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

**ENERGY CONSERVATION TECHNOLOGY
FOR PLAN EXAMINERS AND
CODE ADMINISTRATORS**

DECEMBER 1977

MASTER

**ENERGY CONSERVATION TECHNOLOGY
SERIES 200**

**Prepared For The
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VOLUME III

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ENERGY CONSERVATION TECHNOLOGY SERIES 200

DEVELOPED BY

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

MASTER

FOR

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

DECEMBER 1977

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PREPARED FOR THE

DEPARTMENT OF ENERGY

WORK PERFORMED UNDER CONTRACT No. E(04-3)1230

ECT COURSES

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Stephen N. Davis

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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.

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CHAPTER I

INTRODUCTION TO ENERGY CONSERVATION

(ECT-200)

INTERNATIONAL FACTORS

Modern technology has turned the world into what has been described as a global community. As such, the United States cannot make plans without consideration of international factors. This is particularly true in the field of energy. The nation must be concerned not only about where its imported energy resources are coming from, but also the competition for these reserves among the world's other industrialized nations as well as its many more developing nations.

World Reserves and Resources

It is estimated that world recoverable energy reserves exceed 31,173,000,000,000,000 Btu's (31,173 Quadrillion Btu's or quads). Reserves, or the proven inventory that producers must have to continue operations, are not static, however. In fact, it generally is expected that additional resources (two or more times reserves) will be found, developed and added to the reserve inventory.

Although the world obviously has a substantial amount of energy reserves and resources, their geographical concentration has great bearing on their availability. As shown in Tables 200-1 and 200-2, petroleum and natural gas reserves are concentrated in the Eastern Hemisphere, with over half of the world's total in the Middle East and North Africa, and most of the remainder in the Soviet Union. Reserves of the Western Hemisphere represent only 13% of the world total.

WORLD ESTIMATED CRUDE OIL RESERVES - JANUARY 1, 1975

Area	Billion bbl
United States	34.2
Other Western Hemisphere countries	32.0
Western Europe	20.1
Africa	57.9
Mid-East	326.0
Far East and Oceania	20.6
Sino-Soviet bloc	65.3
World total	556.1

TABLE 200-1¹

WORLD ESTIMATED NATURAL GAS RESERVES - JANUARY 1, 1975

Area	Trillion ft. ³
United States	1237.1
Other Western Hemisphere countries	136.3
Western Europe	155.0
Africa	196.5
Mid-East	594.6
Far East and Oceania	89.1
Sino-Soviet bloc	737.7
World total	2,146.3

¹Proved reserves, excluding natural gas liquids.
 Note.—There is no international standard defining categories of natural gas liquids.

TABLE 200-2²

Based on world rates of production in 1974, total reserves of petroleum will last for another 35 years. World coal reserves (Figure 200-3) will last for about 175 years. These global averages can be deceiving, however, because not all producers have equal call on the existing stock and demand can be expected to increase in the future.

FIGURE 200-1³

The extent to which world reserves can be stretched to meet future demand depends substantially on the development of resources into new reserves. Based on all data available, however, it appears that development of new reserves by all nations will not substantially affect the current geographic distribution. As such, the United States is likely to remain dependent on foreign energy --especially petroleum-- unless it can begin to alter its energy mix, that is, the amount of different types of raw fuels used to meet its ultimate energy demand.

The International Energy Mix

In spite of rising costs, the worldwide trend toward greater dependence on oil and gas has continued.

Developed noncommunist countries and many of the less developed nations rely on gas and oil, particularly imported oil, for three-fourths of their energy needs. Reliance on coal is minimal in the less developed regions, except in a few countries such as India and Korea. Communist economies, however, rely on coal for over half of their total energy supply and on oil and gas for most of the remainder.

In many countries, there are few alternatives to imported oil. The prospects for coal are not encouraging since incentives and advantages will continue to favor rapid development of oil and gas until new energy sources are available. The less developed countries would benefit greatly from new technologies to use solar and other renewable resources. Developed countries can undoubtedly be of assistance in transferring and applying such technologies.

In short, circumstances favoring use of oil and gas, the difficulty of converting to other resource bases, and the absence of alternative domestic energy resources in some countries (e.g., Japan) will all contribute to increased worldwide dependence on oil and gas and increasing demand.

The Nation

The United States is an "energy intensive" nation: it comprises only 6% of the earth's population but consumes 31% of the world's annual energy output. America's per capita consumption of energy is eight times that of the rest of the world. Its demand for energy has been increasing at an annual rate of 4% to 5% for the past decade.

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 (TVA) and later by the Rural Electrification Administration (REA).

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 is currently facing serious economic dislocations as natural gas consumption patterns are being reordered.

U.S. ENERGY DEMAND BY CONSUMING SECTOR

Total U.S. energy (Figure 200-2) 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. 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.

Non-Energy: the Non-Energy sector reflects the utilization of oil, gas and metallurgical coal or raw materials, rather than as fuel, in the manufacture of such products as petrochemicals, asphalt, gas, 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 thru 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.

TOTAL U.S. ENERGY SUPPLY

The growth rates of the total U.S. energy supply is shown in Figure 200-3.

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.

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.

QBTU/Y*

MB/DOE*

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

EFFECTS OF OIL EMBARGO

While most Americans remember the embargo as a near-panic created by severe gasoline shortages, statistics indicate that far more than temporary inconvenience was involved.

In fact, the nation's gross national product (GNP) dropped by \$10 to \$20 Billion dollars; 500,000 workers became unemployed, and drastic inflationary cost escalations were forced upon all petroleum-based goods and services.

In retrospect, many now regard the oil embargo as a blessing in disguise. It had the positive effect of making the nation aware of its serious energy problems. This awareness, in turn, has resulted in comprehensive planning and action to overcome these problems and make the United States energy independent for the mid- and long-term future.

Unfortunately, these plans have not moved along as quickly as had been projected. As a result:

- domestic production of petroleum and natural gas is down;

- cost of an imported barrel of oil is up;

- the rate of coal production has not changed;

- utility companies have cancelled or deferred, for economic reasons, a substantial portion of additional planned electric-generating capacity; and

- energy waste continues.

In fact, the United States is more vulnerable to an oil embargo now than it was in the fall of 1973.

WHY AN ENERGY CODE?

One way of looking at energy end uses is shown in Figure 200-4 which identifies specific purposes to which energy is put rather than the sectors which are using them.

As can be seen, approximately 30% of all energy consumed is used for space heating and cooling, water heating, and lighting, primarily in buildings.

U.S. GROSS ENERGY END USES

TOTAL GROSS ENERGY USE: 74.7 QUADRILLION BTU

FIGURE 200-46

Figure 200-5 indicates an approximate breakdown of energy consumption in residential and commercial building. Both cases indicate energy used for heating and air conditioning accounts for approximately 70%-76% of total consumption.

Numerous surveys and research studies indicate that the amount of energy consumed in buildings is substantially more than is absolutely required to accomplish the goals for which it is consumed. In other words, a great deal of the energy used is wasted.

The reasons for energy waste are not difficult to define. Prior to the embargo, energy was considered to be inexhaustible. Its relatively low price reinforced the erroneous supposition. The result was that owners and design professionals concentrated on getting a building built at the lowest possible cost. This meant that many of the techniques and

FIGURE 200-57

systems available to conserve energy, which were relatively more expensive than others, were not utilized. As such, buildings designed and built prior to the embargo are inherently wasteful. In addition, because of the low cost of energy, many Americans had fallen into wasteful habits which magnified the overall waste even more.

Accordingly, three national model code organizations (Building Officials and Code Administrators International, Inc., International Conference of Building Officials and Southern Building Code Congress International, Inc.⁸) developed a code for new construction which identifies the various ways in which systems can be designed and built to be as efficient as possible. By following requirements of the new code, new buildings will consume as much as 50% less energy than some of their counterparts designed without benefit of the new technology and energy awareness which exists today.

Since this energy code is based on the material in ASHRAE Standard 90-75, the results of a study by the Arthur D. Little Company¹⁰ of the impact of ASHRAE Standard 90-75 will be of interest. This report considers energy consumption, initial cost, and operating costs of five different type buildings located in each of four major census regions of the United States. 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 ASHRAE Standard 90-75.

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. (See Table 200-3.)

Within the report are many findings, observations, and recommendations concerning ASHRAE Standard 90-75 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 Standard 90-75 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%

SUMMARY OF ECONOMIC IMPACTS DUE TO ASHRAE 90

	<u>Total Annual Market</u> (\$MM)	<u>Market Affected by ASHRAE 90</u> (\$MM) (Z)	<u>Maximum Potential Impact of ASHRAE 90</u> (\$MM)	<u>Percent of Total Market</u> (Z)	<u>Percent of Affected Market</u> (Z)
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.

TABLE 200-39

- 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.

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 broad 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 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 ranged from \$0.04 to \$0.94 per square foot, with the greatest savings experienced in office buildings.

ASHRAE 90-75 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:

Dollars Per Square Foot

	<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.

The potential energy which could be saved by implementation 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.

A more detailed and complete analysis of the Arthur D. Little Report is provided in Chapter 4 of this manual.

It is obvious that you, the Code Official, can have an impact on alleviating the energy crisis in the United States. This you can accomplish by seeing that your local community adopts an energy code and you properly and intelligently enforce the code. The next three chapters of this manual will provide you with the information to accomplish this task.

CHAPTER II

ENERGY FUNDAMENTALS

(ECT-201)

ENERGY AND HEAT

Energy is defined as the capacity to do work or transform substances or environments. The term used to denote the rate of energy use is power.

There are various forms of energy. Energy of motion, kinetic or mechanical energy, is the most familiar "active" form. Heat is a form of mechanical energy because it occurs due to the motion of molecules. One also must consider "potential" energy, stored energy, inherent in most substances. Thus, any falling object - such as a book falling off a desk - experiences conversion from potential gravitational energy to kinetic energy as it falls. Other common terms used for energy are:

- Electrical Energy
- Nuclear Energy
- Chemical Energy
- Heat Energy

Although energy can be neither created or destroyed, it can be converted from one form to another. For example, the chemical energy of coal is transformed into heat energy when it is burned. The heat energy may be released in the form of steam which then can be converted into mechanical energy in a steam turbine, then into electrical energy in a generator, then into mechanical energy in an electric motor, or back into heat energy by an electric heater.

The energy requirements of a building comprise the total amount of energy used by that building each year to maintain selected inside environmental conditions under the dynamic impact of a typical year's climate. Energy requirements include raw fossil fuel consumed in the building for heat fuels to provide lighting and power.

Heating and cooling require approximately 70% of the total energy consumed in any building. To understand how much heat must be removed from or added to a building and the size of the equipment required to maintain comfort conditions, one first must understand how heat is measured, how it flows, and how its various forms move.

HEAT MEASUREMENT

The intensity of heat within an object or substance is measured by its temperature. In this country, temperature usually is measured in

degrees Fahrenheit (F). In scientific work and in many other nations, temperature is measured in degrees Celsius (C) (Figure 201-1).

Figure 201-1

The interrelationship between Fahrenheit and Celsius temperature can be expressed by the following formulas:

1. $^{\circ}\text{F} = (32 + 9/5^{\circ}\text{C})$
2. $^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$

Intensity of heat should not be confused with quantity of heat. The pilot flame of a gas-fired boiler may have the same temperature as the main burner flame, but the quantity of heat given off by each is different.

The basic unit used in this country to measure quantity of heat is the British Thermal Unit or Btu. A Btu is defined as the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit (Figure 201-2). Thus, it takes 24 Btu's to raise 12 pounds of water 2 degrees ($12 \times 2 = 24$). It also requires 24 Btu's to raise 2 pounds of water 12°F . The usefulness of Btu's becomes apparent when it is realized that all forms of heat energy can be transformed into Btu's. Thus, one kilowatt of electricity equals 3,413 Btu's; one cubic foot of natural gas equals 1,031 Btu's, etc.

Figure 201-2

SENSIBLE AND LATENT HEAT

In heating and cooling of structures, two forms of heat are encountered—sensible heat and latent heat.

Sensible heat is that energy which results in a change of temperature of a substance. You can sense or feel this change in temperature. It can be measured by ordinary dry bulb thermometer.

SENSIBLE HEAT

Figure 201-3

Latent heat, sometimes called heat of fusion, is defined as the amount of heat which must be added to or removed from a substance to cause a change of state and which cannot be sensed or measured by a thermometer (Figure 201-4). For example, although 32°F is the freezing point of water, all water in a given sample will not instantly freeze at 32°F. It will begin to freeze. Thus latent heat is the full amount of heat which must be removed from a given sample of water (substance) remaining at the same temperature before it turns into ice (changes state). As an example, it takes 144 Btu's to convert one pound of ice at 32°F to one pound of water

at 32°F. Similarly, it requires 970.3 Btu's to convert one pound of water at 212°F to steam at the same temperature and atmospheric conditions.

Figure 201-4

ENTHALPY

Enthalpy is the property of a substance which is a measure of the total heat content of a substance - both latent and sensible.

DRY BULB AND WET BULB TEMPERATURES

Dry bulb temperature is the temperature of the air as measured by an accurate dry bulb thermometer (a typical thermometer seen every day). The dry bulb temperature is a measure of sensible heat only.

Wet bulb temperature is the temperature measured by a thermometer whose bulb is covered by a wick which has been wetted in water and then exposed to a stream of rapidly moving air. The wet bulb temperature subtracts from the temperature the cooling effect caused by evaporation. The amount of cooling caused by evaporation depends upon the moisture content of the air and is, therefore, a measure of latent heat present under a given condition. If the relative humidity of the air is less than 100%, there will be evaporation and, thus, a temperature difference. Therefore, it could be said that a difference in wet bulb and dry bulb temperatures represents the presence of latent heat (Figure 201-5).

FUNDAMENTALS OF COMFORT

Comfort conditioning can be described as a process through which environmental factors of a given space are controlled simultaneously to

provide occupants with a maximum degree of comfort. These environmental factors include the temperature, humidity, cleanliness, distribution and motion of the air within a space, as well as the radiant heat effect, odors, and noise (acoustic level).

Figure 201-5

While most forms of comfort conditioning can treat some of these factors, only a well designed and well installed system can provide control of all of them in a way which will achieve maximum comfort.

Comfort may be assumed to exist when occupants of a space feel neither warm nor cool; that is, when they are unaware of their thermal environment.

Like any other machine, the human body works best at certain temperatures. Although human beings have been subjected to environmental air temperatures ranging from less than -60°F to more than 140°F and have survived, it is only within a small range of about 20°F (from, say, 65°F to 85°F) that most people feel comfortable.

Body Heat Regulation

The human body is an amazing machine. It extracts energy from foods, liquids and oxygen and uses it to do work and to keep itself at a nearly constant internal temperature of 98.6°F .

Because the human body has an efficiency of approximately 20%, it must reject to the environment a portion of its energy intake. This rejection takes the form of heat. Regardless of the surrounding temperature, the human body always is discarding its heat. Therefore, when we feel warm, it is not because there is a net heat flow to the body (which never occurs), but rather because the body is having

difficulty discarding heat. When we feel cold, it is because the body is discarding heat more rapidly.

The rate at which the body produces heat is termed the metabolic rate. Its value varies greatly, from a lower limit of 200 Btu's/h (the basal metabolic rate equal to the heat given off by a normal person asleep) to approximately 1,500 Btu's/h (for a person engaged in a strenuous work activity).

Body Heat Transfer

There are four modes of body heat transfer:

1. evaporation
2. radiation
3. convection
4. conduction

Evaporation: The body continually loses heat through evaporation whether you see it or not. As moisture (perspiration) is given off through the pores of the skin, it absorbs body heat and turns into a vapor state (Figure 201-6). This absorption of heat by moisture results in a cooling effect to the body surface. When you actually see drops of perspiration it means that the body is producing more heat than it can reject at a normal rate. At rest, 24% of the heat loss from the body is in the form of insensible perspiration - light work, 40% and heavy work, 60%.

EVAPORATION

Figure 201-6

Radiation: The body loses heat to its environment by radiation when its average surface temperature is higher than that of surrounding surfaces (Figure 201-7). This is so because heat always flows from a substance or object of higher temperature to one of lower temperature. Air temperature between the body and other surfaces has no effect on radiation. It is the same principle as when you warm yourself by sitting near a fire. This radiation process is reversed if the temperature of the surrounding surface is higher than the temperature of the body.

RADIATION

Figure 201-7

Convection: The body loses heat by convection when the air closest to it becomes warmer (due to body heat) than the air which is away from it (Figure 201-8). Since warm air is lighter than cool air, the warmer air floats upwards and is replaced by the cooler air. Convection heat loss occurs only when the average surface temperature of the body exceeds the temperature of the ambient air.

CONVECTION

Figure 201-8

Conduction: Conduction refers to heat flow through a substance. For example, the heat in a hot cup of coffee will be conducted to a metal spoon placed in it. Because the amount and time of bodily contact with a solid or surface (furniture, etc.) usually is slight, it is not of importance in terms of body heat transfer.

PHYSIOLOGICAL RESPONSE OF THE HUMAN BODY TO THERMAL ENVIRONMENT

The physiological response of the human body to the thermal environment depends on the thermodynamic process of heat exchange between the body and the environment. The heat balance equation for the body may be expressed as:

$$S = M - E + R + C$$

Where S = the rate of heat storage in the body and may be either positive or negative.

Where M = the rate of metabolism; heat produced within the body.

Where E = rate of evaporative heat loss.

Where R = rate of radiation heat loss or gain.

Where C = rate of convective heat loss or gain.

Where S is zero the body is in a state of thermal equilibrium. If this is accomplished without activating the thermoregulatory mechanisms of shivering, sweating, or strong vasomotor activity, thermal comfort exists. If S is negative there will be a decrease in stored energy and a cold stress will be imposed on the body; the body tissues will be chilled and the body temperature will decrease. Conversely, when S is positive there will be an increase in stored energy, and heat stress will be imposed; the body temperature will increase and the body tissue will be heated.

FACTORS AFFECTING COMFORT

The most significant factors which affect human comfort are as follows:

Temperature: A lower ambient air temperature speeds the rate of convection because it draws more heat from the body. As the temperature of the surrounding air rises, the rate of convective heat loss is reduced. As the temperature of the surrounding surfaces approaches skin temperature, the radiative heat loss also is slowed. With greater increases of surrounding surface temperature, the radiation process is reversed and heat flows from the surface to the

body. Therefore, the body has to give off even more heat through convection and evaporation if it is to remain comfortable.

Relative Humidity: The relative humidity (RH) of air is a term used to express the amount of moisture in a given sample of air in comparison with the moisture the air would hold if totally saturated at the temperature of the sample. Relative humidity is referred to as a percentage, such as 50%, 40%, etc. The relative humidity of the air affects the rate of evaporation. The more moisture there is in the air, the less dry air there is to absorb the moisture given off by the body. The more dry air there is, the more rapidly the moisture will be absorbed. If the relative humidity of surrounding air falls below about 20%, evaporation from the body and nasal passages takes place too quickly for comfort. Recommended RH limits are between 20% and 60%.

Air Motion: The motion of air also affects comfort. If cool dry air is circulated past a warm body, the evaporation rate increases greatly, as does the convection rate. Indoors, during the heating season, a lack of air movement can tend to cause the indoor air to stratify; that is, the cooler air will remain close to the floor and the warmer air will remain close to the ceiling. In such cases forced air movement can be used to create a better mixture of the air and, therefore, more uniform temperature in the room.

Air Purity: Air purity is another factor greatly influencing comfort. Because of pollution of one sort or another, the air is likely to contain different kinds of particles. Typically, these include smog, dust and dirt. Some of them also carry odors. In some cases these particles can create discomfort to the nose, throat and eyes. They also can cause indirect discomfort by soiling surroundings, clothing, etc. Air purity can be maintained by use of air filtration equipment. Special filtering media (chemical or activated charcoal) may be required for odor control.

Noise: Noise can be an important factor affecting comfort, especially when the space involved is used for work or other activities which require concentration.

Type of Activity: The type of activity performed in an area relates to comfort. A person sitting requires a higher surrounding temperature for comfort than someone engaging in physical activity.

Type of Equipment: The type of equipment in an area affects comfort in terms of the heat and noise which it generates.

Personal Characteristics of Occupants: Personal characteristics of occupants are important in terms of their deviation from what is loosely termed "normal". Older persons, for example, usually require higher temperatures for comfort; certain persons are far more discomforted by dust, pollen and other airborne particles than others, and so on. In designing a comfort conditioning system, one can only hope to determine that set of conditions which will be pleasing to most persons. If just one or two persons out of several hundred are sensitive to a certain interior condition, an adjustment to conditions would not be considered. Conversely, if many persons are sensitive to the conditions, an adjustment would be considered.

Clothing: Clothing contributes to comfort by screening the body from the effects of radiation, either cold or hot. It also contributes to comfort in cooler temperature by containing natural body heat which normally would be convected away.

ENVIRONMENTAL INDICES

A number of indices have been proposed to describe an environment and its effect on human occupants. A few of the more common ones are listed here:

1. Dry-bulb temperature (t_{db})
2. Effective Temperature (ET)
3. Wind-Chill Index (WCI)
4. Belding-Hatch Heat Stress Index (HSI)
5. Wet-Bulb Globe Temperature Index (WBGT)

Dry Bulb Temperature: As discussed previously, the measure of the temperature of the air.

Effective Temperature: This is one of the most widely used indices for warm atmospheres. This index considers dry bulb temperature, relative humidity and movement of the air with air space. The effective temperature was developed by a research team of the American Society of Heating and Ventilating Engineers (ASHVE, now ASHRAE). Test subjects were exposed to atmospheres with different temperatures, humidities and air movements and were asked to make comparative ratings of their sensations of warmth and coolness. The effective temperature may also be approximated by the empirical equation:

$$ET = 0.4 (WBT + DBT) + 15$$

WBT - Wet Bulb Temperature

DBT - Dry Bulb Temperature

Wind Chill Index: This index describes the rate of heat loss from a liter cylinder of water at 33°C (91.4°F) as a function of ambient temperature and wind velocity. This index can be determined by the following formula:

$$(WCI) = (5.71 + 7.78 \sqrt{V} - 0.284V) (91.4 - t_a)$$

V - Velocity of Wind in MPH

t_a - Ambient Temperature

This index has provided ways of expressing the combined effects of wind and temperature on subjective discomfort and has also proven useful for ordering the relative severity of the environment.

Rather than express the wind chill level as a numerical index, it has become common practice to use the corresponding equivalent wind chill temperature, which is defined as the ambient temperature which in a calm (i.e., 4 mph) wind velocity, would yield the same WCI. Equivalent wind chill temperature (t_{eq}) may be readily calculated by:

$$t_{eq} = -0.88 (WCI) + 91.4 \text{ for } F$$

Belding-Hatch Heat Stress Index (HSI): The HSI expresses the heat stress in terms of the amount of sweat which must be evaporated to maintain heat balance ($S = 0$ in the equation $S = M - E + R + C = 0$) compared to the maximum possible evaporative heat loss at an arbitrarily assumed skin temperature of 95°F. An HSI of zero indicates no thermal strain.

Wet-Bulb Globe Temperature Index (WBGT): The measurement of air velocities for the determination of effective temperature is a difficult procedure. The ET also does not take into account any radiant heat. The WBGT index suggests the use of a black globe instead of a dry bulb thermometer since the globe temperature will reflect the effects of air movement provided that radiant heat is present. The WBGT reading is obtained from:

$$WBGT = 0.7 WBT + 0.3 GT$$

WBT - Wet-Bulb Temperature

GT - Globe Temperature

The ASHRAE Comfort Chart (Figure 201-9) was developed in an effort to define conditions which will maximize the thermal acceptability of environment for a large group of adults, similarly clothed and active, and will minimize the fraction of potential complainers in the group occupying the space. It applies generally to altitudes from sea level to 7000 feet and to the most common special case for indoor thermal environments in which mean radiant temperature is nearly equal to dry-bulb air temperature and air velocity is less than 45 fpm. For this case, the thermal environment is well specified by the two variables shown: dry-bulb air temperatures and the humidity ratio.

The ASHRAE Comfort envelope is useful in evaluating the environment for lightly clothed subjects, resting and working at desk.

THE FLOW OF HEAT

The fundamental law of heat flow holds that heat always flows from a warm object or substance to one that is colder (Figure 201-10). It is important to note that nothing can stop the flow of heat, although, there are substances which slow down the rate of heat flow to a greater or lesser extent.

Figure 201-10

*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. d7.
 New Effective Temperature Scale (ET*)

Figure 201-911

Heat is transferred or transmitted from one substance to another by three basic processes: conduction, convection and radiation. Conduction is the flow of heat directly through a substance as a result of direct contact between two objects or substances having different temperatures. Convection is the transfer of heat by a current of fluid either a liquid or gas (such as water or air). Radiation is the transfer of heat by electromagnetic waves which heat objects and not the air in between.

Heat flow through elements of the building envelope (walls, roof, floors, doors, windows, etc.) depends on three factors:

1. Area: The larger the area of the element, the more heat it will conduct. A 400 foot square wall will conduct twice as much as a 200 foot square wall.
2. Temperature Difference: The greater the difference is, the more heat flow will occur in the element. For example, if the temperature difference between inside and outside temperature is increased from 30°F to 60°F, the flow of heat through the element will double.
3. Material Properties: The material and thickness of building envelope elements are spoken of in terms of four factors; conductivity, conductance, resistance and overall coefficient of heat transfer.
 - a. Conductivity: The ability of various materials to conduct heat. The good conductors are metals. The poorer conductors, such as wood, asbestos, gases, cork and felt, are called insulators. How well a substance transmits heat by conduction is a physical property of the particular material called thermal conductivity. The symbol for thermal conductivity is "k".
 - b. Thermal conductivity: Is defined as the amount of heat (Btu's) that passes through a homogeneous material 1 inch thick and 1 foot square in area, in an hour's time, with a temperature difference of 1°F between the outer and inner surfaces. Values "k" are expressed in (Btu's/hr-°F-inch-ft²). The lower a material's "k", the higher its insulating value.
 - c. Conductance: Conductance is similar to conductivity except that it is a measure of the rate of heat flow for the actual thickness of a material or an air space (either more or less than 1 inch), 1 foot square in area, at a temperature difference of 1°F. If conductivity (k) of a material is known,

the conductance (C) can be determined as follows:

$$C = \frac{k}{x}$$

Where x = thickness

The lower the C, the higher the insulating value.

4. Resistance: Resistance is a measure of a material's ability to retard heat flow rather than promote it. Resistance generally is referred to as thermal resistance and is usually symbolized by "R". A number to the R indicates the ability of one specific material, or a specific group of materials to resist heat flow. Resistance (R) is the numerical reciprocal of conductance (C), thus:

An example for conductance is when

$$C = 0.10, \text{ then } R = \frac{1}{0.10} = 10 \text{ hr ft}^2/\text{Btu}$$

The higher the R number, the higher the insulating value.

5. Overall Coefficient of Heat Transfer: The overall coefficient of heat transfer refers to value of all the materials in a building in series materials, air spaces, and surface air films. The overall coefficient of heat transfer generally is spoken of as "U value" and is expressed in terms of Btuh per ft² of area per °F temperature difference.

The overall coefficient of heat transfer is the reciprocal of the total resistance which equals the sum of separate resistances. Thus:

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

$$\text{Where } R_T = R_1 + R_2 + R_3 \text{ --- } + R_n$$

The lower the U value, the higher the insulating value.

COMBINING THERMAL PROPERTIES OF MATERIALS

Thermal properties of typical Building and Insulation Materials, Air Spaces and Air Films, are provided in tables in most engineering manuals. With the exception of the Air Space table, the thermal property tables in this manual are copies of the same tables contained in the 1977 Edition of the ASHRAE Handbook of Fundamentals.¹² The values

indicated in Table 201-2 for Air Spaces has been extracted from Table 2A of the 1977 Edition of the ASHRAE Handbook of Fundamentals for Air Spaces with a mean temperature of 50°F, a temperature differential of 10°F and an emissivity of 0.82. The temperature and emissivity values are those normally associated with thermal resistance values indicated in other technical manuals. It should be emphasized that the use of Table 201-2 should be limited to plan review, and one should anticipate different values for engineering calculations provided with the plans.

The thermal properties for Building and Insulation Materials in Table 201-1 used most often in heat flow calculations are expressed in two forms under the Resistance (R) column. The (1/k) column indicates the Resistance (R) per inch thickness of the material, while the (1/C) column indicates the Resistance (R) for the specific thickness of the material indicated in the Description column. If, for example, one desires to determine the Thermal Resistance of a 2 x 4 stud wall, the value could be determined in the following manner under the Description column for Woods:

For fir, pine, and similar softwoods, a value of 1.25 is indicated under the (1/k) column.

Multiplying the (1/k) value by 3.5 will result in the Thermal Resistance of the 2 x 4 stud.

$$R = 1.25 \times 3.5 = 4.38$$

If this value is compared with the (1/C) value for fir, pine, and similar softwoods of 3 1/2" thickness, it's noted that a difference of .08 (4.38 - 4.35) occurs. This difference is the result of rounding off.

Table 201-3 indicates the thermal properties of Windows, Skylights and Light Transmitting Partitions. Caution should be exercised in the using of this table as the Thermal Transfer Properties are expressed as a Coefficient of Heat Transfer (U) and separate values are indicated for Winter and Summer conditions.

Table 201-4 indicates the Thermal Properties of Slab Doors. Caution should also be exercised in using this table as the Thermal Transfer Properties are expressed as Coefficient of Heat Transfer (U).

Table 201-5 indicates the Thermal Properties of Air Reflectivity and Emittance Values of Various Surfaces and Effective Emittance of Air Space.

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	Customary Unit					SI Unit		
	Density (lb/ft ³)	Conduc- tivity (<i>k</i>)	Conduc- tance (<i>C</i>)	Resistance ^b (<i>R</i>)		Specific Heat, Btu/(lb (deg F)	Resistance ^b (<i>R</i>)	
				Per inch thickness (1/ <i>k</i>)	For thick- ness listed (1/ <i>C</i>)		(m ² · 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	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		0.03
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			0.03
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 201-112

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	
	0.5 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 ⁰	0.17–0.23		1.23
approx. * 3–3.5 in.	0.3–2.0	—	—	0.091	—	11 ⁴			1.94
approx. * 3.50–6.5	0.3–2.0	—	—	0.053	—	19 ⁴			3.35
approx. * 6–7 in.	0.3–2.0	—	—	0.045	—	22 ⁴			3.87
approx. * 8.5 in.	0.3–2.0	—	—	0.033	—	30 ⁴			5.28
BROWN 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	37.53	
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 ^f (R-11-exp.)	1.5	0.16	—	6.25	—	—	0.38	43.82	
(Thickness 1 in. or greater)	2.5	—	—	—	—	—	—	—	—

Table 201-112 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	—	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 to 0.12		1.39 to 8.33			0.24 to 1.47
Consult individual manufacturers for actual thickness of their material.								
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	—		0.53	
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

Table 201-1¹² Continued

Thermal Properties of Typical Building and Insulating Materials—(Design Values)^a

Description	Density (lb./ft. ³)	Conduc- tivity (λ)	Conduc- tance (C)	Customary Unit		Specific Heat, Btu/(lb.) (deg F)	SI Unit	
				Resistance ^b (R)			Resistance ^b (R)	
				Per inch thickness (1/in.)	For thick- ness listed (1/C)		(m·K) W	(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	3 in.	—	0.79	—	1.27	0.21		0.22
or slag; pumice)	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. ^{a)}	—	—	0.96	—	1.04	0.22		0.18
Same with filled cores ^{a)}	—	—	0.52	—	1.93	0.22		0.34
Lightweight aggregate (expanded shale,								
clay, slate or slag, pumice):								
3 core, 6 in. 19 lb. ^{a)}	—	—	0.61	—	1.65	0.21		0.29
Same with filled cores ^{a)}	—	—	0.33	—	2.99			0.53
2 core, 8 in. 24 lb. ^{a)}	—	—	0.46	—	2.18			0.38
Same with filled cores ^{a)}	—	—	0.20	—	5.03			0.89
3 core, 12 in. 38 lb. ^{a)}	—	—	0.40	—	2.48			0.44
Same with filled cores ^{a)}	—	—	0.17	—	5.82			1.02
Stone, lime or sand								
		12.50	—	0.08	—	0.19	0.53	
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			0.26
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			0.05
Lightweight aggregate 0.625 in.	45	—	2.67	—	0.39			0.07
Lightweight agg. on metal lath 0.75 in.	45	—	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
SIDING 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	0.35		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	0.30		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	4.65	

Table 201-112 Continued

Thermal Properties of Typical Building and Insulating Materials—(Design Values)^a

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
Aluminum or Steel ^c , over sheathing	—	—	1.61	—	0.61	0.29		0.11
Hollow-backed	—	—	—	—	—	—		—
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								
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 0.75 in.	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 Performed 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 mixes, 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 201-1¹² continued
THERMAL RESISTANCE (R) VALUES FOR AIR SPACES

POSITION OF AIR SPACE	DIRECTION OF HEAT FLOW	THICKNESS OF AIR SPACE			
		1/2"	3/4"	1½"	3½"
Horizontal	Up	0.84	0.87	0.89	0.93
45° Slope	Up	0.90	0.94	0.91	0.96
Vertical	Horizontal	0.91	1.01	1.02	1.01
Horizontal	Down	0.92	1.02	1.14	1.21
45° Slope	Down	0.92	1.02	1.09	1.05

Table 201-2¹²

Coefficients of Transmission (U) of Windows, Skylights, and Light Transmitting Partitions

These 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 ^e	0.49	0.56	0.46	0.5-in. air space ^e	0.59	0.49	0.56
0.5-in. air space, low emittance coating ^f ε = 0.20	0.32	0.38	0.32	0.5-in. air space, low emittance coating ^f ε = 0.20	0.48	0.36	0.39
ε = 0.40	0.38	0.45	0.38	ε = 0.40	0.52	0.42	0.45
ε = 0.60	0.43	0.51	0.42	ε = 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 ^h single-walled	1.15	0.80	—
Plastic Sheet single glazed	—	—	—	double-walled	0.70	0.46	—
0.125-in. thick	1.06	0.98	—	PART C—ADJUSTMENT FACTORS FOR VARIOUS WINDOW AND SLIDING PATIO DOOR TYPES (MULTIPLY U VALUES IN PARTS A AND B BY THESE FACTORS)			
0.25-in. thick	0.96	0.89	—	Description	Single Glass	Double or Triple Glass	Storm Windows
0.5-in. thick	0.81	0.76	—				
insulating unit—double ^c 0.25-in. air space ^d	0.55	0.56	—	Windows			
0.5-in. air space ^e	0.43	0.45	—	All Glass ⁱ	1.00	1.00	1.00
Glass Block ^b				Wood Sash—80% Glass	0.90	0.95	0.90
6 × 6 × 4 in. thick	0.60	0.57	0.46	Wood Sash—60% Glass	0.80	0.85	0.80
8 × 8 × 4 in. thick	0.56	0.54	0.44	Metal Sash—80% Glass	1.00	1.20 ^m	1.20 ^m
— with cavity divider	0.48	0.46	0.38	Sliding Patio Doors			
12 × 12 × 4 in. thick	0.52	0.50	0.41	Wood Frame	0.95	1.00	—
— with cavity divider	0.44	0.42	0.36	Metal Frame	1.00	1.10 ^m	—
12 × 12 × 2 in. thick	0.60	0.57	0.46				

^aSee Part C for adjustment for various window and sliding patio door types.

^bEmissance of uncoated glass surface = 0.84.

^cDouble and triple refer to the 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.

^hDimensions are nominal.

ⁱFor heat flow up.

^jFor heat flow down.

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

^lRefers to windows with negligible opaque area.

^mValues 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.

Table 201-3¹²

Btu per (hr · ft ² · F)				
Thickness ^a	Winter		Summer	
	Solid Wood, No Storm Door	Storm Door ^b		No Storm Door
		Wood	Metal	
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 ¹⁴				
1.75 in.				
A ^c	0.59	—	—	0.58
B ^d	0.19	—	—	0.18
C ^e	0.47	—	—	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.

Coefficients of Transmission (U) for Slab Doors

Table 201-4¹²

All conductance values expressed in Btu/(hr · ft² · 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,d}							SECTION B. Reflectivity and Emittance Values of Various Surfaces ^c 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 emittances; the other 0.90				Both surfaces emittances ϵ	
			h_1	R	h_2	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)		h_a	R	h_a	R	h_a	R	Building materials: wood, paper, masonry, nonmetallic paints	5 to 15	0.90	0.82	0.82
15-mph Wind (for winter)	Any	6.00	0.17					Regular glass	5 to 15	0.84	0.77	0.72
7.5-mph Wind (for summer)	Any	4.00	0.25									

^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.

Surface Conductances and Resistances for Air

Table 201-5¹²

The following problems indicate typical examples of the uses of Tables 201-1 - 201-5:

EXAMPLE 1--Calculating U Coefficient through Cavity of Stud Wall

	Resistance Units	Table
Inside Air Film.....	0.68	5(Vertical-Horizontal)
1/2" Plasterboard.....	0.45	1
Air space between studs.....	1.01	2(Vertical-Horizontal)
Plywood sheathing, 3/4".....	0.93	1
Hollow-backed metal siding..	0.61	1
Outside air film.....	0.17	5(Winter)
Total R_T	3.85	
Flow of Heat		
$U = \frac{1}{R_T} = \frac{1}{3.85} = .260$		

EXAMPLE 2--Calculating U Coefficient through Framing Member of Stud Wall

	Resistance Units	Table
Inside Air Film.....	0.68	5(Vertical-Horizontal)
1/2" Plasterboard.....	0.45	1
2" x 4" Stud 16" OC.....	4.35	1
Plywood sheathing, 3/4 inch.	0.93	1
Hollow-backed metal siding..	0.61	1
Outside air film.....	0.17	5(Winter)
Total R_T	7.19	
Flow of Heat		
$U = \frac{1}{R_T} = \frac{1}{7.19} = .139$		

EXAMPLE 3--Calculating the Overall U_o Coefficient for the Opaque Wall in Examples 1 and 2.

Normally the framing in a wall will approximate the percentage of the OPAQUE AREA indicated in the following table.

FRAME SPACING	12"	16"	24"
% OPAQUE AREA	17	15	10

Based on the 16" OC spacing indicated in Example 2, 15% of the OPAQUE AREA of the wall is framing and 85% ($100 - 15 = 85$) is cavity; therefore, the overall U_o coefficient may be calculated as follows:

	U	%/100	U x %/100
CAVITY:	.260	.85	0.221
FRAMING:	.139	.15	<u>0.021</u>
U_o :			0.242

EXAMPLE 4--Calculating the Overall U_o Coefficient for an exterior wall having an OPAQUE AREA of 800 sq.ft. and a window area of 200 sq.ft. The window glass is single pane, and the opaque wall is constructed as indicated in Examples 1 and 2.

From Example 3, it has been determined that the U_o coefficient for the OPAQUE AREA is 0.242. From table 3 for single glass winter design, it is determined that the window area U coefficient is 1.10. Using the U coefficient, the overall U_o coefficient can be calculated as follows:

	AREA	U	U x A
OPAQUE AREA	800	0.242	193.6
WINDOW	<u>200</u>	1.10	<u>220.0</u>
TOTALS	1000		413.6

$$U_o = \frac{U \times A}{A_o} = \frac{413.6}{1000} = 0.414$$

APPLICATION OF HEAT-TRANSFER PROCESS TO AIR CONDITIONING

Both the heating and cooling loads of air conditioned buildings are made up in large part by conduction heat losses and gains through ceilings, walls and floors. Conduction is also important in the design of air conditioning equipment. Cooling coils, condensers, water chillers, boiler tubes and furnace boxes must all be designed and fabricated to promote heat transfer by conduction.

Convection currents, too, play a significant part in the air conditioning load. Doors and windows are frequently opened and closed and they leak around the cracks, letting hot air enter in the summer cooling season and letting it escape in the winter heating season. Convection is the primary method of supplying heat where it is desired and removing it from places where its presence is objectionable. Air in ducts carries heat by convection to rooms for winter air conditioning and in summer, warm air returning through ducts to the air conditioner has some of its heat removed and is sent back to the rooms as chilled air which will absorb more room heat. Hot water, steam and chilled water used as heat transfer processes are also examples of convection.

Radiation adds to the summer cooling load in two ways: through glass and as direct sun load on walls and roofs, creating a much higher surface temperature than that of the surrounding air. This high surface temperature causes an increased heat flow by conduction through the wall or roof into the conditioned space.

Conduction and radiation contribute only sensible heat to the summer cooling load. Convection, however, may and usually does contribute to both sensible and latent loads.

ENERGY INTERRELATIONSHIPS

The amount of energy consumed in a given building depends on a variety of different factors, including the types of systems installed, the way in which they are operated and maintained, user needs, climatological conditions in the area and the way in which the building's envelope was designed and built, among others, as shown below.

FACTORS EFFECTING ENERGY CONSUMPTION IN BUILDINGS

- User needs
- Climate
- Site
- Orientation
- Configuration
- Building envelope
- Structure

Building Plan
Infiltration
Ventilation
Heating, ventilating and air conditioning
Lighting
Power
Operating and maintenance practices

Understanding how these different factors interrelate with one another to cause a building to consume energy will give you the basic information you need to understand:

- a. how new buildings can be made as energy efficient as current technology permits;
- b. how this efficiency can be made compatible with the overall goals of aesthetic and economical building design; and
- c. how to apply the new Model Energy Conservation Code.

