones would not require any mixing of hot and cool air for space temperature control. This minimizes energy waste for this type of system.

Recooling systems are the opposite of terminal reheat systems in that air is cooled at the terminal zone instead of being heated. For this type of system, automatic controls must be provided to reset the warm air supply temperature to the lowest possible level that will satisfy the zone requiring the warmest air.

Automatic reset controls are not required for air handling systems under 5000 cfm or less than 20 percent of the total system supply air, whichever is less.

Systems which have concurrent operation of independent heating and cooling units serving common spaces are required to minimize new energy expended for heating and cooling by providing sequential temperature control of heating and cooling equipment or by limiting heat energy input through automatic reset controls to that amount of heat required for heat loss due to transmission, infiltration and outside air requirements.

4. Heat Recovery Systems

a. Rotary regenerative type, "Heat Wheel". (See Figure 303-4-23.)

- (1) Description - Revolving cylinder packed with air permeable media having a large surface exposed to air stream.

For transfer of latent heat, media may be treated to make it hygroscopic.

As cylinder is rotated, adjacent streams of exhaust air and supply air pass through it.

Transfer of sensible heat is caused by dry bulb temperature difference.

Rotary Regenerative Heat Exchanger with Purge Section
Figure 303-4-23

Scheme of Air Flow for Rotary
Air-to-Air Heat Exchangers

Scheme of Air Flow for Rotary Air-to-Air Heat Exchangers
Figure 303-4-24

Transfer of total heat is a function of temperature difference and vapor pressure difference.

For heating, each segment of cylinder rotates through exhaust air stream where media is heated. That segment then rotates into supply air stream where its heat is given up.

Units are available in capacities from 600 cfm.

(2) Effectiveness (See Fig. 303-4-24)

Rotary air-to-air heat exchangers may be rated on their effectiveness to recover:

- (a) Sensible heat (dry bulb temperature)
- (b) Latent heat (humidity ratio)
- (c) Total heat (enthalpy)

Effectiveness indicates the performance of an exchanger:

$$= \frac{W_s (X_1 - X_2)}{W_{\min} (X_1 - X_3)}$$

where:

- = sensible, latent, or total heat effectiveness
- X = dry bulb temperature, humidity ratio or enthalpy respectively, at locations indicated in Figure 303-4-24
- W_s = mass flow of supply, pounds of dry air per hour
- W_e = mass flow of exhaust, pounds of dry air per hour
- $W_{\min}$ = minimum value of W_s or W_e

The effectiveness of a rotary air-to-air heat exchanger is a function of:

- air mass flow rate
- air mass flow ratio
- energy transfer characteristics of a particular heat exchanger

Typical values of effectiveness for normal ventilation systems are 60-80 percent for both sensible and total heat. Catalog effectiveness ratings are usually given for equal mass flows.

(3) Design Considerations

(a) Savings

Two areas of savings to be considered for new construction:

- 1) Winter design - Heat recovery equipment will reduce the installed heating capacity needed to meet the peak heating load. In addition other equipment may be eliminated which would otherwise be needed such as preheat coil costs.
- 2) Summer design - Again heat recovery systems will lower the peak cooling load which will reduce initial cooling equipment investment.

(b) Additional Costs

- 1) Cost of heat exchangers and their installation.
- 2) Additional duct work to bring the exhaust and outdoor air streams adjacent to each other to accommodate the heat exchange by the water.
- 3) Additional fan horsepower to overcome the pressure drops across the unit.

(4) Cross Contamination

During rotation some entrained exhaust air may be rotated to the supply air. This is kept to less than 1 percent by volume with the use of a purge section. This small amount of contamination is not usually a problem.

(5) Condensation and Freeze-up

Condensation occurs on non-hygroscopic metallic heat

transfer media when the dry bulb temperature of one air stream is below the dew point of the other air stream.

Under heating conditions with subfreezing outdoor air temperatures, icing or frost buildup on the media in the exhaust air stream may occur.

Frosting can be controlled by by-passing outside air past the exchanger or by using a preheat coil in the supply air stream to the exchanger or by controlling the speed of the wheel. All of these methods reduce the effectiveness.

b. Plate Type (See Fig. 303-4-25.)

Figure 303-4-25 Plate Type Heat Exchanger

(1) Description

Fixed surface plate type exchangers may be made of non-porous materials such as metal or plastic and transfer only sensible heat. Or they can be made of an absorbent inert material such as asbestos and will transfer total heat. Air flow is usually cross flow or counter flow. Counter flow provides more heat transfer but cross flow can give more convenient air connections.

(2) Effectiveness

Sensible and total recovery effectivenesses are 40 to 60 percent.

(3) Design Considerations

Similar to rotary units

(4) Cross contamination

Non-porous plates will have no cross contamination; total heat exchangers will have cross contamination which is usually less than 1%.

(5) Condensation and Freeze-up

Under freezing conditions, recovery may be limited and controlled through the use of face and bypass dampers, or a preheat coil can be used to heat the outside air.

c. Multiple Tower, Run-Around Desiccant Spray Type Exchanger

(1) Description

This system uses a hygroscopic liquid such as lithium chloride and water to transfer heat, Fig. 303-4-26. A spray tower in the exhaust stream allows the transfer media to pick up heat and moisture; the media is then pumped to a spray tower in the supply stream where the heat and moisture are released to the supply air. The reverse happens in the summer.

Towers are available in sizes ranging from 5,000 cfm to 90,000 cfm in capacity.

Figure 303-4-26 Twin Tower Run-Around Desiccant Spray Type

(2) Effectiveness

For normal ventilating systems the effectiveness is in excess of 60 percent for both sensible and total heat.

(3) Design Considerations

(a) Savings

Savings considerations are the same as for the heat wheels.

(b) Additional Costs

The supply and exhaust air streams can be separated since the towers are connected by pipes. In fact, a number of exhaust towers may be piped to a single supply tower. This saves a considerable amount of duct-work.

(4) Cross Contamination

Since the supply and exhaust ducts are separated, there is no cross contamination.

Lithium chloride is bacteriostatic which gives the added benefit of up to 95 percent bacteria removal efficiency.

(5) Condensation and Freeze-up

A solution heater is often used to deliver a constant temperature spray to the supply air in freezing weather.

Make-up water is automatically supplied to prevent over drying of the desiccant.

d. Run-Around Coil Type

(1) Description

This system, Fig. 303-4-27, uses standard extended surface finned-tube water coils in place of spray towers.

One or more coils are placed in the exhaust air streams and another is placed in the supply air stream.

A glycol solution is pumped through the coils to transfer the heat. Only sensible heat is exchanged.

Arrangement of Run-Around Coil System

Figure 303-4-27

(2) Effectiveness

Coils and flow rates are selected to give efficiencies of 40 to 60 percent sensible heat.

(3) Design Considerations

(a) Savings

Only sensible heat transfer savings; in warm climates the summer savings are low.

(b) Additional Costs

As in the spray towers, the supply and exhaust streams do not have to be ducted together.

Additional fans or fan horsepower is needed to overcome pressure drops across coils.

(4) Cross Contamination

None

(5) Condensation and Freeze-up

A glycol solution is used to prevent solution freezing.

Face and bypass dampers can be used to control effectiveness, or a preheat coil can be used to control frost buildup on the coils.

e. Heat Pipe (See Fig. 303-4-28.)

(1) Description

A heat pipe is a reversible isothermal super

conducting device. It is completely sealed and has no moving parts.

Figure 303-4-28 Arrangement of Heat Pipe

When installed in a system, one end is placed in the exhaust air stream and the other in the supply air stream.

Heat will automatically flow from the hot end to the cold end.

Fins are connected to each end to increase the heat transfer from the air to the tube.

The exchanger unit contains many heat pipes. Only sensible heat is exchanged.

(2) Effectiveness

Sensible heat recovery effectiveness ranges from 60 to 70 percent.

(3) Design Considerations

(a) Savings

As with any sensible heat exchanger, the summer savings may be small.

(b) Additional Costs

Increased fan horsepower will be necessary to overcome pressure drops.

Supply and exhaust air must be ducted next to one another, preferably to give counter flow.

(4) Cross Contamination

There is no internal cross contamination, but the exhaust and supply openings must be designed so that the exhaust air does not blow into the supply inlet.

(5) Condensation and Freeze-up

The effectiveness of a heat pipe exchanger can be controlled and limited by tilting the heat pipes or by using face and by-pass dampers.

B. Automatic Temperature Controls

1. Proper design of automatic temperature control systems is required in order to minimize energy consumption. The control system must be capable of being reset to reduce energy used during unoccupied periods, as well as being able to respond to changes in the environment both within the building and outside to take advantage of opportunities to reduce energy use.

In order to do this, systems must be designed with adequate ranges on thermostats and must be zoned properly to prevent excessive heating and cooling in some areas while satisfying other zones. Therefore, as a minimum, each HVAC system must have at least one thermostat and in multi-story buildings, each floor must have at least one thermostat.

Looking beyond the minimum code requirements, zoning of controls and systems by type of occupancy and exposure can also improve energy consumption. For example, serving interior zones that require cooling summer and winter with HVAC systems which are separate from exterior systems can allow the designer to eliminate all heating for the interior units and, thus, eliminate the possibility of simultaneous heating and cooling. The potential for energy reduction with proper design of control system is a significant design consideration.

C. Distribution System Design

1. Air Duct System

Energy losses from air duct systems occur in three ways:

- a. Conductive losses through the duct wall.

- b. Air leakage losses through joints.
- c. Excessive resistance to flow which results in high fan horsepower.

The Code addresses itself to all three areas of energy loss by requiring thermal insulation, air leakage tests and by establishing a standard for air delivery efficiency. The air transport factor must be at least 4.0 for air duct systems.

2. Piping Systems

The Code addresses itself to the problem of conductive heat loss from piping systems by requiring high and low temperature pipes to have insulation. While piping systems can have serious leakage problems, especially in steam piping at traps and valves, this problem is not addressed in the Code because it is more of a maintenance problem than a design problem.

PART 5 CASE STUDIES OF ENERGY CONSERVATION IN COMMERCIAL BUILDINGS

I. OHIO LEGAL CENTER (LEGAL AIDS) BUILDING

A. Boiler Efficiencies

1. The Legal Aids Buildings, a three-story office structure on The Ohio State University campus is equipped with a Rite Engineering hot water boiler. It is rated at 1,800,000 Btuh input and 1,440,000 Btuh output. Design heat load for this structure 1,003,000 Btuh; thus the boiler is oversized by a factor of 1.44.
2. The observed boiler efficiency under actual field conditions was approximately 76%.
3. Figure 303-5-1 shows a frequency distribution for the ratio of the actual calculated load to the design load. This ratio was below 70% approximately 92.8% of the time. Maximum operating time occurs at about 55% of the calculated design load.
4. Attention should be given to the proper sizing of boilers for buildings. It should be realized that the boilers are subjected to design heating loads for only a very small period of time during the life of the unit. Oversizing is expensive from the standpoint of first cost, operating cost, and loss of usable floor space.

Figure 303-5-1

THE OHIO STATE UNIVERSITY
ENGINEERING EXPERIMENT STATION
LEGAL ADS.
BOILER EFFICIENCY VS. % RATING
FIGURE 5

Figure 303-5-2

5. Where it is necessary to have back-up or standby boilers, it is recommended that one approximately half the size be selected, rather than duplicating the size of the original unit. This smaller size should be sufficient to carry the load the majority of the time.
6. An efficiency curve for this particular boiler is shown in Figure 303-5-2. It can be seen that at part-load operation, the boiler efficiency is drastically reduced.

II. CASE STUDIES OF 35 BUILDINGS ON THE OHIO STATE UNIVERSITY CAMPUS^{23,24}

The Ohio State University is well into the fourth year of an energy conservation project which is committed to increasing the operating efficiency of the campus buildings without interfering with the functions of the occupants.

The Columbus campus has been faced with past annual utility bills in excess of five million dollars. Increasing unit costs of natural gas, oil and electricity, reductions of natural gas allotments, plans for new construction, and pressures to maintain a high level of education at reasonable costs make energy conservation an important key to the future.