User Needs

User needs essentially are those which relate to needs for business productivity and human comfort, safety and security. In general, the comfort consideration, which involves heating, ventilation and cooling, is one of the most important factors in terms of energy consumption and it also has great bearing on productivity.

Obviously, building systems must be compatible with user needs. The problem in the past has been, however, that most user needs were met almost exclusively through energy-consuming systems, and even then, by systems which were largely inefficient.

In the case of heating, for example, we know that heat loss can be reduced greatly by insuring that design minimizes the impact of wind, infiltration, and transmission, just as heat gain can be supported through such things as proper siting and fenestration to take maximum advantage of solar heat. The amount of energy consumed to heat also can be reduced substantially by specifying ventilation rates that are consistent with occupants' needs. All too often far more fresh air than is necessary is brought into a building, with the result that conditioned air is thrown away -- along with the energy which was required to condition it -- while new air continually has to be conditioned to make up for that which was exhausted.

In essence, the amount of energy expended for all user needs must be kept to a minimum through design, so that the building provides heating,

cooling, ventilation, lighting, hot water heating, interior transportation and other functions required to support what actually is needed.

In all cases, of course, the need for energy efficiency must be kept in balance with the need to observe proper health and safety standards, fire security, air quality and structural integrity.

Climate

Climate and meteorological conditions, perhaps more than any other factors, influence the building form, choice of materials, and energy requirements for heating, cooling, ventilation, and to a slightly lesser extent, illumination. For example, if outdoor temperature and humidity are very close to indoor design conditions, energy consumption depends mainly on energy for artificial lighting, for heating domestic hot water, perhaps for indoor transportation, and -- depending upon building plan and configuration -- for natural and/or forced ventilation.

Temperature: The duration of a given outdoor temperature affects heat loss and heat gain, and the magnitude of temperature peaks. These factors also influence the size of mechanical and electrical equipment.

Daily variations in temperature also affect equipment sizing, especially in terms of the size required to meet peak conditions. Diurnal(daily)variations are a function of many meteorological conditions at a specific location or site. A building located at the base of a mountain is likely to be subjected to a great range of diurnal temperatures. Large diurnal variations in temperature also occur in desert areas, and very often in locations that have a high percentage of clear skies and sunshine.

Large diurnal variations in temperature provide an opportunity to utilize heating and cooling storage systems which can result in a considerable reduction in energy consumption.

Sun and Wind: Except in extreme northern sections of the United States, the sun has more impact on building design and energy consumption than wind. In fact, the sun is perhaps the single most important natural element to consider in building design, affecting everything from building site and orientation, to building envelope and glazing, HVAC and lighting systems, and operating and maintenance policies.

The yearly heating energy consumption of two buildings in different geographic areas experiencing the same number of degree days could vary by as much as 30% or more, depending upon average cloudcover and available sunshine. To make the best from conditions in both cases,

however, east, west and south walls should be designed to take maximum advantage of the region's winter sun through fenestration for heating, and appropriate solar control in summer to reduce heat gain.

The extent and type of solar control depend on the intensity and duration of sunlight. Heat gain due to transmission and radiation can vary between two buildings at the same latitude, greatly modifying the requirements for cooling and thus the seasonal energy requirements placed on air conditioning systems.

Monthly solar loads must be accurately calculated to determine their impact on each building facade. Solar irradiation for each hour of the day may be an important factor in determining building shape, configuration and orientation. Solar controls, such as internal or external shading devices for glazed areas, or cooling ponds can manipulate sunlight to achieve maximum energy savings. Sunlight can also be used in solar collectors for heating, cooling, and domestic hot water, and eventually for power generation as well.

The amount and duration of solar radiation can affect the use of color for walls and roof (Figure 201-11), dark for absorption on north walls in cold climates, dark for absorption on roofs in cold climates, light for reflection from roofs in warm climates.

FIGURE 201-11

The wind velocity and prevailing direction of winds on a given site affect the shape and orientation of a building as well as the components of its envelope.

Wind disturbs the still air film that usually surrounds a building and contributes to the insulating U values of roof and wall elements, thus increasing heating and cooling loads. This effect becomes more marked as the U value increases. Wind can also evaporate moisture on wet surfaces and thus cool the skin to temperatures lower than the ambient air.

In the northern hemisphere, the north and west sides of a building are most exposed to wind. Therefore, buildings should have their most vulnerable portions, which include entrance and glazed areas, oriented away from the prevailing winds to avoid atmospheric leakage around doors, windows and any other openings. If there must be an entrance on the north or west, it should be shielded. The intensity and duration of outdoor temperature conditions determines the amount of energy required to overcome infiltration loads for any given quantity of air leakage in the building. A combination of high winds and low temperatures in winter amplifies the need for wind protection to reduce infiltration.

In many areas of the country, wind can be used to good advantage for natural cooling when properly directed into the building.

Snow: Snowfall has an effect on building energy consumption in a number of different ways. In areas where snowfall is heavy and fairly well predictable on a seasonal basis, snow cover on roofs which are constructed to retain it, may reduce the amount of insulation needed. The reflecting effect of snow on the ground and on adjacent low buildings increases the value of natural illumination systems, and the effectiveness and efficiency of flat plate solar collectors.

Topography: The specific site for a building can either diminish or increase the effect of climate on energy consumption. The topography of the site and existing or proposed structures adjacent to the building site can increase or decrease wind velocities from any direction, and modify the direction and intensity of sunlight which will impinge on the building envelope.

The type of trees that can be grown in the area depends on the climate. However, a sufficient number and type of trees can be grown in any climate to provide either shade or windbreaks. The type of trees that can be planted adjacent to a building depends primarily on the site selected and particularly upon the subsurface soil and water conditions. Trees emit water vapor into the environment and may locally modify the outdoor humidity.

Site

Site influences the amount and duration of light available for natural

illumination. In climates where natural illumination can provide a net gain in energy conservation, the location of the building on the site in relationship to adjacent structures and natural features (trees, hills) should be optimized.

The shape of the site and its resulting impact on building configuration affects the magnitude of energy consumption.

Sites for rectangular buildings may have a length to depth relationship which will affect the ability of building configuration to take maximum advantage of sun and wind. The site also may influence the direction of the building axis. A building with a north-south major axis presents greater exposure to solar irradiation than one with an east-west major axis anywhere in the country.

It must be understood that the following factors are greatly influenced by building shape and orientation which, in turn, may be influenced by the particular site:

1. trade-offs between heat loss and heat gain on each exposure with particular regard to wind and sun;
2. the utilization of natural daylight versus heat loss and heat gain and glare problems peculiar to each exposure;
3. the beneficial effects of direct solar radiation for heating versus the adverse effects during the cooling season; and
4. the extent to which the selection of the building envelope maximizes energy conservation benefits in evaluating all the trade-offs.

In order to maximize the energy benefits of a particular site, it may be desirable to allow changes in the configuration of the building by increasing or decreasing the height.

Orientation

The orientation of each facade and the roof has a unique effect on energy consumption depending on the climate, site and geographic location involved. For instance, a sloping roof facing south will be subjected to more solar irradiation in any climate in the United States than on the north and even on the east and west slopes. Similarly, wind velocities are greatest in cold climates on the north and west facades of the building so that each surface is subjected to different environmental influences even for two buildings located in the same latitude in the United States.

Orientation has little effect on ventilating loads or systems. However, it can influence the location of intakes or exhaust outlets. Orientation has little or no effect on the requirements of solid waste or domestic hot water systems, but may affect the power for lighting systems by its effects on the available light outdoors for natural illumination.

Configuration

The configuration of a building, as well as its orientation and envelope, affect the amount of energy used. Where energy can be saved by using natural illumination, the building perimeter should be increased and its interior space proportionately decreased, resulting in different building forms, such as multiple courtyards, atriums, light wells, finger buildings, and low buildings with skylights. If more energy can be conserved by using artificial lighting systems with reduced window areas, then reducing the perimeter exposure should be considered.

A configuration that resists unwanted heat gains or losses results in energy conservation. The exceptions are buildings which are located where outdoor climate is generally comfortable all year round and heating and air conditioning loads are not primarily responsible for the building's yearly energy requirements. A spherical or round building has less surface, hence less heat gain or loss than any other shape for an equal amount of total floor space. As shown in Figure 201-12, a square building has less surface area than a rectangular one of equal area per floor and so experiences less thermal transmission loss or heat gain.

FIGURE 201-12

Building Envelope

The building envelope, which consists of solid walls, windows, doors and other openings, roof, and floor surfaces, is subjected to the influences of climate by its individual orientations. The building envelope directly influences the heating and cooling peaks and the capacity requirements of the HVAC system.

The building envelope's response to climatic conditions is a major determinant of the amount of energy required to maintain the desired building thermal environment. Windows have the greatest effect on energy consumption, since they are major contributors to overall heat loss/heat gain. Their use for natural lighting reduces artificial illumination requirements, but the energy saved must be weighed against energy loss from other factors.

Thermal properties of the envelope are determined by the combination of wall mass, thermal resistance, insulation location, exterior surface color and texture percentage, and the type and location of glazing. All these factors affect energy consumption differently in summer and winter. In both seasons, their effect is dependent upon the mode of operation of the heating and cooling systems. The building envelope also affects infiltration rates, and influences the type of heating and cooling distribution systems specified, and the amount of energy used by either requiring heating elements at the perimeter (as in the case of poor thermal resistance), or by eliminating the need for perimeter systems entirely with better thermal performance. The U factor alone does not determine the yearly energy consumption for heating and cooling for each square foot of wall, but must be considered in concert with mass, color, and insulation location.

Structure

The structure can affect the type, complexity and energy usage of the heating, ventilating and air conditioning systems -- primarily in the characteristics of the distribution systems which require energy for fluid flow, and, to a lesser extent, the influence in the location of the central station equipment. The use of berms or sod covered roofs for energy conservation imposes additional loads on the structural system, affecting the amount of material required.

Opportunities for energy conservation in the structural system are functions of building configuration, orientation and height, building plan and envelope.

Building Plan

The building plan can have a significant effect on the energy required

to maintain comfort conditions. In northern climates, location of corridors, equipment spaces, toilet rooms and other service areas can act as buffer spaces -- against the cold in northern climates when located on a north wall, or against excessive thermal loads in southern climates when located on east, west or south perimeters.

The building plan and interior finishes affect the efficiency of the illumination system. Open space planning and few partitions require less lamp lumens than the more conventional plan with ceiling height partitions. Light colored walls, floors and ceilings provide greater inter-reflectance than dark colors and result in more effective use of available light.

In general, if overhead lighting is used, and if the lighting is an integral part of the ceiling, the ceiling height should be decreased to make it possible to save lighting wattage by bringing the fixture closer to the task. Less lighting wattage may be needed if the ceiling is lowered (perhaps independently of the lighting) and if task lighting, rather than general overhead lighting, is used to take advantage of the reflected light of the ceiling surface.

Higher ceilings improve environmental conditions in summer by permitting warm air to rise. However, greater ceiling heights increase the perimeter surface areas, thus increasing heat transmission through the walls. Grouping spaces that have similar environmental control needs can reduce the extent and complexity of the mechanical systems and permit heating, cooling, ventilation and lighting to be concentrated in areas that have maximum requirements. Thus, it is not necessary to provide the same degree of environmental comfort throughout the entire floor area.

Although building plan has little influence on energy required for domestic hot water and ventilation, it does influence the length and complexity of water and air distribution systems which do affect the amount of energy required. Long duct and pipe runs with many elbows and fittings offer more resistance to fluid flow and require more energy for pumps and fans, unless the ducts and pipes are increased in size and cost. A plan which can reduce the extent of the distribution systems leads to operating economy and energy conservation. If planning allows segregation of smoking areas from nonsmoking areas, then ventilation systems can be smaller, handling less air with less energy consumption.

Areas which have high internal heat gains are best located adjacent to exterior surfaces in cold climates to permit dissipation of excess heat without mechanical assistance.

Grouping toilet rooms on a floor and above each other on multiple floors simplifies the exhaust systems, and the plumbing systems generally

require less energy for the distribution systems. Grouping also permits a flow of air from clean areas through the toilet rooms for exhaust, reducing the total amount of air required for ventilation.

Grouping also simplifies the installation of heat recovery devices or air purification devices, such as charcoal filters, for recirculation back into the building.

Where kitchens and cafeterias are installed, locating them on the same level and adjacent to each other permits the use of exhaust air from the cafeteria to be transferred directly and efficiently to kitchen hoods for make-up air, reducing the energy required for that purpose.

If skylights are used for natural lighting, the height should be minimized for maximum lighting benefit. They should also be double or triple glazed where heat loss is a significant factor.

If windows are used for natural lighting, some evidence shows that the light is more effective as the window is raised in height in the wall. If the floor-to-ceiling height is increased in order to accomplish this, then the gains in natural lighting must be weighed against the decreased wattage for artificial lighting and the increased energy required by the possible increase in exterior building skin.

Reducing the number of exits and entries into a building lowers the energy requirements in a number of ways; e.g., infiltration is reduced, more efficient utilization of space is possible, less security lighting is required and less heat loss and heat gain is experienced; however, life safety standards must be maintained.

Increasing the percentage of usable area to gross area can result in smaller buildings with corresponding conservation of energy.

Infiltration

Infiltration is air leakage into the building through open doors and windows, cracks around doors, windows and other openings, construction joints and through building materials as well. The amount of energy required to heat and/or cool infiltrated air depends on the temperature difference between outdoor and indoor conditions.

The amount of infiltration depends on the structure, type of openings, amount of exhaust air which must be replaced, and the velocity, direction and duration of the wind. The influence of wind can be reduced by orientation and siting as discussed earlier, solar control devices and building configuration.

The building plan also influences the amount of infiltration. Fewer doors and entrances, fewer windows, weather stripping on doors and gasketed windows all reduce infiltration. Vestibules and wind barriers in front of entrances subjected to wind velocities, and breaks at intermediate levels of structures are other devices which can be used to control infiltration.

Ventilation

Ventilation is the amount of outdoor air or treated air supplied for physiological purposes.

Ventilation has a significant impact on a building's total energy consumption. Each cubic foot of air brought into the building must be either heated or cooled and, in some cases, humidified and dehumidified.

In many cases excessive amounts of outdoor air are brought in. It is particularly wasteful to ventilate space when the building is sparsely populated or unoccupied altogether. Selected ventilation would reduce energy consumption considerably if areas in the building were ventilated in accordance with their function. For example, smoking areas, high density occupied areas, kitchens, cafeterias and laboratories require greater amounts of ventilation, while auditoriums where ceilings are higher and no smoking is permitted can get along with less ventilation per capita.

It is important to analyze the physical requirements of each space and the user's needs and then provide only that ventilation necessary to handle those specific needs.

Geographic location may also influence ventilation requirements. In many urban areas, outdoor air is contaminated and would actually decrease the indoor air quality rather than better it as the outdoor air CFM is increased. In these cases, better ventilation results from special filtration systems. A close relationship exists between the exhausted quantity of air from a building and that introduced by ventilation and infiltration. Reducing exhaust air quantity can reduce both other elements. Passing contaminated air through charcoal and similar filters to remove odors and then recycling the clean air can reduce exhaust air quantities and thus reduce ventilation and infiltration.

The greatest savings can be realized by reducing ventilation air quantities, and by increasing the efficiency of ventilation systems so they require less energy to deliver the air required. Some examples are: proper fan and duct design, resistance filters, and a building plan which permits shorter ducts, reducing air friction and fan horsepower.

Opportunities to reduce the energy demands of ventilation systems also include transferring environmental control without use of mechanical systems, which is ideal. In many cases, however, systems designed for natural ventilation or for solar benefits may enjoy only brief periods of energy conservation during the year. Some facilities which are designed to allow the use of natural elements may create energy burdens for the remainder of the year. For example, using windows and louvers for natural ventilation may increase infiltration rates for long periods in the winter, increasing the energy requirements for heating.

Most equipment requires more energy input per energy output in like units at part load conditions than at full capacity. Matching the equipment to the load without using excessive safety factors conserves energy.

Duct and fan systems should be selected for the lowest pressure drop possible, consistent with the space available. Increasing pipe sizes to decrease frictional head only slightly increases the cost of piping, which may be more than offset by a reduction in cost of the pumps, and on a lifecycle basis, by the savings in operating costs.

Utilization of waste heat or energy rejected at one level that can be used for another process reduces energy consumption. Waste heat is available from many processes -- rejected heat of compression, refrigeration units, building exhaust air, heat from lights, hot water drains, solar energy which has been stored in the building mass, solid waste incinerators, heat from the boiler breaching, and kitchen equipment. It requires a high degree of integration of systems to make maximum use of this energy, but there is a very high potential for energy conservation. It is important not to unnecessarily degrade high grade heat which has been stored for later use. Multiple storage tanks are useful to take maximum advantage of the thermodynamic quality of the stored energy.

To provide exchangers to transfer sensible heat only is less costly than for both sensible and latent heat. However, many applications can use both effectively. For instance, in a climate with high relative humidity in the summertime, the use of latent and sensible devices provides much greater opportunity for energy conservation than capturing sensible heat only. Conversely, in an arid area in the summer, latent heat transfer has a low energy conservation potential, but the potential for sensible heat can be high.

Because the HVAC system consumes the largest single "block" of building energy each year, the quality of operating and maintenance practices and the effectiveness of controls are particularly important. Proper opera-

tion and maintenance help ensure that systems continually operate at peak efficiencies, thus keeping energy consumption to a minimum while extending the useful life of the systems involved. Likewise, controls which are kept in proper calibration and which are checked frequently to ensure proper operation will help ensure minimum expenditures of energy for heating, ventilating and air conditioning.

Lighting

Lighting influences the amount of energy consumed both in terms of power required for luminaires and for the energy required for air conditioning due to heat from the lights.

Past practice has often confused quantity with quality. This has resulted in overlighted building, poor visual performance, increased cooling loads and excessive energy consumption. The true user needs for both quality and quantity should be recognized and should form the basis of the design criteria.

A proposed building scheme must be examined to provide the most favorable length to width ratios, orientation and building shape for ratio of interior areas to perimeter areas and ratio of perimeter wall area to glazing area for optimization of energy conservation for heating, cooling, ventilation and illumination.

Natural illumination can serve only perimeter areas and even with open space planning cannot penetrate deeply (maximum 15 ft.) into the interior of a large building.

The footcandle has become the traditional measurement of light intensity but by itself indicates only the gross quantity of light without recognizing its quality or actual usefulness. A room that is very bright with a high footcandle measurement may still leave users unable to perform their tasks because of veiling reflections (which partially hide the details of a task and lower task contrast, rendering, for example, the black print on a white page unreadable).

Equivalent Spherical Illumination (ESI) has been introduced as a new definition of effective light. Essentially, ESI is a glare-free footcandle. Using it as the measure of a room's lighting often results in lower light intensity and, therefore, lower energy consumption.

Lighting should be designed for specific areas according to the tasks to be performed. Task lighting can reduce footcandle levels in a room and lead to savings up to 20% to 50% in a building's demand for electrical energy. Although lighting standards usually refer to uniform lighting levels in a room, it obviously is unnecessary to light such areas as

the water fountain, office supply room, and a secretary's wastebasket as intensely as a desk surface or reading chair in an office area. Efficient task lighting requires a more extensive switching system. Thorough analysis of each task for duration and difficulty is important in the design of task lighting. Since this is not always possible and tasks change, an adaptable lighting system is required so that it can be changed readily to accommodate changing functions.

Types of Illumination:

1. Natural Lighting: The amount of natural light available to building users depends on the time of day, weather conditions, air quality and the time of year. The building is also a determining factor; the size and location of the windows and skylights; the shape of the building and corresponding ratio of interior and perimeter areas and the position, shape and color of interior partitions, ceilings, floors and furnishings, all have impact.

Natural light saves electrical power and reduces cooling loads where it eliminates interior heat buildup caused by alternative, artificial lighting. Because natural light is diffused, and therefore has better quality, more footcandles of artificial light are required than of natural light to produce the same visual effect. In other words, natural light can save more energy than its footcandle level would indicate.

2. Artificial Lighting: The more usable light, or lumens, that a lighting fixture provides per watt, the more efficient it is in terms of energy. Efficiencies, or efficacies, vary greatly. Not all lamps that consume the same number of watts provide the same illumination levels or task visibility. Not all lamps provide the same quality of light or longevity. These factors and the needs of the total building system must be considered.

Types of Lamps:

1. Fluorescent lamps provide three times the lumens per watt of a standard filament bulb. Since fluorescent lamps lose efficiency at their ends, the use of fewer and longer tubes (one 8 ft. versus two 4 ft. tubes) and U-shapes versus linear tubes of the same length are generally more efficient. Two 24 in. cool white lamps give 50 lumens per watt; two 48 in. cool white lamps give 70; two 96 in. (800) lamps offer 73.
2. High Intensity Discharge (H.I.D.) lamps are available using high-pressure sodium and metal halides and include a range of bulb options. A 400-watt phosphor-coated mercury lamp gives

about 50 lumens per watt; a 1,000-watt version provides 55 lumens per watt. A 40 watt metal halide lamp gives 75 lumens per watt; a 1,000-watt version 85. Most efficient is a high-pressure sodium lamp -- a 400-watt model gives 100 lumens per watt.

Lighting Design:

1. Fixtures designed to cut glare and reflections should be used for intensive tasks. Shielded, low brightness luminaires can cut disability glare. Note that poorly designed shields may cut relatively little glare, yet block a great percentage of the light from entering a room. In general, direct and semi-direct fluorescent fixtures (industrial type) are useful in areas where glare is not a problem, such as halls, storage equipment rooms and non-intense task areas. Direct fluorescent fixtures with lenses are the next most efficient.
2. The position of a lighting fixture can greatly affect its usefulness. The angle and distance of lighting in relation to a task area influence light efficiency. Overhead and forward lighting can cause high veiling reflections while lighting from the side can cut veiling reflections.
3. Switching can have a great effect on energy consumption in lighting. Contrary to frequent rumor, it is rarely economical in terms of energy to let a light burn rather than turn it off and on. Yet, some buildings are designed so that people cannot individually turn off their lights at night and during other unoccupied times, because switches were never installed.

How much energy a sophisticated switching system can save depends on how and what lights they control and whether or not the switches are organized and located so that people can easily use them.

Effective switching systems often include automatic controls. For example, photocell switches can be installed to integrate natural and artificial lighting by turning interior lights on when outside light dims. Photocells can also be used to save lighting energy in exterior areas -- for parking lots, building entrances, security, etc. Time-clock switches with manual overrides can turn off office lights at a certain hour, yet can be reactivated manually as needed. Timed devices can also be installed in toilet rooms, corridors, storage and equipment areas, and be set to automatically turn off in five or however many minutes a person is likely to remain there. Low-voltage switches can also help conserve energy.

No amount of special equipment and devices, however, can realize its potential unless building personnel and users are encouraged and understand how to operate and maintain them.

People must learn to turn off lights when they don't need them. The switching and lighting lay-outs should allow them to do this. Benefits can also accrue from such procedures as scheduling custodial work during normal working hours instead of putting it off until night and then lighting the building to do it.

Power

The capacity of the power system is directly dependent upon the diversified peak power demands of the installed electrical lighting and apparatus, and independent of virtually all other considerations. Power losses and corresponding energy requirements increase as the demand increases. Load leveling, operating major electrical equipment at off-peak times, load shedding and matching motor sizes closely to the actual brake horsepower demand reduce the size and capacity of transformers, switchgear, conductors and motors, and heat gain from these items.

Operating and Maintenance Practices

Proper operating and maintenance procedures are initially important. Obviously, a building can be designed and built to exacting standards and specifications, but if the people who operate and maintain the systems don't do their job well, a substantial amount of the efficiency which has been designed in will be lost. If mechanical systems are operated improperly or are not maintained on a regular basis, their efficiency will begin to decline rapidly. If broken windows are left broken or leaking pipes left leaking, substantial energy losses will occur. For this reason, it is essential that designers strive to make systems as foolproof as possible and provide clear, concise operating and maintenance instructions that will enable people who are willing to try their best to do the job right.

As one can see, energy conservation is complex and involves many areas of building design and construction; insulation of the structural envelope is only a partial solution to conserving energy in building.

HVAC LOAD CALCULATIONS

General

The efficiency of a given HVAC system depends, among other things, on the adequacy of its size. In the past, standard practice was to over-size systems so they could handle just about any feasible variation in climatic conditions. This practice was acceptable because energy was considered inexhaustible and it was very inexpensive. Today that has changed, so it is imperative that systems be sized so that the least amount of energy is expended to get the job done. Correct sizing requires the use of carefully developed calculations. In order for the code official to evaluate the accuracy of these calculations, and the assumptions upon which they are based, it is essential that he understands how to make them.

In general, it can be stated that HVAC systems are designed to handle heating and cooling loads to create comfortable conditions. Load demands usually involve heating in winter and cooling in summer and often require either humidification or dehumidification, especially in small nonresidential buildings. Buildings gain sensible heat in summer and lose it in winter by conduction, convection, and radiation. They also may gain and lose moisture (latent heat). Both sensible and latent heat may be produced within buildings by occupants or by machines and equipment. Before an HVAC system can be designed, all loads must be analyzed to determine the proper size of equipment to offset these loads. The summer cooling load is the amount of heat which must be removed per hour to produce and maintain the design condition in the space. The winter heating load is the amount of heat which must be supplied per hour to maintain design conditions.

Both the summer cooling load and the winter heating load are measured in Btu's per hour.

This portion of the material deals with a study of heating and cooling loads. It will detail the factors that a designer considers in calculating the heating and cooling loads and the general procedure to be followed giving examples of the calculations. The intent is not to make you proficient designers, but only to make you familiar with how calculations are made. The majority of the material deals with cooling loads since they are more complex.

Design Conditions

Design conditions selected for calculation have a direct impact on the heating and cooling load. As was stated earlier, the rate of heat flow through walls, roof, etc., is substantially dependent on the temperature difference between one side of the element and the other.

Indoor design conditions are those that are required to maintain comfort. The recommended indoor design temperatures are 72F for heating and 78F for cooling.

There should not be any energy expended to humidify a space to more than 30% nor to dehumidify a space to less than 60%. For cooling, the design relative humidity should be within the comfort envelope defined by A-B-C-D on the new ASHRAE Comfort Chart in Figure 201-9.

Outside design temperatures are chosen based on the actual conditions experienced in the geographic location. This information can be established based on local weather data or can be obtained from Chapter 33 of the ASHRAE Handbook of Fundamentals. These tables are shown in Table 201-10.

In calculation of the cooling loads, the outside design dry-and-wet-bulb temperatures are to be chosen from the 2 1/2% value column in the Table. The 2 1/2% value indicates that on the average, the outside temperature in the summer will be higher than the value shown only 2 1/2% of the time. Since there are 2928 hours in the cooling season,....June through September....the actual conditions should be higher than those shown for 73 hours of the entire cooling season ($2928 \times .025 = 73.2$).

Similarly, the outside winter design temperature is to be chosen from the 97 1/2% column. This indicates that over the entire heating season of 2160 hours the actual outside temperature should not be any lower than indicated 97 1/2% of the time.

So 97 1/2% of the time, the actual temperature will be lower than those indicated or a total of 54 hours ($2160 \times .975 = 2106$; $2160 - 2106 = 54$).

You can see the pattern here that, in both summer and winter, we are not designing for the worst condition but that the HVAC system will be permitted to be overloaded for a short period, namely 2 1/2% of the time. Although the system will theoretically be overworked for that period of time, the concept is still energy conserving since the assumed outside temperatures should result in smaller sized HVAC equipment.

Load Classifications

Cooling load calculations deal with heat gains of two kinds:

1. Sensible Heat: As sensible heat flows into or is produced in a space it causes a temperature rise in the space.
2. Latent Heat: Latent heat occurs in the form of moisture. Although it does not cause a temperature rise, it does change the condition of the air in the space, resulting in a higher relative humidity.

Heating load calculations deal generally with sensible heat losses only.

1. Sensible heat gains to (losses from) the space include:

- * heat transmission through the building structure as a result of conduction, convection, and radiation;
- * sensible heat brought in (removed) with the outside air introduced for ventilation;
- * sensible heat produced by occupants;
- * sensible heat produced in the space by lights, appliances, motors, etc., and
- * sensible heat extracted from materials or products brought into the space.

2. Latent heat (moisture) gains may be classified as:

- * latent heat from outside air (both that introduced for ventilation and that which infiltrates into the space);
- * latent heat from occupants;
- * latent heat from cooking, hot baths, or other vaporization processes in the space, and
- * latent heat from products or materials brought into the space.

Figure 201-13 shows the source and nature of some of the major components of both summer and winter air conditioning loads.

A further load classification which is frequently used is based on the source of the heat. Loads are:

1. external, if they come from without the conditioned space, or
2. internal, if they are produced within the conditioned space.

Present-day trends favor complete air conditioning with close control of both temperature and humidity. Such requirements, together with the complexity of the air conditioning load, demand careful analysis of the building and precise calculation of the load specifications. Accuracy in estimating the heating and cooling requirements demands detailed information and knowledge of the building and load factors. It is advisable to keep in mind that a load calculation is only as accurate as the information upon which it is based. A detailed survey of the

existing building or the plans together with careful evaluation of the available data are prime requisites to any load calculation.

FIGURE 201-13

Calculation of Heating Load

A. Procedure

Calculation of the heating load is somewhat simpler than that of the cooling load. Internal and external loads need not be separated, allowances for radiation and internal sensible and latent heat loads are not made for calculating peak loads. However, consideration should be given to solar loads, lighting and occupants as they generate heat within the space.

The general procedure for calculating the heating load can be summarized as follows:

1. Determine the outdoor design conditions: temperature, wind direction, and wind speed.
2. Select the indoor air temperature that is to be maintained in each room during the coldest weather.
3. Estimate temperatures in adjacent unheated spaces.
4. Select or compute the overall thermal transmission value (U_o) for all elements of the building envelope. The envelope consists of any wall, floor, or roof-ceiling assembly that separates a heated or cooled space from an unheated or uncooled space.
5. Determine net areas of the building envelope elements, including areas of glass and skylights.
6. Compute the heat conduction losses for each kind of wall, glass, floor, ceiling, and roof in the building by multiplying the heat transmission coefficient in each case by the area of the surface in square feet and the temperature difference between the indoor and unheated space or outdoor air. $Q = U \times A \times TD$
7. Compute heat losses from basement floors or grade-level slab floors.
8. Select unit values and compute the heat equivalent of the infiltration of cold air taking place around outside doors and windows. These unit values depend on the kind or width of crack, wind speed, and temperature difference between the indoor and outdoor air. The result expresses the heat required to warm up the cold air leaking into the building per hour.
9. When positive ventilation using outdoor air is provided by the comfort conditioning unit, the heat required to warm the outdoor air to room temperature also must be provided by the unit. If mechanical exhaust from the room is provided in an amount equal to the outdoor air drawn in by the unit, the natural infiltration losses also must be provided for by the unit. If no mechanical exhaust is used and the outdoor air supply equals or exceeds the amount of natural infiltration that would occur without ventilation, the natural infiltration may be neglected.
10. The total heating load (in Btu/h) is the sum of the conduction losses or heat conducted through the confining walls, floor,

ceiling, glass, and other surfaces plus the heat equivalent of the cold air entering by infiltration or required to replace mechanical exhaust.

11. In buildings which have a reasonably steady internal heat release of appreciable magnitude from sources other than the heating system, a computation of this heat release under design conditions should be made for deduction from the total of the heat losses computed in Items 1 - 10. This is especially important for heating systems of high initial cost or those for which a demand charge is based on installed capacity.
12. Additional heating capacity may be required for intermittently heated buildings to bring the temperature of the air, confining surfaces, and contents of the building to the design indoor temperature within a specified time.

B. Sources of Heat Loss:

There are two primary factors associated with heat loss from buildings: Heat loss by conduction through the building envelope and heat loss by air that leaks in and out or is exhausted out of the building.

1. Conduction Heat Loss: Heat is transferred by conduction from the space to be conditioned through walls, roof, floors above unconditioned areas, doors and other elements for the building envelope.

In general, the amount of conducted heat loss which a structure will experience is dependent upon two factors: the design temperature difference and the thermal resistance of the structure's envelope.

The design temperature difference already has been defined, as well as the basic law of heat flow which states that heat always flows from a warm object or substance to one that is cooler. Therefore, the greater the difference between indoor temperature and outdoor temperature, the more heat which will be conducted.

The rate at which the heat is conducted depends on the thermal resistance of the structure. The more resistance which the construction materials provide, the slower the rate of heat gain. The resistance to heat flow of various building elements is known as the overall coefficient of heat transmission and is commonly called the U value or U factor. In equation form, heat loss can be represented as:

$$Q = U_o \times A \times TD$$

where U_o = overall coefficient of heat transmission

A = area of the assembly in square feet

TD = temperature difference in degrees F.

EXAMPLE: If a wall 20' high by 40' long has a U_o value of 0.30 and the design temperatures were 70°F and 0°F, what would the heat loss through the wall be?

$$Q = U \times A \times TD$$

$$= 0.30 \frac{\text{Btu}}{\text{hr-ft}^2 \text{ } ^\circ\text{F}} \times (20' \times 40') \times (70^\circ\text{F} - 0^\circ\text{F})$$

$$= .30 (800) (70) \text{ Btu/h}$$

$$= 16,800 \text{ Btu/h}$$

2. Heat Loss from Basement Spaces: If a basement is heated, the loss through the basement walls and floor should be calculated. For those portions of the wall above grade, the conduction heat loss is calculated the same as previously using the same relationship - $Q = U \times A \times TD$.

The heat loss through the below grade portion of the basement does not use the same calculation since the heat flow is air to ground instead of air to air. Heat loss factors (Btu/ft.²) can be chosen from the ASHRAE Handbook of Fundamentals (shown in Table 201-6). The heat is calculated by multiplying the appropriate factor by the area (square feet) of the assembly.

Heat Loss below Grade in Basement Walls* [Btuh/(ft ²)(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)	8.63	0.079	0.060	0.048	0.040
6-7 (7th)	10.28	0.069	0.054	0.044	0.037

$$k_{\text{soil}} = 9.6(\text{Btuh})(\text{in.})/(\text{ft}^2)(\text{F}); k_{\text{insulation}} = 0.24(\text{Btuh})(\text{in.})/(\text{ft}^2)(\text{F}).$$

Heat Loss through Basement Floors [Btu/(h)(ft ²)(F)]				
Depth of Foundation Wall below Grade (ft)	Width of House			
	20 (ft)	24 (ft)	28 (ft)	32 (ft)
3	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

TABLE 201-6¹²

3. Slab-on-grade Heat Loss: Buildings of slab-on-grade type construction experience a loss of heat around the perimeter of the slab. This loss is determined by multiplying the perimeter of the slab (P) in feet by a heat loss factor (F) in Btuh/ft where:

$$Q = P \times F$$

The values of F where there is no perimeter or edge insulation are 50 for unheated slabs and 75 for heated slabs. The F factors for slabs having perimeter insulation can be chosen from the ASHRAE Handbook of Fundamentals (shown in Table 201-7).

EXAMPLE: Calculate the heat loss from a floor 12x15 ft. wide with two exposures. The floor is an unheated concrete slab which is insulated at the edge with 2" of insulation extending horizontally for a distance of 2' from the edge. The outdoor design temperature is -5°F, and thermal resistance of the insulation is 3.75.

SOLUTION: From Table 201-7, the heat loss per foot of exposed edge is 38 Btuh. The length of exposed edge is 12' + 15' = 27'. The total edge loss is then 27 x 38 = 1026 Btuh.

Heat Loss of Concrete Floors at or Near Grade Level per Foot of Exposed Edge		
Heat Loss per Foot of Exposed Edge, Btuh		
Outdoor Design Temperature, F	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 ^a
-20 to -30	60	75
-10 to -20	55	65
0 to -10	50	60

^aThis construction not recommended; shown for comparison only.

Floor Heat Loss to be Used When Warm Air Perimeter Heating Ducts Are Embedded in Slabs ^a Btuh per (linear foot of heated edge)			
Outdoor Design Temperature, F	Edge Insulation		
	1-in. Vertical Extend- ing Down 18 in. Below Floor Surface	1-in. L-Type Extend- ing at Least 12 in. Deep and 12 in. Under	2-in. L-Type Extend- ing at Least 12 in. Down and 12 in. Under
-30	105	100	85
-10	95	90	75
0	85	80	65
10	75	70	55
20	65	57	45

^a Factors include loss downward through inner area of slab.

TABLE 201-7¹²

4. Heat Loss Due to Infiltration and Ventilation

a. General

Air that enters a building from the outside must be heated to maintain indoor comfort conditions. This represents another heating load. Before the infiltration and ventilation load can be calculated, the amount of air involved in cubic feet per minute must be determined.

There are two methods of determining the air infiltration rate which will be discussed shortly with some examples. They are the "air change" method and the "crack" method. Both estimate the quantity and rate of air movement in units of cubic feet per minute. Similarly, ventilation rates are expressed in terms of cfm and are established based on the requirements of the mechanical code or other local requirements. Knowing the quantity of infiltration and ventilation air, the heating load sensible and latent heat which must be offset can be calculated as follows:

Sensible Heat = cfm x TD x 1.10 where,

TD = Temperature inside - Temperature outside.

Latent Heat = cfm x (W₁ - W₂) x 4,840, where

W₁ = humidity ratio at entering condition*

W₂ = humidity ratio at leaving condition*

*(Humidity ratios for calculating latent heat are determined easily from the psychrometrics chart shown in Figure 201-13.)

In accounting for the addition to the heating load resulting from infiltration and ventilation, consider the load from both sources. In cases where exhaust loads are in use, however, the amount of air exhausted by these loads also should be determined. If the amount of air exhausted through hoods is more near that resulting for ventilation or infiltration, then this highest amount should be used as the basis for the ventilation/infiltration heat loss calculations.

b. Other Heat Sources

During the heating season, the heating plant is aided by many other sources of heat. Practically all energy expended in a building eventually becomes heat. In commercial buildings,

the heat supplied by these sources must always be ascertained, but allowances must be made only after careful analysis of all local conditions. In any analysis the effects of nighttime hours, weekends, and other unoccupied periods must be evaluated. In general, where people are present, the heating system must have sufficient capacity to bring the building to the stipulated indoor temperature before the people arrive.

The methods of calculating heat gain from solar radiation, lights, people, electrical motors, and machinery are discussed in the following topic of this course. These heat gains are not usually taken as a credit, but must be considered when designing the system.

The amount of ventilation air always must be at least equal to the total exhaust plus exfiltration (air leakage to the outside) through doors and windows. It is always best to add another 10% to 15% to the ventilation air required for positive interior pressurization. This provides for an outward escape of air through cracks in windows and doors and thus eliminates the need for figuring the infiltration load.

EXAMPLE: Given that:

- (1) ventilation and infiltration air quantities = 400 cfm,
- (2) outside design condition = 0F,
- (3) inside design condition = 72F

determine the sensible heat loss by the outside air.

SOLUTION: The sensible heat load can be calculated by use of the sensible heat equation. The only unknowns in this equation are the air quantity and temperature difference. On inspection of data given to us, we note that there is information for both these unknowns. Therefore:

$$\begin{aligned}\text{Sensible heat} &= \text{cfm} \times \text{TD} \times 1.10 \\ &= 400 \times (72 - 0) \times 1.10 \\ &= 400 \times 72 \times 1.10 \\ &= 400 \times 79.2 \\ &= 31,680 \text{ Btu/hr.}\end{aligned}$$

c. Infiltration; Air Change and Crack Methods

There are two methods of estimating air infiltration in buildings. In one case the estimate is based on measured leakage characteristics of the building components and

DB -	Dry-bulb temperature
WB -	Wet-bulb temperature
RH -	Relative humidity
DP -	Dew-point temperature
W -	Specific humidity
H -	Enthalpy
Spv -	Specific volume

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selected pressure differences. This is known as the crack method, since cracks around windows and doors are usually the major source of air leakage. The other method is known as the air change method and consists of assuming a certain number of air changes per hour for each room, the number of changes assumed being dependent upon the type, use, and location of the room. The crack method is generally regarded as being more accurate, provided that leakage characteristics and pressure differences can be properly evaluated. Otherwise the air change method may be justified.

- 1) Air Change Method: There are few published data on the air change rates for different buildings. Experience and judgement are required to obtain satisfactory estimates by this method. The values in Table 201-8 may be used with reasonable precision for residences, and are the requirements for each room. Some engineers assume that the total infiltration allowance of the individual rooms, since whatever air enters on the windward side generally leaves the building on the leeward side, and the infiltration requirements do not exist simultaneously on all sides or in all rooms.

The air quantity is computed as follows:

$$\frac{(H) \times (L) \times (W) \times (AC)}{60} = \text{Ft}^3/\text{min}$$

Where H = room height, ft.
 L = length, ft.
 W = room width, ft.
 AC = air changes per hour

Air Changes Occurring Under Average Conditions in Residences, Exclusive of Air Provided for Ventilation*	
Kind of room	Number of Air Changes per hour
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side	1
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exterior doors on three sides	2
Entrance halls	2

* For rooms with weatherstripped windows or with storm sash, use two-thirds these values.