The original project called for the study of 35 buildings. This has been expanded to a total of 44 buildings. As of July 1976, 34 buildings had been investigated and of these, seven have had approved energy conservation modifications implemented. A total cost avoidance of \$3.8 million has been attributed to the program over the past three years.

The procedure followed for this project consists of a complete building survey and preparation of a report which is presented to the University Administration. The report contains suggested energy savings modifications to the building along with estimated construction costs and utility cost savings. Modifications, which are funded based primarily on the estimated pay back periods, are then implemented. Metered utility consumption is taken after implementation and compared to consumption of previous years to verify the savings estimated.

A. Allied Medical Building²⁵

The Allied Medical Facilities Building is a five-story main building consisting of offices, laboratories and classrooms with

with a two-story wing which is used for audio and television studios, television control and tape storage.

The cooling system consists of a hot water absorption chiller with the cooling tower located in the penthouse. Medium temperature hot water for cooling and heating is provided by two gas-fired hot-water boilers also located in the penthouse.

The two main building air handling units are high velocity, dual-duct. Each unit is 36,000 cfm which provides 0.95 cfm/sq.ft. with approximately 35% outside air. The TV wing has three single-zone and one multi-zone low velocity air-handling units which deliver a total of 35,000 cfm to the 19,000 sq.ft. area or 1.84 cfm/sq.ft.

The building control system is pneumatic with a remote control panel in an adjacent building, Graves Hall, approximately two blocks away.

This building energy study was conducted in three stages. The first stage was to review contract documents and confirm operation by tests and observations of the existing system. The tests were performed to establish actual air flow rates and motor amperage readings while a room by room survey showed individual space usage, lighting wattage and occupancy.

The second stage was the arrangement and analysis of data which allowed the energy consumption of the building to be broken down into categories. First, the electrical consumption was estimated for the following categories:

1. Heating auxiliaries
2. Cooling auxiliaries
3. Lighting
4. Elevators
5. Ventilation
6. Miscellaneous

with the results as shown in Fig. 303-5-3. The difference between the consumption estimated for items 1 through 5 and the actual metered electricity was placed in the miscellaneous category which consists of office machines, laboratory equipment, etc.

Then calculations were made to divide the gas consumption into heating, cooling, and miscellaneous categories. The breakdown of the building usage is shown in Fig. 303-5-4.

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

TOTAL ELECTRICAL CONSUMPTION 2,983,000 KW-HRS

DISTRIBUTION OF EXISTING ELECTRICAL ENERGY CONSUMED

Figure 303-5-3

ALLIED MEDICAL FACILITIES
THE OHIO STATE UNIVERSITY

TOTAL GAS CONSUMPTION 37,500 MCF

DISTRIBUTION OF EXISTING GAS
ENERGY CONSUMED.

Figure 303-5-4

ALLIED MEDICAL FACILITIES
THE OHIO STATE UNIVERSITY

TOTAL GAS AND ELECTRICAL COST \$ 72,870

- COST OF GAS FIGURED AT \$1.03 PER MCF
- COST OF ELECTRICITY FIGURED AT \$0.01148 PER KW-HR

COST OF ELECTRICAL
AND GAS ENERGY CONSUMED

Figure 303-5-5

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

Figure 303-5-6

330

COMPARISON OF INSTALLED CAPACITIES
VERSUS ACTUAL YEARLY ENERGY USE

Fig. 303-5-5 shows the cost of energy consumed by this building using actual metered data from the fiscal year 1972-1973, and average gas and electrical cost to the University for April, 1974. Note that all costs and savings in this report are based on average gas and electric costs to the University for the stated one month period, and do not reflect actual costs which are based on complex rate schedules.

Fig. 303-5-6 shows a comparison of installed kw and kwh consumption for ventilation equipment, lighting, cooling auxiliaries and heating auxiliaries. It can be seen from this figure that ventilation and lighting offer great potential savings.

With the above information, the group was able to establish four energy savings methods which were analyzed in the third stage of the study. These modifications are discussed below. Calculations were made using the same methods previously used to determine the gas and electric usage breakdown for the building.

1. Lighting reduction

The first energy conservation modification to be analyzed was removal of excess lights. Room surveys showed that the lighting levels met or exceeded Illuminating Engineering Society standards, but were above levels required for the tasks being performed. Fig. 303-5-7 shows the estimated electric lighting cost avoidance as \$2,500 per year.

2. Volume reduction and variable volume

The second energy saving modification to be studied was to reduce air volumes. This analysis was made using the approach of combining the reduction of air volumes to space where lights were removed with conversion of existing constant-volume mixing boxes to variable volume boxes in areas where cooling load variations were anticipated. Fig. 303-5-8 shows the estimated yearly cost avoidance for reducing air volumes by an average of 24,000 cfm as \$10,748. By the use of lower volumes, the amount of gas used for reheat was reduced. It should be noted that volume reduction was accomplished without violating codes and provided increased comfort due to lower room air velocities.

3. Unoccupied shutdown

The third energy modification studied was the unoccupied shutdown of the main building air-handling systems. A

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

ESTIMATED ANNUAL EFFECT ON ENERGY CONSUMPTION FOR
REDUCED LIGHTING LEVELS.....MODIFICATION NO. I

Figure 303-5-7

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

ESTIMATED ANNUAL EFFECT ON ENERGY CONSUMPTION FOR REDUCED
SUPPLY AIR VOLUMES & CONVERTING SELECTED AREAS TO
VARIABLE VOLUME.....MODIFICATION NO. 2

Figure 303-5-8

review of the building occupancy showed that operation of the fan system was required for only ten hours a day, five days a week. Thus, for fourteen hours a day plus weekends and holidays, motors totaling 193 hp could be shut down, and 23,000 cfm of outside air would not require heating or cooling. Fig. 303-5-9 shows that as a result of unoccupied cycle operation, the cost avoidance of \$21,101 a year in gas and electric costs, or a total reduction of 29.1% can be realized.

4. Two-speed fan drives for studio supply air

The last modification was the result of reviewing the actual equipment and lighting load in the TV area. First, it was found that the 35,000 cfm circulated could be reduced to 25,000 cfm when lighting and equipment diversity were taken into account.

Second, it was noted that the space was difficult to use due to excess air noise and humidity. After it was determined that 25,000 cfm would be required for only a few hours a day when actual televising was being done, it was decided that the motors and drives could be changed to a two-speed drive system to provide 25,000 cfm at high speed and about 17,000 cfm at low speed. During occupied periods the outside air is open and the fan operates at low speed, except when high equipment usage requires additional cooling. Figure 303-5-10 shows an energy cost avoidance of \$4,053 per year for this modification.

5. Combined estimated savings

Since it was felt that all four of these modifications should be incorporated into the building, and it was realized that the savings calculated for each individual modification were not additive, it was necessary to perform a calculation estimating savings realized when all modifications were incorporated into the building. As shown in Figure 303-5-11, the total yearly cost avoidance was \$29,050 or 39.9 percent.

6. Modification costs

All four of the modifications submitted in the report were recommended for implementation by The Ohio State University Energy Conservation Committee; \$30,000 was approved in July 1974 for implementation.

7. Actual energy savings

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

ESTIMATED ANNUAL EFFECT ON ENERGY CONSUMPTION FOR
UNOCCUPIED CYCLES OF OPERATION OF MAIN
BUILDING AIR HANDLING UNITS.....MODIFICATION NO. 3

Figure 303-5-9

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

ESTIMATED ANNUAL EFFECT ON ENERGY CONSUMPTION FOR
AV-TV AREA REDUCED AIR QUANTITIES & UNOCCUPIED CYCLE
.....MODIFICATION NO. 4

Figure 303-5-10

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

ESTIMATED ANNUAL SAVINGS & IMPLEMENTATION COST OF ALL MODIFICATIONS

Figure 303-5-11

ALLIED MEDICAL FACILITIES THE OHIO STATE UNIVERSITY

ENERGY SAVINGS FOR THE FIRST HALF - 1975

(CALCULATED USING JUNE 1975 COSTS OF \$ 1.34/MCF AND \$ 0.0187/KWH)

Figure 303-5-12

The estimated cost avoidance for Allied Medical was purposely kept conservative. As shown in Fig. 303-5-12, the actual cost avoidance was 58 percent.

B. McCampbell Hall^{26,27}

The second building study performed by the project was on McCampbell Hall, which is a four-story building consisting of offices and conference rooms and is used by the Nisonger Center for the Mentally Retarded. It also contains six small apartments used by those receiving the services of the Center. Gross floor area is about 109,000 sq. ft.

1. Building Systems

The cooling system is a 385 ton centrifugal chiller (sized for future expansion) with a cooling tower in the penthouse. Heating hot water is provided by two 150 hp gas fired hot water boilers, which are also located in the penthouse. Steam for humidification and for equipment located in a small kitchen used for teaching purposes is provided by a 60 hp steam generator located in the penthouse.

The four main building air handling units are high velocity, dual duct; each unit originally provided approximately 25,000 cfm, which breaks down to 0.95 cfm per sq. ft. of floor area, with approximately 20 percent outside air.

The building control system is pneumatic with a central control console located in the penthouse.

2. Energy Consumption

The electrical consumption was divided in the following classifications: ventilation, lights, cooling auxiliaries, elevators, heating auxiliaries and miscellaneous.

Manual calculations were used to establish the percentage of use of each classification. The results are shown in Fig. 303-5-13.

Then, calculations were made to divide the gas consumption into winter, summer and mixed seasons heating, and miscellaneous gas categories. This percent breakdown is shown in Fig. 303-5-14.

Fig. 303-5-15 shows the cost of energy consumed by McCampbell Hall using actual metered data from the fiscal year 1972-73 and average gas and electrical cost to the University in

McCampbell Hall
Total Gas and Electric
1972

Figure 303-5-15

McCampbell Hall
Gas - 1972

Figure 303-5-14

McCampbell Hall
Electric-1972

Figure 303-5-13

September, 1974.

3. Energy Conservation Modifications.

With this information, the study group was able to establish five energy savings methods that were analyzed in the third stage of the study. Calculations were made using the same manual methods previously used to determine the gas and electric usage breakdown.

a. Unoccupied Cycle

The first energy modification studied was the initiation of unoccupied shutdown of air handling systems. A review of occupancy showed that, with the exception of the six apartments, operation of the fan systems was needed only ten hours a day, five days a week. Thus, for 14 hours per day plus weekends and holidays, 190 hp of electric motors could be shut down. Therefore, during these periods, 19,000 cfm of outside air would not require heating or cooling. Fig. 303-5-16 shows a cost avoidance of \$23,850 per year in gas and electricity, or a total reduction of 44.1 percent.

b. Exhaust Reduction

The second modification analyzed was the reduction of outside air quantities. The survey showed that 3000 cfm of outside air could be eliminated by shutting down several unnecessary exhaust fans. The cost avoidance realized by reduced exhaust during occupied hours is shown as \$120 per year in Fig. 303-5-17. This economy was calculated assuming that the unoccupied modification would be implemented; therefore, savings for the night and weekend heating and cooling outside air are not included.

c. Lighting Reduction

The third energy conservation modification analyzed was removal of excess lights. Room surveys showed that lighting levels were above those required for the tasks being performed.

Lighting reduction was accomplished by use of a guide to lighting level adjustment, which was developed during the energy conservation project.

Review of the building lighting, using these guidelines,

The effect on energy consumption in McCampbell Hall by Modification No. 1, unoccupied cycles.

Figure 303-5-16

The effect on energy consumption due to Modification No. 2, reduced exhaust in McCampbell Hall.

Figure 303-5-17

reduced lighting and cooling loads and allowed the supply air volume to be lowered. An added benefit, air noise that had been a problem was eliminated.

Figure 303-5-18 shows an estimated cost avoidance for reduced lighting and air volume of \$4980 or 9.2 percent of the total utility costs. Again, the unoccupied modification was assumed to be implemented so that savings for air volume reduction were calculated only for the ten hours per day, five days per week operation period.

d. Variable Volume Conversion

The fourth energy saving modification study was the conversion of the constant volume system to a variable volume system. This analysis was made using the approach of changing the existing constant volume boxes to provide variable volume in interior spaces where large cooling load variations were anticipated due to widely fluctuating occupancies. Fig. 303-5-19 shows the estimated yearly cost avoidance for this modification as \$7110.