TABLE 201-8¹²

- 2) Crack Method: The crack method considers leakage through cracks in windows and doors. In the crack method, the basis for calculation is as follows: The amount of crack used for computing the infiltration heat loss should be not less than half of the total length of crack in the outside walls of the room. For a building having no partitions, air entering through the cracks on the windward side must leave through the cracks on the leeward side. Therefore, take one-half the total crack for computing each side and end of the building. In a room with one exposed wall, take all cracks; and with three or four exposed walls, take the wall having the crack that will result in the greater air leakage; but in no case take less than half of the total crack.

In small residences the total infiltration loss of the house is generally considered to be equal to the sum of the infiltration losses of the various rooms. However, this is not necessarily accurate, because at any given time infiltration will take place only on the windward side or sides and not on the leeward side. Therefore, for determining the total heating or cooling requirements of larger buildings, it is more accurate to base the total infiltration loss or gain on the wall having the most total crack, but in no case less than half of the total crack in the building.

Table 201-9 gives infiltration values for double-hung wood windows, which serve as the basic guide, and surrounding construction. The notes below the Table give comparisons for other types of windows.

The length of the perimeter opening or crack for a double-hung window is equal to three times the width plus two times the height. In other words, it is the outer sash perimeter length, plus the meeting rail length.

EXAMPLE: Determine the infiltration through a wood, double-hung, 3' x 2', locked, non-weatherproofed, loosely fit window (Table 201-9), when outdoor wind velocity is 15 mph.

Infiltration Through Double-Hung Wood Windows						
Expressed in cubic feet per (hour) (foot of crack) ^a						
Type of Window	15	20	25	29	32	Wind Velocity (mph)
	0.10	0.20	0.30	0.40	0.50	Pressure Difference (Inches of Water)
A. Wood Double-Hung Window (Locked) (Leakage expressed as cubic feet per hour per foot of sash crack; only leakage around sash and through frame given)	25	30	35	100	125	
1. Nonweatherstripped, loose fit ^b	77 ^d	122 ^d	150 ^d	194 ^d	225 ^d	
2. Nonweatherstripped, average fit ^b	27 ^d	43 ^d	57 ^d	69 ^d	80 ^d	
3. Weatherstripped, loose fit	28 ^d	44 ^d	58 ^d	70 ^d	81 ^d	
4. Weatherstripped, average fit	14 ^d	23 ^d	30 ^d	36 ^d	42 ^d	
B. Frame-Wall Leakage^c (Leakage is that passing between the frame of a wood double-hung window and the wall)						
1. Around frame in masonry wall, not caulked	17 ^d	26 ^d	34 ^d	41 ^d	48 ^d	
2. Around frame in masonry wall, caulked	3 ^d	5 ^d	6 ^d	7 ^d	8 ^d	
3. Around frame in wood frame wall	13 ^d	21 ^d	29 ^d	35 ^d	42 ^d	

^a A 0.094-in. crack and clearance represents a poorly fitted window, much poorer than average.

^b The fit of the average double-hung wood window was determined as 0.0625-in. crack and 0.007-in. clearance by measurements on approximately 600 windows under heating season conditions.

^c 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.

^d Multiply by 0.0158 for 1/4 per metre of crack.

TABLE 201-9¹²

SOLUTION: First, find the total crack length or perimeter opening. Since perimeter opening is three times width plus two times height, total crack length is:

$$\begin{aligned}
 \text{Total Crack Length} &= 2(3') + 3(2') \\
 &= 6' + 6' \\
 &= 12 \text{ linear ft}
 \end{aligned}$$

Go to Table 201-9, find "Wood Double-Hung Window, Locked, "Non-weather Stripped, Loose Fit." To the right under "15 mph wind velocity" read infiltration as 77 cubic foot per hour per foot of crack.

Therefore, total infiltration through the window is:

$$\text{Crack leakage} = 12 \times 77 = 924 \text{ cfh}$$

$$\text{or } = \frac{924}{60} = 15.4 \text{ cfm}$$

Infiltration through doors must be considered in relation to the type of door and room or building. Where doors are used infrequently, infiltration can be based on the air leakage through cracks between door and frame. Such doors vary greatly in fit because of their tendency to warp. For a well fitted door, the leakage values for a poorly fitted double-hung wood window may be used. If poorly fitted, twice this figure should be used. If weather stripped, the values may be reduced one-half. A single door that is frequently opened, as might be the case in a small store, should have a value applied three times that for a well fitted door.

This extra allowance is for opening and closing losses, and is kept from being greater by the fact that doors are not used as much in the coldest and windiest weather. Large rates of leakage can occur with doors in use and this must be taken into account in commercial establishments where high traffic rates are expected. Information on the infiltration characteristics of swinging and revolving doors has been quite limited and predictions for purposes of load calculations generally have been a matter of engineering judgment. It should also be noted that the Model Code regulates the infiltration rate of doors and windows. Where assemblies with known infiltration rates are used, the actual values should be used in the calculations.

d. Heat Loss Summary

In summary, heat loss in winter occurs by conduction through the building envelope, through floor slabs, around the perimeter of floor slabs and by infiltration of cold air or escape of warm air by ventilation.

These factors and their basic equations can be summarized as shown in Figure 201-15.

The total heating load of the building then becomes the sum of the individually calculated heat losses. The unit of measurement of calculated heat loss is Btu per hour (Btu/h).

This is the same unit of measurement that heating equipment is sized according to. If the total heat loss of a building was calculated to be 100,000 Btu/h, the designer will choose a system with a capacity of at least 100,000 Btu/h. Normally, the designer will oversize the system by 10 - 15%.

Calculation of Cooling Load

A. Procedure

Calculation of the cooling load is somewhat more complicated than that for heating load. Internal and external sources of heat gain must be separated and determined. When calculating heating loads, it was said that internal sources of heat gain could be considered and detracted from the heating load, but this was usually neglected. In determining the cooling load, these factors now must be considered and added to the cooling load. Also, solar heat gain effects will also be discussed.

In general, cooling load calculations require the following considerations:

1. Obtain building information and design conditions.
 - a. Obtain characteristics of building. Building materials, component size, and shape are usually determined from building plans and specifications.
 - b. Determine building location, orientation, and external shading. Plans and specifications will have this information. Shading from adjacent buildings may be determined by a site plan or by visiting proposed building site.
 - c. Obtain weather data and outdoor design conditions. Weather data may be obtained from local weather stations, electric utility or the National Climatic Center, Asheville, North Carolina 28801. Outdoor design conditions are provided in Table 201-10.
 - d. Determine indoor design conditions, including the indoor dry bulb temperature, indoor wet bulb temperature, and the ventilation rate.
 - e. Take a survey of lighting, internal equipment, appliances and processes.

Basic Heat Loss Formulas:

- (1) $H_c = AU(t-t_o)$
 - indoor temperature less outdoor temperature in °F
 - overall coefficient of heat transmission in Btuh/ft²/°F
 - area of wall, glass or roof surface in ft²
- (2) $H_e = FP(t-t_o)$
 - see formula number 1
 - perimeter of floor slab in feet
 - edge loss factor: 0.81 for no edge insulation, 0.55 for edge insulation
- (3) $H_i = 0.18q(t-t_o)$
 - see formula number 1
 - total infiltration airflow volume in cubic feet per hour (cfh)
- (4) $H_2 = FA$
 - floor slab (or basement wall) area in ft²
 - conduction loss factor: 2 for floor slabs, 4 for basement walls
- (5) $H.L. = H_c = H_e + H_i + H_s$
 - total heat loss in Btuh

FIGURE 201-15

- f. Determine time of day, day of month, and month of year for heat gain calculations.
 - g. Determine the occupancy load of the building.
- 2. Determine instantaneous heat gain calculations.
 - a. Determine solar heat gain through glass, roofs and exterior walls.
 - b. Locate interior partitions, ceilings and floors.
 - c. Determine heat sources within the conditioned space.
 - d. Establish infiltration and/or ventilation rates.
 - e. Determine other loads.
- 3. Calculate total cooling load.

Specific methods in making calculations are discussed in the following pages. For more information refer to ASHRAE Handbook of Fundamentals.

B. Calculating Heat Gains

The total cooling load depends on the heat gains from various different sources. To determine total load, therefore, you must be able to calculate the amount of heat gain which can be expected from each heat gain source. Bear in mind, however, that total heat gain and total cooling load are not one and the same, due to the fact that peak heat gain from each source never occurs simultaneously.

Total heat gain includes: Conduction heat gain (including solar heat gain through walls, roof, etc.), solar heat gain through glass, heat gain from people, heat gain from electric motors, heat gain from lighting, heat gain from appliances, duct heat gain, and heat gain due to infiltration and/or ventilation. A description of each of these sources and methods to calculate the heat gain involved are discussed below.

1. Conduction Heat Gain: Conduction heat gain occurs in exactly the same manner as conduction heat loss except that the heat flows into the building instead of out of the building due to higher temperatures on the outside. Unlike conduction heat losses, however, there is also a solar heat gain factor which also must be considered in conduction of heat gain. Conduction heat gains must be determined in two steps.

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		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%		
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	5	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	170r	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
Texarkana 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
Bartow 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	75	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

^aTable 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.

^bLatitude, for use in calculating solar loads, and longitude are given to 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'.

^cElevations 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 the sensor.

^dPercentage of winter design data shows the percent of the 3-month period, December through February.

^ePercentage of summer design data shows the percent of 4-month period, June through September.

Table 201-101¹²

CLIMATIC CONDITIONS FOR THE UNITED STATES^a

CLIMATIC CONDITIONS FOR THE UNITED STATES															
Col. 1 State and Station	Col. 2 Lat- tude ^b	Col. 3 Longi- tude ^b	Col. 4 Eleva- tion ^c	Winter ^d				Summer ^e				Col. 8			
				Col. 5		Col. 6		Col. 7							
				Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb		Mean Daily		Design Wet-Bulb					
				99%	97.5%	1%	2.5%	5%	Range	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	47	44	87/69	80/60	78/68	13	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															
Springs 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	-5	1	93/59	91/59	89/59	28	64	63	62	
Durango	37	1	107	5	6530	-6	-1	99/59	87/59	85/59	30	64	63	62	

Table 201-10 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 ^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					
				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	88/75	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	79
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 201-10 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 ^b	Col. 4 Elevation ^c ft	Winter ^d		Summer ^e			Col. 8					
				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%	
La Grange	33	0	85	0	715	19	23	94/76	91/75	89/74	21	78	77	76
Macon AP	32	4	83	4	356	21	25	96/77	93/76	91/75	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 ^e	-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
Dixon	41	5	89	3	696	-7	-2	93/75	90/74	88/73	23	78	77	75
Elgin	42	0	88	2	820	-7	-2	91/75	88/74	86/73	21	78	77	75
Freeport	42	2	89	4	780	-9	-4	91/74	89/73	87/72	24	77	76	74
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 201-10 continued

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Lat- itude ^b	Col. 3 Long- itude ^c	Col. 4 Eleva- tion ^c ft	Winter ^d			Summer ^e							
				Col. 5		Design Dry-Bulb 99% 97.5%	Col. 6			Col. 7 Mean Daily Range	Col. 8			
				Design Dry-Bulb	Design Dry-Bulb and Mean Coincident Wet-Bulb		Design Wet-Bulb							
					1%			2.5%	5%		1%	2.5%	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	948	-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	78	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	27	31	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
Monroe 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 201-10 continued

CLIMATIC CONDITIONS FOR THE UNITED STATES*

CLIMATIC CONDITIONS FOR THE UNITED STATES														
Col. 1 State and Station	Col. 2 Lat- tude ^a	Col. 3 Long- tude ^c	Col. 4 Eleva- tion ^d ft	Winter ^d			Summer ^d			Col. 7 Mean Daily Range	Col. 8			
				Col. 5		Design Dry-Bulb Mean Coincident Wet-Bulb	Col. 6		Design Wet-Bulb 1% 2.5% 5%					
				Design Dry-Bulb	99% 97.5%		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	91/73	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	91/73	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	91/73	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	3	689	-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	23	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														
Ste. 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	-16	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 201-10 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 ^c	Col. 4 Elevation ^d 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,														
Keester 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	93/77	93/77	91/76	22	80	79	78
Greenville AFB	33	3	91	1	139	15	20	93/77	93/77	91/76	21	80	79	78
Greenwood	33	3	90	1	128	15	20	93/77	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	38	4	90	2	465	3	8	98/75	94/75	91/74	18	78	77	76
Sedalia,														
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	5526r	-24	-17	86/58	83/56	80/56	35	60	58	57
Cut Bank AP	48	4	112	2	3838r	-25	-20	88/61	85/61	82/60	35	64	62	61
Glasgow AP (S)	48	1	106	4	2377	-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	3664r	-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 201-10 continued

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^c	Col. 4 Elevation ^e Fe	Winter ^d				Summer ^d				Col. 8			
				Col. 5		Col. 6		Col. 7							
				Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb		Mean Daily		Design Wet-Bulb					
				99%	97.5%	1%	2.5%	5%	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	4673	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,	43	0	71	3	253	-8	-3	91/72	88/71	85/70	24	75	74	72	
Grenier AFB															
Portsmouth,	43	1	70	5	127	-2	2	89/73	85/71	83/70	22	75	74	72	
Pease AFB															
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,	32	5	106	1	4070	14	19	98/64	96/64	94/64	30	69	68	67	
Holloman AFB															
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	
Gallop	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	63	64	63	
Roswell,	33	2	104	3	3643	13	18	100/66	98/66	96/66	33	71	70	69	
Walker AFB															
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 201-10 continued

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 ^a		Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb			Summer ^a		Col. 8 Design Wet-Bulb								
				Col. 5		1%	2.5%	5%	Col. 7 Mean Daily Range	1%	2.5%	5%							
				Design Dry-Bulb															
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	73	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					
Niagara 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					
Oncota	42	3	75	0	1150	-7	-4	86/71	83/69	80/68	24	73	72	70					
Oswego CO	43	3	76	3	300	1	7	86/73	83/71	80/70	20	75	73	72					
Plattsburg 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	73	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					
Goldboro, 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	3	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	23	71	69	68					
Fargo AP	46	5	96	5	900	-22	-18	92/73	89/71	85/69	25	76	74	72					
Grand 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					
Ashland	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 201-10 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		Col. 6			Summer ^d		Col. 8			
				Design Dry-Bulb	Mean Coincident Wet-Bulb	Design Dry-Bulb and Mean Coincident Wet-Bulb		Mean Daily Range	Design Wet-Bulb		%			
						1%	2.5%		1%	2.5%				
Chillicothe	39	2	83	0	638	0	6	95/75	92/74	90/73	22	78	76	74
Cincinnati CO	39	1	84	4	761	1	6	92/73	90/72	88/72	21	77	75	74
Cleveland AP (S)	41	2	81	5	777	1	5	91/73	88/72	86/71	22	76	74	73
Columbus AP (S)	40	0	82	5	812	0	5	92/73	90/73	87/72	24	77	75	74
Dayton AP	39	5	84	1	997	-1	4	91/73	89/72	86/71	20	76	73	73
Defiance	41	2	84	2	700	-1	4	94/74	91/73	88/72	24	77	76	74
Findlay AP	41	0	83	4	797	2	3	92/74	90/73	87/72	24	77	76	74
Fremont	41	2	83	1	600	-3	1	90/73	88/73	85/71	24	76	75	73
Hamilton	39	2	84	3	650	0	5	92/73	90/72	87/71	22	76	73	73
Lancaster	39	4	82	4	920	0	5	93/74	91/73	88/72	23	77	75	74
Lima	40	4	84	0	860	-1	4	94/74	91/73	88/72	24	77	76	74
Mansfield AP	40	5	82	3	1297	0	5	90/73	87/72	85/72	22	76	74	73
Marion	40	4	83	1	920	0	5	93/74	91/73	88/72	23	77	76	74
Middletown	39	3	84	3	635	0	5	92/73	90/72	87/71	22	76	73	73
Newark	40	1	82	3	825	-1	5	94/73	92/73	89/72	23	77	75	74
Norwalk	41	1	82	4	720	-3	1	90/73	88/73	85/71	22	76	75	73
Portsmouth	38	5	83	0	530	5	10	95/76	92/74	89/73	22	78	77	75
Sandusky CO	41	3	82	4	606	1	6	93/73	91/72	88/71	21	76	74	73
Springfield	40	0	83	5	1020	-1	3	91/74	89/73	87/72	21	77	76	74
Steubenville	40	2	80	4	992	1	5	89/72	86/71	84/70	22	74	73	72
Toledo AP	41	4	83	5	676	-3	1	90/73	88/73	85/71	25	76	75	73
Warren	41	2	80	5	900	0	5	89/71	87/71	85/70	23	74	73	71
Wooster	40	5	82	0	1030	1	6	89/72	86/71	84/70	22	75	73	72
Youngstown AP	41	2	80	4	1178	-1	4	88/71	86/71	84/70	23	74	73	71
Zanesville AP	40	0	81	5	881	1	7	93/75	90/74	87/73	23	78	76	75
OKLAHOMA														
Ada	34	5	96	4	1015	10	14	100/74	97/74	95/74	23	77	76	75
Altus AFB	34	4	99	2	1390	11	16	102/73	100/73	98/73	25	77	76	75
Ardmore	34	2	97	1	880	13	17	100/74	98/74	95/74	23	77	77	76
Bartlesville	36	5	96	0	715	6	10	101/73	98/74	95/74	23	77	77	76
Chickasha	35	0	98	0	1085	10	14	101/74	98/74	95/74	24	78	77	76
Enid-Vance AFB	36	2	98	0	1287	9	13	103/74	100/74	97/74	24	79	77	76
Lawton AP	34	3	98	2	1108	12	16	101/74	99/74	96/74	24	78	77	76
McAlester	34	5	95	5	760	14	19	99/74	96/74	93/74	23	77	76	75
Muskogee AP	35	4	95	2	610	10	15	101/74	98/75	95/75	23	79	78	77
Norman	35	1	97	3	1109	9	13	99/74	96/74	94/74	24	77	76	75
Oklahoma City AP (S)	35	2	97	4	1280	9	13	100/74	97/74	95/73	23	78	77	76
Poncha Chy	36	4	91	0	994	5	9	100/74	97/74	94/74	24	77	76	75
Seminole	35	2	96	4	865	11	15	99/74	96/74	94/73	23	77	76	75
Stillwater (S)	36	1	97	1	884	8	13	100/74	96/74	93/74	24	77	76	75
Tulsa AP	36	1	95	5	650	8	13	101/74	98/75	95/75	22	79	78	77
Woodward	36	3	99	3	1900	6	10	100/73	97/73	94/73	26	78	76	75
OREGON														
Albany	44	4	123	1	224	18	22	92/67	89/66	86/65	31	69	67	66
Astoria AP (S)	46	1	123	5	8	25	29	75/65	71/62	68/61	16	65	63	62
Baker AP	44	5	117	5	3368	-1	6	92/63	89/61	86/60	30	65	63	61
Bend	44	0	121	2	3599	-3	4	90/62	87/60	84/59	33	64	62	60
Corvallis (S)	44	3	123	2	221	18	22	92/67	89/66	86/65	31	69	67	66
Eugene AP	44	1	123	1	364	17	22	92/67	89/66	86/65	31	69	67	66
Grants Pass	42	3	123	2	925	20	24	99/69	96/68	93/67	33	71	69	68
Klamath Falls AP	42	1	121	4	4091	4	9	90/61	87/60	84/59	36	63	61	60
Medford AP (S)	42	2	122	5	1298	19	23	98/68	94/67	91/66	35	70	68	67
Pendleton AP	45	4	118	5	1492	-2	5	97/65	93/64	90/62	29	66	63	63
Portland AP	45	4	122	4	21	17	23	89/68	85/67	81/65	23	69	67	66
Portland CO	45	3	122	4	57	18	24	90/68	86/67	82/65	21	69	67	66
Roseburg AP	43	1	123	2	505	18	23	93/67	90/66	87/65	30	69	67	66
Salem AP	45	0	123	0	195	18	23	92/68	88/66	84/65	31	69	68	66
The Dalles	45	4	121	1	102	13	19	93/69	89/68	85/66	28	70	68	67
PENNSYLVANIA														
Allentown AP	40	4	75	3	376	4	9	92/73	88/72	86/72	22	76	75	73
Altoona CO	40	2	78	2	1468	0	5	90/72	87/71	84/70	23	74	73	72
Butler	40	4	80	0	1100	1	6	90/73	87/72	85/71	22	75	74	73
Chambersburg	40	0	77	4	640	4	8	93/75	90/74	87/73	23	77	76	74
Eric AP	42	1	80	1	732	4	9	88/73	85/72	83/71	18	75	74	72
Harrisburg AP	40	1	76	5	335	7	11	94/75	91/74	88/73	21	77	76	75
Johnstown	40	2	78	5	1214	-3	2	86/70	83/70	80/68	23	72	71	70
Lancaster	40	1	76	2	255	4	8	93/75	90/74	87/73	22	77	76	75
Meadville	41	4	80	-1	1065	0	4	88/71	85/70	83/69	21	73	72	71
New Castle	41	0	80	2	825	2	7	91/73	88/72	86/71	23	75	74	73

Table 201-10 continued

CLIMATIC CONDITIONS FOR THE UNITED STATES*

CLIMATIC CONDITIONS FOR THE UNITED STATES														
Col. 1 State and Station	Col. 2 Lat- tude ^a	Col. 3 Long- tude ^a	Col. 4 Eleva- tion ^b Ft	Winter ^d		Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb			Summer ^e		Col. 8			
				Col. 5 Design Dry-Bulb 92% 97.5%	1%	2.5%	5%	Col. 7 Mean Daily Range	15%	2.5%	5%			
Philadelphia AP	39	5	75	2	7	10	14	93/75	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	73	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	25	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	93/73	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	89/65	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	79
Beaumont	30	0	94	0	18	27	31	95/79	93/78	91/78	19	81	80	80
Beville	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	2537	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	79
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	78

Table 201-10 continued

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Lat- itude ^b	Col. 3 Longi- tude ^c	Col. 4 Eleva- tion ^a Ft.	Winter ^d		Summer ^e			Col. 7 Mean Daily Range	Col. 8				
				Col. 5		Col. 6				Col. 8				
				Design Dry-Bulb	Mean Coincident Wet-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%		
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	5	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	544r	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
Harlingen	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	158r	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	2815r	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	3	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	63	63	62
Logan	41	4	111	5	4775	-3	2	93/62	91/61	88/60	33	63	63	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 201-10 continued

CLIMATIC CONDITIONS FOR THE UNITED STATES*

Col. 1 State and Station	Col. 2 Latitude ^b	Col. 3 Longitude ^a	Col. 4 Elevation ^c Ft	Winter ^d		Col. 6 Design Dry-Bulb and Mean Coincident Wet-Bulb			Summer ^e		Col. 8 Design Wet-Bulb			
				Col. 5					Col. 7					
				99%	97.5%	1%	2.5%	5%	Mean Daily Range	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	65	63
Everett-														
Paine AFB	47	5	122	2	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
Charlottesville	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
Marquette	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	22	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	5319	-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	5090	-19	-13	89/60	86/60	83/59	32	64	63	61
Evanson	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	3	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 201-10 continued

CLIMATIC CONDITIONS FOR CANADA

CLIMATIC CONDITIONS FOR CANADA														
Col. 1 Province and Station ^a	Col. 2 Latitude ^c	Col. 3 Longitude ^c	Col. 4 Elevation ^d Ft	WINTER ^f				SUMMER ^f						
				Col. 5		Col. 6		Col. 7	Col. 8					
				Design Dry-Bulb 99% 97.5%		Design Dry Bulb and Mean Coincident Wet-Bulb 1% 2.5% 5%	Mean Daily Range	Design Wet Bulb 1% 2.5% 5%						
ALBERTA														
Calgary AP	51	6	114	1	3540	-27	-23	84/63	81/61	79/60	25	65	63	62
Edmonton AP	53	34	113	31	2219	-29	-25	85/66	82/65	79/63	23	68	66	65
Grande Prairie AP	55	11	118	53	2190	-39	-33	83/64	80/63	78/61	23	66	64	62
Jasper	52	53	118	4	3480	-31	-26	83/64	80/62	77/61	28	66	64	63
Lethbridge AP (S)	49	38	112	48	3018	-27	-22	90/65	87/64	84/63	28	68	66	65
McMurray AP	56	39	111	13	1216	-41	-38	86/67	82/65	79/64	26	69	67	65
Medicine Hat AP	50	1	110	43	2365	-29	-24	93/66	90/65	87/64	28	70	68	66
Red Deer AP	52	11	113	54	2965	-31	-26	84/65	81/64	78/62	25	67	66	64
BRITISH COLUMBIA														
Dawson Creek	55	44	120	11	2164	-37	-33	82/64	79/63	76/61	26	66	64	62
Fort Nelson AP (S)	58	50	122	35	1230	-43	-40	84/64	81/63	78/62	23	67	65	64
Kamloops CO	50	43	120	25	1133	-21	-15	94/66	91/65	88/64	29	68	66	65
Nanaimo (S)	49	11	123	58	230	16	20	83/67	80/65	77/64	21	68	66	65
New Westminster	49	13	122	54	50	14	18	84/68	81/67	78/66	19	69	68	66
Penticton AP	49	28	119	36	1121	0	4	92/68	89/67	87/66	31	70	68	67
Prince George AP(S)	53	53	122	41	2218	-33	-28	84/64	80/62	77/61	26	66	64	62
Prince Rupert CO	54	17	130	23	170	-2	2	64/59	63/57	61/56	12	60	58	57
Trail	49	8	117	44	1400	-5	0	92/66	89/65	86/64	33	68	67	65
Vancouver AP (S)	49	11	123	10	16	15	19	79/67	77/66	74/65	17	68	67	66
Victoria CO	48	25	123	19	228	20	23	77/64	73/62	70/60	16	64	62	60
MANITOBA														
Brandon	49	52	99	59	1200	-30	-27	89/72	86/70	83/68	25	74	72	70
Churchill AP (S)	58	45	94	4	155	-41	-39	81/66	77/64	74/62	18	67	65	63
Dauphin AP	51	6	100	3	999	-31	-28	87/71	84/70	81/68	23	74	72	70
Flin Flon	54	46	101	51	1098	-41	-37	84/68	81/66	79/65	19	70	68	67
Portage la Prairie AP	49	54	98	16	867	-28	-24	88/73	86/72	83/70	22	76	74	71
The Pas AP (S)	53	58	101	6	894	-37	-33	85/68	82/67	79/66	20	71	69	68
Winnipeg AP (S)	49	54	97	14	786	-30	-27	89/73	86/71	84/70	22	75	73	71
NEW BRUNSWICK														
Campbellton CO	48	0	66	40	25	-18	-14	85/68	82/67	79/66	21	72	70	68
Chatham AP	47	1	65	27	112	-15	-10	89/69	85/68	82/67	22	72	71	69
Edmundston CO	47	22	68	20	500	-21	-16	87/70	83/68	80/67	21	73	71	69
Fredericton AP (S)	45	53	66	32	74	-16	-11	89/71	85/69	82/68	23	73	71	70
Moncton AP (S)	46	7	64	41	248	-12	-8	85/70	82/69	79/67	23	72	71	69
Saint John AP	45	19	65	53	352	-12	-8	80/67	77/65	75/64	19	70	68	66
NEWFOUNDLAND														
Corner Brook	48	58	57	57	15	-5	0	76/64	73/63	71/62	17	67	66	65
Gander AP	48	57	54	34	482	-5	-1	82/66	79/65	77/64	19	69	67	66
Goose Bay AP (S)	53	19	60	25	144	-27	-24	85/66	81/64	77/63	19	68	66	64
St. John's AP (S)	47	37	52	45	463	-3	7	77/66	75/65	73/64	18	69	67	66
St. John's AP (S)	48	32	58	33	44	-3	4	76/65	74/64	71/63	14	67	66	65
NORTHWEST TERR.														
Fort Smith AP (S)	60	1	111	58	665	-49	-45	85/66	81/64	78/63	24	68	66	65
Frobisher AP (S)	63	45	68	33	68	-43	-41	66/53	63/51	59/50	14	54	52	51
Inuvik (S)	68	18	133	29	200	-56	-53	79/62	77/60	75/59	21	64	62	61
Resolute AP (S)	74	43	94	59	209	-50	-47	57/48	54/46	51/45	10	50	48	46
Yellowknife AP	62	28	114	27	682	-49	-46	79/62	77/61	74/60	16	64	63	62
NOVA SCOTIA														
Amherst	45	49	64	13	65	-11	-6	84/69	81/68	79/67	21	72	70	68
Halifax AP (S)	44	39	63	34	83	1	5	79/66	76/65	74/64	16	69	67	66
Kentville (S)	45	3	64	36	40	-3	1	85/69	83/68	80/67	22	72	71	69
New Glasgow	45	37	62	37	317	-9	-5	81/69	79/68	77/67	20	72	70	69
Sydney AP	46	10	60	3	197	-1	3	82/69	80/68	77/66	19	71	70	68
Truro CO	45	22	63	16	131	-8	-5	82/70	80/69	78/68	22	73	71	70
Yarmouth AP	43	50	66	5	136	5	9	74/65	72/64	70/63	15	68	66	65
ONTARIO														
Belleville	44	9	77	24	250	-11	-7	86/73	84/72	82/71	20	75	74	73
Chatham	42	24	82	12	600	0	3	89/74	87/73	85/72	19	76	75	74
Cornwall	45	1	74	45	210	-13	-9	89/73	87/72	84/71	21	75	74	72
Hamilton	43	16	79	54	303	-3	1	88/73	86/72	83/71	21	76	74	73
Kapuskasing AP (S)	49	25	82	28	752	-31	-28	86/70	83/69	80/67	23	72	70	69
Kenora AP	49	48	94	22	1345	-32	-28	84/70	82/69	80/68	19	73	71	70
Kingston	44	16	76	30	300	-11	-7	87/73	84/72	82/71	20	75	74	73

Table 201-10 continued

CLIMATIC CONDITIONS FOR CANADA

Col. 1 Province and Station ^a	Col. 2 Lat- tude ^c	Col. 3 Longi- tude ^c	Col. 4 Eleva- tion ^d ft	WINTER ^e		SUMMER ^f								
				Col. 5		Col. 6			Col. 7		Col. 8			
				Design Dry-Bulb	Mean Colocident Wet-Bulb	Design Dry Bulb and	Mean Colocident Wet-Bulb	Mean	Daily	Range	Design Wet Bulb			
				99%	97.5%	1%	2.5%	5%			1%	2.5%	5%	
Kitchener	43	26	80	30	1125	- 6	- 2	88/73	85/72	83/71	23	75	74	72
London AP	43	2	81	9	912	- 4	0	87/74	85/73	83/72	21	76	74	73
North Bay AP	46	22	79	25	1210	-22	-18	84/68	81/67	79/66	20	71	70	68
Oshawa	43	54	78	52	370	- 6	- 3	88/73	86/72	84/71	20	75	74	73
Ottawa AP (S)	45	19	75	40	413	-17	-13	90/72	87/71	84/70	21	75	73	72
Owen Sound	44	34	80	55	597	- 6	- 2	84/71	82/70	80/69	21	73	72	70
Peterborough	44	17	78	19	635	-13	- 9	87/72	85/71	83/70	21	75	73	72
St. Catharines	43	11	79	14	325	- 1	3	87/73	85/72	83/71	20	76	74	73
Sarnia	42	58	82	22	625	0	3	88/73	86/72	84/71	19	76	74	73
Sault Ste. Marie AP	46	32	84	30	675	-17	-13	85/71	82/69	79/68	22	73	71	70
Sudbury AP	46	37	80	48	1121	-22	-19	86/69	83/67	81/66	22	72	70	68
Thunder Bay AP	48	22	89	19	644	-27	-24	85/70	83/68	80/67	24	72	70	68
Timmins AP	48	34	81	22	965	-33	-29	87/69	84/68	81/66	25	72	70	68
Toronto AP (S)	43	41	79	38	578	- 5	- 1	90/73	87/72	85/71	20	75	74	73
Windsor AP	42	16	82	58	637	0	4	90/74	88/73	86/72	20	77	75	74
PRINCE EDWARD ISLAND														
Charlottetown AP (S)	46	17	63	8	186	- 7	- 4	80/69	78/68	76/67	16	71	70	68
Summerside AP	46	26	63	50	78	- 8	- 4	81/69	79/68	77/67	16	72	70	68
QUEBEC														
Baguville AP	48	20	71	0	536	-28	-23	87/70	83/68	80/67	21	72	70	68
Chicoutimi	48	25	71	5	150	-26	-22	86/70	83/68	80/67	20	72	70	68
Drummondville	45	53	72	29	270	-18	-14	88/72	85/71	82/69	21	75	73	71
Granby	45	23	72	42	550	-19	-14	88/72	85/71	83/70	21	75	73	72
Hull	45	26	75	44	200	-18	-14	90/72	87/71	84/70	21	75	73	72
Mégantic AP	45	35	70	52	1362	-20	-16	86/71	83/70	81/69	20	74	72	71
Montréal AP (S)	45	28	73	45	98	-16	-10	88/73	85/72	83/71	17	75	74	72
Québec AP	46	48	71	23	245	-19	-14	87/72	84/70	81/68	20	74	72	70
Rimouski	48	27	68	32	117	-16	-12	83/68	79/66	76/65	18	71	69	67
St. Jean	45	18	73	16	129	-15	-11	88/73	86/72	84/71	20	75	74	72
St. Jérôme	45	48	74	1	556	-17	-13	88/72	86/71	83/70	23	75	73	72
Sept. Îles AP (S)	50	13	66	16	190	-26	-21	76/63	73/61	70/60	17	67	65	63
Shawinigan	46	34	72	43	306	-18	-14	86/72	84/70	82/69	21	74	72	71
Sherbrooke CO	45	24	71	54	595	-25	-21	86/72	84/71	81/69	20	74	73	71
Thetford Mines	46	4	71	19	1020	-19	-14	87/71	84/70	81/69	21	74	72	71
Trois Rivières	46	21	72	35	50	-17	-13	88/72	85/70	82/69	23	74	72	71
Val d'Or AP	48	3	77	47	1108	-32	-27	85/70	83/68	80/67	22	72	70	68
Valleyfield	45	16	74	6	150	-14	-10	89/73	86/72	84/71	20	75	74	72
SASKATCHEWAN														
Estevan AP	49	4	103	0	1884	-30	-25	92/70	89/68	86/67	26	72	70	69
Moose Jaw AP	50	20	105	33	1857	-29	-25	93/69	89/67	86/66	27	71	69	68
North Battleford AP	52	46	108	15	1796	-33	-30	88/67	82/66	82/65	23	69	68	66
Prince Albert AP	53	13	105	41	1414	-42	-35	87/67	84/66	81/65	25	70	68	67
Regina AP	50	26	104	40	1884	-33	-29	91/69	88/68	84/67	26	72	70	68
Saskatoon AP (S)	52	10	106	41	1645	-35	-31	89/68	86/66	83/65	26	70	68	67
Swift Current (AP) (S)	50	17	107	41	2677	-28	-25	93/68	90/66	87/65	25	70	69	67
Yorkton AP	51	16	102	28	1653	-35	-30	87/69	84/68	80/66	23	72	70	68
YUKON TERRITORY														
Whitehorse AP (S)	60	43	135	4	2289	-46	-43	80/59	77/58	74/56	22	61	59	58

^a Table 2 was prepared by ASHRAE Technical Committee 4.2 using data compiled from official weather stations where hourly weather observations are made by trained observers.

^b When airport temperature observations were used to develop design data, "AP" follows the station name. Data for stations followed by "CO" come from office locations within an urban area and generally reflect an influence of the surroundings area. Stations without designation can be considered semirural and can be directly compared to most airport data.

^c Latitude, for use in calculating solar loads, and longitude are given to the nearest minute.

^d Elevations are ground elevations for each station as of 1964. Temperature readings are generally made at an elevation of 5 ft above ground.

^e The winter design data are based on the month of January only.

^f The summer design data are based on the month of July only. See also Ref 7.

Table 201-10 continued

The first computation for conduction heat gain is the same as heat loss using the formula:

$$Q = U \times A \times TD, \text{ where}$$

Q = sensible heat gain in Btu's per hour

A = area

U = overall coefficient of heat transmission

TD = temperature difference of the two spaces separated

The solar heat gain factor occurs due to additional radiated heat that will flow through the walls, roof and glass areas when the sun's rays fall directly upon these surfaces.

To accurately calculate the cooling load, therefore, one must properly account for the heat gain from direct exposure to the sun. Obviously, some areas of the building will experience more solar heat gains than others, depending on the orientation of the building, time of day, etc. In addition, remember that there usually is a three-hour time lag in normal building structures for heat to travel from outer to inner wall surfaces.

The greatest solar gains occur on the east and west building surfaces. The amount of heat transferred depends primarily upon:

- a. the color and smoothness of the surface, and
- b. the angle at which the rays strike the surface.

A dark-colored wall or roof surface will absorb and conduct more radiant heat than a similar surface of lighter color. For heat gain calculation purposes, exterior colors usually are designated as light and dark.

The angle at which the sun's rays impinge upon opaque surfaces influences heat gain. If they impinge at a 90° angle, they have less chance of being reflected than if they strike the surface from some other angle. If this energy is not reflected it increases the surface temperature. The angle at which rays impinge upon the surface of a building depends upon the latitude, season of the year, and the time of day. Due to rotation of the Earth, this angle changes continuously. As a result, the surface temperatures of the exposed walls and roof are changing continuously throughout the day.

By knowing the latitude, orientation, and color, one can calculate the correct heat gain through walls and roof. Instead

of using the original equation,

$$Q = A \times U \times TD,$$

it is adjusted to read as follows:

$$Q = A \times U \times ETD.$$

Note that TD has been changed to ETD, which stands for "Equivalent Temperature Difference". This factor takes into account the difference between outside and interior surface temperature and also considers the effect of direct solar radiation and the heat transmission from the wall to the room air by radiation, convection and conduction.

Tables 201-11 and 201-12 give the total equivalent temperature differentials for calculating heat gains through constructions at various times of day for roofs and walls respectively. Instructions on the application and correction of the values also are provided. Descriptions of wall constructions for ETD calculation are listed in Table 201-13.

Problem: Determine the ETD for a dark wall constructed of 4" face brick and 8" common brick facing west at 4:00 PM north latitude.

Solution: Refer to Table 201-13. Identify group code of this construction, which is H. Then refer to Table 201-12 and data referring to the H group. Locate west ("W") for the north latitude wall facing and read right to the "D" (Dark) section of the "4PM" column. The ETD of the wall is 18F.

Problem: Assume that the wall referenced above is 20' high by 60' long. Determine the heat gain through this wall at 4:00 P.M.

Solution: To do this, first determine the U value from Table 201-13 for the specified wall construction (Group H, 4" face brick plus 8" common brick) as 0.280. Using the equation discussed earlier, calculate heat gain:

$$\begin{aligned} Q &= U \times A \times ETD \\ &= 0.28 \times (20 \times 60) \times 18 \\ &= 0.28 \times (1,200) \times 18 \\ &= 5.04 (1,200) \\ &= 6,048 \text{ Btu/hr} \end{aligned}$$

CAUTION: Be careful about the units used. Area must always be in square feet.

Cooling Load Temperature Differences for Calculating Cooling Load from Flat Roofs

Roof No	Description of Construction	Weight lb./sq. ft.	U-value Btu/(h ft ² ·°F)	Solar Time, hr																			Hour of Max. Min. Difference									
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	CLTD	CLTD	CLTD	CLTD	
Without Suspended Ceiling																																
1	Steel sheet with 1-in. (for 2-in.) insulation	7 (8)	0.213 (0.134)	1	-2	-3	-3	-5	-3	6	19	34	49	61	71	78	79	77	70	59	45	31	18	12	0	5	3	14	-5	79	84	
2	1-in. wood with 1-in. insulation	8	0.170	6	3	0	-1	-3	-3	-4	14	27	39	52	62	70	74	70	62	51	38	25	14	9	16	-3	-4	74	74	77		
3	4-in. l.w. concrete	18	0.213	9	5	2	0	-2	-3	-4	1	9	20	32	44	53	64	70	73	71	66	57	44	34	25	18	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	24	0.158	22	17	13	9	6	3	1	3	7	15	23	33	43	51	58	62	64	62	57	50	42	33	25	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	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	7	9	13	25	33	39	46	50	53	54	53	49	45	40	30	7	54	47		
9	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	52 (32)	0.200 (0.120)	35	32	28	19	15	12	9	8	8	10	14	20	26	33	40	46	50	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	34	31	28	25	22	19	16	14	13	13	15	18	22	26	31	36	40	44	45	46	45	43	40	37	20	13	46	33	
12	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	75 (75)	0.192 (0.117)	31	28	25	22	30	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 (18)	0.106 (0.078)	38	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 (10)	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	79	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	55	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	4	19	29	39	48	56	62	65	64	61	54	46	38	30	24	17	0	65	65	63		
4	2-in. h.w. concrete with 1-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	29	20	16	13	10	7	5	3	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	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	15	16	18	21	25	30	34	38	41	43	44	44	42	40	37	21	15	44	29	
8	8-in. l.w. concrete	33	0.093	39	36	33	29	26	23	20	18	15	15	14	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	54 (54)	0.128 (0.090)	30	29	27	26	24	22	21	20	20	22	22	24	27	29	32	34	36	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	18	20	22	25	28	32	35	38	40	41	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	22	23	25	26	28	29	31	32	33	33	33	33	32	32	22	22	33	11	
12	4-in. h.w. concrete with 1-in. (for 2-in.) insulation	77 (77)	0.125 (0.088)	29	28	27	26	25	24	23	22	21	21	22	23	25	26	28	30	32	33	34	34	34	34	33	32	31	20	21	34	13
13	4-in. wood with 1-in (for 2-in.) insulation	19 (20)	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	

APPENDIX: TMM values may be used for all normal air-conditioning estimates; usually without correction (except as noted below) in latitude 0° to 30° North or South when the load is calculated for the hottest weather.