The conversion to variable volume was rather simple for this system since the fans were equipped with inlet vanes. Fan speeds were reduced to accommodate the air requirement of 0.62 cfm per sq.ft. versus the original 0.95 cfm per sq.ft. The fan system required only the proper controls to modulate the inlet vanes to change volume according to the demand of the terminal units.

The existing constant volume terminal units were converted to variable volume units by installation of a sheet metal blank-off plate in the hot duct connection to the boxes. Fig. 303-5-20 shows operation of the converted box. With flow through the hot duct, the mixing damper acts as a volume damper on the cold duct.

e. Enthalpy Control

The fifth modification includes enthalpy control and economizer reset. The original system controls were set so that at outdoor temperatures above 55°F, the chiller comes on, and 100 percent outside air is drawn until the outside temperature reaches 70°F. Above 70°F, only minimum outside air is taken in. Above 70°F setpoint for changeover to minimum outside air is a very good choice for Columbus, Ohio. Therefore, the added savings

The effect on energy consumption due to Modification No. 3, reduced lighting levels and air volumes combined with unoccupied cycles.

Figure 303-5-18

The effect on energy consumption due to Modification No. 4, variable volume with unoccupied cycles.

Figure 303-5-19

Figure 303-5-20

Effect on energy consumption due to Modification No. 5, enthalpy control and economizer changeover combined with unoccupied cycles.

Figure 303-5-21

for enthalpy control shown in Figure 303-5-21 of \$290 per year are very low.

f. Combination

Since it was felt that all five of these modifications should be incorporated into McCampbell Hall, and it was realized that the savings calculated for each individual modification were not additive, it was necessary to perform a calculation estimating savings realized when all five modifications were incorporated into the building. As shown in Fig. 303-5-22, the yearly estimated cost saving was \$34,580 or 63.9 percent.

4. Actual Savings

All of the above modifications are implemented with the exception of the enthalpy control. The actual savings achieved during the 1975-1976 fiscal year were \$59,195 based on utility rates in effect during that period. The overall energy reduction was 60 percent as shown in Fig. 303-5-23.

Figure 303-5-22

McCAMPBELL HALL ENERGY CONSUMPTION

BEFORE MODIFICATIONS

AFTER MODIFICATIONS

YEARLY ENERGY USE IN DOLLARS

FIGURE 303-5-23

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APPENDIX A
MODEL ENERGY CONSERVATION CODE APPLICATION
MATERIALS IDENTIFICATION AND FIELD INSPECTION
(ECT - 303)

MATERIALS IDENTIFICATION AND FIELD INSPECTION

INSULATION

Substances which are poor conductors of heat are called insulators. In general, a material is a good insulator if it is porous and if its molecular structure is irregular. Since gases are the best insulators, any solid material which contains pockets of air is a good insulator. Cork, sawdust, shredded bark, and certain manufactured materials such as mineral wool, pressed cane fiberboard and cellulose are excellent insulators.

By retarding heat flow, insulation, when properly installed, may serve to:

1. Conserve energy by reducing heat loss or gain through building envelope, piping, ducts and equipment.
2. Control surface temperature of equipment for personnel protection and comfort.
3. Prevent water vapor transmission.
4. Reduce temperature fluctuations within an enclosure when heating or cooling is not needed or available.

Insulating Materials

Commonly used insulating materials include:

Mineral Wool: Mineral wool usually consists of the spun fibers of rock, slag, or glass. They are inorganic, noncombustible, rot-proof, and vermin-proof.

Cellulose: Cellulose insulation usually consists of macerated paper or wood fibers, usually chemically-treated to make it water-repellent.

Aluminum Foil: Aluminum foil resists heat flow only through reflection.

Plastics: Plastic insulation usually comes as a foamed material either in the form of a rigid board or for foaming in place.

Insulating Identification

The insulation materials available are manufactured in a variety of

forms for different applications, as follows:

Batts and Blankets: Batts and blankets usually consist of mineral wool either in a long roll (blanket) or cut to specified lengths (batt). They are used mostly for walls, roofs, ceilings and floors over unheated areas.

Batts and blankets have the R value on the package, or on the vapor barrier. Note the difference in stated R values caused by the placement of the material in floor, wall or roof.

Blown: Blown insulation, applied by means of a high pressure hose, is loose cellulose or modulated mineral wool. It is the only type insulation that can be added to existing walls and is frequently used for roof and ceiling insulation.

Loose fill insulation must be blown into the walls, floors and ceilings so that the proper density (lbs. per sq.in.) is obtained. Insulation should be blown into each wall cavity at both top and bottom so that all spaces will be filled and variations in density will be minimized. Variations in insulation density will affect the effectiveness of the material. It is important to note that the label lists both the thickness of material and the coverage per bag. It is important that this be obtained.

Reflective: Reflective insulation is composed of one or more sheets of aluminum foil. When more than one sheet is used, the air between sheets provides some insulation in addition to that provided through reflection. Application is limited primarily to floors over crawl spaces where humidity or moisture is a problem.

Batt/Blanket and Reflective: Batts and blankets may be obtained with an aluminum foil attached to one or both sides, thus adding reflective thermal resistance to regular batts and blanket insulating qualities.

Rigid: Rigid insulation consists of boards, sheets and slabs cut to specific lengths. They are usually composed of cellulose fiber, polystyrene, urethane, mineral wool, cork, or cellular glass. Rigid insulation is used primarily for wall sheathing and for insulating the edges of a concrete slab floor.

Foam: Foam insulation usually is composed of urethane which is applied in a manner similar to that used for sprayed insulation and for similar applications.

Sprayed: Sprayed insulation generally is the same as blown except that a binder such as asphalt is added so that the material sticks

to whatever surface it is sprayed onto. It often is used for insulation on masonry walls.

Insulation is specified on the basis of its performance in reducing heat transfer (R-number), not by insulation thickness in inches. Insulation materials vary in their ability to restrict heat transfer, depending on the type of insulation material, its fiber or cell structure, density, moisture content, and other physical characteristics, and by the protection provided by enclosing liners, and the method and care of application.

Reference 303-4-2, Chapter 20, shows the number and relative heat resisting values of several of these materials. The R number for batt, blanket and loose fill insulation as listed in these figures are for a thickness of one inch. The R number for greater thicknesses can be determined by multiplying the thickness desired, in inches, by the R number listed. For example, the R number for 1 inch of wood fiber is 4, so the R number for 3 inches is four times three, or R equals 12. Always remember the greater the R number, the greater the insulating value of the material.

Chapter 20 of the above reference also shows the insulating value and R number of a wall section with different amounts of insulation. It also shows the R number of each material in the wall. The heat loss through the wall section with 3-5/8 inches of insulation is 31% less than it is through the wall containing only 2 inches of insulation.

In homes and apartments insulation can be applied effectively as follows:

1. Exterior walls.
2. Ceiling with cold spaces above and dormer ceilings. The attic access panel can be insulated by stapling the edges of a piece of blanket insulation to its top. Use of adhesive backed foam tape on the bottom side around the edge of the attic access panel is a convenient method of weatherstripping that opening.
3. Knee walls when attic space is finished as living quarters.
4. Between collar beams, leaving open space above for ventilation.
5. Around the perimeter of a slab-on-grade when required.
6. Floors above vented crawl spaces. When a crawl space is used as a plenum, insulation is applied to crawl space walls instead of the floor above.

7. Floors over an unheated or an open space such as over a garage or a porch and the cantilevered portion of a floor.
8. Basement walls when below-grade is finished for living purposes. Sill sealer (insulation) between sill and foundation provides an effective wind infiltration barrier.
9. In back of band or header joists.

Other Locations for Insulation

There are special locations in apartment buildings where thermal insulation may be effective. Walls of unheated stairwells common to living units; floors of living units over boiler or other heat-producing mechanical equipment rooms; floors of conditioned spaces over unheated entrances or halls, and even, in some cases, walls of living units adjacent to incinerator and elevator shafts.

Thermal insulation is used frequently in apartments for acoustical purposes as well.

Most buildings also will benefit from insulation being applied to ducts and pipe runs, primarily to reduce the impact of ambient temperature on the temperature of the treated air or water being moved. Analyses of temperature change, heat loss or heat gain, and other factors affecting the economics of thermal insulation are seldom made for residential installations, but are essential for large commercial and industrial projects.

Ducts within buildings may be of sheet metal, or fibrous glass which provides combined air barrier, thermal insulation, and sound absorption. Ducts for embedding in or below floor slabs may be of compressed fiber, asbestos cement, ceramic tile, or other rigid materials.

Duct insulations include semi-rigid boards and flexible-blanket types, composed of organic and inorganic materials in fibrous, cellular, or bonded particle forms. Insulations for exterior surface application may have attached vapor barriers or facings, or vapor barriers may be separately applied.

Large pipes may be insulated with curved or flat segmental, or cylindrical half-, third-, or quarter-sections of insulation, particularly where removal for frequent servicing of the pipe is necessary. Fittings (valves, tees, elbows, etc.) are insulated with preformed fitting insulation, fabricated fitting insulation, or individual pieces cut from sectional straight pipe insulation, or insulating cements. Fitting insulation should be consistent with the

pipe insulation.

Pipe insulation finish indoors will be governed generally by location. The simplest finish is a laminate of kraft paper, glass fiber reinforcing, and a vapor seal membrane. For maximum fire safety, unusual exposure conditions, or appearance, factory or separately applied metal jackets may be used.

Finish outdoors must primarily protect the insulation from the weather, with chemical exposure, mechanical abuse, and appearance as additional considerations.

Installation

For insulation to be effective, it is critical that it be installed correctly. There are numerous publications now available which indicate precisely how certain forms of insulation should be applied to specific areas of buildings to achieve maximum benefit.

Notes on Installation

In many cases, a vapor barrier is used to protect the insulation from moisture damage due to water condensation in winter.

A vapor barrier usually consists of a thin sheet of plastic or some other material which prevents passage of moisture to those forms of insulation which are susceptible to moisture damage. The vapor barrier should cover the insulation on the inside or the warm surface side of the insulated wall, ceiling, etc., so that moisture contained in the inside air does not reach the insulation. Effectiveness of the vapor barrier will be greatly reduced if openings, even though very small, exist in the barrier. Many forms of insulation are available with a factory applied vapor barrier.

Irregular areas must be given careful attention when any insulation is installed. At the top and bottom of wall cavities (areas between the studs), blanket-type insulation should be sealed by stapling and/or taping to the floor and ceiling plates. Insulating material should be carefully fitted around all piping, wiring, and other projections. The proper thickness should be maintained throughout the walls, ceilings and floors.

Typical Insulation Problems

Particular areas tend to be overlooked by the insulation installer and may also be difficult for the inspector to see. These include:

Walls:

Wall between living space and an unheated garage or storage room, dormer walls, and the portion of wall above the ceiling of an adjacent section of a split level home.

- Behind bath tubs and prefabricated showers, the fixtures may prevent inspection of the wall behind them.
- Behind electrical boxes and pipes.
- Behind and under stairways.
- In plywood shear walls.
- Spaces around openings between jambs and framing.

Floors:

In this case, the insulation is exposed to the weather since it is installed before the floor sheathing is in place and is unprotected from rain and dampness. It is difficult to inspect the supports (wires or staples) for the floor insulation without crawling under the building.

Building Envelope - Other Considerations

Windows and Doors: Windows and doors in exterior walls (other than required fire windows and doors) must be caulked, weatherstripped, or gasketed to reduce air infiltration.

Air leakage through the joints in windows and doors is controlled during manufacture. Inspection for labels or certifications relative to infiltration may be difficult because labels may fall off during transport and construction, or may be removed by the contractor during final clean up.

For non-residential occupancies, all doors are regulated. For residential occupancies, only sliding glass doors are regulated.

OTHER SYSTEMS

MECHANICAL SYSTEMS:

HVAC Equipment:

Fuel Burning (gas and oil) - The code gives the requirements to which HVAC equipment must be built. The label on the gas

furnace, or on the oil burner and furnace, will contain either the statement that the combustion efficiency is at least 75% or will give input BTU's and output BTU's. Combustion efficiency can be found simply by this formula -

$$\frac{\text{Output (BTU)}}{\text{Input (BTU)}} \times 100 = 75\% \text{ or more}$$

Electrically Operated HVAC Equipment - See Section 503.4(b) and Table 5-4 (heating) and Table 5-5 (cooling) of the Code.

In the case of electrically operated units you cannot determine the Coefficient of Performance in the field without special equipment. Therefore the information must appear on the label of the equipment. The tables referred to above give the precise numbers which must be reached.

Air Delivery - Field installed equipment must be checked for conformance with approved plans. Any unitary system that has the fan as a part of the unit, with the unit labeled in accordance with the requirements above, will be satisfactory.

Temperature Control (Code Section 503.8) - In plain language, any modern thermostat designed for use with the equipment being installed will meet the requirements.

Hot Water Heaters (Code Section 504.2) - As of this date, labels on domestic hot water heaters in retail outlets do not contain any of the information required in part (a). However, any of the automatic storage tank hot water heaters that are labeled by accepted inspection agencies exceed these requirements. The labels to be found are American Gas Association (AGA) for gas or Underwriters Laboratories, Inc. (UL) for electric. All hot water heaters must now be automatic.

Inspection Points

Ceilings: Full coverage over top plates is necessary, but soffit vents should not be blocked.

Fastening and Workmanship: Under floors - wires holding batts in or insulation falls away from the floor.

Walls: Emphasis on quick installation may result in dependence on friction fit rather than proper stapling. Some products are intended to be installed with a friction fit, but others are designed to be stapled.

Attics: Eave vents in attics must be protected by baffles to prevent blocking of the vent with insulation material.

Pipes and Penetrations: Uninsulated pipes may provide a significant gap in the exterior envelope insulation of the building.

Penetrations through walls, if not carefully sealed, may permit unacceptable amounts of air infiltration.

CODE INTERACTION

Conflicts with other regulations, and with desirable design practice, may occur as a result of the Energy Conservation Code. Of special concern are ventilation and fire problems.

Ventilation:

Restriction of air infiltration may result in inadequate ventilation, especially for supply to, and exhaust from, combustion processes. There may be no requirements for exhaust equipment for gas ranges because of a tacit assumption that air infiltration around windows and doors will provide sufficient ventilation to permit safe operation of such equipment. Such may not be the case where labeled windows are used. While exhaust and ventilation equipment could be required in new construction it could be much more difficult to require addition of such equipment in retrofit projects which may involve little more than window replacement and may not even require a building permit.

Fire:

Fire problems resulting from insulation requirements may be due to high flame spread of materials or to the heat retaining properties of the insulation itself.

Flame spread problems as well as fire propagation problems may result from the materials used, particularly in board type insulation. It is incorrect to assume that the location of insulation makes this unimportant, because a significant number of fires originate in electrical wiring located within walls. Materials used in rigid insulation may cause unacceptable generation of smoke and toxic gases. Such factors are compounded by the location of insulation because any concealed space presents special detection and extinguishment problems.

Inspection:

Inspection of insulation and mechanical systems for configuration performance is not difficult. It is necessary that exact information relative to products be included on the plans. Products must then be examined to determine that they are those specified. The inspector will check for required labels on windows and insulation materials. Ducts and piping will be inspected for required insulation and sealing.

The inspector will check for thermostats and water-conserving shower heads as required. In public facilities, hot water faucets are required to be of water-conserving type.

Electrical:

Controls for lights should permit selective use. Frequently, energy can be saved if lights can be turned off during the hours when an area receives ample natural light. Also during the time when janitorial crews are working, light is needed only in areas actually being cleaned. If control locations make it necessary to illuminate an entire building or floor at a time, much energy is wasted.

PLAN REQUIREMENTS

When application is made for a building permit, two sets of plans and specifications will be submitted to the enforcement official. These plans and specifications are required to provide adequate description of the building's energy conservation equipment, such as --

- Component materials of exterior envelope
- U Values of respective elements (except insulation)
- R Values of insulating materials
- Size and type of apparatus and equipment
- Equipment and systems controls
- Any other data required to demonstrate conformance with code requirements.

APPENDIX B
MODEL ENERGY CONSERVATION CODE APPLICATION
EXAMPLES
(ECT-303)

EXAMPLES

Now that we have seen that the application of the Model Code can be accomplished in one manner, let's examine how a set of plans submitted for plan review prior to permit issuance can be alternatively reviewed. Four examples will be given which will demonstrate the use of the Model Code in varying climatic conditions. Each example will demonstrate:

1. A conforming envelope design.
2. A nonconforming envelope design.
3. Use of the accepted practice section (Section 6 of the Model Code).

A conforming envelope design is defined as one in which all elements of the building (the walls, floors, roof-ceiling) have U_o values equal to or less than the values set forth in Tables 5-1 and 5-2 of the Code. Section 502.1 allows the U_o value of any one assembly to be increased above the allowable U_o value providing the overall heat gain or loss for the entire building envelope does not exceed the total resulting from conformance with the maximum U_o values specified. The use of this provision is referred to as a nonconforming envelope design.

Section 6 of the Model Code provides for the use of tables in checking for compliance with the maximum U_o values set forth in the Code. The use of this Section is referred to as Accepted Practice.

The values specified in the design temperature table and Table 5-1 must be determined for each climatic area specified in the examples. The determination of these values was discussed previously during the chapter on the Model Code so we will not extensively discuss them in this chapter. The heating degree days, design dry-bulb and design wet-bulb temperatures may be obtained from the ASHRAE Handbook of Fundamentals or other sources. The U_o values are obtained from charts contained in ASHRAE 90-75.

When the specific examples are discussed, the values from the completed design temperature tables and Table 5-1 will be provided. The values given in the tables may be checked as indicated above.

Before we proceed with the examples, we must have a clear understanding of the difference between U and U_o . U is the thermal transmittance of a specific material or component of a wall, floor or roof-ceiling. Thermal transmittance, of course, is defined as the overall coefficient of heat transmission expressed in units of Btu per hour per square foot per degree F. U_o is the overall (average) heat transmission of the

gross area of a wall, floor or roof-ceiling. Table 5-1 of the Model Code gives maximum U_O values. An example, a wood frame exterior wall of a building may consist of several elements, each possessing different U values such as:

1. The cavity area (space between studs).
2. The solid wood areas (stud, plate and blocking).
3. Windows.
4. Doors.

The U values for each of these components must somehow be combined to give a U_O (average or equivalent) value for the entire wall. The equation specified in Section 5 of the Model Code is used for this purpose and is referred to as the weighted average equation.

$$U_O = \frac{U_w A_w + U_g A_g + U_d A_d + \dots}{A_O}$$

Where:

U_O = the average or combined transmittance of the gross exterior wall, floor or roof-ceiling.

A_O = the gross exterior wall, floor or roof-ceiling area.

U_w = the thermal transmittance of the opaque area.

A_w = the area of the opaque section.

U_g = the thermal transmittance of the glazing (window or skylight) area.

A_g = glazing area.

U_d = the thermal transmittance of the door.

A_d = door area.

If more than one type of wall or other element is used, those items would be expanded, such as:

$$U_{w1} A_{w1} + U_{w2} A_{w2} + U_{w3} A_{w3} + \dots$$

The U_O equation could then likely appear as:

$$U_o = \frac{U_{w1}A_{w1} + U_{w2}A_{w2} + U_{w3}A_{w3} + U_{g1}A_{g1} + U_{g2}A_{g2} + U_dA_d}{A_o}$$

To utilize this equation, the U and A values for each element must be obtained.

Each of the examples will be a single-family detached dwelling of identical dimensions, 26 feet by 35 feet. The foundation system will vary depending upon the climatic condition. Remember that this is a plan review exercise, not a design example. Therefore, the framing size, spacing and amount of insulation in each case will be given.

EXAMPLE I

The building is a detached single-family dwelling with 26 foot by 35 foot dimensions located in Minneapolis, Minnesota. The exterior walls are wood stud with 2x4's @ 16" on center and the building has a full basement. The building has two exterior doors and several double glazed windows.

Winter Design Temperature	-10°F
Degree Days Heating	8382
	U_o
Walls	0.18
Roof-ceiling	0.04
Floors over unheated spaces	0.08

What is the comfort envelope in our example? It includes:

1. The ceiling area since we have an insulated ceiling and a ventilated attic area.
2. The exterior wall above grade including the basement wall, rim joist area and wood frame wall above basement.

CONFORMING ENVELOPE DESIGN

Wall Area Analysis

A_{w1} = 736 square feet (insulated area between studs - cavity)

A_{w2} = 95 square feet (stud-framing area-solid wood)

A_{w3} = 91 Square feet (rim joist area)

A_{w4} = 81 square feet (concrete block area-basement-above grade)

$A_d = 38$ square feet (area of doors)

$A_g = 118$ square feet (area of glazing-windows)

$A_o = 1159$ Square feet (total gross area)

Note that in this example A_{w1} and A_{w2} were calculated. A designer normally will not do this but instead will indicate that A_{w2} equals 10 or 12 percent of the opaque 2x4 wood stud wall area.

1. Insulated area between studs

	<u>R-Value</u>
	0.68 Interior air film
	0.45 1/2 inch wallboard
	9.00 R-9 batt insulation
	1.22 1/2 inch fiberboard sheathing
	0.81 Wood bevel siding (1/2 x 8)
	<u>0.17</u> Exterior air film
	12.33 Total R_{w1} Value

Note the magnitude of the above R values. The batt insulation accounts for 9 of the total 12.33 R value, while everything else only totals 3.33. Obviously, the insulation is most important; however, a designer is entitled to use the other R values, no matter how small they are.

Care must be exercised in selecting the correct air film value. The value varies depending upon the direction of heat flow.

U is the reciprocal of R, so:

$$U = \frac{1}{R}$$

$$U_{w1} = \frac{1}{R_{w1}} = \frac{1}{12.33} = 0.081$$

2. Stud-framing area

	<u>R-Value</u>
	0.68 Interior air film
	0.45 1/2 inch wallboard
	4.38 3 1/2 inches of soft wood
	1.22 1/2 inch fiberboard sheathing
	0.81 Wood bevel siding (1/2 x 8)
	<u>0.17</u> Exterior air film
	7.71 Total R_{w2} Value

$$U_{w2} = \frac{1}{R_{w2}} = \frac{1}{7.71} = 0.13$$

3. Rim joist area

	<u>R-Value</u>
	0.68 Interior air film
	9.00 R-9 batt insulation
	1.88 1 1/2 inches soft wood
	1.22 1/2 inch fiberboard sheathing
	0.81 Wood bevel siding (1/2 x 8)
	<u>0.17</u> Exterior air film

Concrete block wall

13.76 Total R_{w3} Value

$$U_{w3} = \frac{1}{R_{w3}} = \frac{1}{13.76} = 0.073$$

Note that 1 1/2 inches of wood was used for the full depth of the rim joist area including the plate on the concrete block basement wall. The area could have been broken down to reflect the 3 1/2 inch plate thickness; however, that much of a refinement is not necessary.

4. Foundation wall area

Section 2 of the Model Code specifies that the exterior wall area only includes wall area above grade. In this example with a basement, only the portion of the basement wall above grade is included as part of the gross wall area.

$$U_{w4} = \frac{1}{R_{w4}} = \frac{1}{2.13} = 0.47$$

5. Door area

The door units have been tested and found to have an R value of 7.81 including air films.

$$U_d = \frac{1}{R_d} = \frac{1}{7.81} = 0.128$$

6. Glazed area (windows)

The windows are double glazed glass with a 1/2 inch air space with a U value of 0.50 including air films.

$$U_g = 0.50$$

Now that all of the U values for the various elements in the exterior wall have been determined, the U_o (overall average) value for the exterior wall must be calculated. The weighted average equation discussed previously will be used.

$$U_o = \frac{U_{w1}A_{w1} + U_{w2}A_{w2} + U_{w3}A_{w3} + U_{w4}A_{w4} + U_dA_d + U_gA_g}{A_o}$$

$$U_o = \frac{\begin{array}{l} \text{Insulation} \quad \text{Wood} \quad \text{Rim Joist} \quad \text{Foundation} \quad \text{Doors} \quad \text{Windows} \\ 0.081 \times 736 + 0.13 \times 95 + 0.073 \times 91 + 0.47 \times 81 + 0.128 \times 38 + 0.50 \times 118 \end{array}}{1159}$$

$$U_O = \frac{59.62 + 12.35 + 6.64 + 38.1 + 4.9 + 59}{1159}$$

$$U_O = \frac{180.61}{1159} = 0.156$$

Since 0.156 is less than the Code maximum of 0.18, the wall is conforming.