2 Correction: 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 (11-34 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 Attics 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.

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

Table 201-11¹²

Cooling Load Temperature Differences for Calculating Cooling Load from Sunlit Walls

		Solar Time, hr																								Hr of Max- imum	Max- imum	Max- imum	Differ- ence	
North Latitude Wall Facing		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	CLTD	CLTD	CLTD	CLTD	
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	17	18	18	19	19	20	20	20	22	15	20	5			
E	24	24	23	23	22	21	20	20	19	18	18	18	18	19	20	21	22	23	24	24	24	24	24	22	18	24	6			
SE	26	26	25	25	24	23	22	21	20	19	18	18	19	20	21	22	23	24	24	24	24	24	24	22	18	24	6			
S	28	28	27	27	26	25	24	23	22	21	20	19	18	18	19	20	21	22	23	23	23	23	23	23	20	24	6			
SW	25	25	25	24	24	23	22	21	20	19	18	17	17	17	18	19	20	22	23	24	24	25	25	24	17	25	8			
W	27	27	26	26	25	24	23	22	21	20	19	18	18	18	18	19	20	22	23	23	23	23	23	26	1	18	27	9		
NW	23	23	23	23	22	21	20	19	18	17	16	16	15	14	14	14	15	15	16	17	18	19	20	21	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	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	15	9			
E	23	22	21	20	19	18	17	16	15	15	16	17	18	19	20	21	22	23	24	25	26	27	26	25	20	15	27	12		
SE	23	22	21	20	19	18	17	16	15	14	14	15	16	17	18	19	20	21	22	23	24	25	26	25	24	21	26	12		
S	21	20	19	18	17	16	15	14	13	12	11	11	11	12	13	14	15	17	19	20	21	22	22	22	21	20	22	11		
SW	27	26	25	24	23	22	21	20	19	18	16	15	14	14	15	16	17	20	23	25	27	28	28	28	24	13	28	15		
W	29	28	27	26	25	24	23	22	21	19	18	17	16	15	14	14	15	17	19	22	25	27	29	29	24	14	30	16		
NW	25	24	23	23	22	21	20	19	18	17	15	14	13	12	12	13	14	15	17	19	21	22	23	23	24	11	23	9		
Group C Walls																														
N	13	14	13	12	11	10	9	8	8	7	7	7	7	8	9	10	12	13	14	15	16	17	17	17	16	22	7	17	10	
NE	19	17	16	15	14	13	12	11	10	10	11	12	13	14	15	16	17	18	19	20	21	22	22	21	20	10	23	13		
E	22	21	19	17	15	14	12	11	10	10	11	12	13	14	15	16	17	18	19	20	21	22	23	23	22	12	30	18		
SE	22	21	19	17	15	14	12	11	10	10	11	12	13	14	15	16	17	18	19	20	21	22	23	23	22	12	29	17		
S	21	19	18	16	14	13	12	10	9	9	9	10	11	12	13	14	15	17	19	20	21	22	23	23	22	9	26	17		
SW	29	27	25	23	20	18	15	13	12	11	11	11	11	12	13	14	15	18	22	26	29	32	33	33	32	31	22	11	33	22
W	31	29	27	25	22	20	18	16	14	13	12	12	12	13	14	15	16	20	24	29	32	35	35	35	32	32	12	35	23	
NW	25	23	21	20	18	16	14	13	11	10	10	10	10	11	12	13	14	15	18	22	25	27	27	26	22	10	27	17		
Group D Walls																														
N	13	13	12	10	9	7	6	6	6	6	6	6	7	8	9	10	12	13	14	15	17	18	19	19	18	16	21	6	19	13
NE	17	15	13	11	10	8	7	6	6	6	6	6	7	8	9	10	12	13	14	15	17	18	19	19	18	16	21	7	25	18
E	19	17	15	13	11	9	8	8	8	9	10	11	12	13	14	15	17	18	19	20	21	22	22	21	16	8	32	24		
SE	20	17	15	13	11	10	8	8	8	8	9	10	11	12	13	14	15	17	18	19	20	21	22	22	21	16	8	32	24	
S	19	17	15	13	11	9	8	8	8	8	9	10	11	12	13	14	15	17	18	19	20	21	22	22	21	16	8	32	24	
SW	26	23	22	19	16	14	12	10	9	8	8	8	9	10	11	12	13	14	15	17	18	19	20	21	21	16	8	32	24	
W	31	27	26	23	18	15	13	11	10	9	9	9	9	10	11	12	13	14	15	17	18	19	20	21	21	16	8	32	24	
NW	23	22	19	17	14	12	10	9	8	7	7	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	2	40	33	
Group E Walls																														
N	12	10	8	7	5	4	3	4	5	6	7	9	11	13	15	17	19	20	21	22	23	20	18	16	14	20	3	22	19	
NE	13	11	9	7	6	4	3	4	5	6	7	9	11	13	15	17	19	20	21	22	23	20	18	16	14	20	3	22	19	
E	14	12	10	8	6	5	4	5	6	7	8	10	12	14	16	18	20	21	22	23	24	21	19	17	15	13	4	26	22	
SE	15	13	10	8	7	5	4	5	6	7	8	10	12	14	16	18	20	21	22	23	24	21	19	17	15	13	4	26	22	
S	15	13	10	8	7	5	4	4	4	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	2	40	33
SW	22	19	15	12	10	8	6	5	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	2	40	33	
W	23	21	17	14	11	9	7	6	5	6	7	8	9	11	13	15	17	19	20	21	22	23	24	21	19	17	3	34	31	
NW	20	17	14	11	9	7	6	5	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	2	40	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	10	1	23	23		
NE	9	7	5	3	2	1	2	4	6	7	9	11	14	17	19	21	22	23	24	23	20	16	13	11	10	1	23	23		
E	10	7	6	4	3	2	3	5	8	10	12	15	18	20	22	23	24	23	20	16	13	11	10	9	8	1	23	23		
SE	10	7	6	4	3	2	3	5	8	10	12	15	18	20	22	23	24	23	20	16	13	11	10	9	8	1	23	23		
S	10	8	6	4	3	2	1	3	7	13	20	27	34	38	39	38	35	31	26	22	18	13	10	8	7	1	39	36		
SW	15	11	9	6	5	3	2	4	9	11	17	26	35	44	49	48	43	37	31	25	20	15	11	8	7	1	43	40		
W	17	13	10	7	5	4	3	4	9	11	17	26	35	44	49	48	43	37	31	25	20	15	11	8	7	1	43	40		
NW	14	10	8	6	4	3	2	3	5	8	10	13	15	23	32	37	35	32	28	23	18	13	10	8	7	1	46	44		
Group G Walls																														
N	3	2	1	0	-1	2	7	8	9	12	15	18	21	23	24	25	26	22	15	11	9	7	5	18	-1	26	27			
NE	3	2	1	0	-1	2	7	8	9	12	15	18	21	23	24	25	26	22	15	11	9	7	5	18	-1	26	27			
E	4	2	1	0	-1	1	11	31	47	54	53	30	40	33	31	30	29	27	34	19	15	12	10	8	6	10	-1	35	36	
SE	4	2	1	0	-1	1	11	31	47	54	53	30	40	33	31	30	29	27	34	19	15	12	10	8	6	10	-1	35	36	
S	5	3	1	1	0	2	5	8	12	16	26	38	50	59	61	60	57	52	43	33	23	15	10	8	6	10	-1	35	36	
SW	6	3	2	1	0	1	2	5	8	11	19	27	41	56	67	72	67	62	49	39	29	15	11	8	7	1	72	71		
W	5	3	2	1	0	2	5	8	11	19	27	41	56	67	72	67	62	49	39	29	15	11	8	7	1	72	71			
NW	3	3	2	1	0	2	5	8	11	19	27	41	56	67	72	67	62	49	39	29	15	11	8	7	1	72	71			

Wall Construction Group Description				
Group No.	Description of Construction	Weight(lb/ft ²)	U-value (Btu/(h·ft ² ·F))	Code Numbers of Layers
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
B	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 201-131²

Heat gain from the roof is calculated in the same manner. The U factors for roofs and ceilings with different construction are calculated and given in Table 201-14. U factors for floors are also given in Table 201-14.

Remember; The time at which the heat gain is calculated for the structure is the hour at which the internal and external heat gain are maximum.

2. Solar Heat Gain Through Glass: Solar heat gains through glass comprise one of the major sources of heat gain in a building. The quantity of gain depends on factors such as latitude, window orientation, time of day and year, amount of haze in atmosphere, type of glass, and shading devices used, most of which have been discussed.

Since solar transmission through glass is practically instantaneous, tables for window and skylights do not allow for any time lag.

When sunlight strikes glazing, all of the solar radiation is either transmitted to the inside, absorbed by the glass or reflected back to the outside. The shading coefficient (SC) of a glazing system is defined as the ratio of the solar heat gain of the glazing compared to the solar heat gain of double-strength sheet glass. It represents a relative ability of any type of glazing to transmit solar heat. The Solar Heat Gain Factor (SHGF) is a term that has been calculated for double-strength sheet glass based on certain orientations to the angle of the sun under given conditions. Therefore, for any other glazing material, once the shading coefficient (SC) is known, the solar heat gain can be determined by multiplying the actual shading coefficient by the solar heat gain factor and the actual area of the glazing material.

The heat gain from glass can be calculated by the use of the following equation:

$$Q = A (SHGF) S.C. + U (TD) A$$

Where A = Area of glass exposed to sun

SHGF = Solar heat gain factor

S.C. = Shading coefficient

U = Heat transmission coefficient

TD = Direct temperature difference between outside and indoor glass surface

HEAT TRANSMISSION FACTORS
(U-values)*

Construction	U-value	
	Summer	Winter
WALLS		
Frame with wood siding, sheathing, and inside finish		
No insulation	.22	.23
R-7 insulation (2 in.-2 1/2 in.)	.09	.09
R-11 insulation (3 in.-3 1/2 in.)	.07	.07
Frame with 4 in. brick or stone veneer, sheathing, and inside finish		
No insulation	.24	.24
R-7 insulation	.09	.09
R-11 insulation	.07	.07
Frame with 1 in. stucco, sheathing, and inside finish		
No insulation	.29	.29
R-7 insulation	.10	.10
R-11 insulation	.07	.07
Masonry:		
8 in. concrete block, no finish	.49	.51
12 in. concrete block, no finish	.45	.47
Masonry (8 in. concrete block):		
Inside finish:		
furred gypsum wallboard (1/2 in.); no insulation	.29	.30
furred, foil-backed gypsum wallboard (1/2 in.); no insulation	.29	.30
1 in. polystyrene insulation board (R-5), and 1/2 in. gypsum wallboard	.13	.13
Masonry (8 in. cinder block or hollow clay tile):		
Inside finish:		
furred gypsum wallboard (1/2 in.); no insulation	.26	.26
furred, foil-backed gypsum wallboard (1/2 in.); no insulation	.17	.17
1 in. polystyrene insulation board (R-5), and 1/2 in. gypsum wallboard	.12	.12
Masonry (4 in. face brick and 8 in. cinder block or 8 in. hollow clay tile):		
Inside finish:		
furred gypsum wallboard (1/2 in.); no insulation	.22	.22
furred, foil-backed gypsum wallboard (1/2 in.); no insulation	.18	.18
1 in. polystyrene insulation board (R-5), and 1/2 in. gypsum wallboard	.12	.12
Masonry (12 in. hollow clay tile or 12 in. cinder block):		
Inside finish:		
furred gypsum wallboard (1/2 in.); no insulation	.24	.24
furred, foil-backed gypsum wallboard (1/2 in.); no insulation	.18	.17
1 in. polystyrene insulation board (R-5), and 1/2 in. gypsum wallboard	.12	.12
Masonry (4 in. face brick, 4 in. common brick):		
Inside finish:		
furred gypsum wallboard (1/2 in.); no insulation	.28	.28
furred, foil-backed gypsum wallboard (1/2 in.); no insulation	.18	.19
1 in. polystyrene insulation board (R-5), and 1/2 in. gypsum wallboard	.13	.13
Masonry (8 in. concrete or 8 in. stone):		
Inside finish:		
furred gypsum wallboard (1/2 in.); no insulation	.33	.34
furred, foil-backed gypsum wallboard (1/2 in.); no insulation	.21	.21
1 in. polystyrene insulation board (R-5), and 1/2 in. gypsum wallboard	.14	.14
Metal with vinyl inside finish, R-7 (3 in. glass fiber batt)	.14	.14

*Btu per hour, sq ft, deg temp difference.

$$\left[\frac{\text{Btu/h}}{(\text{ft}^2) \times (\text{TD, deg F})} \right]$$

Table 201-14¹⁴

Construction	U-value	
	Summer	Winter
PARTITIONS		
Frame (½ in. gypsum wallboard one side only): No insulation	.55	.55
Frame (½ in. gypsum wallboard each side): No insulation	.31	.31
R-11 insulation	.08	.08
Masonry (4 in. cinder block): No insulation, no finish	.40	.40
No insulation, one side furred gypsum wallboard (½ in.)	.28	.28
No insulation, both sides furred gypsum wallboard (½ in.)	.19	.19
One side 1 in. polystyrene insulation board (R-5), and ½ in. gypsum wallboard	.13	.13
CEILING-FLOOR		
Frame (asphalt tile floor, 5/8 in. plywood, 25/32 in. wood subfloor, finished ceiling): Heat flow up	.23	.23
Heat flow down	.20	.19
Concrete (asphalt tile floor, 4 in. concrete deck, air space, finished ceiling): Heat flow up	.34	.33
Heat flow down	.28	.26
ROOF (flat roof, no finished ceiling)		
Steel deck: No insulation	.64	.68
1 in. insulation (R-2.78)	.23	.26
2 in. insulation (R-5.56)	.15	.16
1 in. Wood deck: No insulation	.40	.48
1 in. insulation (R-2.78)	.19	.21
2 in. insulation (R-5.56)	.12	.13
2.5 in. Wood deck: No insulation	.25	.28
1 in. insulation (R-2.78)	.15	.16
2 in. insulation (R-5.56)	.10	.11
4 in. Wood deck: No insulation	.17	.18
1 in. insulation (R-2.78)	.12	.12
2 in. insulation (R-5.56)	.09	.09
ROOF-CEILING (flat roof, finished ceiling)		
Steel deck: No insulation	.33	.40
1 in. insulation (R-2.78)	.17	.19
2 in. insulation (R-5.56)	.12	.13
1 in. Wood deck: No insulation	.26	.29
1 in. insulation (R-2.78)	.15	.16
2 in. insulation (R-5.56)	.11	.11
2.5 in. Wood deck: No insulation	.18	.20
1 in. insulation (R-2.78)	.12	.13
2 in. insulation (R-5.56)	.09	.10
4 in. Wood deck: No insulation	.14	.15
1 in. insulation (R-2.78)	.10	.10
2 in. insulation (R-5.56)	.08	.08
4 in. Light weight concrete deck: No insulation	.14	.15

Table 201-14 continued

Construction	U-value	
	Summer	Winter
ROOF-CEILING (continued)		
6 in. Light weight concrete deck: No insulation	.10	.11
8 in. Light weight concrete deck: No insulation	.08	.09
2 in. Heavy weight concrete deck: No insulation	.32	.38
1 in. insulation (R-2.78)	.17	.19
2 in. insulation (R-5.56)	.11	.12
4 in. Heavy weight concrete deck: No insulation	.30	.36
1 in. insulation (R-2.78)	.16	.18
2 in. insulation (R-5.56)	.11	.12
6 in. Heavy weight concrete deck: No insulation	.28	.33
1 in. insulation (R-2.78)	.16	.17
2 in. insulation (R-5.56)	.11	.12
ROOF-CEILING (wood frame pitched roof, finished ceiling on rafters)		
No insulation	.28	.29
R-19 insulation (5½ in.—6½ in.)	.05	.05
ROOF-ATTIC-CEILING (attic with natural ventilation)		
No insulation	.15	.29
R-19 insulation (5½ in.—6½ in.)	.04	.05
FLOORS		
Concrete slab on grade:		
No insulation	0	50*
1 in. expanded polystyrene board, 2 ft deep or 2 ft wide	0	30*
Floor over unconditioned space, no ceiling		
Wood frame:		
No insulation	.33	.27
R-7 insulation (2 in.—2½ in.)	.09	.08
Concrete deck:		
No insulation	.59	.43
R-7 insulation	.10	.09
DOORS		
Solid wood:		
1 in. thick	.61	.64
1½ in. thick	.47	.49
2 in. thick	.42	.43
Steel:		
1½ in. thick, mineral fiber core	.58	.59
1½ in. thick, polystyrene core	.46	.47
1½ in. thick, urethane foam core	.39	.40

*Btu/h per linear foot of exposed edge.

Table 201-14 continued

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

Date	Solar Time am	Direct Normal Solar Intensity 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		FOR
Jan 21	8	142	5	5	17	73	111	123	133	114	73	22	6	5	5	5	5	14	4	
	9	229	12	12	13	74	154	205	224	209	160	62	13	12	12	12	12	35	3	
	10	274	16	16	16	71	199	241	246	213	146	71	17	16	16	16	16	96	2	
	11	289	19	19	19	20	61	136	222	252	244	198	118	28	19	19	19	124	1	
	12	284	20	20	20	20	21	90	179	254	254	234	179	90	21	20	20	133	12	
	HALF DAY TOTALS	61	61	73	199	452	734	904	932	813	561	273	101	62	61	61	61	354	12	
Feb 21	7	35	2	3	23	40	51	53	47	34	14	2	2	2	2	2	2	4	5	
	8	219	10	11	30	129	183	206	199	160	94	18	10	10	10	10	10	43	4	
	9	271	16	16	22	107	186	234	243	218	157	66	17	16	16	16	16	98	3	
	10	284	21	21	21	49	143	211	246	243	203	129	38	21	21	21	21	143	2	
	11	284	23	23	23	24	71	160	219	244	241	184	103	27	23	23	23	171	1	
	12	287	24	24	24	24	23	86	170	222	241	222	170	86	23	24	24	180	12	
Mar 21	HALF DAY TOTALS	84	84	132	361	648	916	1049	1013	821	508	250	114	63	64	64	64	548	12	
	7	171	9	29	93	140	163	161	133	86	22	8	8	8	8	8	8	26	5	
	8	230	16	18	94	169	218	232	211	177	74	17	16	16	16	16	16	85	4	
	9	282	21	22	47	136	203	238	236	198	128	40	22	21	21	21	21	143	3	
	10	287	25	25	27	72	153	207	229	216	171	193	29	25	25	25	25	186	2	
	11	280	28	28	28	30	78	151	190	213	197	150	77	30	28	28	28	213	1	
Apr 21	12	287	29	29	29	29	31	75	145	194	208	191	145	75	29	29	29	223	12	
	HALF DAY TOTALS	114	129	302	543	832	1053	1087	968	694	403	220	132	114	113	113	113	784	12	
	6	89	11	46	72	87	88	76	52	18	5	5	5	5	5	5	5	11	6	
	7	206	16	71	140	185	201	186	143	75	16	14	14	14	14	14	14	64	5	
	8	252	22	44	128	190	224	223	188	134	41	22	21	21	21	21	21	123	4	
	9	274	27	29	80	153	202	219	203	156	83	29	27	27	27	27	27	177	3	
May 21	10	286	31	31	37	92	153	187	193	170	121	56	32	31	31	31	31	41	217	2
	11	282	33	33	34	36	81	130	166	146	102	52	33	33	33	33	33	243	1	
	12	283	34	34	34	34	36	82	108	142	154	142	108	62	36	34	34	252	12	
	HALF DAY TOTALS	154	283	501	758	957	1051	994	782	488	294	199	127	148	147	147	147	957	12	
	5	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	7	
	6	144	36	90	128	145	141	115	71	18	10	10	10	10	10	10	10	11	6	
Jun 21	7	216	28	102	165	202	209	184	131	54	20	19	19	19	19	19	19	87	5	
	8	250	27	73	149	199	220	208	164	93	29	25	25	25	25	25	25	146	4	
	9	287	31	42	105	164	197	200	173	121	53	32	30	30	30	30	30	195	3	
	10	277	34	36	54	105	148	163	153	123	83	40	35	34	34	34	34	234	2	
	11	283	36	36	38	48	81	113	130	127	105	70	42	38	36	36	36	237	1	
	12	284	37	37	37	38	40	54	82	104	113	104	82	54	40	38	37	265	12	
Jul 21	HALF DAY TOTALS	215	404	666	893	1024	1025	881	601	358	247	200	180	176	173	174	175	1083	12	
	5	22	10	17	21	22	20	14	6	2	1	1	1	1	1	1	1	2	7	
	6	153	48	104	143	159	151	123	70	17	13	13	13	13	13	13	14	40	6	
	7	218	37	113	172	205	207	178	122	46	22	21	21	21	21	21	21	97	5	
	8	266	30	80	156	201	216	199	152	80	29	27	27	27	27	27	27	153	4	
	9	283	33	51	114	166	192	190	161	105	45	33	32	32	32	32	32	201	3	
Aug 21	10	272	35	38	63	109	143	158	148	116	69	39	36	35	35	35	35	238	2	
	11	277	38	39	40	52	81	105	116	110	88	40	41	39	38	38	38	260	1	
	12	279	38	38	38	40	41	52	72	89	95	89	72	52	41	40	38	267	12	
	HALF DAY TOTALS	253	470	754	941	1038	999	818	523	315	236	204	191	188	187	186	186	1126	12	
	5	2	1	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	7	
	6	158	37	89	135	142	137	112	68	18	11	11	11	11	11	11	11	52	6	
Sep 21	7	208	30	102	163	198	204	179	127	53	21	20	20	20	20	20	20	88	5	
	8	241	28	75	148	196	216	203	160	90	30	25	26	26	26	26	26	145	4	
	9	299	32	44	108	163	193	196	170	118	52	33	31	31	31	31	31	194	3	
	10	289	35	37	56	106	146	163	159	129	81	41	36	35	35	35	35	231	2	
	11	273	37	38	40	50	81	111	127	123	102	69	43	39	37	37	37	254	1	
	12	276	38	38	38	40	41	55	85	101	109	101	80	55	41	40	38	262	12	
Oct 21	HALF DAY TOTALS	323	411	666	883	1008	1003	838	584	353	248	204	186	181	180	180	180	1076	12	
	5	12	4	6	6	6	6	6	5	4	3	3	3	3	3	3	3	12	6	
	6	191	17	71	135	177	191	177	135	70	17	16	16	16	16	16	16	62	5	
	7	237	24	47	126	185	216	214	180	118	41	23	23	23	23	23	23	122	4	
	8	280	28	31	62	153	197	212	196	151	80	31	28	28	28	28	28	174	3	
	9	272	32	33	40	93	150	182	187	165	116	56	34	32	32	32	32	214	2	
Nov 21	10	278	35	35	36	41	81	128	156	160	141	99	52	37	35	35	35	239	1	
	11	280	35	35	35	36	38	53	108	138	149	138	106	63	38	36	35	247	12	
	HALF DAY TOTALS	164	273	498	741	922	1013	956	751	474	296	205	166	157	156	156	156	946	12	
	5	149	9	27	84	125	146	144	121	77	21	9	9	9	9	9	9	25	5	
	6	230	17	19	87	160	205	218	199	148	71	18	17	17	17	17	17	82	4	
	7	283	22	23	47	131	194	227	226	190	124	41	23	22	22	22	22	138	3	
Dec 21	8	280	27	27	28	71	148	200	221	209	163	93	30	27	27	27	27	180	2	
	9	287	29	29	29	31	78	147	192	207	191	146	77	31	29	29	29	206	1	
	10	280	30	30	30	30	32	75	143	185	200	183	142	79	32	30	30	215	12	
	HALF DAY TOTALS	119	142	281	534	787	980	1033	925	672	396	222	137	119	118	118	118	738	12	
	5	40	2	3	20	36	45	47	42	30	12	2	2	2	2	2	2	4	5	
	6	204	13	13	48	123	173	195	188	151	89	18	11	11	11	11	11	43	4	
Jan 21	7	257	17	17	23	104	180	225	235	209	151	64	18	17	17	17	17	97	3	
	8	280	21	21	22	50	139	205	238	233	194	125	38	22	21	21	21	140	2	
	9	291	24	24	24	25	73	156	213	224	214	176	101	28	24	24	24	168	1	
	10	294	25	25	25	25	27	85	165	218	218	191	125	45	24	24	24	177	12	
	HALF DAY TOTALS	88	89	132	351	623	878	1005	974	791	493	247	117	89	88	88	88	540	12	
	5	136	5	5	18	69	108	128	129	110	72	21	6	5	5	5	5	14	4	
Feb 21	6	232	12	12	13	73	151	201	219	204	156	80	13	12	12	12	12	30	3	
	7																			

Table 201-15 gives the solar heat gain factors for different dates and times for 40° North Latitude. Data for other latitudes are provided in the ASHRAE Handbook of Fundamentals.

From the equation, we can see the two different heat gain factors previously mentioned. The factors $A \times SHGF \times SC$ represent the solar heat gain contribution and the factors on the right $U \times A \times TD$ represent the conduction heat gain which is the same equation used for heat loss in winter.

The overall coefficient of heat transfer for different types of window glass and skylights is given in Table 201-3.

The shading coefficients for different types of window glass are given in Table 201-16.

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 ^c	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 201-16¹²

EXAMPLE: Find the heat gain through a 10' x 5', clear, 1/4" window glass without any external or internal shading, at 4:00 PM July 21st for west orientation. Building location is 40° north. Assume outside and inside dry bulb temperature to be 92F and 75F respectively.

SOLUTION: The solar heat gain factor from Table 201-15 4:00 PM on July 21st for west glass is 216. The overall coefficient of heat transfer (U) is determined from Table 201-3 to be 1.06. The shading coefficient in this case is 1.0 since there is no external or internal shading.

By substituting these values in the previous equation, we can calculate the heat gain through the glass.

$$\begin{aligned}Q &= A (\text{SHGF}) \text{ S.C.} + U (\text{TD}) A \\Q &= 50 (216) 1.0 + 1.06 (92 - 75) 50 \\Q &= 50 (216.00 + 18.02) \\Q &= 50 \times 234 \\Q &= 11,700 \text{ Btu/hr}\end{aligned}$$

a. Internal Shading Devices

Most windows and skylights are provided with some type of internal shading. The effectiveness of this shading depends upon its ability to reflect the incoming solar radiation back through the windows before it can be absorbed and converted into heat.

Shading coefficients for venetian blinds and roller shades are given in Table 201-17. If we add light-colored venetian blinds behind the window glass to the above example, the heat gain through glass will be:

$$\begin{aligned}Q &= A (\text{SHGF}) \text{ S.C.} + U (\text{TD}) A \\Q &= 50 (216) 0.55 + 1.06 (92 - 75) 50 \\Q &= 50 (118.80 + 18.02) \\Q &= 50 \times 136.82 \\Q &= 6,841 \text{ Btu/hr}\end{aligned}$$

b. External Shading Devices

Overhangs, screen walls, horizontal and vertical louvers, and vented awnings are typical external shading devices. Methods of calculating glass areas in sun and shade for different outdoor projections are discussed in detail in Chapter 28 of ASHRAE Handbook of Fundamentals.

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	White	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							
S.C. ^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 0.23 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.

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	White	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.

Shading Coefficients for Double Glazing with Between-Glass Shading

Type of Glass	Nominal Each Pane, in.	Solar Trans. ^a		Description of Air Space	Type of Shading		
		Outer Pane	Inner Pane		Venetian Blinds		Lowered Sun Screen
					Light	Medium	
Clear Out	3/32, 1/8	0.87	0.87	Shade in contact with glass or shade separated from glass by air space.	0.33	0.36	0.43
Clear In				Shade in contact with glass-voids filled with plastic.	—	—	0.49
Clear Out	1/4	0.80	0.80				
Clear In							
Heat-Abs. ^b Out				Shade in contact with glass or shade separated from glass by air space.	0.28	0.30	0.37
Clear In	1/4	0.46	0.80	Shade in contact with glass-voids filled with plastic.	—	—	0.41

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

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

Table 201-17¹²

3. Heat Gain from People: Another important heat source which must be considered in cooling load calculations is the heat that is given off by people. In assembly type occupancies experiencing large occupancy loads in confined spaces, the heat gain from the occupants may represent up to 40% of the total heat gain.

Table 201-18 lists the sensible and latent heat rates given off by the human body under different activity conditions. As can be expected, the body gives off more heat under strenuous activity than it does when walking slowly, for example. The heat liberation rates will vary depending on the age and sex of the individuals, state of activity, environmental influences and duration and extent of occupancy.

Table 201-18 indicates that for a bank, where the degree of activity is "standing: walking slowly", the heat gain from each person would be:

Sensible Heat - 250 Btu/hr
Latent Heat - 250 Btu/hr

If the total number of people in the store is 50, then the total heat gain from occupants in that store would be:

Sensible $250 \times 50 = 12,500$ Btu/hr
Latent $250 \times 50 = 12,500$ Btu/hr
Total = 25,000 Btu/hr

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	Btus	btu/hr	Watts	Btus	btu/hr	Watts	Btus	btu/hr	Watts	Btus	btu/hr
Seated at rest	Theater, movie	115	400	100	100	350	90	60	210	55	40	140	30
Seated, very light work writing	Offices, hotels, apt.	140	480	130	120	420	105	65	230	55	55	190	50
Seated, eating	Restaurants ^c	150	520	130	170	580 ^d	145	75	255	60	95	325	80
Seated, light work, typing	Offices, hotels, apt.	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	95	325	80
Light bench work	Factory	255	880	220	250	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	1220	300	280	960	240	100	345	90	180	615	150
Moderate dancing	Dance hall	400	1360	340	375	1280	320	130	405	100	255	875	220
Heavy work, heavy machine work, lifting	Factory	470	1600	400	470	1600	400	165	565	140	300	1035	260
Heavy work, athletics	Gymnasium	525	2000	500	525	1800	450	185	635	160	340	1165	290

^aNotes: Tabularized 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 6% 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 Btus 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 Btus) or standing and walking slowly (700 Btus).

Also refer to Tables 4 and 5, Chapter 8.

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

Table 201-18¹²

4. Heat Gain from Electric Motors: Electric motors and the machinery they drive add sensible heat to the space in which they are located. Heat gain from electric motors is given in Table 201-19 where figures are for continuous operation. They can be corrected for intermittent operation by multiplying by the appropriate usage factor.
5. Heat Gain from Lighting: Electric lighting adds sensible heat to a space. Since lights usually are on most of the day in commercial and industrial facilities, the heat generated can be significant. The total light wattage is obtained from the ratings of all fixtures installed.

Heat Gain from Electric Motors (Continuous Operation*)

Nameplate ^a or Brake Horsepower	Full Load Motor Efficiency Percent	Location of Equipment with Respect to Conditioned Space or Air Stream ^b		
		Motor In- Driven Machines in	Motor Out- Driven Machine in	Motor In- Driven Machine out
		$HP \times 2545$	$HP \times 2545$	$HP \times 2545 (1 - \% \text{ Eff.})$
		% Eff	% = Eff	% = Eff
Btu per Hour				
1/2	40	320	120	190
3/4	49	430	210	220
1	55	580	320	260
1 1/4	60	710	430	280
1 1/2	64	1,000	640	360
2	66	1,290	850	440
2 1/2	70	1,820	1,290	540
3	72	2,680	1,930	750
3 1/2	79	3,220	2,540	680
4	80	4,770	3,820	950
5	80	6,350	5,100	1,280
6	81	9,450	7,850	1,600
7	82	15,600	12,800	2,800
7 1/2	85	22,500	19,100	3,400
10	85	30,000	25,500	4,500
15	86	44,500	38,200	6,300
20	87	58,500	51,000	7,500
25	88	72,400	63,600	8,800
30	89	85,900	76,400	9,400
40	89	115,000	102,000	13,000
50	89	145,000	127,000	18,000
60	89	172,000	153,000	19,000
75	90	212,000	191,000	21,000
100	90	284,000	255,000	29,000
125	90	354,000	318,000	36,000
150	91	420,000	382,000	38,000
200	91	560,000	510,000	50,000
250	91	700,000	636,000	64,000

* For intermittent operation, an appropriate usage factor should be used, preferably measured.

^b If motors are overloaded and amount of overloading is unknown, multiply the above heat gain factors by the following maximum service factors:

Maximum Service Factors						
Horsepower	1/2-1	1-1 1/2	1 1/2-2	2	2 1/2-3	3-250
AC Open Type	1.4	1.35	1.25	1.25	1.20	1.15
DC Open Type	—	—	—	1.15	1.15	1.15

No overload is allowable with enclosed motors.

^c For a fan or pump in air conditioned space, exhausting air, and pumping fluid to outside of space, use values in last column.

TABLE 201-19¹³

The amount of heat dissipated by an incandescent light bulb is 3.4 Btu/hr/watt. Fluorescent lamps also dissipate 3.4 Btu/hr/watt, but a special allowance factor of 1.20 is recommended to allow for heat dissipated by the ballast.

For example, a 40 watt incandescent light bulb will dissipate $(40 \times 3.4) = 136$ Btu/hr. However, a 40 watt fluorescent lamp will dissipate $(40 \times 3.4 \times 1.2) = 163.2$ Btu/hr.

Ventilated or recessed fixtures do not permit the entire power wattage to enter the conditioned space. Much of the heat generated will enter the space above the ceiling or be carried off by ventilation air. For these types of fixtures, manufacturer's catalogs should be consulted to determine the fraction of total wattage which may be expected to enter the conditioned space.

6. Heat Gain From Appliances: The most common heat-producing appliances in the conditioned area are those used for food preparation. Table 201-20 provides data on heat released from such appliances. Again, values for sensible and latent heat are given in Btu/hr.

EXAMPLE: Find the heat gain from a three-gallon electric coffee urn.

SOLUTION: From Table 201-20 under "Electric, Counter Type" read "Coffee Urn", move to the right and read 3 gal. Move further to the right and read (under "Without Hood") 2,550 Btu/hr sensible heat gain, and 850 Btu/hr latent heat gain for a total of 3,400 Btu/hr. If there were a hood over the coffee urn, then only sensible heat would be added to the conditioned space because most of the vapor or latent heat would be removed by the exhaust system.

A value of 1200 Btu/hr of sensible heat release by kitchen appliances has been found to be satisfactory for residential cooling load calculations. It is recognized that this does not equal the load that can be imposed by even one top burner or element of a domestic range. Nevertheless, such factors as intermittent use of appliances, flywheel effects and use of kitchen ventilating fans make this a reasonable and practical value to use.

7. Heat Gain from Infiltration and Ventilation: As previously discussed for heating load calculations, ventilation air

**Recommended Rate of Heat Gain from Commercial Cooking Appliances Located
in the Air-Conditioned Area***

AS THE FAN CONTROLLED TYPE										
Appliances	Capacity	Overall Dim., Inches Width x Depth x Height	Manufacturer's Data (Dimensions in inches)	Manufacturer's Input Rating		Probable Max. Hourly Input Btu	Recommended Rate of Heat Gain, Btu			
				Btu by or Watts	Btu		Without Hood			With Hood ^a
							Sensible	Latent	Total		All Sensible
Gas-Burning, Counter Type										
Broiler-griddle		31 x 20 x 18			36,000	18,000	11,700	6,300	18,000	3,600
Coffee brewer per burner			With warm position		1,500	2,500	1,750	750	2,500	500
Water heater burner			With storage tank		11,000	5,000	3,850	1,650	5,500	1,100
Coffee urn	3 gal.	12-inch dia.			10,000	5,000	3,500	1,500	5,000	1,000
	5 gal.	14-inch dia.			15,000	7,500	5,250	2,250	7,500	1,500
	8 gal. twin	25-inch wide			20,000	10,000	7,000	3,000	10,000	2,000
Deep fat fryer	15 lb fat	14 x 21 x 15			30,000	15,000	7,500	7,500	15,000	3,000
Dry food warmer per sq ft of top					1,400	700	500	140	700	140
Griddle, frying per sq ft of top					15,000	7,500	4,900	2,600	7,500	1,500
Short order stove, per burner			Open grates		10,000	5,000	3,200	1,800	5,000	1,000
Steam table per sq ft of top					2,500	1,250	750	500	1,250	250
Toaster, continuous	360 slices/hr	19 x 14 x 30	2 slices wide		12,000	6,000	1,600	2,400	6,000	1,200
	720 slices/hr	24 x 14 x 30	4 slices wide		20,000	10,000	6,000	4,000	10,000	2,000
Gas-Burning, Floor Mounted Type										
Broiler, rack		24 x 26 grid	Same burner heats oven		70,000	35,000				7,000
Deep fat fryer	32 lb fat		14-in. kettle		65,000	32,500				6,500
	56 lb fat		18-in. kettle		100,000	50,000				10,000
Oven, deck, per sq ft of hearth area			Same for 7 and 12 high decks		4,000	2,000				400
Oven, rotating		32 x 32 x 60	Two ovens—24 x 28 x 15		80,000	40,000	Exhaust hood required	Exhaust hood required	Exhaust hood required	8,000
Range, heavy duty Top section		32 x 42 x 33	32 wide x 39 deep		64,000	32,000				6,400
Oven			28 x 28 x 15		40,000	20,000				4,000
Range, jr., heavy duty Top section		31 x 33 x 33	31 wide x 32 deep		45,000	22,500				4,500
Oven			24 x 28 x 15		35,000	17,500				3,500
Range, restaurant type Per 2-burner sect.			32 wide x 28 deep		24,000	12,000				2,400
Per oven			24 x 22 x 14		30,000	15,000				3,000
Per broiler-griddle			24 wide x 26 deep		35,000	17,500				3,500
Electric, Counter Type										
Coffee brewer per burner				625	2,130	1,000	770	330	1,000	340
per warmer/ automatic	240 cups per hr	27 x 21 x 22	4-burner + water hr.	160	545	300	230	70	300	90
				5,000	17,000	8,500	6,500	2,000	8,500	1,700
Coffee urn	3 gal.			2,000	6,800	3,400	2,550	850	3,400	1,000
	5 gal.			3,000	10,200	5,100	3,850	1,250	5,100	1,600
	8 gal. twin			4,000	13,600	6,800	5,200	1,600	6,800	2,100
Deep fat fryer	14 lb fat	13 x 22 x 10		5,500	18,750	9,400	2,800	6,600	9,400	1,000
	21 lb fat	14 x 22 x 10		8,000	27,300	13,700	4,100	9,600	13,700	4,300
Dry food warmer, per sq ft of top				240	820	400	320	80	400	130
Egg boiler	2 eggs	10 x 13 x 25		1,100	3,750	1,900	1,140	760	1,900	600
Griddle, frying, per sq ft of top				2,700	9,300	4,600	3,000	1,600	4,600	1,900
Griddle-Grill		18 x 20 x 13	Grid, 200 sq in.	6,000	20,400	10,200	6,600	3,600	10,200	3,200
Mopplate		18 x 20 x 13	2 heating units	5,200	17,700	8,900	5,300	3,600	8,900	2,800
Roaster		18 x 20 x 13		1,450	5,620	2,800	1,700	1,100	2,800	900
Roll warmer		18 x 20 x 13		1,450	5,620	2,800	2,600	200	2,800	900
Toaster, continuous	360 slices/hr	15 x 15 x 28	2 slices wide	2,200	7,500	3,700	1,960	1,740	3,700	1,200
	720 slices/hr	20 x 15 x 28	4 slices wide	3,000	10,200	5,100	2,700	2,400	5,100	1,600
Toaster, pop-up	4 slices	12 x 11 x 9		2,540	8,330	4,200	2,250	1,970	4,200	1,300
Waffle iron		18 x 20 x 13	2 grids	1,450	5,620	2,800	1,680	1,120	2,800	900

Table 201-2012

includes both sensible and latent heat. It is calculated by the same equations:

$$\begin{aligned}\text{Sensible Heat} &= \text{cfm} \times \text{TD} \times 1.10 \\ \text{Latent Heat} &= \text{cfm} \times (W_1 \times W_2) \times 4840\end{aligned}$$

EXAMPLE: Given that:

- (1) ventilation air quantities = 400 cfm,
- (2) outside design condition = 75F DB/77 F WB, and
- (3) inside design condition = 75 F DB/62.5 F WB,

determine the sensible heat load added by the outside air.

SOLUTION: The sensible heat load can be calculated by use of the sensible heat equation. The only unknowns in this equation are the air quantity and temperature difference. On inspection of data given to us, we note that there is information for both these unknowns. Therefore:

$$\begin{aligned}\text{Sensible Heat} &= \text{cfm} \times \text{TD} \times 1.10 \\ &= 400 \times (92 - 75) \times 1.10 \\ &= 400 \times 17 \times 1.10 \\ &= 400 \times 18.7 \\ &= 7,489 \text{ Btu/hr}\end{aligned}$$

8. Duct Heat Gain: If supply and return ducts are located outside the conditioned space, for example, in a hot attic, and if they are uninsulated, the heat gain from this situation may be considerable; perhaps as much as 25% of the total sensible load. To minimize these gains all ducts should be insulated if they run through spaces where the ambient air temperature is 25F greater than the air temperature of the air flowing in the duct. Insulation is also necessary to prevent condensation of moisture on the cold surfaces of supply ducts conveying conditioned (cooled) air.