If the values in the U_O equation are examined, it can be seen that the glazing accounts for the largest portion. This demonstrates the need to control the exterior window openings in a building for energy conservation. What would happen to the U_O value if single glazed windows were used?

For single glazed openings, the $U = 1.10$ including air films. If this value is substituted into the U_O equation,

$$U_O = \frac{59.62 + 12.35 + 6.64 + 38.1 + 4.9 + 1.10 \times 118}{1159}$$

$$U_O = \frac{59.62 + 12.35 + 6.64 + 38.1 + 4.9 + 129.8}{1159}$$

$$= \frac{251.41}{1159} = 0.217$$

Since $U_O = 0.22$ exceeds the Code maximum of 0.18, the wall is now non-conforming.

Now that we have determined that the exterior wall with double glazed openings is conforming, we must check the other element of the envelope, the roof-ceiling. The ceiling joists are 2 x 6's at 24 inches on center and there are no openings into the attic other than an attic scuttle which is insulated equivalent to the ceiling area.

Area Analysis (from plans)

1. Insulated area between joists

<u>R-Value</u>
	0.61 Interior air film
	28.00 R-28 blown insulation
	0.45 1/2 inch gypsum wallboard
	<u>0.61</u> Interior air film
	29.67 Total R_{R1} Value

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{29.67} = 0.034$$

2. Joist-solid framing area

$$U_{R2} = \frac{1}{R_{R2}} = \frac{1}{8.55} = 0.117$$

Since R-28 blown insulation is deeper than 5 1/2 inches, it will cover the ceiling joists. This could be taken into account in the above calculation if the specific insulation brand is known to determine its actual thickness. Since it is not known, it is not taken into account in the example.

The U_o value must now be determined using the weighted average equation.

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.034 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{29 + 7.4}{910}$$

$$U_o = \frac{36.4}{910} = 0.04$$

The roof-ceiling is conforming since the calculated value equals or is less than the Code maximum of 0.04.

Since both elements of the envelope conform to Code requirements, the envelope is conforming and would be accepted by the plan reviewer. In summary:

	<u>U_o Values</u>	
	<u>As Planned</u>	<u>Code Maximum</u>
Wall	0.162	0.18
Roof-ceiling	0.04	0.04

NONCONFORMING ENVELOPE DESIGN

Section 502.1 of the Model Code states that the U_o value of any element of the envelope may be increased above the Code maximum provided the overall heat gain or loss for the entire envelope does not exceed the total resulting from compliance with the Code U_o values.

In our example, if the designer so wished, the U_o value for the roof-ceiling (or wall) could have been increased above the Code maximum U_o, provided the wall U_o value is low enough. To check this, heat loss calculations must be made. Heat loss may be calculated using:

$$Q = U A \Delta t$$

where:

Q = Btu per hour loss, which is generally written as Btu/hr. or Btuh.

U = thermal transmittance

A = area

Δt = temperature difference between outside and inside design temperatures. In this example, the outside design temperature = -10°F and, according to Section 3 of the Code, the inside design temperature is 72°F.

$$\Delta t = 72 - (-10) = 82^{\circ}\text{F}$$

The heat loss must be calculated for the maximum U_o values specified in the Code.

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.18	x	1159	x	82	=	17107 Btuh
Roof-ceiling	0.04	x	910	x	82	=	<u>2985</u> Btuh
Total Allowable Heat Loss						=	20092 Btuh

The U_o's in our example may be increased as long as it does not result in a higher heat loss than calculated above.

Using the U_o 's from our example, the heat loss for the plans as submitted is:

$$\begin{array}{rclcl} \underline{U} & \times & \underline{A} & \times \underline{\Delta t} & = & \underline{Q} \\ \text{Walls} & & 0.156 & \times 1159 & \times 82 & = 14826 \text{ Btuh} \\ \text{Roof-ceiling} & & 0.04 & \times 910 & \times 82 & = \underline{2985} \text{ Btuh} \\ \text{Total Heat Loss} & & & & & = 17811 \text{ Btuh} \end{array}$$

The maximum additional heat loss that could have been permitted is therefore:

$$20092 - 17811 = 2281 \text{ Btuh.}$$

Assume that the designer had reduced the insulation in the roof-ceiling from R-28 blown insulation to R-19 six inch batts.

<u>R-Value</u>	
0.61	Interior air film
19.00	R-19 insulation
0.45	1/2 inch gypsum wallboard
0.61	Interior air film
<u>20.67</u>	Total RR1 Value

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{20.67} = 0.048$$

The U_{R2} value remains the same for the joist area as previously calculated.

$$U_{R2} = 0.117$$

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.048 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{40.7 + 7.4}{910}$$

$$U_o = \frac{48.1}{910} = 0.053$$

0.053 exceeds the Code maximum of 0.04, so we must check the heat loss to see if it is acceptable.

$$\begin{array}{rcl} & \underline{U} & \times \quad \underline{A} \times \underline{\Delta t} = \quad \underline{Q} \\ \text{Walls} & 0.156 & \times 1159 \times 82 = 14826 \text{ Btuh} \\ \text{Roof-ceiling} & 0.053 & \times 910 \times 82 = \underline{3955} \text{ Btuh} \end{array}$$

$$\text{Total Heat Loss} = 18781 \text{ Btuh}$$

Since 18,781 Btuh is less than the allowable of 20,092 Btuh, the envelope is acceptable. Actually, additional adjustments could have been made as long as the allowable heat loss of 20,092 Btuh was not exceeded.

ACCEPTED PRACTICE

Accepted practice refers to Section 6 of the Model Code. Through the use of charts and tables, many of the calculations we have just gone through can be eliminated. Since in this example we had two different types of exterior wall, wood stud and concrete block, it is difficult to use Section 6 and demonstrate the accepted practice method. It is suggested that the accepted practice analysis Examples II, III and IV be referred to.

EXAMPLE II

The building is a detached single-family dwelling with 26 foot by 35 foot dimensions located in Worcester, Massachusetts. The exterior walls are 2x4's at 16 inches on center wood studs with a raised floor. The underfloor area is unheated. The building has two exterior doors and several double glazed windows.

Winter Design Temperature	1°F
Degree Days Heating	7000

	<u>U_o</u>
Walls	0.20
Roof-ceiling	0.05
Floors over unheated spaces	0.08

What is the comfort envelope in our example? It includes:

1. The ceiling area since we have an insulated ceiling and a ventilated attic area.

2. The exterior wall above grade between the floor and the ceiling.
3. The raised floor system since the underfloor area is unheated and ventilated.

CONFORMING ENVELOPE DESIGN

Wall Area Analysis

A_{w1} = 736 square feet (insulated area between studs-cavity)

A_{w2} = 95 square feet (stud-framing area-solid wood)

A_d = 38 square feet (area of doors)

A_g = 118 square feet (area of glazing-windows)

A_o = 987 square feet (total gross area)

Note that in this example A_{w1} and A_{w2} were calculated. A designer normally will not do this but instead will indicate that A_{w2} equals 10 or 12 percent of the opaque 2x4 wood stud wall area. This is an acceptable practice.

1. Insulated area between studs

Note the magnitude of the above R values. The batt insulation accounts for 9 of the total 12.33 R value, while everything else only totals 3.33. Obviously, the insulation is most important; however, a designer is entitled to use the other R values, no matter how small they are.

Care must be exercised in selecting the correct air film value. The value varies depending upon the direction of heat flow.

$$U_{w1} = \frac{1}{R_{w1}} = \frac{1}{12.33} = 0.081$$

2. Stud-framing area

$$U_{w2} = \frac{1}{R_{w2}} = \frac{1}{7.71} = 0.13$$

3. Door Area

The door units have been tested and found to have an R value of 7.81, including air films.

$$U_d = \frac{1}{R_d} = \frac{1}{7.81} = 0.128$$

4. Glazed area (windows)

The windows are double glazed glass with a 1/2 inch air space with a U value of 0.50 including air films.

$$U_g = 0.50$$

Now that all of the U values for the various elements in the exterior wall have been determined, the U_o (overall average) value for the exterior wall must be calculated. The weighted average equation discussed previously will be used.

$$U_o = \frac{U_{w1}A_{w1} + U_{w2}A_{w2} + U_dA_d + U_gA_g}{A_o}$$

$$U_o = \frac{\begin{array}{c} \text{Wood-} \\ \text{Insulated area framing} \end{array} 0.081 \times 736 + \begin{array}{c} \text{Doors} \\ 0.13 \end{array} \times 95 + \begin{array}{c} \text{Windows} \\ 0.128 \end{array} \times 38 + 0.50 \times 118}{987}$$

$$U_o = \frac{59.62 + 12.35 + 4.9 + 59.0}{987}$$

$$U_o = \frac{135.87}{987} = 0.138$$

Since 0.138 is less than the Code maximum of 0.20, the wall is conforming.

Actually, the calculated U_o value is quite a bit lower than the maximum value. The designer could have done several things:

1. Decrease the amount of insulation in the wall.
2. Increase the window area.
3. Possibly use single glazed instead of double glazed openings.

Let's assume he used single glazed openings. The U value for single glazing = 1.10, including air films. If this value is substituted into the U_o equation,

$$\begin{aligned} U_o &= \frac{59.62 + 12.35 + 4.9 + 1.10 \times 118}{987} \\ &= \frac{59.62 + 12.35 + 4.9 + 129.8}{987} \\ &= \frac{206.67}{987} = 0.209 \end{aligned}$$

Since 0.209 exceeds the Code maximum of 0.20, the wall is now nonconforming. He could, however, increase the wall insulation which would lower the U_o value in this case.

Now that we have determined that the exterior wall with double glazed openings is conforming, the next step is to check the roof-ceiling. The ceiling joists are 2x6's at 24 inches on center and the attic area is ventilated to the exterior. There are no openings into the attic other than an attic scuttle which is insulated equivalent to the ceiling area.

Area Analysis (from plan)

$A_{R1} = 847$ square feet (area between joists)

$A_{R2} = 63$ square feet (joist, solid wood area)

$A_O = 910$ square feet (gross area)

1. Insulated area between joists

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{22.67} = 0.044$$

2. Joist-solid framing area

$$U_{R2} = \frac{1}{R_{R2}} = \frac{1}{8.55} = 0.117$$

The U_O value must now be determined using the weighted average equation.

$$U_O = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_O}$$

$$U_o = \frac{0.044 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{37.27 + 7.4}{910}$$

$$U_o = \frac{44.67}{910} = 0.049$$

The roof-ceiling is conforming since the calculated value of U_o is less than the Code maximum of 0.05.

The last element of the envelope to check is the raised floor area. It is framed with 2x6's at 24 inches on center and the underfloor area is ventilated to the exterior.

Area Analysis (from plan)

A_{F1} = 847 square feet (insulated area between joists)

A_{F2} = 63 square feet (joist framing area)

A_o = 910 square feet (gross area of floor)

1. Insulated area between joists.

	<u>R-Value</u>
	0.92	Interior air film
	0.78	5/8 inch plywood
	0.94	3/4 inch subfloor
	11.00	R-11 batt insulation
	0.92	Interior air film
	14.56	Total R_{F1} Value

$$U_{F1} = \frac{1}{R_{F1}} = \frac{1}{14.56} = 0.069$$

2. Joist framing area

	<u>R-Value</u>
	0.92 Interior air film
	0.78 5/8 inch plywood
	0.94 3/4 inch subfloor
	6.88 5 1/2 inches of soft wood
	0.92 Interior air film
	10.44 Total R _{F2} Value

$$U_{F2} = \frac{1}{R_{F2}} = \frac{1}{10.44} = 0.096$$

The U_O value must now be calculated.

$$U_O = \frac{U_{F1}A_{F1} + U_{F2}A_{F2}}{A_O}$$

$$U_O = \frac{0.069 \times 847 + 0.096 \times 63}{910}$$

$$U_O = \frac{58.44 + 6.05}{910}$$

$$U_O = \frac{64.49}{910} = 0.071$$

Since the calculated U_O value is less than the Code maximum value of 0.08, the floor is conforming.

All three elements of the envelope conform to Code requirements; the envelope is therefore conforming and would be accepted by the plan checker. In summary:

	<u>As Planned</u>	<u>Code Maximum</u>
Wall	0.138	0.20
Roof-ceiling	0.049	0.05
Floor	0.071	0.08

NONCONFORMING ENVELOPE DESIGN

Section 502.1 of the Model Code states that the U_o value of any element of the envelope may be increased above the Code maximum provided the overall heat gain or loss for the entire envelope does not exceed the total resulting from compliance with the Code U_o values. Heat loss calculations must be made to utilize this provision. Heat loss may be calculated by using:

$$Q = U A \Delta t$$

where:

Q = Btu per hour loss, which is generally written as BTU/hr. or Btuh.

U = thermal transmittance

A = area

Δt = temperature difference between outside and inside design temperatures. In this example, the outside design temperature = 1°F and according to Section 3 of the Code, the inside design temperature is 72°F .

$$\Delta t = 72 - 1 = 71^\circ\text{F}$$

The heat loss must be calculated for the maximum U_o values specified in the Code.

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.20	x	987	x	71	=	14015 Btuh
Roof-ceiling	0.05	x	910	x	71	=	3230 Btuh
Floor	0.08	x	910	x	71	=	<u>5169 Btuh</u>
Total Allowable Heat Loss						=	22414 Btuh

The U_o 's for the various elements in our example may be increased as long as it does not result in a higher heat loss than 22414 Btuh. The heat loss from the envelope as submitted in the plans:

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.138	x	987	x	71	=	9760 Btuh
Roof-ceiling	0.049	x	910	x	71	=	3166 Btuh
Floor	0.071	x	910	x	71	=	<u>4587 Btuh</u>
Total Heat Loss						=	17513 Btuh

The maximum additional heat loss that could have been permitted is therefore:

$$22414 - 17513 = 4901 \text{ Btuh.}$$

Assume the designer had reduced the insulation in the ceiling from R-21 to R-11 batts:

R-Value

0.61 Exterior air film

11.00 R-11 insulation

0.45 1/2 inch gypsum wallboard

0.61 Interior air film

12.67 Total R_{R1} Value

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{12.67} = 0.079$$

The U_{R2} value for the joist area remains the same as previously calculated.

$$U_{R2} = 0.117$$

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.079 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{66.91 + 7.4}{910}$$

$$U_o = \frac{74.31}{910} = 0.082$$

0.082 exceeds the Code maximum of 0.05 so we must check the heat loss to see if it is acceptable.

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.138	x	987	x	71	=	9760 Btuh
Roof-ceiling	0.082	x	910	x	71	=	5298 Btuh
Floor	0.071	x	910	x	71	=	<u>4587 Btuh</u>
Total Heat Loss						=	19645 Btuh

Since 19645 Btuh is less than the allowable of 22414 Btuh, the envelope is acceptable. Additional adjustments could have been made as long as the allowable heat loss of 22414 Btuh was not exceeded.

ACCEPTED PRACTICE

Section 6 of the Model Code is referred to as the accepted practice section. Through the use of charts and tables, many of the calculations we have just gone through can be eliminated. Section 6 is applicable to:

1. Buildings less than 5000 square feet in gross floor area and 3 stories or less in height, and
2. Residential buildings that are heated and/or mechanically cooled, or
3. Other buildings that are heated only.

For walls, Charts 6-A and 6-B and Tables 6-1A, 6-1B and 6-1C of the Code are used. We will use the envelope as was presented in the Conforming Envelope portion of this example. First, find the wall section in Table 6-1A. For our example, it is the first wall detail shown with R-9 batt insulation. We must interpolate between insulation values of 7 and 11 to determine our U_w value of 0.105.

This U_w value includes both the cavity and solid wood area of a wood stud wall. We now go to Chart 6-B since we have double glazed openings. In order to use this chart, we must calculate the percentage of window area in the exterior wall.

$A_g = 118$ square feet (area of windows)

$A_o = 987$ square feet (gross area wall)

$$\% \text{ windows} = \frac{118}{987} \times 100 = 11.95\% - \text{use } 12\%$$

Go to Chart 6-B and find 12% along the bottom. Go vertically up the chart and intersect the $U_w = 0.105$ value. It is a diagonal line between 0.10 and 0.12. Then proceed horizontally to the left to find the U_o value 0.175. Since this value is less than the maximum U_o value of 0.20 specified in the Code, the wall section is acceptable.

Charts 6-1A and 6-1B actually solve the weighted average equation used to calculate U_o . You should keep in mind that it is conservative and more accurate results will be obtained by the methods previously reviewed. However, Section 6 provides a convenient and relatively easy way to plan check.

For the roof-ceiling area, we go directly to Table 6-2. Our roof-ceiling in our example is the first detail shown with an attic area. An insulation of R-21 gives a U_R value of 0.05 which is equal to the allowable U_O value of 0.05. The roof-ceiling is therefore acceptable.

The U_O value for the floor section is determined from Table 6-3. For an R-11 insulation, the U_O value is 0.08, which is equal to the Code maximum value. The floor section is acceptable, also.

EXAMPLE III

The building is a detached single-family dwelling with 26 foot by 35 foot dimensions located in Oakland, California. The exterior walls are 2x4's at 16 inches on center wood stud with a concrete slab floor. The building has two exterior doors and several single glazed windows.

Winter Design Temperature	37°F
Degree Days Heating	2900

	<u>U_O</u>
Walls	0.26
Roof-ceiling	0.05

Slab on Grade - R value = 2.8

What is the comfort envelope in our example? It includes:

1. The ceiling area since we have an insulated ceiling and a ventilated attic area.
2. The exterior wall above grade (between top of slab and ceiling).

CONFORMING ENVELOPE DESIGN

Wall Area Analysis

A_{w1} = 736 square feet (insulated area between studs-cavity)

A_{w2} = 95 square feet (stud-framing area-solid wood)

A_d = 38 square feet (area of doors)

A_g = 118 square feet (area of glazing-windows)

A_O = 987 square feet (total gross exterior wall area)

See note regarding calculation of A_{w2} in Examples I and II.

1. Insulated area between studs

	<u>R-Value</u>
	0.68 Interior air film
	0.45 1/2 inch wallboard
	7.00 R-7 batt insulation
	1.22 1/2 inch fiberboard sheathing
	0.81 Wood bevel siding
	<u>0.17</u> Exterior air film
	10.33 Total R_{w1} Value

$$U_{w1} = \frac{1}{R_{w1}} = \frac{1}{10.33} = 0.097$$

2. Stud-framing area

	<u>R-Value</u>
	0.68 Interior air film
	0.45 1/2 inch wallboard
	4.38 3 1/2 inch soft wood
	1.22 1/2 inch fiberboard sheathing
	0.81 Wood bevel siding
	<u>0.17</u> Exterior air film
	7.71 Total R_{w2} Value

$$U_{w2} = \frac{1}{R_{w2}} = \frac{1}{7.71} = 0.13$$

3. Door area

The door units have been tested and found to have an R value of 7.81, including air films.

$$U_d = \frac{1}{R_d} = \frac{1}{7.81} = 0.128$$

4. Glazed area (windows)

The windows are single glazed glass with a U value of 1.10, including air films.

$$U_g = 1.10$$

Now that all of the U values for the various elements in the exterior wall have been determined, the U_o (overall average) value for the exterior wall must be calculated. The weighted average equation discussed previously will be used.

$$U_o = \frac{U_{w1}A_{w1} + A_{w2}A_{w2} + U_dA_d + U_gA_g}{A_o}$$

$$U_o = \frac{\begin{array}{cccc} \text{Insulation} & \text{Wood} & \text{Doors} & \text{Windows} \\ 0.097 \times 736 & + 0.13 \times 95 & + 0.128 \times 38 & + 1.10 \times 118 \end{array}}{987}$$

$$U_o = \frac{71.39 + 12.35 + 4.86 + 129.8}{987}$$

$$U_o = \frac{218.4}{987} = 0.221$$

Since 0.221 is less than the Code maximum of 0.26, the wall is conforming.

If the values in the U_o equation are examined, it can be seen that the windows account for the largest portion. This demonstrates the need to control the exterior window openings in a building for energy conservation. What happens to the U_o value if double glazed windows are used?

For double glazed windows, the U_o value is 0.50 including air films. If this value is substituted into the U_o equation,

$$U_o = \frac{71.39 + 12.35 + 4.86 + 0.50 \times 118}{987}$$

$$U_o = \frac{71.39 + 12.35 + 4.86 + 59.0}{987}$$

$$U_O = \frac{147.60}{987} = 0.150$$

The double glazing lowers the U_O value from 0.221 to 0.150. This is assuming that no other changes are made in the envelope. This reduction is significant.

Now that we have determined that the exterior wall with single glazed openings is conforming, we must check the other element of the envelope, the roof-ceiling. The ceiling joists are 2x6's at 24 inches on center and the attic area is ventilated to the exterior. There are no openings into the attic other than an attic scuttle which is insulated equivalent to the ceiling area.

Area Analysis (from plans)

A_{R1} = 847 square feet (area between joists)

A_{R2} = 63 square feet (joist, solid wood area)

A_O = 910 square feet (gross area)

1. Insulated area between joists

	<u>R-Value</u>
	0.61 Interior air film
	21.00 R-21 insulation
	0.45 1/2 inch wallboard
	0.61 Interior air film
	<u>22.67 Total R_{R1} Value</u>

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{22.67} = 0.044$$

2. Joist-solid framing area

	<u>R-Value</u>
	0.61 Interior air film
	6.88 5 1/2 inches of soft wood
	0.45 1/2 inch wallboard
	<u>0.61</u> Interior air film
	8.55 Total R _{R2} Value

$$U_{R2} = \frac{1}{R_{R2}} = \frac{1}{8.55} = 0.117$$

The U_o value must now be determined using the weighted average equation.

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.044 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{37.27 + 7.4}{910}$$

$$U_o = \frac{44.67}{910} = 0.049$$

The roof-ceiling is conforming since the calculated value equals or is less than the Code maximum of 0.05.

Since both elements of the envelope (wall and roof-ceiling) conform to Code requirements, the envelope is conforming and would be accepted by the plan checker. In summary:

	<u>U Values</u>	
	<u>As Planned</u>	<u>Code Maximum</u>
Wall	0.221	0.26
Roof-ceiling	0.049	0.05

NONCONFORMING ENVELOPE DESIGN

Section 502.1 of the Model Code states that the U_o value of any element of the envelope may be increased above the Code maximum provided the overall heat gain or loss for the entire envelope does not exceed the total resulting from compliance with the Code U_o values. Heat loss calculations must be made to utilize this provision. Heat loss may be calculated by using:

$$Q = U A \Delta t$$

where:

Q = Heat loss in Btu per hour, which is generally written as Btu/hr. or Btuh.

U = thermal transmittance

A = area

Δt = temperature difference between outside and inside design temperatures. In this example, the outside design temperature = 37°F and according to Section 3 of the Code, the inside design temperature is 72°F.

$$\Delta t = 72 - 37 = 35^\circ\text{F}$$

The heat loss must be calculated for the maximum U_o values specified in the Code.

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.26	x	987	x	35	=	8982 Btuh
Roof-ceiling	0.05	x	910	x	35	=	<u>1592</u> Btuh
Total Allowable Heat Loss						=	10574 Btuh

The U_o 's for the various elements in our example may be increased as long as it does not result in a higher heat loss than 10574 Btuh. The heat loss from the envelope as submitted in the plans:

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.221	x	987	x	35	=	7634 Btuh
Roof-ceiling	0.049	x	910	x	35	=	<u>1561</u> Btuh
Total Heat Loss						=	9195 Btuh

The maximum additional heat loss that could have been permitted is 1379 Btuh, therefore:

$$10574 - 9195 = 1379 \text{ Btuh.}$$

Assume the designer has reduced the insulation in the ceiling from R-21 to R-11.