Duct heat gains are entirely sensible heat and are ordinarily expressed as a percentage to apply to the other sources. Usually 5% to 10% gains are used for ducts in 95F attic spaces, increasing to 10% - 35% if the attic air temperature is 130F.

9. Summary of Heat Gains: The total cooling load is expressed in terms of sensible and latent heat in Btu/hr. The total sensible cooling load is the sum of all the calculated sensible heat gains and the total latent heat load is the sum of the calculated latent heat gains.

Figure 201-16 summarizes heat gains and their basic formula. The total heat gain represents the minimum size cooling unit that should be chosen to maintain the desired comfort conditions in the building. Cooling capacity is often expressed in terms of tons of refrigeration. One ton of refrigeration is equal to 12,000 Btu/hr. To determine the tons of refrigeration required for certain conditions, divide the cooling load in Btu/hr by 12,000.

Variability of the Cooling Load

The actual cooling load in a building is a function of time and of the so-called "flywheel" effect of the building and its contents. Just as an engine flywheel stores rotational kinetic energy during torque peaks and releases it when torque is at a minimum to smooth out the performance of reciprocating engines, so does the mass of a building store heat during the hot part of the day and release it hours later. Conversely, a building may be cooled during the night and early morning hours and thus be ready to absorb a greater amount of heat during the later sunny hours. This "heat inertia" of buildings is referred to as flywheel effect or storage effect.

The flow of heat through walls, roofs, and ceilings of buildings is a very complex problem in summer, varying as it does with time of day, the nature of the weather, the presence of trees or shading devices, and the relative humidity.

Because heat transmission is a function of time, the maximum rate of heat gain into the conditioned space may lag by several hours the maximum rate of heat absorption by the outer layers of the building. Furthermore, owing to dissipation and absorption of heat within walls and attics, the rate of gain into the the conditioned space is never so great as the rate of heat entry at the outside surfaces. Buildings store heat, absorb and dissipate some of it, and transmit the rest into the conditioned space at some later time, the lag varying from one to as much as eight or ten hours.

The lag depends on the building construction, size and orientation of glass surfaces, and the percentages of the total load which is due to radiation through glass and which has no transmission lag characteristics. However, solar radiation transmitted through glass will be absorbed by solid surfaces within the space and finally will create a cooling load due to convection to space air. This heat storage effect appreciably reduces the actual required cooling load in comparison to the peak heat gain. Such effects may be approximately evaluated, and they become significant in any space where the principal loads are through exterior walls and glass. Internal load also affects

Basic Heat Gain Formulas:

- (1) $H = AU(ETD)$
 - equivalent temperature differential in °F (See page 86)
 - overall coefficient of heat transmission in Btuh/ft²/°F
 - area of opaque wall or roof surface in ft²
- (2) $H_c = AU(t_o - t_i)$
 - outdoor temperature less indoor temperature in °F
 - see formula number 1
 - area of glass surface in ft²
- (3) $H_o = AS_g(S.C.)$
 - shading coefficient (no units)
 - solar heat gain in Btuh/ft²
 - area of openings (wall or roof) in ft²
- (4) $H_m = 3.4W$
 - lighting, electrical and mechanical equipment total energy in watts (use 4.3 factor for flourescent lighting)
- (5) $H.G. = 1.30 \quad H + H_c + H_o + H_m + H_p + H_v$
 - total heat gain in Btuh (divide by 12,000 to find cooling load in tons of refrigeration)

H_p = People

H_v = Infiltration and Ventilation

FIGURE 201-16

the timing of peak load, particularly in auditoriums, restaurants, and places where people congregate in large numbers.

In summer the condition of steady-state heat flow through walls and ceilings is probably never attained. Heat-gain maximums from different sources do not occur simultaneously, and the total air conditioning load is usually considerably less than the total obtained by a summation of maximums from transmission, occupancy, and other internal sources. Flywheel effect smooths out these maximums, and a careful load analysis will point the way to the most economical selection of equipment which will successfully cope with the peaks during a 24-hour day.

Figure 201-17 illustrates the variability of the several component loads of an air conditioning load for a restaurant with southeast glass and wall exposures. The predominant load is from interior factors, since there are few exposed areas. Of particular importance is the addition of various load factors (people, cooking, lights, transmission, solar radiation) to obtain a peak total load at approximately noon and 7 PM. If the system is to maintain desired space conditions, sufficient capacity (approximately 220,000 Btu/hr or 18.3 tons) would be needed. However, the necessity of reducing the output capacity to prevent overcooling during the 2 to 7 PM period must be considered. A diagram such as Figure 201-16 graphically portrays the component loads and variation of loads typical of this type of building but does not illustrate the changes in sensible or latent heat.

A requisite of any load estimate is to determine the time of day when the peak load occurs and the potential variation in loads during the periods when control of space conditions is important.

For variable occupancy buildings, such as restaurants and theaters, the hour of maximum heat gains usually is the time when the maximum number of occupants are present. However, some buildings may have large glass areas exposed to sun. Therefore, in such a case, the maximum solar heat gain plus the body heat of just a few people during a period of low occupancy may be larger than the body heat at peak occupancy plus a small solar heat gain. To check this, the total heat gain should be computed for both periods. Similarly, a space may have such brilliant nighttime lighting that the heat gain from it may be greater than the solar heat gain during the day. Hence, the total heat gain due to lights and occupancy may be greater than the total heat gain due to solar heat and occupancy. The night-time heat gains of space should be found when a large lighting load and a maximum occupancy occur at night.

Numerous buildings have a fairly steady occupancy throughout the day. The hour which gives the maximum heat gain in such buildings usually is the one when the sun shines on the walls having the largest window areas and small roof areas. All tall buildings are in this class.

AN HOUR-BY-HOUR GRAPHICAL ANALYSIS OF THE COOLING LOAD OF A TYPICAL RESTAURANT

Figure 201-17

Most one- or two-story buildings spread over a large area have large roof to wall ratio. The solar heat gain through roofs is maximum at about 2 PM, so the total heat gain will in all probability also be at its maximum at this hour. If there is a significant amount of glass or glass block, it would be wise to check the total heat gain at the hour when the sun shines on the walls having the greatest glass areas. If the building has most of its windows on the east wall, solar heat gain will be maximum at 8 AM. If the windows are on the west wall, the solar heat gain usually will be maximum at about 4 PM.

In actual work, the cooling load need not be computed for every hour of the day. Usually calculations at two different hours of the day will determine the time of the maximum cooling load.

Zoning and System Capacity

Variation in solar heat gains on perimeter areas of the building and load fluctuations in various internal parts of the building should be considered in determining the capacity of the refrigeration system. The best way to handle such fluctuations is by grouping areas of similar loads together, called zoning, and separately calculate the heat gains for each zone. As an example, assume a rectangular building as shown in Figure 201-17 which has two sunlight exposures -- one on the west wall and the other on the east wall. The building can be split into two zones: an east zone and a west zone. Assuming that occupancy, lighting, and other internal heat gain factors are the same in both zones, the variation in cooling load will be due primarily to the changing solar load.

Figure 201-18

At 9 AM in the morning, the east zone load is 35 tons (one ton = 12,000 Btu/hr, which is the average amount of heat absorbed by one ton of ice, while melting, in one hour) and the west zone load is 25 tons. The combined total is 60 tons.

If the load were to be calculated at 4 PM, the east zone load would have decreased to 20 tons due to the shift of sunlight, while the west zone load would have increased to 50 tons, thus giving a combined total of 70 tons.

How much refrigeration capacity should be proposed in this case? The answer varies with the type of system being installed. If a central system which has capability of shifting cooling from one zone to another is used, then 70 tons is sufficient. If separate equipment for each zone is to be installed, then it should be able to handle the maximum load in each zone. That would be 35 tons for the east zone and 50 tons for the west zone, for a total load of 85 tons. In either case, the cooling equipment and air quantities must be sized for maximum loads in each zone. The maximum load on the equipment is the sum of the sensible and latent heat gains from all sources including the load of ventilation air.

CHAPTER III
THE ENERGY CODE
(ECT-202)

The code is organized as shown in Figure 202-1. The idea of separating the Code into Building Mechanical Systems, Building Enclosure Elements, etc., stems from conventional building code divisions. Thus, the building mechanical systems section may be incorporated in a separate mechanical code, the hot water section in a plumbing code, and so forth.

The Code is based on the ASHRAE 90-75 standard and it is intended to retain the technical content of this standard, restructure ASHRAE 90-75 and adds accepted practice provisions for certain buildings. These are discussed in more detail below. The intent of this Code is to provide a means of implementing the provisions of ASHRAE 90-75.

The following differences will be found when compared to ASHRAE 90-75:

Metric Equivalents Deleted: The S.I. equivalent formulas and units have been deleted from the draft model code. This is in accordance with the current model code format. It is anticipated that the S.I. units will be added when the building codes include S.I. units throughout.

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 model code will be amended to include the 1980 COP levels at the time they are effective. It is felt that industry is aware of this time schedule and is prepared to meet it.

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 this Code) is the Systems Analysis method, ASHRAE Chapters 10 and 11.

This section establishes 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 of the Code.

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 consumption of one energy source and a decrease 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 this Code) is the Components Design, ASHRAE 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.

Path 3 (Section 6 of this Code) contains acceptable practice provisions for conventional residential buildings of three stories or less or small commercial buildings of wood-frame or masonry-wall construction. This section of acceptable practice permits these 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.

The Code is divided into Sections as follows:

SECTION 1 ADMINISTRATION AND ENFORCEMENT

SECTION 2 DEFINITIONS

SECTION 3 DESIGN CONDITIONS

SECTION 4 BUILDING DESIGN BY SYSTEMS ANALYSIS AND DESIGN OF BUILDINGS,
UTILIZING NON-DEPLETABLE ENERGY SOURCES

SECTION 5 BUILDING DESIGN BY COMPONENT PERFORMANCE APPROACH

SECTION 6 BUILDING DESIGN BY ACCEPTABLE PRACTICE.

Each of these sections will be discussed in detail in the following pages.

SECTION 1 - ADMINISTRATION AND ENFORCEMENT

Section 1 is the Administrative Section of the Code which is a requirement of all codes. As you are aware, the Administrative Section establishes the intent, scope, permit and inspection requirements and validity of the Code.

Intent

The Code regulates the design of building envelopes with adequate thermal resistance and low air leakage and the design and selection of mechanical, electrical and illumination systems and equipment which will enable the effective use of energy in new building construction.

Scope

This Code sets forth minimum requirements for the design of new buildings and structures or portions thereof and additions to existing buildings that provide facilities or shelter for public assembly, educational, business, mercantile, institutional, storage and residential occupancies, as well as those portions of factory and industrial occupancies, designed primarily for human occupancy, regulating their exterior envelopes and selection of their HVAC, service water heating, electrical distribution and illuminating systems and equipment for effective use of energy.

Exempt Buildings:

1. Buildings and structures or portions thereof whose peak design rate of energy usage is less than one (1) watt per square foot or three and four tenths (3.4) Btu/h per square foot of floor area for all purposes.
2. Buildings and structures or portions thereof which are neither heated nor cooled by fossil fuel.

PROPOSED BUILDING ENERGY CONSERVATION CODE

Based on ASHRAE 90-75

FIGURE 202-1
118

Application to Existing Buildings

1. Additions shall conform to the provisions of this Code as they relate to the new construction only.
2. Historic Buildings: Historic buildings are exempt from Code. Those buildings which have been specifically designated as historically significant by the State or local governing body, or listed in "The National Register of Historic Places".
3. Change of Occupancy: Any change in the occupancy or use of any existing building or structure constructed under the Energy Code which would require an increase in demand for either fossil fuel or electrical energy supply shall comply with the requirements of this Code. Note this Section relates only to buildings or structures constructed under the Energy Code.

Materials and Equipment

All materials and equipment shall be labeled to show compliance with the Code.

Alternate Materials - Method of Construction, Design or Insulating Systems

Any material method of construction, design or insulating system not specifically prescribed within the Code may be used provided that the alternate has been approved by the Building Official.

Plans and Specifications

The Building Official may require plans and specifications to be prepared by an engineer or architect licensed to practice by the State. All designs submitted under the provisions of Section 4 shall be prepared by a licensed engineer or architect. The statement is optional, however, because of the complexity of Section 4 design and the possibility of conflict with State Laws. States and local governments are encouraged to adopt this statement.

The plans and specifications must show in sufficient detail design criteria, exterior envelope component materials, U values of the envelope elements, R values of insulating materials, size and type of apparatus and equipment, equipment and systems controls and other pertinent data.

Inspections

All construction or work for which a permit is required shall be inspected as determined by the building official. No construction shall be

covered without inspection approval. A final inspection and approval is required before a building may be occupied.

Validity

As spelled out in any code, if any section, subsection, sentence, clause or phrase is, for any reason, held to be unconstitutional, such decision shall not affect the validity of the remaining portions of the Code.

SECTION 2 - DEFINITIONS

Section 2 consists of the definition of words and terms used in the Code, since many of the words and terms used in the section are familiar to the Building Official. The definitions highlighted in this manual will be those that are unique to the enforcement of the Energy Code.

Air Conditioning. The process of treating air so as to control simultaneously its temperature, humidity, cleanliness and distribution to meet requirements of the conditioned space.

Air Transport Factor. The ratio of the rate of useful sensible heat removal from the conditioned space to the energy input to the supply and return fan motor(s), expressed in consistent units and under the designated operating conditions.

Building Envelope. The elements of a building which enclose conditioned spaces through which thermal energy may be transferred to or from the exterior.

Conditioned Floor Area. The horizontal projection of that portion of interior space which is contained within exterior walls and which is conditioned directly or indirectly by an energy-using system.

Degree Day, Heating. A unit, based upon temperature difference and time, used in estimating fuel consumption and specifying nominal heating load of a building in winter. For any one day, when the mean temperature is less than 65F there exist as many Degree Days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65F. See Table 202-1 for various degree days of cities within the United States.

Gross Floor Area. The sum of areas of the several floors of the building, including basements, cellars, mezzanine and intermediate floored tiers and penthouses of headroom height, measured from the exterior faces of exterior walls or from the center line of walls separating buildings.

Covered walkways, open roofed-over areas, porches and similar spaces shall be excluded.

The gross floor area does not include such features as pipe trenches, exterior terraces or steps, chimneys, room overhangs, etc. It is important to note that the measurements are from exterior face to exterior face.

Gross Wall Area. The vertical projection of the exterior wall area bounding interior space which is conditioned (heated or cooled) by an energy-using system; includes opaque wall, window and door areas.

The gross area of exterior walls consists of all opaque wall areas, including foundation walls above grade, between floor spandrels, peripheral edges of floors, window areas including sash, and door areas, where these surfaces are exposed to outdoor air and enclose a heated or cooled space including interstitial areas between two such spaces.

Heated Space. Space, within a building, which is provided with a positive heat supply to maintain air temperature of 50F or higher.

HVAC System. A system that provides either collectively or individually the process of comfort heating, ventilating, and/or air conditioning within or associated with a building.

Infiltration. The uncontrolled inward air leakage through cracks and interstices in any building element and around windows and doors of a building, caused by the pressure effects of wind and/or the effect of differences in the indoor and outdoor air density.

Luminaire. A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

Non-Depletable Energy Sources. Sources of energy (excluding minerals) derived from incoming solar radiation including photosynthetic processes from phenomena resulting therefrom including wind, waves, and tides, lake or pond thermal differences; and energy derived from the internal heat of the earth, including nocturnal thermal exchanges.

Opaque Areas. All exposed areas of a building envelope which enclose conditioned space, except openings for windows, skylights, doors and building service systems.

Overall Thermal Transfer Value (OTTV). An overall coefficient of heat gain expressed in units of Btu per hour per square foot degree F.

Recovered Energy. Energy utilized which would otherwise be wasted from an energy utilization system.

Residential Building. Living units of one story, two stories or other low rise, single- and multi-family dwellings, not exceeding three stories above grade.

Utilizing this definition for purposes of the Model Code, a building 4 or more stories in height containing dwelling units is not classified as a residential building.

Roof Assembly. A roof assembly shall consist of all components of the roof/ceiling envelope through which heat flows, thereby creating a building transmission heat loss or gain, where such assembly is exposed to outdoor air and encloses a heated or mechanically cooled space.

The gross area of a roof assembly consists of the total interior surface of such assembly, including skylights exposed to the heated or mechanically cooled space.

When return air ceiling plenums are employed, the roof/ceiling assembly shall:

1. For thermal transmittance purposes, not include the ceiling proper nor the plenum space as part of the assembly; and,
2. For gross area purposes, be based upon the interior face of the upper plenum surface.

Room Air Conditioner. An encased assembly designed as a unit primarily for mounting in a window or through a wall, or as a console. It is designed primarily to provide free delivery of conditioned air to an enclosed space room or zone. It includes a prime source of refrigeration for cooling and dehumidification and means for circulating and cleaning air, and may also include means for ventilating and heating.

Room Cavity Ratio (RCR). A number related to room dimensions used in average illumination calculations.

Shading Coefficient (SC).

$$SC = \frac{\text{Solar Heat Gain of Fenestration (West Elev. at 4P.M., 9/21)}}{\text{Solar Heat Gain Unshaded DSB (West Elev. at 4P.M., 9/21)}}$$

where

DS means double strength
B means grade class

Solar Energy Source. Source of thermal, chemical or electrical energy derived directly from conversion of incident solar radiation.

Thermal Transmittance (U). Overall coefficient of heat transmission (air to air) expressed in units of Btu per hour per square foot per degree F. It is the time rate of heat flow. The U value applies to combinations of different materials used in series along the heat flow path, single materials that comprise a building section, cavity air spaces, and surface air films on both sides of a building element.

Thermal transmittance actually refers to heat loss. It is the number of Btu's per hour which will be lost by square foot of surface area per degree F difference between inside and outside design temperatures.

Thermal Transmittance (U_o). Overall (average) heat transmission of a gross area of the exterior building envelope, expressed in units of Btu per hour per square foot per degree F.

The U_o value applies to the combined effect of the time rate of heat flows through the various parallel paths, such as windows, doors, and opaque construction areas, comprising the gross area of one or more exterior building components, such as walls, floors, or roof/ceiling.

Unitary Cooling and Heating Equipment. One or more factory-made assemblies which normally include an evaporator or cooling coil, a compressor and condenser combination, and may include a heating function as well. Where such equipment is provided in more than one assembly, the separate assemblies shall be designed to be used together.

SECTION 3 - DESIGN CONDITIONS

Section 3 includes all of the requirements for designing the envelope and heating, ventilating and air conditioning systems of a building. The requirements include:

1. Buildings to be heated and cooled must meet the more stringent of the heating or cooling requirements when requirements of the exterior envelope differ.
2. When building houses more than one occupancy, each portion of the building shall conform to the requirements for the occupancy housed therein.
3. Where minor accessory uses do not occupy more than 10 percent of the area of any floor of a building, the major use shall be considered the building occupancy.

4. The design of buildings shall not create conditions of accelerated deterioration from moisture condensation.

A table has been designed so that these parameters may be entered into the Code and enforced as a code requirement. The use of the Table 202-1 would eliminate the need for continuous referral to the ASHRAE Handbook of Fundamentals or other technical publications for these values. Copies of the tables published in the National Home Builders Association Instruction Manual are contained in Table 202-2.

EXTERIOR DESIGN CONDITIONS			DATA FROM
WINTER ¹	Design Dry-Bulb	° F	Table 201-10
	Design Dry-Bulb	° F	Table 201-10
SUMMER ¹	Design Wet-Bulb	° F	Table 201-10
DEGREE DAYS HEATING			Table 202-2
DEGREES NORTH LATITUDE			Table 201-10

TABLE 201-1

¹The outdoor design temperature shall be selected from the columns of 97 1/2 percent values for winter and 2 1/2 percent values for summer from the tables in Standard RS-1. Adjustments may be made to reflect local climates which differ from the tabulated temperatures, or local weather experience as determined by the Building Official.

The following four examples will demonstrate the value of Table 202-1

Gainesville, Fla.

EXTERIOR DESIGN CONDITIONS		
WINTER ¹	Design Dry-Bulb	32° F
	Design Dry-Bulb	94° F
SUMMER ¹	Design Wet-Bulb	79° F
DEGREE DAYS HEATING		1000
DEGREES NORTH LATITUDE		29°

Minneapolis/St. Paul, Minn.

EXTERIOR DESIGN CONDITIONS		
WINTER ¹	Design Dry-Bulb	-10°F
	Design Dry-Bulb	89°F
SUMMER ¹	Design Wet-Bulb	75°F
DEGREE DAYS HEATING		8400
DEGREES NORTH LATITUDE		44°

San Francisco, Cal.

EXTERIOR DESIGN CONDITIONS		
WINTER ¹	Design Dry-Bulb	44° F
	Design Dry-Bulb	77° F
SUMMER ¹	Design Wet-Bulb	62° F
DEGREE DAYS HEATING		3000
DEGREES NORTH LATITUDE		37°

Worcester, Mass.

EXTERIOR DESIGN CONDITIONS		
WINTER ¹	Design Dry-Bulb	10°F
	Design Dry-Bulb	87°F
SUMMER ¹	Design Wet-Bulb	73°F
DEGREE DAYS HEATING		7000
DEGREES NORTH LATITUDE		42°

Location	Winter Degree Days	Location	Winter Degree Days	Location	Winter Degree Days	Location	Winter Degree Days
ALABAMA		ARK. (cont'd.)		COLO. (cont'd.)		FLA. (cont'd.)	
Andalusia	1800	Fort Smith	3200	Leadville	10600	West Palm Beach	200
Anniston	2600	Hot Springs	3000	Pueblo	5400	Winter Haven	600
Bessemer	2600	Jonesboro	3600	Sheridan	6200	Winter Park	800
Birmingham	2600	Little Rock	3200	Trinidad	5400		
Decatur	3000	Mountain Home	3600			GEORGIA	
				CONNECTICUT		Albany	1800
Dothan	1800	Pine Bluff	2800	Bridgeport	5600	Athens	3000
Florence	3000	Searcy	3400	Danbury	6000	Atlanta	3000
Huntsville	3000	Stuttgart	3000	Greenwich	5400	Augusta	2400
Mobile	1600	Texarkana	2600	Hartford	6200	Brunswick	1200
Montgomery	2200	Walnut Ridge	3400	Meriden	6000		
						Columbus	2400
Muscle Shoals	3000	CALIFORNIA		New Britain	6000	Dalton	3400
Phenix City	2400	Alameda	2800	New Haven	5800	Gainesville	3200
Selma	2200	Anaheim	2000	Norwalk	5400	La Grange	2600
Sheffield	3000	Bakersfield	2200	Stamford	5400	Macon	2200
Talladega	2600	Berkeley	3000				
		Eureka	4600	DELAWARE		Marietta	3200
Tuscaloosa	2600	Fresno	2600	Dover	4600	Moultrie	1600
		Lafayette	3000	Newark	5000	Rome	3400
ALASKA		Long Beach	1800	Wilmington	5000	Savannah	1800
Anchorage	10800	Los Angeles	2000			Valdosta	1600
		Los Gatos	3000	DIST. OF COLUMBIA			
ARIZONA				Washington	4200	HAWAII	
Bisbee	2600	Merced	2400			Honolulu	(d)
Chandler	1800	Modesto	2400	FLORIDA			
Douglas	2600	Oakland	2800	Cocoa Beach	600	IDAHO	
Flagstaff	7200	Pasadena	2000	Daytona Beach	800	Aberdeen	7000
Gila Bend	1400	Redding	4600	Deland	800	Boise	5800
				Fort Lauderdale	200	Burley	5800
Mesa	1800	Sacramento	2600	Fort Meade	600	Coeur D'Alene	6600
Phoenix	1800	San Bernardino	2000			Idaho Falls	7200
Prescott	4600	San Diego	1400	Fort Myers	400		
Scottsdale	1800	San Francisco	3000	Fort Pierce	400	Lewiston	5600
Tombstone	2400	San Jose	3000	Fl. Walton Beach	1200	Moscow	5800
				Gainesville	1000	Mountain Home	6400
Tucson	1800	San Leandro	2800	Jacksonville	1200	Nampa	5800
Winslow	4800	San Mateo	2800			Pocatello	7000
Yuma	1000	San Rafael	3000	Lakeland	600		
		Santa Ana	2000	Lake Wales	600	Twin Falls	5400
ARKANSAS		Santa Barbara	2000	Lake Worth	200		
Benton	3000			Melbourne	600	ILLINOIS	
Blytheville	3400	Santa Clara	3000	Miami	200	Alton	5000
Dumas	2400	Santa Cruz	2800	Ocala	800	Aurora	6600
El Dorado	2200	Santa Maria	3000	Orlando	800	Belleville	4800
Fayetteville	3400	Santa Monica	2200	Panama City	1400	Bloomington	5600
		Santa Rosa	3000	Pensacola	1400	Cairo	3800
				Punta Gorda	400		
		Stockton	2600			Carbondale	4200
		Yreka	5400	St. Augustine	1000	Champaign	5800
		COLORADO		St. Petersburg	600	Chicago	6600
		Boulder	5600	Sarasota	600	Danville	5400
		Colo. Springs	6400	Tallahassee	1400	Decatur	5400
		Denver	6200	Tampa	600		
		Fort Collins	7000			De Kalb	6600
		Grand Junction	5600	Titusville	600	Elgin	6600
				Venice	600	Evanston	6600
						Galesburg	6200

Table 202-215

Location	Winter Degree Days	Location	Winter Degree Days	Location	Winter Degree Days	Location	Winter Degree Days
ILL. (cont'd.)		IOWA (cont'd.)		MASS. (cont'd.)		MISS. (cont'd.)	
Joliet	6600	Sioux City	7000	Lowell	6800	Picayune	1600
Kankakee	6000	Waterloo	7400	Fittsfield	7600	Vicksburg	2000
Moline	6400			Springfield	6600		
Ottawa	6400	KANSAS		Worcester	7000	MISSOURI	
Peoria	6000	Coffeyville	4000			Cape Girardeau	4200
		Dodge City	5000	MICHIGAN		Columbia	5000
Quincy	5400	Garden City	5200	Adrian	6400	Hannibal	5400
Rantoul	5800	Hutchinson	4600	Alpena	8600	Jefferson City	4800
Rockford	6800	Kansas City	4800	Ann Arbor	6800	Joplin	4000
Rock Island	6400			Battle Creek	6600		
Springfield	5400	Leavenworth	5000	Benton Harbor	6200	Kansas City	4800
		Salina	5000			St. Joseph	5400
Urbana	5800	Topeka	5200	Coldwater	6400	St. Louis	5000
		Wichita	4600	Detroit	6200	Sedalia	5000
INDIANA				Escanaba	8600	Springfield	5000
Anderson	5400	KENTUCKY		Flint	7400		
Bloomington	4800	Covington	5200	Grand Rapids	6800	MONTANA	
Columbus	5400	Hopkinsville	4000			Billings	7000
Connersville	5400	Lexington	4600	Holland	6400	Butte	9800
Elkhart	6400	Louisville	4600	Jackson	6400	Great Falls	7800
		Murray	4000	Kalamazoo	6600	Helena	8200
Franksville	4400			Lansing	7000	Missoula	8200
Fort Wayne	6200	Owensboro	4400	Ludington	7400		
Gary	6200	Paducah	4200			NEBRASKA	
Greensburg	5200			Marquette	8400	Columbus	6600
Hammond	6200	LOUISIANA		Midland	7200	Grand Island	6600
		Alexandria	2000	Monroe	6200	Hastings	6200
Indianapolis	5600	Baton Rouge	1600	Mt. Pleasant	7200	Lincoln	5800
Kokomo	5600	Bossier City	2200	Muskegon	6600	Norfolk	7000
Lafayette	5800	Lafayette	1400				
Marion	5800	Lake Charles	1400	Port Huron	7200	North Platte	6600
Muncie	5600			Saginaw	7000	Omaha	6600
		Monroe	2200	Sault Ste. Marie	9400	Scottsbluff	6600
New Albany	4600	New Orleans	1400	MINNESOTA			
Richmond	5400	Shreveport	2200	Austin	8000	NEVADA	
Seymour	4800			Bloomington	8400	Elko	7400
South Bend	6400	MAINE		Duluth	10000	Las Vegas	2800
Terre Haute	5400	Bangor	8000	Minneapolis	8400	Reno	6400
		Lewiston	7800	Moorhead	9400		
IOWA		Portland	7600			NEW HAMPSHIRE	
Algona	7400			Rochester	8200	Concord	7400
Ames	6800	MARYLAND		St. Cloud	8800	Dover	7200
Burlington	6200	Annapolis	4400	St. Paul	8400	Keene	7400
Cedar Falls	7400	Baltimore	4600			Laconia	7800
Cedar Rapids	6600	Cambridge	4200	MISSISSIPPI		Manchester	7200
		College Park	4400	Biloxi	1600		
Clinton	6800	Cumberland	5200	Columbus	2600	Nashua	7000
Council Bluffs	6600			Greenville	2400	Portsmouth	7200
Davenport	6400	Frederick	5000	Gulfport	1600		
Des Moines	6600	Hagerstown	5200	Hattiesburg	1800	NEW JERSEY	
Dubuque	7400	Rockville	4400			Atlantic City	4800
		Silver Spring	4400	Jackson	2200	Bernardsville	5400
Fort Dodge	7400	Wheaton	4400	Laurel	2000	Camden	4600
Iowa City	6400			Meridian	2200	Cape May	4800
Keokuk	5600	MASSACHUSETTS		Natchez	1800	Clinton	5200
Marshalltown	6800	Attleboro	5800	Pascagoula	1600		
Mason City	7600	Boston	5600			Edison	5000
		Cape Cod	6000			Flemington	5200
Muscatine	6400	Fall River	5800			Lakewood	5400
Ottumwa	6400	Lawrence	6800			Morristown	5600

Table 202-2 continued

Location	Winter Degree Days	Location	Winter Degree Days	Location	Winter Degree Days	Location	Winter Degree Days
N.J. (cont'd.)		NORTH DAKOTA		ORE. (cont'd.)		TENN. (cont'd.)	
Newark	5000	Bismarck	8800	Medford	5000	Knoxville	3400
New Brunswick	5000	Fargo	9200	Pendleton	5200	Memphis	3200
New Milford	5400	Grand Forks	9800	Portland	4600	Nashville	3600
Paterson	5400	Minot	9600	Salem	4800	Oak Ridge	3800
Trenton	5000						
NEW MEXICO		OHIO		PENNSYLVANIA		TEXAS	
Alamogordo	3000	Akron	6000	Allentown	5800	Abilene	2600
Albuquerque	4400	Ashland	5800	Altoona	6200	Amarillo	4000
Carlsbad	2600	Ashtabula	6400	Chambersburg	5400	Austin	1800
Clovis	4200	Canton	6000	Erie	6400	Beaumont	1000
Hobbs	2600	Chillicothe	5000	Gettysburg	5200	Brownsville	600
Las Cruces	2800	Cincinnati	4400	Harrisburg	5200	Brownwood	2200
Roswell	3800	Cleveland	6400	Johnstown	5600	Corpus Christi	1000
Santa Fe	6200	Columbus	5600	Kingston	6200	Dallas	2400
		Dayton	5600	Lancaster	5400	El Paso	2800
		Defiance	6200	Philadelphia	4400	Fort Worth	2400
NEW YORK							
Albany	6800	Dover	6000	Phila. Suburban	5200	Galveston	1200
Binghamton	7200	Elyria	6400	Pittsburgh	6000	Houston	1400
Buffalo	7000	Findlay	6200	Reading	5000	Killeen	2000
Elmira	6400	Greenville	5800	Scranton	6200	Longview	2400
Glens Falls	7200	Lancaster	5200	State College	6200	Lubbock	3600
Hempstead	5200	Lima	6000	Sunbury	5600	Lufkin	1800
New City-Nyack	5800	Mansfield	6400	Uniontown	5200	Midland	2600
New York	5000	Marietta	4800	Washington	5400	Paris	2600
Niagara Falls	7000	Newark	5600	Wilkes-Barre	6200	San Angelo	2200
Poughkeepsie	6200	Norwalk	6200	Williamsport	5800	San Antonio	1600
Rochester	6800	Sandusky	5800	York	5400	Sherman	2600
Rome	7400	Sidney	5800			Texarkana	2600
Schenectady	6800	Springfield	5600	RHODE ISLAND		Victoria	1200
Syracuse	6800	Toledo	5800	Newport	5800	Waco	2000
Watertown	7200	Troy	5600	Providence	6000	Wichita Falls	2800
				Westerly	5800		
White Plains	5600	Wintersville	5800	SOUTH CAROLINA		UTAH	
		Youngstown	6400	Charleston	2000	Ogden	5600
NORTH CAROLINA				Columbia	2400	Salt Lake City	6000
Asheville	4000	OKLAHOMA		Florence	2600		
Burlington	3800	Altus	3000	Greenville	3000	VERMONT	
Charlotte	3200	Bartlesville	4000	Myrtle Beach	(c)	Burlington	8200
Durham	3400	Enid	3800			Montpelier	8800
Elizabeth City	3400	Lawton	3000			Rutland	8000
		Moore	3200	Spartanburg	3000		
Fayetteville	3000			Walhalla	3200	VIRGINIA	
Gastonia	3200	Norman	3200			Alexandria	4200
Greensboro	3800	Oklahoma City	3200	SOUTH DAKOTA		Charlottesville	4200
Jacksonville	2600	Ponca City	4000	Aberdeen	8600	Danville	3600
Kinston	2800	Shawnee	3200	Huron	8200	Lynchburg	4200
		Stillwater	3800	Rapid City	7400	Martinsville	3800
Raleigh	3400	Tulsa	3800	Sioux Falls	7800		
Rocky Mount	3600			Watertown	8400	Newport News	3400
Salisbury	3200	OREGON				Norfolk	3400
Wilmington	2400	Baker	7000	TENNESSEE		Petersburg	3600
Winston-Salem	3600	Corvallis	4800	Chattanooga	3200	Richmond	3800
		Eugene	4800	Jackson	3400	Roanoke	4200
		Grants Pass	5000	Johnson City	4000		
		Klamath Falls	6400			WASHINGTON	
						Bellingham	5400

Table 202-2 continued

Location	Winter Degree Days
WASH. (cont'd.)	
Kennewick	5200
Longview	5200
Olympia	5200
Poulsbo	5200
Seattle	5200
Spokane	6600
Tacoma	5200
Walla Walla	4800
Yakima	6000
WEST VIRGINIA	
Charleston	4400
Clarksburg	5000
Fairmont	5000
Huntington	4400
Parkersburg	4800
Wheeling	5200
WISCONSIN	
Appleton	7800
Beloit	6800
Eau Claire	8000
Fond du Lac	7600
Green Bay	8000
La Crosse	7600
Madison	7800
Milwaukee	7600
Racine	7400
Superior	9800
Watertown	7800
Wausau	8400
WYOMING	
Casper	7400
Cheyenne	7400
Lander	7800
Sheridan	7600

Table 202-2 continued

Indoor Design Temperature shall be 72°F for heating and 78°F for cooling. Other design temperatures may be used for equipment selection if it results in a lower energy usage.

Humidification is limited during heating to a maximum relative humidity of 30 percent. When comfort air conditioning is provided, the actual design relative humidity within the comfort envelope as defined in accordance with ASHRAE Standard 55-74¹⁶.

EXCEPTION: Special applications such as hospitals, laboratories, thermally sensitive equipment, computer rooms and facilities with open refrigerated display cases may be exempted from the requirements of this section when approved by the Building Official.

Ventilation air shall conform to the minimum values contained in Standard 62-73. The ventilation quantities specified are for 100 percent outdoor air ventilating systems. Reductions of up to 33 percent of the specified minimum outdoor air requirement in Section 6 of the standard for recirculating HVAC systems is permitted.

EXCEPTION: If outdoor air quantities other than those specified in the ASHRAE Standard are used, the required outdoor air quantities shall be used as the basis for calculating the heating and cooling design loads.

SECTION 4 - BUILDING DESIGN BY SYSTEMS ANALYSIS AND DESIGN OF BUILDINGS UTILIZING NON-DEPLETABLE ENERGY SOURCES

Section 4 of the Code contains the requirements for the system analysis path for compliance with the Energy Code. This path is not considered to be part of the ECT-200 course, however the Building Official should be familiar with the following (A more detailed study of Section 4 is included in the ECT-300 course.):

General: A building designed in accordance with this section will be deemed as complying with this Code if the calculated annual energy consumption is not greater than a standard building whose enclosure elements and energy consuming systems are designed in accordance with Section 5 of the Code.

An alternate building design to be considered similar to a "standard design" shall utilize the same energy source(s) for the same functions and have equal floor area and the same ratio of envelope area to floor area, environmental requirements, occupancy, climate data and usage operational schedule. The comparison shall be expressed as Btu input per square foot of gross floor area per year.

If the proposed alternative design results in an increase in consumption of one energy source and a decrease in another energy source (even though similar sources are used for similar purposes) the difference in each energy source shall be converted to equivalent energy units for purposes of comparing the total energy used.

Analysis Procedure

The analysis of the annual energy usage of the standard and the proposed alternative building and system design shall meet the following criteria:

The building heating/cooling load calculation procedure used for annual energy consumption analysis shall be detailed to permit the evaluation of effect of factors:

- (a) Design requirements: Environmental requirements as required in Section 3 of the Code.
- (b) Climatic data: Coincident hourly data for temperatures, solar radiation, wind and humidity of typical days in the year representing seasonal variation.
- (c) Building data: Orientation, size, shape, mass, air, moisture and heat transfer characteristics.
- (d) Operational characteristics: Temperature, humidity, ventilation, illumination, control mode for occupied and non-occupied hours.
- (e) Mechanical equipment: Design capacity, part load profile.
- (f) Building loads: Internal heat generation, lighting, equipment, number of people during occupied and non-occupied periods.
- (g) Time: Based on 8760 hours of operation.

Documentation

Proposed alternative designs, submitted as requests for exception to the standard design criteria, shall be accompanied by an energy analysis comparison report. The report shall provide technical detail on the two building and systems designs and on the data used in and resulting from the comparative analysis to verify that both the analysis and the designs meet the requirements of the Code.

EXCEPTION: Proposed alternative designs for single-family dwellings are exempted and for commercial and industrial structures having an

area of 5,000 square feet or less having the indoor temperature controlled from a single point are exempted from the full-year energy analysis. A comparison of energy consumption between the alternative design and the standard design shall be provided.

Building Utilizing Non-Depletable Energy Sources. Any proposed building utilizing solar, geothermal, wind or other non-depletable energy sources for all or part of its energy source shall meet the requirements of the Code, except such non-depletable energy may be excluded from the total annual energy consumption allowed for the building by that section.

The energy derived from non-depletable sources shall be separately identified from the overall building energy use. Supporting documentation, on the basis of the performance estimates for non-depletable energy sources must be submitted.

SECTION 5 - BUILDING DESIGN BY COMPONENT PERFORMANCE APPROACH

Section 5 includes the requirements for the Design Analysis Path for Complying with the Energy Code.

Building Envelope Criteria. Type A-1 - detached one- and two-family dwellings; and Type A-2 - All other residential buildings, three stories or less, designed for heating or cooling shall have a combined thermal transmittance value of the gross area of the elements of the exterior building envelope, not exceeding the values given in Table 5-1 of the Code, reproduced in this text. Figure 202-2, 202-3, 202-4 are also reproduced from the Standard RS-9.

The following examples will provide the opportunity for better understanding of the use of Table 5-1.

EXAMPLE:

Complete Table 5-1 for the cities of Gainesville, Fla., Minneapolis-St. Paul, Minn., San Francisco, Cal. and Worcester, Mass.

SOLUTION:

The first step is to determine the degree days for the four cities. As you are aware, they were determined in example problems 1-4 of Section 3 of this chapter. (See pages 124 and 125.)

The design degree days are:

Gainesville, Fla.	1000
Minneapolis/St. Paul, Minn.	8400
San Francisco, Cal.	3000
Worcester, Mass.	7000

TABLE 5-1¹

ELEMENT	MODE	TYPE A-1 BUILDINGS	TYPE A-2 BUILDINGS
		U_0	U_0
WALLS ²	HEATING OR COOLING	Page 64 Code	Page 64 Code
ROOF/CEILING ³	HEATING OR COOLING	Footnote 3	Footnote 3
FLOORS OVER UNHEATED SPACES	HEATING OR COOLING	Page 68 Code	Page 68 Code
HEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		Page 65 Code	Page 65 Code
UNHEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		Page 65 Code	Page 65 Code

¹Values shall be determined by using the graphs (Figures 1, 2 and 5) contained in Std RS-9, using heating degree days as specified in Section 302.0.

²Walls: The requirements for locations with less than 500 heating degree days shall be:

(a) No maximum U_0 if building is heated only.

(b) If the building is to be mechanically cooled when built, or if provision is made for the future addition of mechanical cooling, the maximum U_0 for walls shall be 0.30 Btu/h ft²F.

³The combined thermal transmittance (U_0) for roof/ceilings shall not exceed 0.05 Btu/h ft²F for geographic areas with 8000 or less Fahrenheit Heating Degree Days and shall not exceed 0.04 Btu/h ft²F for geographic areas with more than 8000 Fahrenheit Heating Degree Days.

EXCEPTION: Roof/ceiling assemblies in which the finished interior surface is the underside of the roof deck, may have a maximum U_0 value of 0.08 Btu/h ft²F. Equation 1 shall be used to determine acceptable combinations to meet the required U_0 values.

The second step is to determine the U_0 values for the various envelope components based on the known degree days from the charts on pages 64, 65 and 66 of the Code.

1. Gainesville - See Figures 202-2, 202-3 and 202-4.

TABLE 5-1¹

ELEMENT	MODE	TYPE A-1 BUILDINGS	TYPE A-2 BUILDINGS
		U_0	U_0
WALLS ²	HEATING OR COOLING	0.29	0.37
ROOF/CEILING ³	HEATING OR COOLING	0.05	0.05
FLOORS OVER UNHEATED SPACES	HEATING OR COOLING	0.32	0.32
HEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		3.2	3.2
UNHEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		2.5	2.5

Note the minimum value of 2.5 was selected for the perimeter insulation around the Unheated Slab. This solution is conservative and if the designer did not indicate perimeter insulation for an unheated slab in Gainesville, his design would be considered as conforming to the Code.

2. Minneapolis/St. Paul - See Figures 202-2, 202-3 and 202-4.

TABLE 5-1¹

ELEMENT	MODE	TYPE A-1 BUILDINGS	TYPE A-2 BUILDINGS
		U_0	U_0
WALLS ²	HEATING OR COOLING	0.185	0.23
ROOF/CEILING ³	HEATING OR COOLING	0.04	0.04
FLOORS OVER UNHEATED SPACES	HEATING OR COOLING	0.08	0.08
HEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		8.8	8.8
UNHEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		6.4	6.4

3. San Francisco - See Figures 202-2, 202-3 and 202-4.

TABLE 5-1¹

ELEMENT	MODE	TYPE A-1 BUILDINGS	TYPE A-2 BUILDINGS
		U ₀	U ₀
WALLS ²	HEATING OR COOLING	0.265	0.33
ROOF/CEILING ³	HEATING OR COOLING	0.05	0.05
FLOORS OVER UNHEATED SPACES	HEATING OR COOLING	0.18	0.18
HEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		4.8	4.8
UNHEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		2.8	2.8

4. Worcester - See Figures 202-2, 202-3 and 202-4.

TABLE 5-1¹

ELEMENT	MODE	TYPE A-1 BUILDINGS	TYPE A-2 BUILDINGS
		U ₀	U ₀
WALLS ²	HEATING OR COOLING	0.205	0.255
ROOF/CEILING ³	HEATING OR COOLING	0.05	0.08
FLOORS OVER UNHEATED SPACES	HEATING OR COOLING	0.08	0.08
HEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		7.7	7.7
UNHEATED SLAB ON GRADE	HEATING	R VALUE	R VALUE
		5.5	5.5

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 202-2

R VALUES—SLAB ON GRADE

FIGURE 202-3

U_o VALUES—FLOORS OVER UNHEATED SPACES

FIGURE 202-4
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Criteria for Buildings other than Type A-1 and A-2: Heating and Cooling
 -- Buildings, except type A-1 and A-2, that are heated shall have a combined thermal transmittance value (U_o) of the gross area of the elements of the exterior building envelope not exceeding the values given in Table 5-2 of the Code, reproduced in this text.

ELEMENT		MODE	VALUE
WALLS	3 STORIES OR LESS	HEATING	U _o
			Page 66 Code
		COOLING	OTTV
			Page 69 Code
			SF*
			Page 70 Code
	OVER 3 STORIES	HEATING	U _o
			Page 66 Code
		COOLING	OTTV
			Page 69 Code
			SF*
			Page 70 Code
ROOF/CEILING		HEATING OR COOLING	U _o
			Page 67 Code
FLOORS OVER UNHEATED SPACES		HEATING OR COOLING	U _o
			Page 68 Code
HEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			Page 65 Code
UNHEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			Page 65 Code

*SF = SOLAR FACTOR

Table 5-2¹

1Values shall be determined by using the graphs(Figures 2,3,4,5 and 6)contained in Std RS-9; using degree days heating as specified in Section 302.0.

2Slab on Grade: Insulation around the perimeter of the floor shall extend downward from the top of the slab for a minimum distance of 24 inches, or downward to the bottom of the slab; then horizontally beneath the slab for a minimum total distance of 24 inches.

The following example demonstrates the use of Table 5-2.

EXAMPLE:

Complete Table 5-2 for the cities of Gainesville, Fla., Minneapolis/St. Paul, Minn., San Francisco, Cal., and Worcester, Mass.

SOLUTION:

When a building is to be designed for both heating and cooling, two of the design parameters included in Table 3-1 of the Code must be used to determine the allowable heating and cooling coefficients. These parameters are the Degrees Days Heating and the Degrees North Latitude. These parameters were determined in example problems 1-4 of Section 3 of this chapter (See pages 134 and 135) and are as follows.

<u>Location</u>	<u>Degree Days</u>	<u>Degree North Latitude</u>
Gainesville, Fla.	1000	29°
Minneapolis/St. Paul., Minn.	8400	44°
San Francisco, Cal.	3000	37°
Worcester, Mass.	7000	42°

The second step is to determine the heating and cooling coefficients from the charts on pages 65, 66, 69 and 70 of the Code using these known design parameters.

1. Gainesville - See Figures 202-5, 202-6, 202-7, 202-8, 202-9 and 202-10.

ELEMENT		MODE	VALUE
WALLS	3 STORIES OR LESS	HEATING	U_o
			0.37
		COOLING	OTTV
			30.4
			SF*
			120
	OVER 3 STORIES	HEATING	U_o
			0.46
		COOLING	OTTV
			30.4
			SF*
			120
ROOF/CEILING		HEATING OR COOLING	U_o
			0.10
FLOORS OVER UNHEATED SPACES		HEATING OR COOLING	U_o
			0.32
HEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			3.2
UNHEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			2.5*

*SF = SOLAR FACTOR

Table 5-2¹

* See comment after Gainesville Example Table 5-1¹

2. Minneapolis/St. Paul - See Figures 202-5, 202-6, 202-7, 202-8, 202-9 and 202-10.

ELEMENT		MODE	VALUE
WALLS	3 STORIES OR LESS	HEATING	U_0
			0.23
		COOLING	OTTV
			34.6
			SF*
			131
	OVER 3 STORIES	HEATING	U_0
			0.28
		COOLING	OTTV
			34.6
			SF*
			131
ROOF/CEILING		HEATING OR COOLING	U_0
			0.06
FLOORS OVER UNHEATED SPACES		HEATING OR COOLING	U_0
			0.08
HEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			8.8
UNHEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			6.4

*SF = SOLAR FACTOR

Table 5-2¹

3. San Francisco - See Figures 202-5, 202-6, 202-7, 202-8, 202-9 and 202-10.

ELEMENT		MODE	VALUE
WALLS	3 STORIES OR LESS	HEATING	U_o
			0.33
		COOLING	OTTV
			32.6
			SF*
			125
	OVER 3 STORIES	HEATING	U_o
			0.41
		COOLING	OTTV
			32.6
			SF*
			125
ROOF/CEILING		HEATING OR COOLING	U_o
			0.10
FLOORS OVER UNHEATED SPACES		HEATING OR COOLING	U_o
			0.18
HEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			4.8
UNHEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			2.8

*SF = SOLAR FACTOR

TABLE 5-2¹

4. Worcester -See Figures 202-5, 202-6, 202-7, 202-8, 202-9 and 202-10.

ELEMENT		MODE	VALUE
WALLS	3 STORIES OR LESS	HEATING	U_0
			0.26
		COOLING	OTTV
			34.0
			SF*
			129
	OVER 3 STORIES	HEATING	U_0
			0.305
		COOLING	OTTV
			34.0
			SF*
			129
ROOF/CEILING		HEATING OR COOLING	U_0
			0.068
FLOORS OVER UNHEATED SPACES		HEATING OR COOLING	U_0
			0.08
HEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			7.7
UNHEATED SLAB ON GRADE		HEATING OR COOLING	R VALUE
			5.5

*SF = SOLAR FACTOR

TABLE 5-2¹

R VALUES—SLAB ON GRADE

FIGURE 202-5

U_o WALLS—HEATING

FOR ALL BUILDINGS NOT REGULATED BY SECTION 502.2

FIGURE 202-6

U_o —ROOFS AND CEILINGS

FOR ALL
BUILDINGS NOT REGULATED BY SECTION
502.2

FIGURE 202-7

U_o VALUES—FLOORS OVER UNHEATED SPACES

FIGURE 202-8

SOLAR FACTOR (SF) VALUES

FOR USE IN EQUATION 2

FIGURE 202-9

OVERALL THERMAL TRANSFER VALUE
WALLS COOLING
FOR ALL
BUILDINGS NOT REGULATED BY SECTION
502.2

FIGURE 202-10
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The following equation (EQUATION 1) is used to determine the average or combined transmittance of the gross exterior wall, floor or roof/ceiling assembly for heating. This value, to satisfy the Code, must be less than the U_o values determined for Tables 5-1 and 5-2 of the Code.

EQUATION 1

$$U_o = \frac{U_w A_w + U_g A_g + U_d A_d + \dots}{A}$$

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:

$$U_{w1} A_{w1} + U_{w2} A_{w2} + U_{w3} A_{w3} + \text{etc.}$$

The following equation (EQUATION 2) is used to determine the average or combined thermal transfer value of the gross exterior wall for cooling. This value, to satisfy the Code, must be less than the OTTV value determined for Table 5-2 of the Code.

EQUATION 2

$$OTTV = \frac{(U_w A_w T_{DEQ}) + (A_f SF_{SC}) + (U_f A_f \Delta t) \dots}{A}$$

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. (See Figure 202-11.)

SC = shading coefficient of the fenestration. (See definitions.)

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:

$$(U_{w1} A_{w1} T_{DEQ1}) + (U_{w2} A_{w2} T_{DEQ2}) + \text{etc.}$$

TABLE FOR TEMPERATURE DIFFERENCE

Wall Construction mass per unit area lbs/ft ²	T_{DEQ}	
	F	C
0 - 25	44	24.5
26 - 40	37	21.0
41 - 70	30	17.0
71 and above	23	13.0

Figure 202-11

Section 203 of this manual will provide a more detailed presentation of the use of these formulas.

Variation of Component Coefficients: The individual U_o value of any assembly, such as roof/ceiling, wall or floor, may be increased and the U_o value for other components decreased provided that the total heat gain or loss for the entire building envelope does not exceed the total resulting from conformance to the U_o values specified in Tables 5-1 and 5-2. Section 203 of this manual presents examples of methods that may be employed to meet this requirement.

Air Leakage for all Buildings: All exterior doors and windows shall be designed to limit air leakage into or from the building. They shall have air infiltration rates not greater than those shown in Table 5-3 of the Code. (See Figure 202-12.)

ALLOWABLE AIR INFILTRATION RATES

WINDOWS	RESIDENTIAL DOORS		NON-RESIDENTIAL DOORS
(cfm per foot of operable sash crack)	(cfm per square foot of door area)		(cfm per lin. foot of crack)
	Sliding Glass (Patio Type)	Swinging	Swinging, Sliding, Revolving
0.5	0.5	1.25	11.0

Figure 202-12

Exterior joints around windows and door frames; openings between walls and foundations, between walls and roof and between wall panels; openings at penetrations of utility services through walls, floors and roofs; and all other such openings in the building envelope shall be caulked, gasketed, and weatherstripped.

Building Mechanical Systems

The design temperatures specified in completed Table 3-1 of the Code shall be the bases for sizing mechanical equipment. Simultaneous heating and cooling, by reheating or recooling supply air or by concurrent operation of independent heating or cooling systems, is restricted to these systems that will conserve energy. Each mechanical ventilation system (supply and/or exhaust) shall be equipped with a readily accessible means for either shut-off or volume reduction and shut-off when ventilation is not required.

Performance Requirements

- a. HVAC - System Heating Equipment Heat Pumps - Heating Mode: Heat pumps whose energy input is entirely electric shall show a coefficient of performance (COP) heating, not less than the values shown in Table 5-4 of the Code. (See Figure 202-13.)

Coefficient of Performance (COP) Heating: The ratio of the rate of net heat output to the rate of total energy input, expressed in consistent units and under designated rating conditions.

MINIMUM COP FOR HEAT PUMPS, HEATING MODE¹

SOURCE AND OUTDOOR TEMPERATURE (F)	MINIMUM COP
Air Source - 47 dB/43WB	2.2
Air Source - 17 dB/15WB	1.2
Water Source - 60 Entering	2.2

¹When tested at the Standard Rating specified in Table 5-9A.

Figure 202-13

b. HVAC - System Combustion Heating Equipment: All gas and oil fired comfort heating equipment shall show a minimum combustion efficiency of 75 percent at maximum rated output. Combustion efficiency is defined as 100 percent minus stack losses in percent of heat input. Stack losses are:

1. Loss due to sensible heat in dry fuel gas
2. Loss due to incomplete combustion
3. Loss due to sensible and latent heat in moisture formed by combustion of hydrogen in the flue

c. HVAC - System Equipment, Electrically Operated, Cooling Mode: HVAC-system equipment as listed below whose energy input in the cooling mode is entirely electric, shall show a Coefficient of Performance (COP) - cooling not less than values shown in Table 5-5 of the Code. (See Figure 202-14.)

**TABLE 5-5 - MINIMUM EER AND COP
FOR ELECTRICALLY DRIVEN HEATING, VENTILATING AND
AIR CONDITIONING SYSTEM EQUIPMENT - COOLING¹**

STANDARD RATING CAPACITY	EER	COP
Under 65,000 Btu/h (19050 watts)	6.1	1.8
65,000 Btu/h (19,050 watts and over)	6.8	2.0

¹When tested at the Standard Rating Conditions specified in Table 5-9B.

Figure 202-14

Coefficient of Performance (COP) Cooling: The ratio of the rate of net heat removal to the rate of total energy input, expressed in consistent units and under designated rating conditions.

The rate of net heat removal shall be defined as the change in the total heat content of the air entering and leaving the equipment (without reheat).

Total energy input shall be determined by combining the energy inputs to all elements of the equipment, including, but not limited to, compressor(s), pump(s), supply-air fan(s), cooling-tower fan(s), and pump(s), and the HVAC - system equipment control circuit.

- d. Applied HVAC-System Components Cooling Mode: These components, whose energy input is entirely electric, shall show a Coefficient of Performance (COP) cooling not less than the values shown in Table 5-6 of the Code. (See Figure 202-15.)

**TABLE 5-6 - MINIMUM EER AND COP
FOR ELECTRICALLY DRIVEN HEATING, VENTILATING AND
AIR CONDITIONING SYSTEM COMPONENTS¹**

COMPONENT	CONDENSING MEANS	AIR		WATER		EVAPORATOR	
		EER	COP	EER	COP	EER	COP
	Centrifugal	7.5	2.2	12.9	3.8		
Self-contained Water chillers	Positive Displacement	7.2	2.1	10.9	3.2		
Condenserless Water Chillers	Positive Displacement	8.9	2.6	10.9	3.2		
Compressor and Condenser units 65,000 Btu/h (19,050 watts and over) ²	Positive Displacement	7.8	2.3	11.3	3.3	11.3	11.3

¹When tested at the Standard Rating Conditions specified in Table 5-9C.

²Ratings in accordance with Std RS-14 as applicable. COP based on condensing unit Standard Rating Capacity and energy input to the unit, all at sea level.

Figure 202-15

- e. HVAC-System Equipment - Heat Operated, Cooling Mode: Efficiency Limitation, Equipment: Heat-operated cooling equipment shall show a (COP) - cooling not less than the values shown in Table 5-7 of the Code. (See Figure 202-16.)

**TABLE 5-7 - MINIMUM COP
FOR HEATING, VENTILATING AND AIR
CONDITIONING SYSTEM HEAT OPERATED
COOLING EQUIPMENT**

HEAT SOURCE	MINIMUM COP
Direct fired (gas, oil)	0.40
Indirect fired (steam, hot water)	0.65

Figure 202-16

Coefficient of Performance: The ratio of the total net cooling output to the total heating input (electrical auxiliary inputs excluded).

Energy for Air Delivery

The air transport factor for each all-air HVAC system shall not be less than 4.0. The factor shall be based on design system air flow for constant volume systems. The factor for variable air volume systems may be based on average conditions of operation. Energy for transfer of air through heat recovery devices shall not be included in determining the factor; however, such energy shall be included in the evaluation of the effectiveness of the heat recovery system.

$$\text{Air Transport Factor} = \frac{\text{Space Sensible Heat Removal}^*}{(\text{Supply} + \text{Return Fan(s) Power Input})^*}$$

*Expressed in Btu/h

Cooling with Outdoor Air

Each fan system shall be designed to use up to and including 100 percent of the fan system capacity for cooling with outdoor air automatically whenever its use will result in lower usage of new energy.

EXCEPTIONS: Cooling with outdoor air is not required under any one or more of the following conditions:

- a. Fan system capacity less than 5,000 ft³/min or 134,000 Btu/h total cooling capacity.
- b. The quality of the outdoor air is so poor as to require extensive treatment of the air and approval by the Building Official.
- c. The need for humidification or dehumidification requires the use of more energy than is conserved by the outdoor air cooling.
- d. The use of outdoor air cooling may affect the operation of other systems so as to increase the overall energy consumption of the building.
- e. Internal/external zone heat recovery or other energy recovery is used.
- f. Annual degree days are less than 2500.
- g. When all space cooling is accomplished by a circulating liquid

which transfers space heat directly or indirectly to a heat rejection device such as a cooling tower without the use of a refrigeration system.

Controls

a. Temperature Control: Each HVAC system shall be provided with at least one thermostat for the regulation of temperature. Each thermostat shall be limited as follows:

1. Where used to control heating only, a maximum temperature of 75F.
2. Where used to control cooling only, a minimum temperature of 70F.
3. Where used to control both heating and cooling it shall have a maximum high temperature setting of 85F and a minimum low temperature setting of 55F and shall be capable of operating the system heating and cooling in sequence. It shall be adjustable to provide a temperature range of up to 10F between full heating and full cooling.

b. Humidity Control: If a HVAC system is equipped with a means for adding moisture to maintain specific selected relative humidities in spaces or zones, a humidistat shall be provided. This device shall be capable of being set to prevent new energy from being used to produce space relative humidity above 30 percent rh. Where a humidistat is used in an HVAC system for controlling moisture removal to maintain specific selected relative humidities in spaces or zones, it shall be capable of being set to prevent new energy from being used to produce a space relative humidity below 60 percent relative humidity.

EXCEPTION: Special occupancies requiring different relative humidities may be permitted by the Building Official.

c. Zoning for Temperature Control:

1. One- and Two-Family Dwellings: At least one thermostat for regulation of space temperature shall be provided for each separate HVAC system. In addition, a readily accessible manual or automatic means shall be provided to partially restrict or shut off the heating and/or cooling input to each zone or floor.
2. Multi-Family Dwellings: For multi-family dwellings, each individual dwelling unit shall be considered separately and shall meet the requirements for one- and two-family dwellings.

3. All Other Types of Buildings or Occupancies: At least one thermostat for regulation of space temperature shall be provided for:

- a. Each separate HVAC system.
- b. Each separate zone with each floor of a building being considered a separate zone.

In a multi-story building where the perimeter system offsets only the transmission losses of the exterior wall, an entire side of uniform exposure may be zoned separately. A readily accessible manual or automatic means shall be provided to partially restrict or shut off the heating and/or cooling input to each floor.

4. Control Setback and Shut-off:

- a. Residential Occupancy Groups: One- and Two-Family and Multi-Family Dwellings - The thermostat, an alternate means including a switch or clock, shall provide a readily accessible means for reducing the energy required for heating and cooling during periods of non-use or reduced need including unoccupied periods and sleeping hours.
- b. Other Buildings and Occupancies: Each HVAC system shall be equipped with a readily accessible means of shutting off or reducing the energy used for HVAC during periods of non-use or alternate uses of the building spaces or zones served by the system.

Air Handling Duct System Insulation

- a. All duct systems shall be insulated to provide a thermal resistance, excluding film resistances of:

$$R = \frac{\Delta t}{15} (h) (F) (ft^2)/Btu$$

where Δt = the design temperature differential between the air in the duct and the surrounding air in F.

EXAMPLE:

The design temperature of air in a duct system is 100°F and it passes through an unheated crawl space. If the design temperature of the crawl space is 40°F, what is the required thermal resistance of the duct insulation?

SOLUTION:

$$\Delta t = 100^{\circ}\text{F} - 40^{\circ}\text{F} = 60^{\circ}\text{F}$$

$$R = \frac{\Delta t}{15} = \frac{60}{15} = 4.0$$

EXCEPTIONS: Duct insulation (except where required to prevent condensation) is not required in any of the following cases:

1. Where Δt is 25F or less.
 2. Supply or return air ducts installed in unventilated crawl spaces, basements or cellars with insulated walls in one- and two-family dwellings.
 3. When the heat gain or loss of the ducts, without insulation, will not increase the energy requirements of the building.
 4. Within HVAC equipment.
 5. Exhaust air ducts.
- b. Vapor barriers and additional insulation shall be provided to prevent condensation.

EXCEPTION: Vapor barriers and additional insulation may be omitted when it can be shown that condensation is not a problem.

Piping Insulation

All piping installed to service buildings and within buildings shall be thermally insulated in accordance with Table 5-8 of the Code. (See Figure 202-17.)

- a. Other Insulation Thickness: Insulation thicknesses in Table 5-8 are based on insulation having thermal resistance in the range of 4.0 h F ft²/Btu to 4.6 h F ft²/Btu per inch of thickness. Minimum insulation thickness shall be increased for materials having R values less than 4.0, or may be reduced for materials having R values greater than 4.6.
1. For materials with thermal resistance greater than R = 4.6, the minimum insulation thickness may be reduced as follows:

$$\frac{4.6 \times \text{Table 5-8 Thickness}}{\text{Actual R}} = \text{New Minimum Thickness}$$

TABLE 5-8 MINIMUM PIPE INSULATION

PIPING SYSTEM TYPES	FLUID TEMPERATURE RANGE, F	INSULATION THICKNESS IN INCHES FOR PIPE SIZES					
		RUN-OUTS UP TO 2" ¹	1" AND LESS	1½ to 2"	2½ to 4"	5" to 6"	8" AND LARGER
HEATING SYSTEMS							
Steam and Hot Water							
High Pressure/Temp	306-450	1½	1½	2	2½	3½	3½
Med. Pressure/Temp	251-305	1½	1½	2	2½	3	3
Low Pressure/Temp	201-250	1	1	1½	1½	2	2
Low Temperature	120-200	½	3/4	1	1	1	1½
Steam Condensate (for Feed Water)	Any	1	1	1	1½	1½	2
COOLING SYSTEMS							
Chilled Water	40-55	½	½	3/4	1	1	1
Refrigerant, or Brine	Below 40	1	1	1½	1½	1½	1½

¹Runouts not exceeding 12' in length to Individual Terminal Units.

Figure 202-17

EXAMPLE:

What is the required thickness of pipe insulation having a thermal resistance (R) of 6 if it is designed to insulate a 3" medium temperature line for a steam heating system?

SOLUTION:

From Figure 202-17, enter the column Piping System Types and under Heating Systems find Medium Pressure/Temp and read from column to right titled 2 1/2" to 4" -- 2 1/2". Substitute this Table 5-8 thickness in the equation.

$$\text{New Minimum Thickness} = \frac{4.6 \times \text{Table 5-8 Thickness}}{\text{Actual R}}$$

$$\begin{aligned} \text{Results in a required thickness of:} &= \frac{4.6 \times 2 \frac{1}{2}}{6} \\ &= 1.91 \text{ or say } 2" \text{ thick} \end{aligned}$$

2. For materials with thermal resistance less than R = 4.0, the minimum insulation thickness shall be increased as follows:

$$\frac{4.0 \times \text{Table 5-8 Thickness}}{\text{Actual R}} = \text{New Minimum Thickness}$$

EXAMPLE:

What is the required thickness of pipe insulation having a thermal resistance (R) of 3 if it is designed to insulate a 1 3/4" low temperature line for hot water heating?

SOLUTION:

From Figure 202-17 enter the column Piping System Types and under Heating Systems find low temperature and read from column to right titled 1 1/4" to 2" - 1". Substitute this Table 5-8 thickness in the equation.

$$\text{New Minimum Thickness} = \frac{4.0 \times \text{Table 5-8 Thickness}}{\text{Actual R}}$$

$$\begin{aligned} \text{Results in a required thickness of:} &= \frac{4.0 \times 1.0}{3.0} \\ &= 1.33 \text{ or say } 1 \frac{3}{8}'' \text{ thick} \end{aligned}$$

EXCEPTIONS: Piping insulation is not required in any of the following cases:

- (1) Piping installed within HVAC equipment.
- (2) Piping at temperatures between 55F and 120F when not required for energy conservation purposes.
- (3) When the heat loss and/or heat gain of the piping, without insulation, does not increase the energy requirements of the building.
- (4) Piping, installed in unventilated crawl spaces and basements or cellars with insulated walls in one- and two-family dwellings.

- b. Vapor barriers and additional insulation shall be provided to prevent condensation.

EXCEPTION: Vapor barriers and additional insulation may be omitted when it can be shown that condensation is not a problem.

Water Heaters, Storage Tanks, Boilers and Piping

a. Performance Efficiency

1. **Electric Storage Water Heaters:** All automatic, electric, storage water heater(s) shall have a stand-by loss not exceeding 4W/ft² of tank surface area.

2. Gas and Oil Fired Storage Water Heaters: All gas and oil fired, automatic storage water heaters shall have a recovery efficiency (E_r not less than 75 percent and a stand-by loss percentage (S) not exceeding:

$$S = 2.3 + 67/V$$

where: V = rated volume in gallons

3. Insulation: Heat loss from unfired hot water storage tanks shall be limited to a maximum of 15 Btu/h ft² of external tank surface area. The design ambient temperature shall be no higher than 65F.
4. Combination Service Water Heating/Space Heating Boilers: Service water heating equipment shall not be dependent on year round operation of space heating boilers; (that is, boilers that have as another function winter space heating).

EXCEPTION: Exempt from these requirements are systems with service/space heating boilers having a stand-by loss Btu/h less than:

$$\frac{13.3 \text{ pmd} + 400}{n}$$

pmd = probable maximum demand in gallons/hour as determined in accordance with Chapter 11 of RS-11.

n = fraction of year when outdoor daily mean temperature exceeds 64.9F.

The stand-by loss is to be determined for a test period of 24 h duration while maintaining a boiler water temperature of 90F above ambient.

b. Temperature Controls

1. Service water heating systems shall be equipped with automatic temperature controls capable of adjustment from the lowest to the highest acceptable temperature settings for the intended use.
2. Shut down: A separate switch shall be provided to permit turning off the energy supplied to electric service water heating systems. A separate valve shall be provided to permit turning off the energy supplied to the main burner(s) of all other types of service water heating systems.
3. Swimming Pools:
 - a. Heated swimming pools shall be equipped with controls to limit heating water temperatures to no more than 80F.

EXCEPTION: Pools used for therapeutic purposes are exempt from this requirement when approved by the Building Official.

- b. Uncovered and unenclosed heated pools shall be controlled so that the electric or fossil-fueled pool water heating systems are inoperative whenever the outdoor air temperature is below 60F.

c. Circulating Systems

1. Pump Operation: Circulating hot water systems shall be arranged so that the circulating pump(s) can be conveniently turned off, automatically or manually, when the hot water system is not in operation.
2. Insulation: For recirculation systems, piping heat loss shall be limited to a maximum of 25 Btu/h ft² of external pipe surface for above ground piping and a maximum of 35 Btu/h ft² of external pipe surface for underground piping. Maximum heat loss shall be determined at a Δt equal to the maximum water temperature minus a design ambient temperature no higher than 65F.

d. Conservation of Hot Water

1. Showers: Showers used for other than safety reasons shall be equipped with flow control devices to limit total flow to a maximum of 3 gpm per shower head.
2. Lavatories in Restrooms of Public Facilities shall:
 - a. Be equipped with outlet devices which limit the flow of hot water to a maximum of 0.5 gpm.
 - b. Be equipped with devices which limit the outlet temperature to a maximum of 110F.
 - c. Be equipped with self closing valves that limit delivery to a maximum of 0.25 gallons of hot water.

Electrical Distribution Systems

Scope

Electrical distribution systems shall be designed for efficient distribution of electrical energy from the service entrance to the points of use.

Power Factor: Utilization equipment, rated greater than 1,000 W and lighting equipment greater than 15 W, with an inductive reactance load component, shall have a power factor of not less than 85 percent under rated load conditions. Power factor of less than 85 percent shall be corrected to at least 90 percent under rated load conditions. Power factor corrective devices, installed to comply with this Code, shall be switched with the utilization equipment, except where this results in an unsafe condition or interferes with the intended operation of the equipment.

Service Voltage: Where a choice of service voltage is available, a computation shall be made to determine which service voltage would produce the least energy loss, and that voltage shall be selected.

Voltage Drop: In any building, the maximum total voltage drop shall not exceed 3 percent in branch circuits or feeders, for a total of 5 percent to the farthest outlet based on steady state design load conditions.

Lighting Switching: Switching shall be provided for each lighting circuit, or for portions of each circuit, so that lighting may be operated selectively.

Electric Energy Determination: In all multi-family dwellings, provisions shall be made to determine the energy consumed by each tenant by separately metering individual dwelling units.

EXCEPTION: Motels, hotels and dormitories are exempt from these requirements.

Lighting Power Budget

The lighting power budget for the building shall be the sum of the power limits computed for all lighted interior and exterior spaces and shall be determined in accordance with the procedures specified in this section.

Calculation Procedure

To establish a lighting power budget, the following procedures shall be used:

a. Determining Illumination Levels and Areas:

1. Determine the visual tasks that are expected to be performed in each space (the commonly found tasks at each work station) and the number of planned work locations where tasks will be performed.
2. Select the illumination level, in footcandles for those expected tasks.

3. Calculate total task areas to be illuminated to the same level by multiplying the number of work locations by 50 ft² per work location. (Total task area shall not exceed actual space area.) If the actual task area is greater than 50 ft², the actual area shall be used. If special task lighting or localized lighting is to be employed, use the actual task areas and point calculation procedures.
4. Calculate the level of general lighting by multiplying the task lighting level by one-third, where there is only one task level, or by taking one-third of the sum of the products of the task levels (2) and their areas (3) divided by the total task areas.
5. Calculate the level of non-critical lighting.

b. Determining Lighting System Data:

1. Determine light source and luminaire types to use.
2. Determine lamp lumens per watt and luminaire coefficients of utilization for room and luminaire mounting height dimensions. In all cases, no luminaire shall have a CU for RCR = 1 or less than that given in Table 5-10 of the Code (See Figure 202-18). Lamp efficacies shall be those listed in Table 10 A of the Code (See Figure 202-18.)

c. Determining Allowable Wattage:

1. Using data from b., the illumination levels and areas determined in a. and the criteria of Table 5-10 C of the Code (See Figure 202-18), calculate the allowable wattages using the lumen method.
2. Calculate the total space wattage by adding the task, general and noncritical lighting loads.
3. Add the wattage of luminaires. This then becomes the light wattage.

LIGHTING BUDGET TERMS

Task Lighting: The levels of illumination for specific work tasks. The levels of illumination may be determined from the IES Lighting Handbook.

General Lighting: In areas surrounding task locations, the average level of general lighting, for budget purposes only, shall be one-third the level for the tasks performed in the area but in no case less than 20 footcandles. Where more than one task level occurs in a space, the general level shall be one-third the weighted average of the specific task levels.

TABLE 5-10 A

LAMP EFFICACIES

Application	Lumens per Watt
Where moderate color rendition is appropriate	55
Where good color rendition is appropriate	40
Where high color rendition is appropriate, spaces are less than 50 ft ² or where use of low wattage High Intensity Discharge (HID) lamps under 250 W or fluorescent lamps under 40 W is appropriate	25

¹The initial lumen output per watt input, including ballast losses.

TABLE 5-10 B

LUMINAIRE COEFFICIENTS OF UTILIZATION (CU)¹

Space Use	Minimum CU (at RCR = 1)
For spaces with tasks subjected to veiling reflections (where design levels of illumination are listed in terms of equivalent sphere illumination (ESI) and where visual comfort is important.	0.55
For spaces without tasks, or with tasks not subjected to veiling reflections, but where visual comfort is important.	0.63
For spaces without tasks and where visual comfort is not a criterion.	0.70

¹Coefficients of utilization (CU's) are to be for luminaires for use in the types of spaces listed, and those luminaires shall have a CU of no less than that listed for each type space for a Room Cavity Ratio (RCR) of 1 and reflect areas as in Table 5-10C.

TABLE 5-10 C

REFLECTANCES & LIGHT LOSS FACTORS

INTERIOR SPACES ¹	REFLECTANCE	LIGHT LOSS FACTOR
Ceiling Cavity	80 percent	0.70
Wall	50 percent	
Floor Cavity	20 percent	

¹For interior spaces, initial cavity and surface reflectances shall be shown.

FIGURE 201-18

Non-Critical Lighting: In circulation and seating areas where no specific visual tasks occur, the average level of illumination shall be one-third of the average general lighting in the adjacent task spaces but in no case less than 10 footcandles.

Lighting System Criteria: For the purposes of establishing a power budget, only lamp efficacies and coefficients of utilization (CU), specified in Table 5-10 of the Code, shall be assumed. (See Figure 202-18.)

Facade Lighting: Facade lighting for budget purposes shall be no greater than 2 percent of the total interior load of the building.

Floodlighting: The beam lumen method and a coefficient of beam utilization (CBU) of 0.75 shall be used for floodlighting calculations.

Exceptions to Criteria

- a. The criteria for calculating the light power budget shall not apply to the following areas when calculating the load:
 1. Portions of residential occupancies except for kitchens, bathrooms and laundry areas and public spaces including lobbies, halls, stairways, basement areas and utility rooms.
 2. Residential type spaces similar to 1 above in institutions, such as hospitals, hotels, funeral homes, churches, museums, etc.
 3. Theatre auditoriums, entertainment, audio-visual presentations and motion picture and television studios where the lighting is an essential technical element for the function performed.
- b. Lamp efficacies and coefficients of utilization (CU), specified in Table 5-10 of the Code, shall not apply to the following lamps and luminaires; however, their use shall be accounted for in the calculation of task lighting loads for specific tasks. The allowable load shall be based on the luminaire wattage to achieve the levels of illumination using the point calculation method.
 1. Luminaires for medical and dental purposes.
 2. Luminaires for highlighting applications, such as sculpture exhibits, art exhibits and individual items of display merchandise.
 3. Luminaires for specialized lighting applications (color matching, where electrical interference cannot be tolerated, etc.).

- c. The criteria of Table 5-10 C of the Code shall not apply in spaces where it is impractical to control reflectances and where a dirty atmosphere cannot be avoided. Where this condition exists, the values for reflectances and light loss factors shall be those expected to be found.

SECTION 6 - BUILDING DESIGN BY ACCEPTABLE PRACTICE

General: The requirements contained in Section 6 are applicable only to buildings less than five thousand square feet in gross floor area and three stories or less in height. The provisions of this section are limited to residential buildings that are heated and/or mechanically cooled and to other buildings that are heated.

Building Envelope:

- a. Walls: The opaque above-grade exterior wall section (U_w) shall be selected from Appendix Table 6-1A, B or C of the Code (See Table 202-A) for the combined thermal transmittance value (U_o value), not exceeding the value specified for walls in Table 5-1 or 5-2 of the Code. The U_w value is determined by the use of Appendix Charts 6-A or 6-B of the Code (See Charts 202-1A, 202-1B). The following example will provide a better understanding of the use of these tables.

EXAMPLE:

A 4,500 S.F. convenience store is to be constructed in Worcester, Massachusetts. The wall of the building is to be 8" concrete block with voids filled with insulation. The interior finish is 1/2" gypsum wallboard on wood furring strips. The building has 20% doubled glazed openings in the wall. Does the exterior wall construction satisfy the Code?

SOLUTION:

Step One: Determine allowable U_o from Table 5-2 (Example 2 in Section 5). It is determined that the U_o required is 0.26.

Step Two: Determine U_w opaque wall from Table 202-B. It is determined that the U_w of the opaque wall is 0.14.

Step Three: Determine U_o of the wall from Chart 202-1B. It is determined that U_o actual is 0.23 which is less than 0.26; therefore the design conforms to the Code.

WALL ASSEMBLIES
TABLE 6-1A

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
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		
<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); margin-right: 5px;">WOOD STUD CONSTRUCTION</div> <div style="flex: 1;"> <div>INTERIOR FINISH SEE SCHEDULE</div> <div style="border-left: 1px solid black; border-right: 1px solid black; height: 100px; position: relative;"> <div style="position: absolute; top: 0; left: 0; right: 0; height: 100%; background: repeating-linear-gradient(45deg, transparent, transparent 2px, black 2px, black 4px);"></div> </div> <div>INSULATION</div> </div> <div style="margin-left: 10px;"> <div>EXTERIOR FINISH SEE SCHEDULE</div> </div> </div>		7	.12
		11	.09
		14	.07
		19	.05
<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); margin-right: 5px;">WOOD STUD CONSTRUCTION</div> <div style="flex: 1;"> <div>AIR SPACE</div> <div style="border-left: 1px solid black; border-right: 1px solid black; height: 100px; position: relative;"> <div style="position: absolute; top: 0; left: 0; right: 0; height: 100%; background: repeating-linear-gradient(45deg, transparent, transparent 2px, black 2px, black 4px);"></div> </div> <div>INTERIOR FINISH SEE SCHEDULE</div> </div> <div style="margin-left: 10px;"> <div>EXTERIOR FINISH SEE SCHEDULE</div> <div>RIGID INSULATION PLAN VIEW</div> </div> </div>		4	.15
		6	.11
		8	.09
		10	.08
		12	.06
<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); margin-right: 5px;">STEEL STUD CONSTRUCTION</div> <div style="flex: 1;"> <div>INTERIOR FINISH SEE SCHEDULE</div> <div style="border-left: 1px solid black; border-right: 1px solid black; height: 100px; position: relative;"> <div style="position: absolute; top: 0; left: 0; right: 0; height: 100%; background: repeating-linear-gradient(45deg, transparent, transparent 2px, black 2px, black 4px);"></div> </div> <div>INSULATION</div> </div> <div style="margin-left: 10px;"> <div>EXTERIOR FINISH SEE SCHEDULE</div> </div> </div>		7	.12
		11	.08
		14	.06
		19	.05
<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); margin-right: 5px;">STEEL STUD CONSTRUCTION</div> <div style="flex: 1;"> <div>AIR SPACE OR INSULATION</div> <div style="border-left: 1px solid black; border-right: 1px solid black; height: 100px; position: relative;"> <div style="position: absolute; top: 0; left: 0; right: 0; height: 100%; background: repeating-linear-gradient(45deg, transparent, transparent 2px, black 2px, black 4px);"></div> </div> <div>INTERIOR FINISH SEE SCHEDULE</div> </div> <div style="margin-left: 10px;"> <div>EXTERIOR FINISH SEE SCHEDULE</div> <div>INSULATION PLAN VIEW</div> </div> </div>		4	.15
		6	.11
		8	.09
		10	.08
		12	.06

Table 202-A

WALL ASSEMBLIES
TABLE 6-1B

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.

MASONRY CONSTRUCTION	WALL DETAILS	R VALUE OF INSULATION	U_w
	INT. FINISH - 1/2" GYPSUM BOARD ON FURRING STRIPS
		NO INSUL.	.37
		LOOSE FILL IN CORES	.18
		NO INSUL.	.34
		LOOSE FILL IN CORES	<u>.14</u>
		NO INSUL. (NO INT. FINISH)	.25
		LOOSE FILL IN CAVITY	.14
		NO INSUL. WITH INT. FIN.	.19
		LOOSE FILL IN CAVITY WITH INT. FINISH	.11
		NO INSUL. INT. FINISH	.23
		LOOSE FILL IN CORES WITH INT. FINISH	.12
		1" RIGID GLASS FIBER INSUL. & INT. FINISH	.14
		R-7 INSUL. WITH INT. FINISH	.10

Table 202-B

WALL ASSEMBLIES
TABLE 6-1C

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
INT. FINISH - 1/2" GYPSUM BOARD APPLIED ON FURRING STRIPS			
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">BRICK</div> <div style="margin-left: 10px;">BRICK</div> </div> <div style="margin-left: 200px;"> <div style="margin-bottom: 5px;">LOOSE FILL</div> </div>	SOLID GROUT IN SPACE		.38
	2" SPACE W/ LOOSE FILL R=4		.16
	4" SPACE W/ LOOSE FILL R=8		.10
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">BRICK</div> <div style="margin-left: 10px;"> <div>INTERIOR FINISH</div> <div>INSULATION</div> </div> </div>	4		.12
	6		.09
	7		.09
	11		.07
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">4"Min.</div> <div style="margin-left: 10px;"> <div>INTERIOR FINISH</div> <div>INSULATION</div> </div> </div> <div style="margin-left: 10px;"> <div>NORMAL WT. CONCRETE</div> </div>	4		.18
	6		.13
	7		.12
	11		.08
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">LT.WT. CONCRETE</div> <div style="margin-left: 10px;"> <div>INTERIOR FINISH</div> <div>INSULATION</div> </div> </div>	4		.17
	6		.12
	7		.11
	11		.08

Table 202-C

Combinations of Wall and Single Glazed Openings for Use with Section 602.2(a)

One-half the opaque door area shall be included in the total glazed openings area.