R-Value

0.61	Interior air film
11.00	R-11 insulation
0.45	1/2 inch gypsum wallboard
0.61	Interior air film
<u>12.67</u>	Total R _{R1} Value

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{12.67} = 0.079$$

The U_{R2} value for the joist area remains the same as previously calculated for this example.

$$U_{R2} = 0.117$$

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.079 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{66.91 + 7.4}{910}$$

$$U_o = \frac{74.31}{910} = 0.08$$

0.08 exceeds the code maximum of 0.05 so we must check the heat loss to see if it is acceptable.

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.221	x	987	x	35	=	7634 Btuh
Roof-ceiling	0.08	x	910	x	35	=	<u>2548</u> Btuh
Total Heat Loss						=	10182 Btuh

Since 10182 Btuh is less than the allowable of 10574 Btuh, the envelope is acceptable. Obviously, the wall insulation could have been decreased

instead of the insulation in the roof-ceiling as long as the maximum allowable heat loss is not exceeded.

ACCEPTED PRACTICE

Section 6 of the Model Code is referred to as the accepted practice section. Through the use of charts and tables, many of the calculations we have just gone through can be eliminated. Section 6 is applicable to:

1. Buildings less than 5000 square feet in gross floor area and 3 stories or less in height, and
2. Residential buildings that are heated and/or mechanically cooled, or
3. Other buildings that are heated only.

For walls, Charts 6-A and 6-B and Tables 6-1A, 6-1B and 6-1C of the Code are used. We will use the envelope as was presented in the Conforming Envelope portion of this example. First, find the wall section in Table 6-1A. For our example, it is the first wall section shown with R-7 insulation. A U_w value of 0.12 is picked from the Table.

This U_w value takes into consideration both the cavity and the solid wood portion of a wood wall. We now go to Chart 6-A since we have single glazed openings. In order to use this chart, we must calculate the percentage of window area in the exterior wall.

$A_g = 118$ square feet (area of windows)

$A_o = 987$ square feet (gross area wall)

$$\% \text{ windows} = \frac{118}{987} \times 100 = 11.95\% - \text{use } 12\%$$

Go to Chart 6-B and find 12% along the bottom. Go vertically up the chart and intersect the diagonal $U_w = 0.12$ line. Then proceed horizontally to the left to find the U_o value 0.24. Since this value is less than the maximum U_o value of 0.26 specified in the Code, the wall section is acceptable.

Charts 6-1A and 6-1B actually solve the weighted average equation used to calculate U_o . The use of the charts and tables is conservative, but it provides a convenient and relatively easy way to plan check for compliance with the Model Code.

For the roof-ceiling area, we go directly to Table 6-2. The roof-ceiling in our example is the first detail shown with an attic area. An insulation of R-21 gives a U_R value of 0.05 which is equal to the allowable U_o value 0.05. The roof-ceiling is therefore acceptable.

EXAMPLE IV

The building is a detached single-family dwelling with 26 foot by 35 foot dimensions located in Gainesville, Florida. The exterior walls are 2x4's at 16 inches on center wood stud with a concrete slab floor. The building has two exterior doors and several single glazed windows.

Winter Design Temperature	32°F
Degree Days Heating	1000

	<u>U_o</u>
Walls	0.29
Roof-ceiling	0.05

Slab on grade - R value = none required.

What is the comfort envelope in our example? It includes:

1. The ceiling area since we have an insulated ceiling and a ventilated attic area.
2. The exterior wall above grade (between top of slab and ceiling).

CONFORMING ENVELOPE DESIGN

Wall Area Analysis

A_{w1} = 736 square feet (insulated area between studs-cavity)

A_{w2} = 95 square feet (stud-framing area-solid wood)

A_d = 38 square feet (area of doors)

A_g = 118 square feet (area of glazing-windows)

A_o = 987 square feet (gross exterior wall area)

1. Insulated area between studs

$$U_{w1} = \frac{1}{R_{w1}} = \frac{1}{10.33} = 0.097$$

2. Stud-framing area

$$U_{w2} = \frac{1}{R_{w2}} = \frac{1}{7.71} = 0.13$$

3. Door Area

The door units have been tested and found to have an R value of 7.81 including air films.

$$U_d = \frac{1}{R_d} = \frac{1}{7.81} = 0.128$$

4. Glazed area (windows)

The windows are single glazed with a U value of 1.10 including air films.

$$U_g = 1.10$$

Now that all of the U values for the various elements in the exterior wall have been determined, the U_o (overall average) value for the exterior wall must be calculated. The weighted average equation discussed previously will be used.

$$U_o = \frac{U_{w1}A_{w1} + U_{w2}A_{w2} + U_dA_d + U_gA_g}{A_o}$$

$$U_o = \frac{\begin{array}{c} \text{Insulation} \quad \text{Wood} \quad \text{Doors} \quad \text{Windows} \\ 0.097 \times 736 + 0.13 \times 95 + 0.128 \times 38 + 1.10 \times 118 \end{array}}{987}$$

$$U_o = \frac{71.39 + 12.35 + 4.86 + 129.8}{987}$$

$$U_o = \frac{218.40}{987} = 0.221$$

Since 0.221 is less than the Code maximum of 0.29, the wall is conforming.

If the values in the U_o equation are examined, it can be seen that the windows account for the largest portion. This demonstrates the need to control the exterior window openings in a building for energy conservation. What happens to the U_o value if double glazed windows were used?

For double glazed windows, the U_o value is 0.50, including air films. If this value is substituted into the U_o equation,

$$U_o = \frac{71.39 + 12.35 + 4.86 + 0.50 \times 118}{987}$$

$$U_o = \frac{71.39 + 12.35 + 4.86 + 59.0}{987}$$

$$U_O = \frac{147.6}{987} = 0.150$$

The double glazing lowers the U_O value from 0.221 to 0.150. This is assuming that no other changes are made in the envelope. This reduction is significant.

Now that we have determined that the exterior wall with single glazed openings is conforming, we must check the other element of the envelope, the roof-ceiling. The ceilings are 2x6's at 24 inches on center and the attic area is ventilated to the exterior. There are no openings into the attic other than an attic scuttle which is insulated equivalent to the ceiling area.

Area Analysis (from plan)

A_{R1} = 847 square feet (area between joists)

A_{R2} = 63 square feet (joist, solid wood area)

A_O = 910 square feet (gross area)

1. Insulated area between joists

	<u>R-Value</u>
	0.61 Interior air film
	21.00 R-21 insulation
	0.45 1/2 inch wallboard
	0.61 Interior air film
	22.67 Total R_{R1} Value

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{22.67} = 0.044$$

2. Joist-solid framing area

<u>R-Value</u>	
0.61	Interior air film
6.88	5 1/2 inches of soft wood
0.45	1/2 inch wallboard
0.61	Interior air film
8.55	Total R _{R2} Value

$$U_{R2} = \frac{1}{R_{R2}} = \frac{1}{8.55} = 0.117$$

The U_o value must now be determined using the weighted average equation.

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.044 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{37.27 + 7.4}{910}$$

$$U_o = \frac{44.67}{910} = 0.049$$

The roof-ceiling is conforming since the calculated value of U_o is less than the Code maximum of 0.05.

Since both elements of the envelope (wall and roof-ceiling) conform to code requirements, the envelope is conforming and would be accepted by a plan checker. In summary:

<u>U Values</u>		
	<u>As Planned</u>	<u>Code Maximum</u>
Wall	0.221	0.29
Roof-ceiling	0.049	0.05

NONCONFORMING ENVELOPE DESIGN

Section 502.1 of the Model Code states that the U_o value of any element of the envelope may be increased above the Code maximum provided the overall heat gain or loss for the entire envelope does not exceed the total resulting from compliance with the Code U_o values. Heat loss calculations must be made to utilize this provision. Heat loss is calculated by using:

$$Q = U A \Delta t$$

where:

Q = Heat loss in Btu per hour, which is generally written as Btu/hr. or Btuh

U = thermal transmittance

A = area

Δt = temperature difference between outside and inside design temperatures. In this example, the outside design temperature = 32°F and according to Section 3 of the Code, the inside design temperature is 72°F.

$$\Delta t = 72 - 32 = 40^\circ\text{F}$$

The heat loss must be calculated for the maximum U_o values specified in the Code.

	$\underline{U}$	$\times$	$\underline{A}$	$\times$	$\underline{\Delta t}$	$=$	$\underline{Q}$
Walls	0.29	x	987	x	40	=	11449 Btuh
Roof-ceiling	0.05	x	910	x	40	=	<u>1820 Btuh</u>
Total Allowable Heat Loss						=	13269 Btuh

The U_o 's for the various elements in our example may be increased as long as it does not result in a higher heat loss than 13269 Btuh. The heat loss from the envelope as submitted in the plans:

	$\underline{U}$	$\times$	$\underline{A}$	$\times$	$\underline{\Delta t}$	$=$	$\underline{Q}$
Walls	0.221	x	987	x	40	=	8725 Btuh
Roof-ceiling	0.049	x	910	x	40	=	<u>1784 Btuh</u>
Total Heat Loss						=	10509 Btuh

The maximum additional heat loss is 2760 Btuh, therefore:

$$13269 - 10509 = 2760$$

Assume the designer has reduced the insulation in the ceiling from R-21 to R-9.

R-Value

0.61	Exterior air film
9.00	R-9 insulation
0.45	1/2 inch wallboard
0.61	Interior air film
<u>10.67</u>	Total R _{R1} Value

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{10.67} = 0.094$$

The U_{R2} value for the joist area remains the same as previously calculated for this example.

$$U_{R2} = 0.117$$

$$U_O = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_O}$$

$$U_O = \frac{0.094 \times 847 + 0.117 \times 63}{910}$$

$$U_O = \frac{79.62 + 7.4}{910}$$

$$U_O = \frac{87.02}{910} = 0.096$$

0.096 exceeds the code maximum of 0.05, so we must check the heat loss to see if it is acceptable.

	<u>U</u>	x	<u>A</u>	x	<u>Δt</u>	=	<u>Q</u>
Walls	0.221	x	987	x	40	=	8725 Btuh
Roof-ceiling	0.096	x	910	x	40	=	<u>3494</u> Btuh
Total Heat Loss						=	12219 Btuh

Since 12219 Btuh is less than the allowable of 13269 Btuh, the envelope is acceptable. Obviously, the wall insulation could have been decreased

instead of the insulation in the roof-ceiling, as long as the maximum allowable heat loss is not exceeded.

ACCEPTED PRACTICE

Section 6 of the Model Code is referred to as the accepted practice section. Through the use of charts and tables, many of the calculations we have just gone through can be eliminated. Section 6 is applicable to:

1. Buildings less than 5000 square feet in gross floor area and 3 stories or less in height, and
2. Residential buildings that are heated and/or mechanically cooled, or
3. Other buildings that are heated only.

For walls, Charts 6-A and 6-B and Tables 6-1B and 6-1C of the Code are used. We will use the envelope as was presented in the Conforming Envelope portion of this example. First, find the wall section in Table 6-1A. For our example, it is the first wall section shown with R-7 insulation. A U_w value of 0.12 is picked from the Table.

This U_w value takes into consideration both the cavity and solid wood portion of the wood stud wall. We now go to Chart 6-A since we have single glazed openings. In order to use this chart, we must calculate the percentage of window area in the exterior wall.

$A_g = 118$ square feet (area of windows)

$A_o = 987$ square feet (gross area wall)

$$\% \text{ windows} = \frac{118}{987} \times 100 = 11.95\% - \text{use } 12\%$$

Go to Chart 6-B and find 12% along the bottom. Go vertically up the chart and intersect the $U_w = 0.12$ line. Then proceed horizontally to the left to find the U_o value of 0.24. Since this value is less than the maximum U_o value of 0.29 specified in the Code, the wall section is acceptable.

Charts 6-1A and 6-1B actually solve the weighted average equation used to calculate U_o . The use of the charts and tables is conservative, but it provides a convenient and relatively easy way to plan check for compliance with Model Code.

For the roof-ceiling area, we go directly to Table 6-2. The roof-ceiling in our example is the first detail shown with an attic area. An insulation of R-21 gives a U_R value of 0.05, which is equal to the allowable U_o value of 0.05. The roof-ceiling is therefore acceptable.

APPENDIX C
MODEL ENERGY CONSERVATION CODE APPLICATION
COOLING EXAMPLES
(ECT - 303)

COOLING EXAMPLES

Although Section 502.2 of the code implies that heating and cooling requirements are combined for detached one- and two-family dwellings (A-1) and all other residential buildings three stories or less (A-2), the only exterior envelope requirements are for the heating mode. When one is reviewing the documentation (plans, specifications, calculations, etc.) supporting a building permit application for types A-1 and A-2 buildings, it will only be necessary to ascertain that the exterior envelope complies with the singular wall, floor and ceiling requirements contained in Table 5-1 of the Code.

Section 502.3 (b) 1 indicates separate requirements for walls of all buildings except types A-1 and A-2 designed for cooling. Although section 502.3 (b) 2 implies separate requirements for roof/ceilings and floors of all buildings except types A-1 and A-2 designed for cooling, these requirements are based only on the heating mode. The values are contained in Table 5-2 of the Code.

Heating requirements have been presented earlier in this chapter and, since these requirements are no different when used in the cooling design, this section will relate only to the cooling requirements for walls of all buildings except types A-1 and A-2. This requirement is based on an allowable overall thermal transfer value (OTTV) which is based on the north latitude of the community in which the building is to be constructed. For example, the four cities whose locations are indicated have the following allowed OTTV:

	<u>Latitude</u>	<u>Allowed OTTV¹</u>
Gainesville, Fla.	29°	30.4
Minneapolis/St. Paul, Minn.	44°	34.6
San Francisco, Cal.	37°	32.6
Worcester, Mass.	42°	34.0

¹See page 69 of the code.

As one might expect, the further south the location, the lower the OTTV. The OTTV of the wall calculated from the following formula must be equal to or less than the allowed OTTV indicated in Table 5-2 of the Code.

EQUATION 2
AIR CONDITIONING ANALYSIS FOR WALLS

$$OTTV = \frac{(U_w A_w T_{DEQ}) + (A_f S F S C) + (U_f A_f \Delta t) \dots}{A}$$

WHERE:

OTTV = average or combined thermal transfer value.
A = gross exterior wall.
U_w = U value of opaque wall. (all elements)
A_w = opaque wall area.
U_f = U value of the fenestration area.
A_f = fenestration area.
T_{DEQ} = temperature difference value. (from table below)
SC = shading coefficient of the fenestration (see definitions)
Δt = temperature difference between exterior and interior design condition °F.
SF = solar factor value¹

The only new terms indicated in this formula are T_{DEQ}, SF, SC and Δt. The T_{DEQ} value is based on the mass per unit area of the exterior wall and is determined from the following table.

TEMPERATURE DIFFERENCES FOR USE WITH EQUATION 2

Wall Construction lbs./ft. ²	TDEQ
0-25	44
16-40	37
41-70	30
71 and above	23

¹SF is a solar factor and is based on the north latitude of the city, town or county in which the building is to be constructed. The following solar factors have been determined from Page of the code.

	<u>Latitude</u>	<u>SF</u>
Gainesville, Fla.	29°	120
Minneapolis/St. Paul, Minn.	44°	131
San Francisco, Cal.	37°	125
Worcester, Mass.	42°	129

Δt is the dry bulb temperature difference between exterior and interior design conditions. Section 302 (b) of the code indicates the interior

design condition for cooling to be 78°F. Based on this value and the outside design temperatures determined from Table 201-8, the following temperature differences are determined for the four cities.

	<u>Outside Design Temperature</u>	<u>Inside Design Temperature</u>	<u>Δt</u>
Gainesville, Fla.	94	78	16°
Minneapolis/St. Paul, Minn.	89	78	11°
San Francisco, Cal.	77	78	-1°
Worcester, Mass.	87	78	9°

It is interesting to note that the Δt value for San Francisco, Cal., is negative and if this value is used in the formula it reduces the actual OTTV. Although this is not significant, it would be conservative to eliminate the negative portion of the equation when it occurs.

The shade coefficient (SC), a factor used to determine the amount of solar radiation that enters through the glass area of a building, is based on characteristics of the glass such as color, tinting, thickness, etc. This value can be determined from Table 201-14 of this manual.

Based on the preceding and the buildings indicated in Cooling Designs 1 and 2, the following four examples will afford the opportunity for better understanding of the cooling calculation requirements. Cooling Design 1 does not have a basement, while Cooling Design 2 does.

Cooling Design 1 is to be reviewed for conformance to the code in San Francisco, Cal. and Gainesville, Fla., and Cooling Design 2 for Worcester, Mass. and Minneapolis/St. Paul, Minn.

The wall section of both designs should be noted as the gross wall area for the two design problems, considered to include the area from the top of the floor to the top of the roof assembly. Certainly this is a conservative approach, as the roof assembly starts approximately 12" below this area. If the designer assumed a wall height of 15'-0" for these buildings, his design would conform to the Code. (See Calculation Sheets 1 and 2.)

The solution to the examples in the order of cities listed in the previous tables follows.

The Thermal Transmission Value of the Opaque Wall (U_w), the Area of the Opaque Wall (A_w), Thermal Transmission Value of the Fenestration (U_f), the Area of fenestration (A_f), the Total area (A) and the shade coefficient (SC) must be determined separately for each building. The calculations necessary to determine U_w , A_w , A_f and A are indicated on Cooling Calculations Forms 1 and 2. As one might anticipate, the basement in

Design Two has no effect on U_w and thus in both cases U_w is the same for both designs.

GAINESVILLE, FLA.

OTTV Allowed 30.4

$$\text{OTTV Actual} = \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f \Delta t)}{A}$$

Solar Factor (SF).....120.00

Δt 16°

U_w 0.214 (See Calculation Sheet 1)

U_f 1.04 (See Table VI.2)

Shade Coefficient (SC)..... 0.88 (See Table VI.3)

T_{DEQ} 37.0

(based on weight of lightweight

block weighing 24 lbs. $24/.89 = 27$ PSF

1/2 gypsum wallboard = $\frac{2}{29}$ PSF

approximate SF weight of wall) = $\frac{29}{29}$ PSF

$A_w = 2090$

$A_f = 470$

$A = 2560$

$$\text{OTTV Actual} = \frac{(0.214 \times 2090 \times 37) + (470 \times 120 \times 0.88) + (1.04 \times 470 \times 16)}{2560}$$

$$\text{OTTV Actual} = \frac{16,549 + 49,632 + 7821}{2560} = 28.9$$

OTTV Actual = 28.9 - 30.4 Design Satisfies Code.

It should be noted that the contribution from solar radiation entering through the glass areas accounts for more than 65% of the total actual OTTV. This clearly indicates that a change in the Shade Coefficient would have the greatest impact on reducing or increasing the OTTV for this design.

MINNEAPOLIS/ST. PAUL, MINN.

OTTV Allowed 34.6

$$\text{OTTV Actual} = \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f t)}{A}$$

Solar Factor (SF).....131.00
 Δt 11°
 U_w 0.214 (see Calculation Sheet 2)
 U_f 0.35 (see Table VI.2)
 Shade Coefficient (SC)..... 0.83 (see Table VI.3)

T_{DEQ} 37.0 (see Gainesville example)

$A_w = 2090$
 $A_f = 470$
 $A = 2560$

$$OTTV \text{ Actual} = \frac{(0.214 \times 2090 \times 37) + (470 \times 131 \times 0.83) + (0.35 \times 470 \times 11)}{2560}$$

$$OTTV \text{ Actual} = \frac{16,549 + 51,103 + 1810}{2560} = 27.13$$

OTTV Actual = 27.13 $\leq$ 34.6 Design Satisfies Code

SAN FRANCISCO, CAL.

OTTV Allowed 32.6

$$OTTV \text{ Actual} = \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f \Delta t)}{A}$$

Solar Factor (SF).....125.00
 Δt-1°
 U_w 0.214 (see Calculation Sheet 1)
 U_f 1.04 (see Table VI.2)
 Shade Coefficient (SC)..... 0.88 (see Table VI.3)

T_{DEQ} 37.0 (see Gainesville example)

$A_w = 2090$
 $A_f = 470$
 $A = 2560$

$$OTTV \text{ Actual} = \frac{(0.214 \times 2090 \times 37) + (470 \times 125 \times 0.88) + (1.04 \times 470 \times (-1))}{2560}$$

$$OTTV \text{ Actual} = \frac{16,549 + 51,700 - 489}{2560} = 26.5$$

OTTV Actual = 26.5 $\leq$ 32.6 Design Satisfies Code

WORCESTER, MASS.

OTTV Allowed 34.0

$$\text{OTTV Actual} = \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f \Delta t)}{A}$$

Solar Factor (SF)..... 129.00

Δt 9°

U_w 0.214 (See Calculation Sheet 2)

U_f 0.34 (See Table VI.2)

Shade Coefficients (SC)..... 0.83 (See Table VI.3)

T_{DEQ} 37.0 (See Gainesville example)

$A_w = 2090$

$Z_f = 470$

$A = 2560$

$$\text{OTTV Actual} = \frac{(0.214 \times 2090 \times 37) + (470 \times 129 \times 0.83) + (0.35 \times 470 \times 9)}{2560}$$

$$\text{OTTV Actual} = \frac{16,549 + 50,323 + 1481}{2560} = 26.7$$

OTTV Actual = 26.7 ≤ 34.0 Design Satisfies Code.

FORTSON 7-12-77

DESIGN 1

U₀ CALCULATIONS FOR WALLS

WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	0.25	0.25
2 OUTER SURFACE	2.18	2.18
3 OUTER SHEATHING		
4 FRAMING	1.89	
5 CAVITY a) INSULATION		
6 b) AIR SPACE		1.01
7 INSIDE SURFACE	0.45	0.45
8 AIR FILM INSIDE	0.68	0.68
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10	5.45	4.57
12 U = 1/R TOTAL	.18	0.22

WALLS HEATING	AREA s.f.	OPAQUE AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL	2560			
14 WINDOW	437			
15 DOOR	33			
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2) 2090			
19 FRAMING		13) .15	5) .18	.027
20 CAVITY		14) .85	6) .22	.187
21 U ₀ = TOTAL LINES		19, 20		.214

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

TABLE B - CAVITY RATIO

STUD SPACING	12"	16"	24"
RATIO	.83	.85	.90

NOTE: These footnotes have been extracted from the form that is utilized to calculate both Heating and Cooling Thermal Transmission Coefficients.

FOOTNOTES:

2. Line 18, OPAQUE AREA, equals line 13 AREA minus line 14, 15, 16 and 17 AREA.
5. Line 12 U VALUE for FRAMING.
6. Line 12 U VALUE for CAVITY.
13. TABLE A RATIO
14. TABLE B RATIO

CALCULATION SHEET #1

DESIGN 2

U₀ CALCULATIONS FOR WALLS

WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	0.25	0.25
2 OUTER SURFACE	2.18	2.18
3 OUTER SHEATHING		
4 FRAMING	1.89	
5 CAVITY a) INSULATION		
6 b) AIR SPACE		1.01
7 INSIDE SURFACE	0.45	0.45
8 AIR FILM INSIDE	0.68	0.68
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10	5.45	4.57
12 U = 1/R TOTAL	.18	0.22

WALLS HEATING	AREA s.f.	OPAQUE AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL	2560			
14 WINDOW	437			
15 DOOR	33			
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2) 2090			
19 FRAMING		13) .15	5) .18	.027
20 CAVITY		14) .85	6) .22	.187
21 U ₀ = TOTAL LINES		19, 20		.214

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
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TABLE B - CAVITY RATIO

STUD SPACING	12"	16"	24"
RATIO	.83	.85	.90

NOTE: These footnotes have been extracted from the form that is utilized to calculate both Heating and Cooling Thermal Transmission Coefficients.

FOOTNOTES:

2. Line 18, OPAQUE AREA, EQUALS line 13 AREA minus line 14, 15, 16, and 17 AREA.
5. Line 12 U VALUE for FRAMING.
6. Line 12 U VALUE for CAVITY.
13. TABLE A RATIO
14. TABLE B RATIO

CALCULATION SHEET #2