Glass, percent of wall surface¹
 Combinations of Wall and Double Glazed Openings for Use with Section 602.2(a)

¹The total area of opaque doors shall be included in the glazed opening area.

- b. Roof/Ceilings: The roof/ceiling assembly shall be selected from Appendix Table 6-2 of the Code (See Table 202-D) for the thermal transmittance value not exceeding the value specified for roof/ceiling in Table 5-1 or 5-2 of the Code. The following example will further the understanding of the use of this Table.

EXAMPLE:

A 4,500 S.F. convenience store is to be constructed in St. Paul, Minnesota. The Roof/Ceiling system of the building is flat and consists of a built up roof over wood sheathing and wood floor joists. The ceiling is gypsum wallboard nailed directly to the joist and the void area between the joists contains R-11 Insulation. Does the Roof/Ceiling Assembly design conform to the Code?

SOLUTION:

Step One: Determine allowable U_o from Table 5-2 (Example 2 in Section 5). It is determined that U_o required is 0.06.

Step Two: Determine Actual U_r from Table 202-D. It is found that U_r actual is 0.08 which is greater than the allowed 0.06; therefore, the design does not conform to the Code.

- c. Floors over Unheated Spaces: The floor section over an unheated space shall be selected from Appendix Table 6-3 of the Code (See Figure 202-E) for the thermal transmittance value (U_o value) not exceeding the value specified for floors in Table 5-1 or 5-2 of the Code. The following example will afford an opportunity to better understand the use of the Table.

EXAMPLE:

A 4,500 S.F. convenience store is to be constructed in San Francisco, California. The floor system consist of asphalt tile over plywood and wood floor joists. The voids between the joists contain insulation with an R value of 11. Does the floor system design conform to the Code?

SOLUTION:

Step One: Determine allowable U_o from Table 5-2 (Example 2 in Section 5). It is determined that U_o maximum is 0.18.

Step Two: Determine Actual U_f from Table 202-E. It is found that U_f actual is 0.15 which is less than the allowed 0.18; therefore, the design conforms to the Code.

ROOF/CEILING ASSEMBLIES
TABLE 6-2

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
	11	.09
	14	.07
	19	.05
	22	.04
	30	.03
	11	.08
	14	.06
	19	.05
	22	.04
	30	.03
CATHEDRAL TYPE CEILING	wood decking 9	.08
	plywood 10	.08

1. SKYLITES NOT EXCEEDING ONE PERCENT OF THE ROOF AREA ARE PERMITTED.

Table 202-D

FLOOR ASSEMBLIES
TABLE 6-3

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. Below it is a sub-floor. The sub-floor is supported by floor joists, which are in turn supported by floor girders. The floor girders are supported by concrete piers. Labels with leader lines point to each component: INSULATION, SUB-FLOOR, FLR. JOIST, FLR. GIRDER, and CONC. PIER.</p>	NO INSULATION	.32
	4	.15
	6	.12
	7	.11
	11	.08

Table 202-E

- d. Slab on Grade Floors: For slab on grade floors, thermal resistance (R) of the insulation around the perimeter of the floor shall not be less than the value given in Table 5-1 of the Code. The insulation shall extend downward from the top of the slab for a minimum distance of 24 inches or downward to the bottom of the slab then horizontally beneath the slab for a minimum total distance of 24 inches. As you may have noted, these requirements are identical to those presented in Section 5.
- e. Air Leakage: These requirements are identical to those discussed in Section 5.
1. Windows and Doors: All windows and doors shall be labeled as conforming to the air infiltration rates specified in Table 5-3 of the Code (See FIGURE 202-12).

ALLOWABLE AIR INFILTRATION RATES

WINDOWS	RESIDENTIAL DOORS	NON-RESIDENTIAL DOORS
(cfm per foot of operable sash crack)	(cfm per square foot of door area)	(cfm per lin. foot of crack)
	Sliding Glass (Patio Type)	Swinging, Sliding, Revolving
0.5	0.5	11.0

Figure 202-12

2. Caulking: Exterior joints around windows and door frames; openings between walls and foundations, between walls and roof and between wall panels; openings at penetrations of utility services through walls, floors and roofs; and all other such openings in the building envelope shall be caulked, gasketed, weatherstripped or otherwise sealed in an approved manner.

BUILDING MECHANICAL SYSTEMS: Generally the requirements in Section 6 are the same as those in Section 5.

General: The design temperatures specified in completed Table 3-1 of the Code shall be the bases for sizing mechanical equipment.

Performance Requirements: All heating and mechanical cooling equipment shall meet the required efficiency factor specified herein or in Tables 6-4, 6-5, 6-6 and 6-7 of the Code. (See Figure 202-19).

**TABLE 6-4
MINIMUM COP FOR HEAT PUMPS, HEATING MODE¹**

SOURCE AND OUTDOOR TEMPERATURE (F)	MINIMUM COP
Air Source - 47 dB/43WB	2.2
Air Source - 17 dB/15WB	1.2
Water Source - 60 Entering	2.2

¹When tested at the Standard Rating specified in Table 5-9A.

**TABLE 6-5 - MINIMUM EER AND COP
FOR ELECTRICALLY DRIVEN HEATING, VENTILATING AND
AIR CONDITIONING SYSTEM EQUIPMENT - COOLING¹**

STANDARD RATING CAPACITY	EER	COP
Under 65,000 Btu/h (19050 watts)	.6.1	1.8
65,000 Btu/h (19,050 watts and over)	6.8	2.0

¹When tested at the Standard Rating Conditions specified in Table 5-9B.

**TABLE 6-6 - MINIMUM EER AND COP
FOR ELECTRICALLY DRIVEN HEATING, VENTILATING AND
AIR CONDITIONING SYSTEM COMPONENTS¹**

COMPONENT	CONDENSING MEANS	AIR		WATER		EVAPORATOR	
		EER	COP	EER	COP	EER	COP
	Centrifugal	7.5	2.2	12.9	3.8		
Self-contained Water chillers	Positive Displacement	7.2	2.1	10.9	3.2		
Condenserless Water Chillers	Positive Displacement	8.9	2.6	10.9	3.2		
Compressor and Condenser units 65,000 Btu/h (19,050 watts and over) ²	Positive Displacement	7.8	2.3	11.3	3.3	11.3	11.3

¹When tested at the Standard Rating Conditions specified in Table 5-9C.

²Ratings in accordance with Std RS-14 as applicable. COP based on condensing unit Standard Rating Capacity and energy input to the unit, all at sea level.

**TABLE 6-7 - MINIMUM COP
FOR HEATING, VENTILATING AND AIR
CONDITIONING SYSTEM HEAT OPERATED
COOLING EQUIPMENT**

HEAT SOURCE	MINIMUM COP
Direct fired (gas, oil)	0.40
Indirect fired (steam, hot water)	0.65

Figure 202-19

Combustion Heating Equipment: All gas and oil fired comfort heating equipment shall show a minimum combustion efficiency of 75 percent at maximum rated output. Combustion efficiency is defined as 100 percent minus stack losses in percent of heat input.

a. Control:

1. Temperature: Each heating system shall be provided with at least one thermostat for the regulation of temperature. Each thermostat shall be capable of being set as follows:

Where used to control heating only -- 55-75F

Where used to control cooling only -- 70-85F

Where used to control both heating and cooling, it shall have a maximum high temperature setting of 85F and a minimum low temperature setting of 55F and shall be capable of operating the system heating and cooling in sequence. It shall be adjustable to provide a temperature range of up to 10F between full heating and full cooling.

b. Zoning for Temperature Control:

1. One- and Two-family Dwellings: At least one thermostat for regulation of space temperature shall be provided for each separate HVAC system. In addition, a readily accessible manual or automatic means shall be provided to partially restrict or shut off the heating or cooling input to each zone or floor.

EXCEPTION: Non-conditioned basements and garages.

2. Multi-family Dwellings: For multi-family dwellings, each individual dwelling unit shall be considered separately and shall meet the requirements of Section 603.1(c)1. Spaces other than living units shall meet the requirements for one- and two-family dwellings.
3. Control Setback and Shutoff: One- and Two-family and Multi-family Dwellings. The thermostat required in (1) and (2) or an alternate means, such as a switch or clock, shall provide a readily accessible, manual or automatic means for reducing the energy required for heating and cooling during periods of non-use or reduced need including but not limited to, unoccupied periods and sleeping hours. Lowering thermostat set points to reduce energy consumption of heating systems shall not cause energy to be expended to reach the reduced setting.

Identical Subsections

The following subsections of Section 6 are identical to those in Section 5.

AIR HANDLING

DUCT SYSTEM INSULATION

PIPING INSULATION

SERVICE WATER HEATING

ELECTRICAL POWER AND LIGHTING, with the exception that one- and two-family detached dwellings and the dwelling portion of multi-family dwellings are exempt from a Lighting Power Budget.

CHAPTER IV

MODEL ENERGY CODE APPLICATIONS

(ECT-203)

In this section, we will present a study showing the impact of the Model Energy Code on new building construction. This study will be followed by practical exercises presenting the student with the type of plans and data he will be required to review prior to issuance of a building permit. These examples will cover a broad range of climatic conditions and include examples of:

- Conforming envelope design
- Non-conforming envelope design
- Accepted practice

MODEL CODE STUDY

The Model Code Study was accomplished by testing ASHRAE 90-75, the code on which the Model Code was based. This study was performed by Arthur D. Little, Inc.

The Arthur D. Little Study

As discussed earlier the purpose of the Arthur D. Little, Inc. (ADL) investigation was to analyze the various energy, economic and institutional impacts that might occur following broad adoption of ASHRAE Standard 90-75. 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.

For each case, ADL estimated annual energy consumption using established methods for single-family residences and computer-based simulation techniques for non-residential structures. Two sets of calculations were made: one for the "conventional" building; and, one for the "ASHRAE 90 modified" building.

Next, ADL determined the comparative impact of ASHRAE 90 on each of the following

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

The ADL report presents many findings, observations and recommendations concerning ASHRAE 90's effect on building energy consumption, its influences on physical changes in the buildings 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.

Construction costs for the ADL report were based on 1973 construction practices. This date was prior to the major concern with energy conservation and energy shortages which resulted in many construction practice changes. Even at that time, however, many energy conservation measures were being taken and are reflected in the study.

REPRESENTATIVE LOCATIONS SELECTED FOR COMPUTER
ANALYSIS OF PROTOTYPICAL BUILDINGS

		Location Selected		
	<u>City</u>	<u>Degree Days</u>	<u>Summer Design Conditions</u>	
			<u>db</u>	<u>wb</u>
Northeast	New York (Airport)	5,219	87°	76°
North Central	Omaha	6,612	94°	78°
South	Atlanta	2,961	92°	77°
West	Albuquerque	4,348	94°	65°

TABLE 203-1

The buildings selected for study were considered representative. In the residential sector, the majority of the dwellings constructed within the United States in any given year are detached single-family residences. The remaining volume is referred to as multi-family and consists of low-density housing (2-4 units), low-rise apartments (e.g., garden apartments, townhouses, etc.) and high-rise apartments. Structures of three stories or less (i.e., low-rise) typically account for 75% to 80% of the multi-family units erected, with high-rise construction (i.e., greater than seven stories) responsible for the remainder. On the basis of this volume, the two residential building types which were selected for analysis were a single-family house and a low-rise apartment building.

Sixteen major classifications of building types comprise the nonresidential sector. On the basis of the comparative square footage

of new floor area, a representative building type was selected for each of the three largest classifications:

- a single-story retail store (store and mercantile),
- a low-rise office building (offices and banks),
- a single-story school (educational).

It was felt that the suburban school building chosen was also indicative of college and university buildings. ADL also assumed that government buildings were similar to the commercial office building already selected.

A review of the building types selected shows a spectrum of energy demand for comfort conditioning which includes both intensive daytime usage (retail stores, office buildings, school) and continuous 24-hour demand (residential). Note that the buildings selected are prototypical and do not represent the average building within each region. In reality, there is an extreme diversity in the nonresidential category, and there is no statistically representative structure for any building type.

The four testing sites selected and their respective climatic data are shown in Table 203-1. Table 203-2 indicates which prototypical buildings were selected for which geographical regions. Table 203-3 summarizes the characteristics of each of the prototypical buildings.

BUILDING TYPE/LOCATION MATRIX

	<u>Northeast</u>	<u>North Central</u>	<u>South</u>	<u>West</u>
Single-Family Residence	SF ₁	SF ₁	SF ₂	SF ₃
Low-Rise Apartment Building	MFL ₁	MFL ₁	MFL ₂	MFL ₂
Office Building	OB ₁	OB ₁	OB ₂	OB ₂
Retail Store	RS ₁	RS ₁	RS ₁	RS ₁
School Building	SCH ₁	SCH ₁	SCH ₂	SCH ₂

TABLE 203-2

The single-family homes (SF₁, SF₂ and SF₃) were either of lapped wood siding, brick or stucco exterior depending upon geographical location. Sizes ranged from 1600 to 1700 square feet in area. All are single-story ranch style with sloped roofs. The amount of insulation assumed was based on discussions with several developers and home builders, and may or may not meet FHA insulation standards for federally assisted

residential construction. (The majority of new housing starts are not undertaken by large national developers nor are they financed under government programs.) In those buildings shown, wall insulation is roughly similar to either Standard R-7 or R-11 of the Code, and roof insulation is generally similar to Standard R-11. Window area was assumed to be 15% for all walls.

Perhaps the most important exercise in the entire project was the interpretation of the standard and its application to the prototypical buildings. Not only were the characteristics of the conventional building critical in selecting what had to be modified, but where there was a choice among several alternatives, it had to be determined how the building was to be modified.

The approach in modifying the conventional buildings was based upon professional design judgment as to what the architect/engineer would be most likely to do, and what the client would be most likely to permit aesthetically. In applying the standard, recommended numerical values listed in the standard were assumed to be targets, and as such, only the barest minimum of modification was undertaken to meet the targets. The philosophy was to meet, but not purposely exceed the standard, as it was felt that the client and design community will not choose to adopt major modifications in either building appearance or system performance. Such decisions are typically not controlled by life-cycle economics.

Using ASHRAE 90 on a case-by-case basis, changes were made in indoor and outdoor design conditions, exterior wall and roof heat transmittance, lighting levels, window area and type, etc. For each modification, actual materials and/or different HVAC equipment were selected which later formed the basis for determining the impact on the selected industry subsectors.

Tables 203-4 and 203-5 summarize the major physical changes made in prototypical single-family residences and low-rise apartment buildings. For reference purposes, the appropriate section of ASHRAE 90 is shown for each design parameter changed.

Figures 203-1, 203-2, 203-3, 203-4 and 203-5 indicate the savings achieved and the source of savings by applying ASHRAE 90 to the five prototypical buildings.

Table 203-6 lists eight selected parameters which contribute to the reduction of energy consumption under the prescriptive/performance approach of ASHRAE 90. For each parameter, a quantitative approximation reflecting the extent to which it contributes to annual energy reduction is given. The total reduction shown for each building type is the percent reduction for that building type averaged across the four regions.

DESCRIPTION OF CONVENTIONAL BUILDINGS USED IN THE ANALYSIS

Building	Total Area (Sq. Ft.)	Configuration (Ft.)	Number of Floors	Total Height (Ft.)	Exterior Wall Construction	Penetration	Roof Construction
BP ₁	1,600	32' x 50'	1, unheated basement	10	1/2" lapped wood siding; 1/2" plywood sheathing; 2" x 4" stud framing (16" o.c.); 3/4" fiberglass insulation; 1/2" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingles; 1/2" plywood sheathing; 3/4" fiberglass insulation; 1/2" Gypsum wallboard; ventilated attic; roof slopes: 3 in. 12.
BP ₂	1,675	33'6" x 50'	1, slab on grade	10	4" common brick, 2" x 4" stud framing (16" o.c.); 3/4" fiberglass insulation; 1/2" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingles; 1/2" plywood sheathing; 3/4" fiberglass insulation; 1/2" Gypsum wallboard; ventilated attic; roof slopes: 3 in. 12.
BP ₃	1,705	30' x 50'	1, crawl space	10	3/4" stucco; 8" concrete block; 3/4" fiberglass insulation; light framing; 1/2" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingles; 1/2" plywood sheathing; 3/4" fiberglass insulation; 1/2" Gypsum wallboard; ventilated attic; roof slopes: 3 in. 12.
MP ₁	18,000	50' x 180'	2, heated basement	24	1/2" lapped wood siding; 1/2" plywood sheathing; 2" x 4" stud framing (16" o.c.); 3/4" fiberglass insulation; 1/2" Gypsum wallboard.	Single-strength sheet; 30% sidewalls; 0% and walls.	Asphalt shingles; 1/2" plywood sheathing; 3/4" fiberglass insulation; 1/2" Gypsum wallboard; ventilated attic; roof slopes: 3 in. 12.
MP ₂	18,000	50' x 180'	2, slab on grade	24	4" common brick; 1/2" plywood sheathing; light framing; no insulation; 1/2" Gypsum wallboard.	Single-strength sheet; 30% sidewalls; 0% and walls.	Asphalt shingles; 1/2" plywood sheathing; 3/4" fiberglass insulation; 1/2" Gypsum wallboard; ventilated attic; roof slopes: 3 in. 12.
OS ₁	40,000	90' x 150'	3	36	6" precast concrete panels.	1/2" plate; 30% all walls.	4-ply built-up roofing with gravel; 2" rigid insulation; steel decking; open web joists; 1/2" softboard.
OS ₂	40,000	90' x 150'	3	36	1" insulated sandwich panel with aluminum mullions; structural steel framing.	1/2" plate; 30% all walls.	Metal deck; 4" poured concrete roofing; structural steel framing; 1/2" softwood hung ceiling.
BS ₁	32,400	180' x 180'	1	15	12" concrete block, painted both sides.	1/2" plate; 60% South wall; 0% all other walls.	4-ply built-up roofing with gravel; 2" rigid insulation; steel decking; open web joists; 1/2" softboard.
S ₁	40,000	180' x 400'	1	14	4" common brick, 1" fiberglass insulation, 4" concrete block.	Single-strength sheet; 20% all walls.	4-ply built-up roofing with gravel; 2" rigid insulation; steel decking; open web joists; 1/2" softboard.
S ₂	40,000	180' x 400'	1	14	4" common brick, no insulation, 4" concrete block.	Single-strength sheet; 20% all walls.	4-ply built-up roofing with gravel; 1" rigid insulation; 4" concrete plank; structural steel framing; 1/2" softboard.

TABLE 203-3

SINGLE FAMILY RESIDENCE: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

Design Variable	Applicable Section of ASHRAE 90-75	Northeast		North Central		South		West		
		Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75	
Design Conditions:										
Summer	Outdoor, °F DB/°F WB	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
	Indoor, °F DB/ TRM max		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
Winter	Outdoor, °F DB		12	21	-12	-1	14	23	6	17
	Indoor, °F DB		75	72	75	72	75	72	75	72
Exterior Envelopes:										
Glass Area (percent of gross wall area)	North	4.3.2.1	15	15	15	14.4	15	15	15	14.8
	East		15	15	15	14.4	15	15	15	14.8
	South		15	15	15	14.4	15	15	15	14.8
	West		15	15	15	14.4	15	15	15	14.8
Glass U (Btu/hr. ft. ² °F)			1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Wall U (Btu/hr. ft. ² °F)			0.087	0.063	0.087	0.063	0.087	0.087	0.087	0.087
Overall Wall "Uo" (Btu/hr. ft. ² °F)			0.24	0.22	0.24	0.21	0.24	0.24	0.24	0.24
Roof U (Btu/hr. ft. ² °F)		4.3.2.2	0.074	0.050	0.074	0.050	0.048	0.045	0.048	0.045
Floor Perimeter U (Btu/hr. ft. ² °F)		4.3.2.3, 4.3.2.4								
Lighting/Power (Watts/sq. ft.)		9.3, 9.4	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8
Ventilation (cfm/sq. ft.)										
Infiltration (Air Change/hr.)		4.5.3, 5.3.2.4	1.0	0.93	1.0	0.93	1.0	0.93	1.0	0.93
Domestic Hot Water Temperature Rise (°F)		7.3	100	70	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE 203-4

LOW-RISE APARTMENT BUILDING: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

Design Variable		Applicable Section of ASHRAE 90-75	Northeast		North Central		South		West	
			Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75
Design Conditions:										
Summer	Outdoor, °F DB/°F WB	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
	Indoor, °F DB/ RH max		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
Winter	Outdoor, °F DB		12	21	-12	-1	14	23	6	17
	Indoor, °F DB		75	72	75	72	75	72	75	72
Exterior Envelope:										
Glass Area (percent of gross wall area)	North	4.3.2.1	30	26.7	30	23.6	30	30	30	28.2
	East		0	0	0	0	0	0	0	0
	South		30	26.7	30	23.6	30	30	30	28.2
	West		0	0	0	0	0	0	0	0
Glass U (Btu/hr. ft. ² °F)			1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Wall U (Btu/hr. ft. ² °F)			0.093	0.068	0.093	0.068	0.370	0.072	0.370	0.072
Overall Wall "Uo" (Btu/hr. ft. ² °F)			0.340	0.290	0.340	0.264	0.550	0.334	0.550	0.305
Roof U (Btu/hr. ft. ² °F)		4.3.2.2	0.070	0.045	0.070	0.045	0.070	0.045	0.070	0.045
Floor Perimeter U (Btu/hr. ft. ² °F)		4.3.2.3, 4.3.2.4	0.20	0.16	0.20	0.14	0.41	0.21	0.41	0.17
Lighting/Power (Watts/sq. ft.)		9.3, 9.4	1	.8	1	.8	1	.8	1	.8
Ventilation (cfm/sq. ft.)		5.3.2.3	.05	.025	.05	.025	.05	.025	.05	.025
Infiltration (Air Change/hr.)		4.3.3, 5.3.2.4	.5	.3	.5	.3	.5	.3	.5	.3
Domestic Hot Water Temperature Rise (°F)		7.3	100	70	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

FIGURE 203-1
188

*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

FIGURE 203-2
189

*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

FIGURE 203-3
190

*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

FIGURE 203-4
191

*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

FIGURE 203-5
192

*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, *SCHOOL BUILDINGS CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL SCHOOL BUILDINGS

PARAMETERS ATTRIBUTABLE TO ENERGY REDUCTION^{1,2}
(Percent)

<u>Parameter (Applicable Sections from ASHRAE 90)</u>	<u>Single-Family Residence</u>	<u>Low-Rise Apartment</u>	<u>Office Building</u>	<u>Retail Store</u>	<u>School</u>
• 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 _o (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
• HVA/C 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

¹Figures shown are an average of the prototypical buildings analyzed.

²Attributed reduction is based upon educated judgment. Further analysis is required to determine a more accurate impact on contributing parameters.

SOURCE: Kling-Lindquist, Inc. Estimates

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 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>U_o</u>
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

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_T , so:

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

$$U_{w1} = \frac{1}{R_{w1}} = \frac{1}{12.33} = 0.081$$

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.

$$U_o = \frac{U_{w1}A_{w1} + U_{w2}A_{w2} + U_{w3}A_{w3} + U_{w4}A_{w4} + U_dA_d + U_gA_g}{A_o}$$

$$U_o = \frac{\text{Insulation } 0.081 \times 736 + \text{Wood } 0.13 \times 95 + \text{Rim Joist } 0.073 \times 91 + \text{Foundation } 0.47 \times 81 + \text{Doors } 0.128 \times 38 + \text{Windows } 0.50 \times 118}{1159}$$

$$U_o = \frac{59.62 + 12.35 + 6.64 + 38.1 + 4.9 + 59}{1159}$$

$$U_o = \frac{180.61}{1159} = 0.156$$

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 nonconforming.

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 the 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
	0.61 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:

U₀ Values

	<u>As Planned</u>	<u>Code Maximum</u>
Wall	0.156	0.18
Roof-ceiling	0.04	0.04

NONCONFORMING ENVELOPE DESIGN

Section 502.1 of the Model Code states that the U₀ 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 U₀ values.

In our example, if the designer so wished, the U₀ value for the roof-ceiling (or wall) could have been increased above the Code maximum U₀, provided the wall U₀ 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 U₀ 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 U₀'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:

$$\begin{array}{rcl} \underline{U} \times \underline{A} \times \underline{\Delta t} & = & \underline{Q} \\ \text{Walls} & 0.156 \times 1159 \times 82 & = 14826 \text{ Btuh} \\ \text{Roof-ceiling} & 0.04 \times 910 \times 82 & = \underline{2985} \text{ Btuh} \\ \text{Total Heat Loss} & & = 17811 \text{ Btuh} \end{array}$$

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.

R-Value

$$\begin{array}{rcl} 0.61 & \text{Interior air film} & \\ 19.00 & \text{R-19 insulation} & \\ 0.45 & \text{1/2 inch gypsum wallboard} & \\ 0.61 & \text{Interior air film} & \\ \hline 20.67 & \text{Total } R_{R1} \text{ Value} & \end{array}$$

$$U_{R1} = \frac{1}{R_{R1}} = \frac{1}{20.67} = 0.048$$

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.

$$\begin{array}{rcl} \underline{U} & \times & \underline{A} \times \underline{\Delta t} = \underline{Q} \\ \text{Walls} & 0.156 \times 1159 \times 82 = & 14826 \text{ Btuh} \\ \text{Roof-ceiling} & 0.053 \times 910 \times 82 = & \underline{3955} \text{ Btuh} \\ & \text{Total Heat Loss} = & 18781 \text{ Btuh} \end{array}$$

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

	<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
	0.17 Exterior air film
	<u>12.33 Total R_{w1} Value</u>

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>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
	<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.

$$U_d = \frac{1}{R_d} = \frac{1}{7.18} = 0.128$$

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>R-Value</u>
	0.61 Interior air film
	21.00 R-21 blown insulation
	0.45 1/2 inch gypsum 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 film
	6.88 5 1/2 inches soft wood
	0.45 1/2 inch gypsum 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.

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>
Interior air film	0.92
5/8 inch plywood	0.78
3/4 inch subfloor	0.94
5 1/2 inches of soft wood	6.88
Interior air film	0.92
Total R_{F2} Value	10.44

$$U_{F2} = \frac{1}{R_{F2}} = \frac{1}{10.44} = 0.096$$

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 Values

	<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>

$$\text{Total Allowable Heat Loss} = 22414 \text{ Btuh}$$

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>

$$\text{Total Heat Loss} = 17513 \text{ Btuh}$$

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
<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.

$$U_{R2} = 0.117$$

$$U_o = \frac{U_{R1}A_{R1} + U_{R2}A_{R2}}{A_o}$$

$$U_o = \frac{0.079 \times 847 + 0.117 \times 63}{910}$$

$$U_o = \frac{66.91 + 7.4}{910}$$

$$U_o = \frac{74.31}{910} = 0.082$$

0.082 exceeds the code maximum of 0.05 so we must check the heat loss to see if it is acceptable.

	$U \times A \times \Delta t$	=	Q
Walls	$0.138 \times 987 \times 71$	=	9760 Btuh
Roof-ceiling	$0.082 \times 910 \times 71$	=	5298 Btuh
Floor	$0.071 \times 910 \times 71$	=	<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' at 16 inches on center wood stud with a concrete slab floor. The building has two exterior doors and several 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

$$U_{w1} = \frac{1}{R_{w1}} = \frac{1}{10.33} = 0.97$$

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.

$$U_o = \frac{U_{w1}A_{w1} + A_{w2}A_{w2} + U_dA_d + U_gA_g}{A_o}$$

Insulation	Wood	Doors	Windows
0.097 x 736	+ 0.13 x 95	+ 0.128 x 38	+ 1.10 x 118

$$U_o = \frac{\quad}{987}$$

$$U_o = \frac{71.39 + 12.35 + 4.86 + 129.8}{987}$$

$$U_o = \frac{218.4}{987} = 0.221$$

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
	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 inchs 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.

	$\underline{U}$	$\times$	$\underline{A}$	$\times$	$\underline{\Delta t}$	$=$	$\underline{Q}$
Walls	0.26	$\times$	987	$\times$	35	$=$	8982 Btuh
Roof-ceiling	0.05	$\times$	910	$\times$	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:

	$\underline{U}$	$\times$	$\underline{A}$	$\times$	$\underline{\Delta t}$	$=$	$\underline{Q}$
Walls	0.221	$\times$	987	$\times$	35	$=$	7634 Btuh
Roof-ceiling	0.049	$\times$	910	$\times$	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 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>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 inches of 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 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.

$$U_o = \frac{U_{w1}A_{w1} + U_{w2}A_{w2} + U_dA_d + U_gA_g}{A_o}$$

$$U_o = \frac{\begin{array}{cccc} \text{Insulation} & \text{Wood} & \text{Doors} & \text{Windows} \\ 0.097 \times 736 & + 0.13 \times 95 & + 0.128 \times 38 & + 1.10 \times 118 \end{array}}{987}$$

$$U_o = \frac{71.39 + 12.35 + 4.86 + 129.8}{987}$$

$$U_o = \frac{218.40}{987} = 0.221$$

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

$$U_{R2} = \frac{1}{R_{R2}} = \frac{1}{8.55} = 0.117$$

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.

	<u>U</u>	<u>A</u>	<u>Δt</u>	<u>Q</u>
Walls	0.29	987	40	= 11449 Btuh
Roof-ceiling	0.05	910	40	= <u>1820</u> Btuh
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:

	<u>U</u>	<u>x</u>	<u>A</u>	<u>x</u>	<u>Δt</u>	<u>=</u>	<u>Q</u>
Walls	0.221	x	987	x	40	=	8725 Btuh
Roof-ceiling	0.049	x	910	x	40	=	<u>1784</u> Btuh
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.

THERMAL ENVELOPE PLAN REVIEW - COOLING

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 OTTV (1)</u>
Gainesville, Fla.	29°	30.4
Minneapolis/St. Paul, Minn.	44°	34.6
San Francisco, Cal.	37°	32.6
Worcester, Mass.	42°	34.0

(1) See 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

$$OTTV = \frac{(U_w A_w T_{DEQ}) + (A_f S F SC) + (U_f A_f \Delta t) \dots \dots}{A}$$

WHERE:

OTTV = average or combined thermal tranfer 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 value

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	T_{DEQ}
0-25	44
16-40	37
41-70	30
71 and above	23

SF 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 70 of the code.

	<u>Latitude</u>	<u>S.F.</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_{fU}), 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 is found from Table 201-1 and SC from Table 201-14 of this manual.

GAINESVILLE, FLA.

OTTV Allowed 30.1

$$\text{OTTV Actual} = \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f \Delta t)}{A}$$

Solar Factor (SF).....120.00

ΔT 16°

U_w 0.214 (See Calculation Sheet 1)

U_f 1.04 (See Table 201-3)

Shade Coefficient (SC)..... 0.88 (See Table 201-14)

T_{DEQ} 37.0

(based on weight of lightweight
block weighing 24 lbs. $24/.89 = 27$ PSF
1/2 gypsum wallboard = 2
approximate SF weight of wall) = 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

$$\text{OTTV Actual} = \frac{(U_w A_w T_{DEQ}) + (A_f SF SC) + (U_f A_f \Delta t)}{A}$$

FORSON 7-12-77

Problem 7.11.77

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

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	U _X RATIO
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	.017	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 #2

Solar Factor (SF).....131.00
 ΔT 11°
 U_w 0.214 (see Calculation Sheet 2)
 U_f 0.35 (see Table 201-3)
 Shade Coefficient (SC)..... 0.83 (see Table 201-14)

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 = 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 201-3)
 Shade Coefficient (SC)..... 0.88 (see Table 201-14)

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 = 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 201-3)

Shade Coefficients (SC)..... 0.83 (See Table 201-14)

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.

PART I - MATERIALS IDENTIFICATION AND FIELD INSPECTION

I. THERMAL INSULATION OF THE BUILDING ENVELOPE

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.

A. 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.

B. Insulation 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, roof, ceiling, 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.

C. Common Insulation Locations

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.

D. Other Locations for Insulation

There are special locations in 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.

E. 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. Proper insulation installation instruction practices are shown in Appendix A.

F. 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, ceiling, and floors.

G. 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 or 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.

H. 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. It is recommended that the contractor be informed of the necessity to retain labels on all windows and doors.

For non-residential occupancies, all doors are regulated. For residential occupancies, only sliding glass doors are regulated.

I. 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, and must be.

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.

II. OTHER SYSTEMS

A. 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.

III. 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.

A. 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.

B. 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.

Further fire problems are caused by the insulation function per se, because the increased retention of heat accelerates the combustion process within the building, resulting in a probable reduction in time during which escape is possible. Unless this factor is compensated for, improved insulation will probably cause increases in fire deaths.

IV. FIELD INSPECTION

Inspection of insulation and mechanical systems for code conformance 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 a water conserving type.

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.

V. 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 system controls
- Any other data required to demonstrate conformance with requirements.

PART II - PRACTICAL APPLICATIONS; EXAMPLES

Considerable discussion has heretofore been devoted to the definition of terms as they relate to the thermal performance of a building; the process by which the thermal transmission values can be calculated; and the requirements of the Model Code and their effect on the inspection process.

"Thermal Performance" is the key word that is being stressed in the Model Code and in this course material. The Code is a performance oriented document and above all permits the use of any system of construction that performs in the manner established as the minimum performance level. In order to demonstrate the compliance process of the thermal performance of a building, the following practical exercise is offered. This exercise should demonstrate the following objectives:

1. How to analyze a given building for code compliance;
2. Show the flexibility (hence, performance) of how a building may comply with the code; and
3. Provide a useful tool for making the compliance process as easy as possible.

The tool here is somewhat of a plan review form which aids in keeping the data used in calculations in a neat and orderly fashion in order to reduce confusion and possible error. These sheets, shown in Figure 203-1 are one of many possible methods which can be used to make the analysis easier. It is certainly not the only method possible, but is helpful in keeping the data in a logical format in as little space as necessary. Above all, the user should keep in mind that forms can be altered to suit his needs as long as the basis of the calculations remains intact.

The basis of the calculations lies in two mathematical formulae. One, which has been discussed in detail, is the calculation method for a U value; that is, adding the R values of the materials and taking the reciprocal to determine the U value. These equations look like this:

$$R_t = R_1 + R_2 + R_3 + \dots$$

$$1/R_t = U$$

The second equation used as a basis for tables is the equation previously discussed for combining the different U values of sub-assemblies that exist in any wall, floor or roof-ceiling assembly.

This equation looks like this:

$$U_o = \frac{U_1A_1 + U_2A_2 + U_3A_3 + \dots}{A_o}$$

To derive the different portions of the tables requires only the setting up of spaces on the sheet for data as necessary to complete the above equations. To determine individual compliance of the various envelope elements (walls, roof-ceiling, floors), there are two charts, each corresponding to one of the equations above.

The first, reproduced below, deals with calculations of the U values for the two different assemblies of the blank envelope element, namely, the portion containing the framing member and the portion containing the cavity. The R value of each material is entered and totaled. The final space will contain the reciprocal of the R_t value which is the U value of the sub-assembly. It should be noted that there may be more spaces than values and that some may be left blank. For example, under the column for framing there will be no value for "insulation" or "air space" since there is a 2" x X" framing member where the cavity would normally occur. It should also be noted that if another calculation is necessary for additional sub-assemblies, such as a wall that is 1/2 brick veneer, a third column could be added. Throughout the sheets there are also entry spaces designated as "other" should there be a need.

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R_T = TOTAL LINES 1-10		
12 U = $1/R$ TOTAL		

The second sheet, reproduced below, corresponds to the second equation for combining the U values of sub-assemblies to determine the overall U_0 value.

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL				
14 WINDOW				
15 DOOR				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2)			
19 FRAMING	3)		5)	
20 CAVITY	4)		6)	
21 U_0 = TOTAL LINES 14, 15, 16, 17, 19, 20				

The first column is the entry for the area (square feet) of the sub-assemblies. The area of the blank envelope element that contains a framing is relatively constant for a given stud or rafter space. Therefore, the framing area ratios shown may be used. These represent the percentage of blank envelope element that is framing member. (Read carefully the notes corresponding to the tables!) The gross area (A_0) is the total area of exterior assembly including all sub-assemblies.

The second column is the gross area ratio. This is the ratio of the area of the sub-assembly to the gross area.

The third column contains entries for the calculated U values of the sub-assemblies. You will note that the U values to be entered for the cavity and framing portion are the same as calculated in the previous chart. The U values for doors and windows (skylights) are a straight entry with no previous calculation since most materials such as those from the Handbook of Fundamentals give the U values rather than R values, hence no calculation is necessary.

The last column is the product of multiplying the gross area ratio (column 2) by the U value (column 3). The overall U_0 value for the entire assembly is then determined by adding the values in the last column.

This relationship can be proven to be valid by manipulating the basic equation:

$$U_0 = \frac{U_1 \times A_1 + U_2 \times A_2 + U_3 \times A_3 + \dots}{A_0}$$

This equation can also be written as follows; and this then shows the steps that were just described in the table.

$$U_0 = U_1 \times \frac{(A_1)}{(A_0)} + U_2 \times \frac{(A_2)}{(A_0)} + U_3 \times \frac{(A_3)}{(A_0)} + \dots$$

where $\frac{A_1}{A_0}$, $\frac{A_2}{A_0}$ and $\frac{A_3}{A_0}$ are the gross area ratios in column 2;

where U_1 , U_2 and U_3 are the U values in column 3;

where $U_1 (A_1/A_0)$, etc. are the product of columns 2 and 3 shown in column 4; and where the entire equation is the sum of the values in column 4.

The same basic approach is taken for figuring walls (first page) and for figuring roof-ceiling and floors (second page). The third page contains two charts for combining the U_0 values of each envelope assembly to determine and compare an overall U_t value for the building should it be necessary to calculate one. (Reference is made to the trade-off aspect permitted by the code discussed earlier). The third page also contains a simplified method for determining compliance with the cooling requirements for walls. In the types of buildings we are concentrating on (small residential) this calculation does not come into play.

INSTRUCTIONS

Instructions on the use of the tables are included on pages 256 and 257.

U₀ CALCULATIONS FOR WALLS

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL				
14 WINDOW				
15 DOOR				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2)			
19 FRAMING	3)		5)	
20 CAVITY	4)		6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

THESE FOOTNOTES APPLICABLE TO ALL PAGES

- 1) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area. For example, the ratio of line 19 -

$$\text{FRAMING} = \frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$$

- 2) Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- 3) FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- 4) CAVITY AREA equals line 18 minus line 19 AREA.
- 5) Line 12 U VALUE for FRAMING.
- 6) Line 12 U VALUE for CAVITY.
- 7) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- 8) The U VALUES obtained from Table 5-1 or 5-2.
- 9) This U VALUE is the value indicated on line 21 page 1.
- 10) This U VALUE is the value indicated on line 21 page 2 for floors.
- 11) This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
- 12) U x Ratio Allowed total must be greater than U x Ratio Actual Total.
- 13) TABLE A RATIO.
- 14) TABLE B RATIO.

U_o CALCULATIONS FOR FLOORS AND ROOF-CEILING

FLOOR HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R_T = TOTAL LINES 1-10		
12 $U = 1/R$ TOTAL		

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	$U \times$ RATIO
13 GROSS FLOOR				
14 OTHER (Specify)				
15 OTHER (Specify)				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE FLOOR 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U_o = TOTAL LINES 14, 15, 16, 17, 19, 20				

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9) OTHER a)		
10 (Specify) b)		
11 R_T = TOTAL LINES 1-10		
12 $U = 1/R$ TOTAL		

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	$U \times$ RATIO
13 GROSS ROOF-CEIL.				
14 SKYLIGHT				
15 ROOF SCUPPER				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE ROOF-CEIL. 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U_o = TOTAL LINES 14, 15, 16, 17, 19, 20				

FIGURE 203-1 (cont.)

COMBINING COMPONENTS

$$U \text{ ACTUAL} \leq U \text{ ALLOWED}$$

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO	ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL					22 WALL			9)	
23 FLOOR					23 FLOOR			10)	
24 CEILING- ROOF					24 CEILING- ROOF			11)	
25 TOTAL		$U_T \text{ ALLOWED} =$			25 TOTAL		$U_T \text{ ACTUAL} =$		

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

WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY	WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
1 AIR FILM OUTSIDE			13 GROSS WALL				
2 OUTER SURFACE			14 WINDOW				
3 OUTER SHEATHING			15 DOOR				
4 FRAMING			16 OTHER (Specify)				
5 CAVITY a) INSULATION			17 OTHER (Specify)				
6 b) AIR SPACE			18 OPAQUE WALL	2)			
7 INSIDE SURFACE			19 FRAMING	3)	13)	5)	
8 AIR FILM INSIDE			20 CAVITY	4)	14)	6)	
9 OTHER a)			21 $U_o = \text{TOTAL LINES 19, 20}$				
10 (Specify) b)							
11 $R_T = \text{TOTAL LINES 1-10}$							
12 $U = 1/R \text{ TOTAL}$							

FIGURE 203-1 (cont.)

**CALCULATING COMPONENT THERMAL TRANSMISSION
VALUES (U_o) HEATING**

- STEP 1.** Determine the individual R values in series in the section and list them in the appropriate blank lines 1-10. Note entries required for both cavity and framing sections.
- STEP 2.** Total lines 1-10 and enter results line 11.
- STEP 3.** Take the reciprocal of line 11. This is the Thermal Transmission Coefficient and the value should be entered on line 12.
- STEP 4.** Determine the GROSS AREA of the component line 13.
- STEP 5.** Determine the areas of the component that are composed of different materials lines 14-20. See footnote 3 and 4.
- STEP 6.** Determine GROSS AREA RATIO - see footnote 1. Enter values lines 14-17, 19 and 20.
- STEP 7.** Enter thermal coefficients U values for various component areas, lines 14-17, 19 and 20. See footnote 5 and 6.
- STEP 8.** Multiply GROSS AREA RATIO by their respective Thermal Coefficient Values (U_o). Lines 14-17, 19 and 20.
- STEP 9.** Total lines 14-17, 19 and 20. This is the overall Thermal Transmission value of the component.

**CALCULATING BUILDING ENVELOPE EQUIVALENT
THERMAL TRANSMISSION COEFFICIENT**

- STEP 1.** Enter the GROSS AREAS of the components (wall, roofing, ceiling, and floors) lines 22-24.
- STEP 2.** Add the individual areas, lines 22-24.
- STEP 3.** Determine GROSS AREA RATIO - See footnote 7. Enter lines 22-24.
- STEP 4.** Enter thermal coefficients for various components. See footnotes 8, 9, 10, 11.
- STEP 5.** Multiply GROSS AREA RATIO by the respective Thermal Coefficient value (U_o). Lines 22-24.
- STEP 6.** Add the U x Ratio values of the components.
- STEP 7.** Compare U x Ratio value allowed with U x Ratio value actual. See footnote 12.

FIGURE 203-1 (cont.)

**CALCULATING THERMAL TRANSMISSION COEFFICIENTS
U VALUES: COOLING WALLS ONLY**

STEP 1. Repeat steps 1-5 Heating.

STEP 2. Determine OPAQUE AREA RATIO - See footnote 13, 14, enter these values, lines 19 and 20.

STEP 3. Enter Thermal Transmission Coefficient values for framing and cavity - see footnote 5 and 6.

STEP 4. Multiply OPAQUE AREA RATIO by the respective Thermal Transmission value, lines 19 and 20.

STEP 5. Add the U x Ratio values, lines 19 and 20. This value is the Thermal Transmission value for the opaque wall and is used in calculating the U_{OV} .

FIGURE 203-1 (cont.) |

SUMMARY

The basic procedure for analyzing a building for compliance with Section 5 of the Code can be summarized as follows:

Procedure

1. Determine the location of the building and the annual heating degree day value for the location.
2. Analyze the wall components.
 - a. Determine the blank wall section and establish the R values of individual materials (From Tables 203-1), including air film resistances. (Two calculations are necessary to account for the portion of the blank wall that consists of framing members and the portion containing cavity space.)
 - b. Add the R values and take the reciprocal to determine the U value ($U = 1/R$).
 - c. Determine the U or R values as appropriate for the doors and windows.
 - d. Calculate the gross wall area, the window area and the door area.
 - e. Determine the blank or opaque wall area. (Gross wall area minus the sum of the door and window areas.)
 - f. Determine the framing area by multiplying the opaque wall area by the appropriate framing ratio.
 - g. Determine the gross area ratios of the different assemblies of materials. These represent the ratio of window area to gross area, framing area to gross area, cavity area to gross area, etc.
 - h. Multiply the U values of the different assemblies by their respective gross area ratios.
 - i. The overall U_o value for the wall is the sum total of the U values times the area ratios of each different assembly of materials.
3. Analyze the floor and roof-ceiling components.
 - a. The same procedure is followed as for walls. As with walls,

care must be taken to separately calculate the U values for each section of the roof that comprises a different assembly of materials (e.g., framing, cavity, skylight, etc.)

4. Determine from the Model Code reference the maximum U_o for walls, floors and roof for the appropriate degree day value.
5. Determine individual code compliance of the walls, floor and roof.
 - a. If the actual U_o of an element is less than the maximum U_o permitted by the Code, the assembly complies.
 - b. If all elements comply individually, the entire building complies and the analysis is complete.
 - c. If all elements do not comply individually, we know the entire building does not comply and the design must be revised by the permit applicant.
 - d. If one or more elements comply with the code and one or more elements do not comply, we must combine the effects of all the elements and determine an overall U_t for the entire building. The code permits an assembly, such as a wall, to have a higher U_o value than permitted for walls as long as another assembly such as a roof, has a U_o value sufficiently less than the maximum permitted for roofs such that the overall building will not have a greater heat loss than it would if the building had met all of the specified maximum U_o values. This can be established according to the following steps.
6. Determine the maximum U_t for the building that would be permitted by the Code.
 - a. Indicate the gross wall, roof and floor areas of the actual building. (Previously calculated.) Add these areas to determine the overall gross area of the building envelope.
 - b. Determine the area ratios of the floor, wall and roof assemblies by dividing the gross area of each assembly by the gross area of the building envelope.
 - c. Multiply these ratios by the U_o value permitted by the Code for each assembly.
 - d. Add the U_o permitted times area ratio values. The sum total is the maximum U_t for that building permitted by the Code.
7. Determine the actual U_t for the building as proposed.

- a. Steps 6.a and 6.b above are the same. Since we are comparing the same building as proposed versus meeting the maximum Code requirements, the wall, roof and floor areas are the same and the area ratios are the same.
- b. Continue with steps 6.c and 6.d above but inserting the actual U_o values previously calculated for the wall, roof and floor assemblies instead of the maximum U_o value permitted by the Code. This results in an actual U_t for the proposed building.
- c. If the actual U_t is less than the maximum U_t permitted, the entire building complies with the Code. If the actual U_t is greater than the maximum, this indicates that the building will permit a greater heat loss than the same building would if it met all the maximum U_o values prescribed by the Code.

The following are problems and solutions of a small residential building for various degree day locations in the United States. Determine whether the building is in compliance with the Model Code.

Problem 1. 1 story residential building, located in Gainesville, Florida.

Given: Plan Sheet A.

Problem 2. 1 story residential building, located in San Francisco, California.

Given: Plan Sheet B.

Problem 3. 1 story residential building, located in Worcester, Massachusetts.

Given: Plan Sheet C.

FLOOR PLAN

900 SQ. FT.

SECTION

NOTES

1. ALL WINDOWS ARE SINGLE GLAZING
2. ALL DOORS ARE 1" SOLID WOOD W/O STORM DOORS.

PLAN SHEET A

EXAMPLE PROBLEM - RESIDENTIAL
MODEL ENERGY CONSERVATION CODE
LOCATION: GAINESVILLE, FLORIDA
(1000 D.D.)

U₀ CALCULATIONS FOR WALLS

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	U x RATIO
13 GROSS WALL				
14 WINDOW				
15 DOOR				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

THESE FOOTNOTES APPLICABLE TO ALL PAGES

- 1) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area. For example, the ratio of line 19 -

$$\text{FRAMING} = \frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$$

- 2) Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- 3) FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- 4) CAVITY AREA equals line 18 minus line 19 AREA.
- 5) Line 12 U VALUE for FRAMING.
- 6) Line 12 U VALUE for CAVITY.
- 7) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- 8) The U VALUES obtained from Table 5-1 or 5-2.
- 9) This U VALUE is the value indicated on line 21 page 1.
- 10) This U VALUE is the value indicated on line 21 page 2 for floors.
- 11) This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
- 12) U x Ratio Allowed total must be greater than U x Ratio Actual Total.
- 13) TABLE A RATIO.
- 14) TABLE B RATIO.

U_0 CALCULATIONS FOR FLOORS AND ROOF-CEILING

FLOOR HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R_T = TOTAL LINES 1-10		
12 $U = 1/R$ TOTAL		

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	$U \times$ RATIO
13 GROSS FLOOR				
14 OTHER (Specify)				
15 OTHER (Specify)				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE FLOOR 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U_0 = TOTAL LINES 14, 15, 16, 17, 19, 20				

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9) OTHER a)		
10 (Specify) b)		
11 R_T = TOTAL LINES 1-10		
12 $U = 1/R$ TOTAL		

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	$U \times$ RATIO
13 GROSS ROOF-CEIL.				
14 SKYLIGHT				
15 ROOF SCUPPER				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE ROOF-CEIL. 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U_0 = TOTAL LINES 14, 15, 16, 17, 19, 20				

COMBINING COMPONENTS

$$U \text{ ACTUAL} \leq U \text{ ALLOWED}$$

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO	ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL					22 WALL			9)	
23 FLOOR					23 FLOOR			10)	
24 CEILING- ROOF					24 CEILING- ROOF			11)	
25 TOTAL		$U_T \text{ ALLOWED} =$			25 TOTAL		$U_T \text{ ACTUAL} =$		

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

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WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY	WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
1 AIR FILM OUTSIDE			13 GROSS WALL				
2 OUTER SURFACE			14 WINDOW				
3 OUTER SHEATHING			15 DOOR				
4 FRAMING			16 OTHER (Specify)				
5 CAVITY a) INSULATION			17 OTHER (Specify)				
6 b) AIR SPACE			18 OPAQUE WALL	2)			
7 INSIDE SURFACE			19 FRAMING	3)	13)	5)	
8 AIR FILM INSIDE			20 CAVITY	4)	14)	6)	
9 OTHER a)			21 $U_o = \text{TOTAL LINES 19, 20}$				
10 (Specify) b)							
11 $R_T = \text{TOTAL LINES 1-10}$							
12 $U = 1/R \text{ TOTAL}$

NOTES

1. ALL WINDOWS ARE DOUBLE GLAZING W/1" AIR SPACE.
2. ALL DOORS ARE 1 1/2" SOLID WOOD W/O STORM DOORS.

PLAN SHEET B

EXAMPLE PROBLEM - RESIDENTIAL
MODEL ENERGY CONSERVATION CODE
LOCATION: SAN FRANCISCO, CALIF.
(3000 D.D.)

U₀ CALCULATIONS FOR WALLS

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL				
14 WINDOW				
15 DOOR				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2)			
19 FRAMING	3)		5)	
20 CAVITY	4)		6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

THESE FOOTNOTES APPLICABLE TO ALL PAGES

- 1) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area. For example, the ratio of line 19 -

$$\text{FRAMING} = \frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$$

- 2) Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- 3) FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- 4) CAVITY AREA equals line 18 minus line 19 AREA.
- 5) Line 12 U VALUE for FRAMING.
- 6) Line 12 U VALUE for CAVITY.
- 7) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- 8) The U VALUES obtained from Table 5-1 or 5-2.
- 9) This U VALUE is the value indicated on line 21 page 1.
- 10) This U VALUE is the value indicated on line 21 page 2 for floors.
- 11) This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
- 12) U x Ratio Allowed total must be greater than U x Ratio Actual Total.
- 3) TABLE A RATIO.
- 4) TABLE B RATIO.

U₀ CALCULATIONS FOR FLOORS AND ROOF-CEILING

FLOOR HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS FLOOR				
14 OTHER (Specify)				
15 OTHER (Specify)				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE FLOOR 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS ROOF-CEIL.				
14 SKYLIGHT				
15 ROOF SCUPPER				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE ROOF-CEIL. 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

COMBINING COMPONENTS

$U_{\text{ACTUAL}} \leq U_{\text{ALLOWED}}$

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO	ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL					22 WALL			9)	
23 FLOOR					23 FLOOR			10)	
24 CEILING- ROOF					24 CEILING- ROOF			11)	
25 TOTAL		$U_T \text{ ALLOWED} =$			25 TOTAL		$U_T \text{ ACTUAL} =$		

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

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WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY	WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
1 AIR FILM OUTSIDE			13 GROSS WALL				
2 OUTER SURFACE			14 WINDOW				
3 OUTER SHEATHING			15 DOOR				
4 FRAMING			16 OTHER (Specify)				
5 CAVITY a) INSULATION			17 OTHER (Specify)				
6 b) AIR SPACE			18 OPAQUE WALL	2)			
7 INSIDE SURFACE			19 FRAMING	3)	13)	5)	
8 AIR FILM INSIDE			20 CAVITY	4)	14)	6)	
9 OTHER a)			21 $U_o = \text{TOTAL LINES 19, 20}$				
10 (Specify) b)							
11 $R_T = \text{TOTAL LINES 1-10}$							
12 $U = 1/R \text{ TOTAL}$

FLOOR PLAN

900 SQ. FT.

NOTES

1. ALL WINDOWS ARE TRIPLE GLAZING w/ 1/2" AIR SPACE.
2. ALL DOORS ARE 1" SOLID WOOD w/O STORM DOORS.

PLAN SHEET C

FRONT ELEVATION

EXAMPLE PROBLEM - RESIDENTIAL
MODEL ENERGY CONSERVATION CODE
LOCATION: WORCHESTER, MASS.
(7200 D.D.)

U₀ CALCULATIONS FOR WALLS

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL				
14 WINDOW				
15 DOOR				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2)			
19 FRAMING	3)		5)	
20 CAVITY	4)		6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

THESE FOOTNOTES APPLICABLE TO ALL PAGES

- 1) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area. For example, the ratio of line 19 - FRAMING = $\frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$
- 2) Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- 3) FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- 4) CAVITY AREA equals line 18 minus line 19 AREA.
- 5) Line 12 U VALUE for FRAMING.
- 6) Line 12 U VALUE for CAVITY.
- 7) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- 8) The U VALUES obtained from Table 5-1 or 5-2.
- 9) This U VALUE is the value indicated on line 21 page 1.
- 10) This U VALUE is the value indicated on line 21 page 2 for floors.
- 11) This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
- 12) U x Ratio Allowed total must be greater than U x Ratio Actual Total.
- 3) TABLE A RATIO.
- 4) TABLE B RATIO.

U₀ CALCULATIONS FOR FLOORS AND ROOF-CEILING

FLOOR HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS FLOOR				
14 OTHER (Specify)				
15 OTHER (Specify)				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE FLOOR 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS ROOF-CEIL.				
14 SKYLIGHT				
15 ROOF SCUPPER				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE ROOF-CEIL. 2)				
19 FRAMING 3)			5)	
20 CAVITY 4)			6)	
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				

COMBINING COMPONENTS

U ACTUAL ≤ U ALLOWED

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO	ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL					22 WALL			9)	
23 FLOOR					23 FLOOR			10)	
24 CEILING- ROOF					24 CEILING- ROOF			11)	
25 TOTAL		U _T ALLOWED =			25 TOTAL		U _T ACTUAL =		

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

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WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY	WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
1 AIR FILM OUTSIDE			13 GROSS WALL				
2 OUTER SURFACE			14 WINDOW				
3 OUTER SHEATHING			15 DOOR				
4 FRAMING			16 OTHER (Specify)				
5 CAVITY a) INSULATION			17 OTHER (Specify)				
6 b) AIR SPACE			18 OPAQUE WALL	2)			
7 INSIDE SURFACE			19 FRAMING	3)	13)	5)	
8 AIR FILM INSIDE			20 CAVITY	4)	14)	6)	
9 OTHER a)			21 U ₀ = TOTAL LINES 19, 20				
10 (Specify) b)							
11 R _T = TOTAL LINES 1-10							
12 U = 1/R TOTAL							

PRACTICAL EXERCISE - LIGHTING DESIGN

LIGHTING DESIGN PLAN REVIEW

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 type of 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 a set of illumination levels recommended for various specific tasks. 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.

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 the 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:

1. 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.
2. 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:

$$\text{Room Cavity Ratio (RCR)} = \frac{5 H (\text{Room Length} + \text{Room Width})}{\text{Room Length} \times \text{Room Width}}$$

Where 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 Handbook¹⁷). 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.

As an example: From Item 28, Figure 9-12, page 9-22 of the Handbook:

The coefficient of utilization for ceiling reflectance of 70% to wall reflectance of 50% and RCR of 3 is .45.

3. 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.

- a. 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 .95; for ballasts not bearing the CBM label, the lumen output is usually lower.

Specifications standards are not available for mercury vapor ballasts. Consult with ballast manufacturer for this light loss factor.

- b. 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.
 - c. 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.
 - d. 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 of the IES Lighting Handbook). 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.
4. Calculate the number of lamps and luminaires required. The number of luminaires and lamps can be calculated from the following formulas:

$$\text{Total Lumens} = \frac{\text{Foot Candles} \times \text{Area}}{\text{Coefficient of Utilization} \times \text{Light Loss Factor}}$$

$$\text{Number of Luminaires (or fixtures)} = \frac{\text{Total Lumens}}{\text{Lumens/Lamp} \times \text{Lamps/Luminaire (or fixtures)}}$$

LIGHTING POWER BUDGET:

The determination of the lighting power budget is then simply a matter of applying the formula.

$$\text{Lighting Power Budget} = \text{Number of Luminaires (fixtures)} \times \text{Watts/Luminaire (fixtures)}$$

A simple form to use in applying these formulae is shown in Figure 203-E-1.

EXAMPLE:

Small service store 48'x 32' with a 13' ceiling height -- assume the mounting height of the fixtures is 9'. See Cooling Design 1 and 2.

The design lighting level is 100 footcandles, the minimum recommended by IES becomes the maximum allowed. From Table 5-10 of the Code, the following factors are determined:

Reflection Factors:

Ceiling 89%
Walls 50%
Floor 20%

$$\begin{array}{ll} \text{Coefficient of Utilization} & .63 \\ \text{Light Loss Factor} & .70 \\ \text{Room Cavity Ratio} & \frac{5H(L+W)}{L \times W} = \frac{5 \times 9(80)}{48 \times 32} = 2.34 \end{array}$$

From the manufacturers literature --

4-40 Lamps/Fixtures

200 Watts/Fixture (4 @ 40 = 10 Watt Ballast Loss)

Large type F40T12 Lumens/Lamp = 3100

$$\text{Total Lumens} = \frac{\text{Footcandle} \times \text{Area}}{\text{Coefficient of Utilization} \times \text{Light Loss Factor}}$$

$$= \frac{100 \times (48 \times 32)}{.63 \times .70} = 340,140$$

$$\text{Number Fixtures} = \frac{\text{Total Lumens}}{\text{Lumens/Lamp} \times \text{Lamps/Fixture}}$$

$$= \frac{340,140}{3100 \times 4} = 27.4 \text{ use } 28$$

$$\text{Lighting Power Budget} = \text{Number of Fixtures} \times \text{Watts/Fixture}$$

$$28 \times 200 = 5600 \text{ Watts}$$

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/FIXTURES 4 WATTS/FIXTURE 200

LAMP TYPE F40T12 LUMENS/LAMP 3100

TOTAL LUMENS $\frac{\text{FT.C.} \times \text{A}}{\text{CU.LL}}$ $\frac{100 \times 1500}{.63 \times .70}$ 340140

NO. FIXT. = $\frac{\text{TOTAL LUMENS}}{\text{LUMENS/LAMP} \times \text{LAMPS/FIXTURE}}$ = $\frac{340140}{3100 \times 4}$ = 27.4
call 28

LIGHTING POWER BUDGET-NO. FIXT. 28 X WATTS/FIXT. 200 = 5600 WATTS

FIGURE 203-E-1

FOOTNOTES

- 1, 2 World Oil, Houston, Texas, August 15, 1975
- 3 World Energy Conference, Survey of Energy Resources, New York, 1974
- 4 Ibid
- 5 Ibid
- 6 Ibid
- 7 United States Department of Interior, Bureau of Mines
- 8 The Model Code Groups. Building Officials and Code Administrators International, Inc. (BOCA); International Conference of Building Officials (ICBO); Southern Building Code Congress International, Inc. (SBCC)
- 9, 10 An Impact Assessment of ASHRAE Standard 90-75, "Energy Conservation in New Building Design", Report to Federal Energy Administration, December 1975. C-78309. Arthur D. Little, Inc.
- 11, 12 ASHRAE Handbook of Fundamentals. American Society of Heating, Ventilating and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017. 1977
- 13 Ibid, 1972
- 14 Load Calculation for Commercial Summer and Winter Air Conditioning (Using Unitary Equipment). National Environmental Systems Contractors Association, 1501 Wilson Blvd., Arlington, Va. 22209. 1976
- 15 Ibid 12, modified
- 16 ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy. 1974 (See 12)
- 17 IES Lighting Handbook, 5th Edition, Illuminating Engineering Society, 345 East 47th Street, New York, N.Y. 10017. 1972

APPENDIX A

1. Ceilings

There are three methods of installing blanket insulation in ceilings:

1. Stapling from below (Fig. 1a and 1b).
2. Installing unfaced (without a vapor barrier), pressure-fit blankets (Fig. 2).
3. Laying the insulation in from above when the ceiling finish material is in place.

Fig. 1a

Fig. 1b

Staple flanges to the ceiling joists as shown in Fig. 1a and 1b. Extend the insulation entirely across the top plate, keeping the blanket as close to the plate as possible. If necessary, stuff the gap between blanket and plate with loose insulation. When eave vents are used, the insulation should not block air movement from eave to space above insulation.

Wedge unfaced, pressure-fit blankets between ceiling joists (Fig. 2). Allow insulation to overlap the top plate of the exterior wall, but not enough to block eave ventilation. The insulation should touch the top of the plate to avoid heat loss and wind penetration beneath the insulation.

A separate vapor barrier is unnecessary under some conditions. For instance, if the ratio of total net free ventilating area to area of ceiling is 1/300 or more and half of that area is provided by ventilators located in the upper portion of the space to be ventilated (at least 3 feet above eave or cornice vents) and the balance of required ventilating area is provided by eave or cornice vents, no separate vapor barrier is necessary. This meets the requirements of the FHA Minimum Property Standards. See Page 19.

Fig. 2

2. Walls

Fig. 3a

Fig. 3b

Push blankets into stud spaces so they touch the sheathing or siding. Working from the top down, space staples about 8 inches apart, pulling down flanges to fit snugly against studs. Cut blanket ends to fit tight against top and bottom plates (Fig. 3a). As an alternate, cut blankets slightly overlapped and staple through the vapor barrier to the plates by compressing the insulation (Fig. 3b).

Fig. 4

When pressure-fit blankets without a vapor barrier are used, wedge them into place. Cover inside face of wall studs with a 2-mil-thick polyethylene vapor barrier (Fig. 4), stapled to top and bottom plates. Unroll the sheet across the entire wall area including window and door openings. Cut out openings later. Foil-backed gypsumboard may be used as a vapor barrier instead of polyethylene.

Fig. 5

Push insulation behind (cold side in winter) pipes, ducts, and electrical boxes (Fig. 5). As an alternate, the space may be packed with loose insulation or a piece of insulation of the proper size can be cut and fit into place.

Fig. 6

Stuff small spaces between rough framing and door and window heads, jambs, and sills with pieces of insulation (Fig. 6). Staple insulation vapor barrier paper or polyethylene to cover these small spaces.

Fig. 7a

Fig. 7b

Insulate non-standard-width stud or joist spaces by cutting the insulation and vapor barrier an inch or so wider than the space to be filled (Fig. 7a). Staple uncut flange as usual. Pull the vapor barrier on the cut side to the other stud, compressing the insulation behind it, and staple through vapor barrier to stud. (Fig. 7b). Unfaced blankets are cut slightly oversize and wedged into place.

3. Masonry Walls

Fig. 8a

Fig. 8b

Masonry walls may be insulated using either nominal 2 x 2 or 1 x 2 furring strips. Furring strips may be 16 or 24 inches o.c., depending on thickness and type of wall finish. Two kinds of insulation may be used. For 1 x 2 furring (Fig. 8a), masonry wall insulation nominally 1-inch-thick (about R-3) of the pressure-fit type is available without a vapor barrier. In this case, use a separate 2-mil polyethylene film or foil-backed gypsumboard for the vapor barrier. For 2 x 2 furring (Fig. 8b), R-7 insulation with vapor barrier may be used. When R-7 insulation is compressed to 1 3/4 inches (1 1/2 inches plus 1/4-inch of shim), its thermal resistance is reduced to about R-6. For the R-7 insulation with a vapor barrier, staple the blanket flange to the face of the furring strip (the 1-3/4-inch space is not adequate to recess the insulation and staple flanges to the side of the furring strip as recommended for walls). When the R-7 is used, furring strips can be 24 inches on center since the compressed insulation provides intermediate support for "thin" paneling.

Fig. 10a

Fig. 10b

If perimeter insulation is needed for slab-on-ground construction, install it as shown in Fig. 10a or Fig. 10b.

4. Dropped Soffits—Kitchen/Bath

Insulation of dropped soffits over kitchen cabinets, bathtubs, or showers may need special attention when they are exposed to the attic. If the dropped soffit is framed before ceiling finish material is applied, a "board" (plywood, hardboard, gypsumboard, etc.) needs to be installed over the cavity to support blown insulation. The dropped soffit area is no problem with blanket insulation or when blown attic insulation is used and the ceiling finish material extends over the cavity. When using blanket insulation, stuff it between trusses or rafters to extend over and span the dropped soffit cavity.

In apartments with back-to-back kitchens or baths, it is preferable to extend ceiling finish material over dropped soffits to the party wall to avoid acoustical short circuits.

4. Pipes and Wires

Pack insulation in the space around pipes and wires that pass through wall plates into attics and vented crawl spaces.

5. Recessed Light Fixtures

Install insulation around, not over, recessed light fixtures in roof/ceiling constructions to preclude excessive heat build up. Holes in such rough-in recess boxes provide a moisture vapor opening and no practical way is known to seal them. However, recessed light fixtures are widely used and moisture vapor problems traceable to these fixtures are virtually unknown. Nonetheless, it is suggested that when they are used in cathedral, flat, or mansard roof/ceilings in cold climates, particular attention be given to ventilating the space between roof and ceiling.

In apartment construction, the holes in these fixtures can create acoustical flanking paths through attics.

7. Floors and Crawl Spaces

Floors over crawl spaces may be insulated either by insulating the foundation walls if the crawl space is *unvented*, or if the crawl space is *vented* by placing insulation between the joists. The former method, as described below, is usually more economical.

Place the vapor barrier (polyethylene film) covering the crawl space ground against the wall (Fig. 9a), using occasional pieces of tape to hold it against the wall until the insulation has been put into place. If the inside surface of the crawl space wall is not over 21 inches high, use nominal 2-foot-wide blanket insulation, or if the wall is not over 12-13 inches high, use nominal 16-inch-wide insulation. Place one edge of insulation on top of foundation wall, taping it temporarily in place as needed. The remainder of the insulation should drape over and against the inside of the wall. Insulation is held permanently in place by the sill plate or header joist if no sill plate is used. If the bottom of the insulation stands away from the wall, use stones, bricks or blocks spaced as needed to hold it against the wall. The vapor barrier on the insulation should face inward (the warm side in winter). In this method of installation, the insulation also serves as a sill sealer.

Walls of *unvented* crawl spaces also may be insulated by fastening rigid insulation board to the inside face of the wall extending from ground to top of wall. Follow manufacturer's instructions for method and type of adhesive or fasteners.

Floors over *vented* crawl spaces (Fig. 9b) can be insulated by installing insulation between the joists and holding it in place by:

1. Using heavy-gage wires pointed at both ends and made especially for this purpose. Bow the wires and wedge them under insulation and between joists.
2. Lacing wire back and forth between nails placed in bottom of joists.
3. Nailing chicken wire to bottom of joists.

In all cases, the vapor barrier side of the insulation should face the floor above—that is, be adjacent to the warm side in winter. Polyethylene may be used as a vapor barrier to cover the ground. If it is desired to protect the insulation from the weather, such as may be the case in open crawl spaces, nail standard, interior grade softwood plywood, nail-base insulation board, or similar covering to the bottom of floor joists.

In basement and *unvented* crawl space constructions, sill sealer insulation may be used if necessary to prevent air infiltration between sill and foundation or between header joist and foundation. The sill sealer is merely unrolled on top of foundation wall and temporarily taped in place as necessary (Fig. 9c).

Wedge or staple short pieces of blanket insulation behind band or header joists (Fig. 9c and 9d). As an alternative, when using insulation at the bottom of joists, the header joist may be insulated by "folding" the end of the blanket up 90 degrees and pushing it against the header (Fig. 9c).

Headers in cantilevered floor construction (Fig. 9e) can be insulated as mentioned above. Insulate soffits below cantilevered floors by cutting blanket to fit and wedging it in place, vapor barrier facing up. As an alternate, these headers and soffits can be insulated by folding the end of the blanket against the header, as shown in the righthand section of Fig. 9c.

SOLUTION TO PROBLEMS

U₀ CALCULATIONS FOR WALLS

1000 D. D.

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.17	.17
2 OUTER SURFACE	1.46	1.46
3 OUTER SHEATHING	.62	.62
4 FRAMING	4.35	
5 CAVITY a) INSULATION		7.00
6 b) AIR SPACE		-
7 INSIDE SURFACE	.45	.45
8 AIR FILM INSIDE	.68	.68
9 OTHER a)	-	-
10 (Specify) b)	-	-
11 R _T = TOTAL LINES 1-10	7.73	10.38
12 U = 1/R TOTAL	.129	.096

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	U x RATIO
13 GROSS WALL	960			
14 WINDOW	225	.234	.140	.257
15 DOOR	40	.042	.64	.027
16 OTHER (Specify)	-	-	-	-
17 OTHER (Specify)	-	-	-	-
18 OPAQUE WALL	2) 695			
19 FRAMING	3) 105	.109	5) .129	.014
20 CAVITY	4) 590	.615	6) .096	.059
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.357

PROBLEM 1

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

THESE FOOTNOTES APPLICABLE TO ALL PAGES

1) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area. For example, the ratio of line 19 -

$$\text{FRAMING} = \frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$$

- Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- CAVITY AREA equals line 18 minus line 19 AREA.
- Line 12 U VALUE for FRAMING.
- Line 12 U VALUE for CAVITY.
- GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- The U VALUES obtained from Table 5-1 or 5-2.
- This U VALUE is the value indicated on line 21 page 1.
- This U VALUE is the value indicated on line 21 page 2 for floors.
- This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
- U x Ratio Allowed total must be greater than U x Ratio Actual Total.

- TABLE A RATIO.
- TABLE B RATIO.

U₀ CALCULATIONS FOR FLOORS AND ROOF-CEILING

FLOOR HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.92	.92
2 OUTER SURFACE	—	—
3 OUTER SHEATHING	1.25	1.25
4 FRAMING	11.88	—
5 CAVITY a) INSULATION	—	—
6 b) AIR SPACE	—	—
7 INSIDE SURFACE	2.08	2.08
8 AIR FILM INSIDE	.92	.92
9 OTHER a)	—	—
10 (Specify) b)	—	—
11 R _T = TOTAL LINES 1-10	17.05	5.17
12 U = 1/R TOTAL	.059	.193

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS FLOOR	900	—	—	—
14 OTHER (Specify)	—	—	—	—
15 OTHER (Specify)	—	—	—	—
16 OTHER (Specify)	—	—	—	—
17 OTHER (Specify)	—	—	—	—
18 OPAQUE FLOOR	2) 900	—	—	—
19 FRAMING	3) 90	.10	5) .059	.006
20 CAVITY	4) 810	.90	6) .193	.174
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.180

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.61	.61
2 OUTER SURFACE	—	—
3 OUTER SHEATHING	—	—
4 FRAMING	9.38	—
5 CAVITY a) INSULATION	—	15.00
6 b) AIR SPACE	—	—
7 INSIDE SURFACE	.45	.45
8 AIR FILM INSIDE	.61	.61
9) OTHER a)	—	—
10 (Specify) b)	—	—
11 R _T = TOTAL LINES 1-10	11.05	16.67
12 U = 1/R TOTAL	.090	.060

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS ROOF-CEIL.	900	—	—	—
14 SKYLIGHT	—	—	—	—
15 ROOF SCUPPER	—	—	—	—
16 OTHER (Specify)	—	—	—	—
17 OTHER (Specify)	—	—	—	—
18 OPAQUE ROOF-CEIL.	2) 900	—	—	—
19 FRAMING	3) 90	.10	5) .090	.009
20 CAVITY	4) 810	.90	6) .060	.054
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.063

COMBINING COMPONENTS

U ACTUAL $\leq$ U ALLOWED

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO	ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL	960	.348	.29	.101	22 WALL	960	.348	.357 9)	.124
23 FLOOR	900	.326	.32	.104	23 FLOOR	900	.326	.180 10)	.059
24 CEILING- ROOF	900	.326	.05	.016	24 CEILING- ROOF	900	.326	.063 11)	.021
25 TOTAL	2760	U_T ALLOWED =		.221	25 TOTAL	2760	U_T ACTUAL =		.204

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

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WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY	WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
1 AIR FILM OUTSIDE			13 GROSS WALL				
2 OUTER SURFACE			14 WINDOW				
3 OUTER SHEATHING			15 DOOR				
4 FRAMING			16 OTHER (Specify)				
5 CAVITY a) INSULATION			17 OTHER (Specify)				
6 b) AIR SPACE			18 OPAQUE WALL	2)			
7 INSIDE SURFACE			19 FRAMING	3)	13)	5)	
8 AIR FILM INSIDE			20 CAVITY	4)	14)	6)	
9 OTHER a)			21 U_o = TOTAL LINES 19, 20				
10 (Specify) b)							
11 R_T = TOTAL LINES 1-10							
12 U = 1/R TOTAL							

U₀ CALCULATIONS FOR WALLS

3000 D. D.

PROBLEM 2

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.17	.17
2 OUTER SURFACE	1.46	1.46
3 OUTER SHEATHING	.62	.62
4 FRAMING	4.35	
5 CAVITY a) INSULATION		7.00
6 b) AIR SPACE		-
7 INSIDE SURFACE	.45	.45
8 AIR FILM INSIDE	.68	.68
9 OTHER a)	-	-
10 (Specify) b)	-	-
11 R _T = TOTAL LINES 1-10	7.73	10.38
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WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS WALL	960			
14 WINDOW	225	.234	.58	.136
15 DOOR	40	.042	.49	.021
16 OTHER (Specify)	-	-	-	-
17 OTHER (Specify)	-	-	-	-
18 OPAQUE WALL	2) 695			
19 FRAMING	3) 105	.109	5) .129	.014
20 CAVITY	4) 590	.615	6) .096	.059
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.23

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

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$$\text{FRAMING} = \frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$$

- 2) Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- 3) FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- 4) CAVITY AREA equals line 18 minus line 19 AREA.
- 5) Line 12 U VALUE for FRAMING.
- 6) Line 12 U VALUE for CAVITY.
- 7) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- 8) The U VALUES obtained from Table 5-1 or 5-2.
- 9) This U VALUE is the value indicated on line 21 page 1.
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- 11) This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
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- 14) TABLE B RATIO.

U₀ CALCULATIONS FOR FLOORS AND ROOF-CEILING

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3 OUTER SHEATHING	1.25	1.25
4 FRAMING	11.88	—
5 CAVITY a) INSULATION	—	—
6 b) AIR SPACE	—	—
7 INSIDE SURFACE	2.08	2.08
8 AIR FILM INSIDE	.92	.92
9 OTHER a)	—	—
10 (Specify) b)	—	—
11 R _T = TOTAL LINES 1-10	17.05	5.17
12 U = 1/R TOTAL	.059	.193

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS FLOOR	900	—	—	—
14 OTHER (Specify)	—	—	—	—
15 OTHER (Specify)	—	—	—	—
16 OTHER (Specify)	—	—	—	—
17 OTHER (Specify)	—	—	—	—
18 OPAQUE FLOOR	2) 900	—	—	—
19 FRAMING	3) 90	.10	5) .059	.006
20 CAVITY	4) 810	.70	6) .113	.174
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.180

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.61	.61
2 OUTER SURFACE	—	—
3 OUTER SHEATHING	—	—
4 FRAMING	9.38	—
5 CAVITY a) INSULATION	—	15.00
6 b) AIR SPACE	—	—
7 INSIDE SURFACE	.45	.45
8 AIR FILM INSIDE	.61	.61
9) OTHER a)	—	—
10 (Specify) b)	—	—
11 R _T = TOTAL LINES 1-10	11.05	16.67
12 U = 1/R TOTAL	.090	.060

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS ROOF-CEIL.	900	—	—	—
14 SKYLIGHT	—	—	—	—
15 ROOF SCUPPER	—	—	—	—
16 OTHER (Specify)	—	—	—	—
17 OTHER (Specify)	—	—	—	—
18 OPAQUE ROOF-CEIL.	2) 900	—	—	—
19 FRAMING	3) 90	.10	5) .090	.009
20 CAVITY	4) 810	.70	6) .060	.061
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.06

COMBINING COMPONENTS

U ACTUAL $\leq$ U ALLOWED

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO	ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL	960	.348	.26	.091	22 WALL	960	.348	.230 9)	.080
23 FLOOR	900	.326	.18	.059	23 FLOOR	900	.326	.18 10)	.059
24 CEILING- ROOF	900	.326	.05	.016	24 CEILING- ROOF	900	.326	.063 11)	.021
25 TOTAL	2760	U_T ALLOWED =		.166	25 TOTAL	2760	U_T ACTUAL =		.160

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

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WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY	WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
1 AIR FILM OUTSIDE			13 GROSS WALL				
2 OUTER SURFACE			14 WINDOW				
3 OUTER SHEATHING			15 DOOR				
4 FRAMING			16 OTHER (Specify)				
5 CAVITY a) INSULATION			17 OTHER (Specify)				
6 b) AIR SPACE			18 OPAQUE WALL	2)			
7 INSIDE SURFACE			19 FRAMING	3)	13)	5)	
8 AIR FILM INSIDE			20 CAVITY	4)	14)	6)	
9 OTHER a)			21 U_o = TOTAL LINES 19, 20				
10 (Specify) b)							
11 R_T = TOTAL LINES 1-10							
12 U = 1/R TOTAL							

U₀ CALCULATIONS FOR WALLS

7200 D. D.

WALLS HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.17	.17
2 OUTER SURFACE	1.46	1.46
3 OUTER SHEATHING	.62	.62
4 FRAMING	4.35	
5 CAVITY a) INSULATION		11.00
6 b) AIR SPACE		
7 INSIDE SURFACE	.45	.45
8 AIR FILM INSIDE	.68	.68
9 OTHER a)		
10 (Specify) b)		
11 R _T = TOTAL LINES 1-10	7.73	14.38
12 U = 1/R TOTAL	.129	.070

WALLS HEATING	AREA s.f.	GROSS AREA RATIO 1)	U VALUE	U x RATIO
13 GROSS WALL	960			
14 WINDOW	225	.234	.33	.077
15 DOOR	40	.042	.64	.027
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2) 695			
19 FRAMING	3) 105	.109	5) .129	.014
20 CAVITY	4) 590	.615	6) .070	.043
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.161

PROBLEM 3

TABLE A - STUD FRAMING RATIO

STUD SPACING	12"	16"	24"
RATIO	0.17	0.15	0.10

THESE FOOTNOTES APPLICABLE TO ALL PAGES

- 1) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area. For example, the ratio of line 19 -

$$\text{FRAMING} = \frac{\text{Framing Area} - \text{line 19}}{\text{Gross Area} - \text{line 13}}$$

- 2) Line 18 OPAQUE AREA, equals line 13 AREA minus 14, 15, 16, and 17 AREA.
- 3) FRAMING AREA equals line 18 AREA times appropriate FRAMING RATIO TABLE A.
- 4) CAVITY AREA equals line 18 minus line 19 AREA.
- 5) Line 12 U VALUE for FRAMING.
- 6) Line 12 U VALUE for CAVITY.
- 7) GROSS AREA RATIO equals ratio of individual areas to gross area. This ratio may be obtained by dividing each individual line area by the gross area.
- 8) The U VALUES obtained from Table 5-1 or 5-2.
- 9) This U VALUE is the value indicated on line 21 page 1.
- 10) This U VALUE is the value indicated on line 21 page 2 for floors.
- 11) This U VALUE is the value indicated on line 21 page 2 for ceiling-roof.
- 12) U x Ratio Allowed total must be greater than U x Ratio Actual Total.
- 1) TABLE A RATIO.
- 1) TABLE B RATIO.

U₀ CALCULATIONS FOR FLOORS AND ROOF-CEILING

FLOOR HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.92	.92
2 OUTER SURFACE	—	—
3 OUTER SHEATHING	.62	.62
4 FRAMING	11.88	—
5 CAVITY a) INSULATION	—	19.00
6 b) AIR SPACE	—	—
7 INSIDE SURFACE	2.08	2.08
8 AIR FILM INSIDE	.92	.92
9 OTHER a)	—	—
10 (Specify) b)	—	—
11 R _T = TOTAL LINES 1-10	16.42	23.54
12 U = 1/R TOTAL	.061	.042

FLOOR HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS FLOOR	900	—	—	—
14 OTHER (Specify)	—	—	—	—
15 OTHER (Specify)	—	—	—	—
16 OTHER (Specify)	—	—	—	—
17 OTHER (Specify)	—	—	—	—
18 OPAQUE FLOOR	2) 900	—	—	—
19 FRAMING	3) 90	.10	5) .061	.006
20 CAVITY	4) 810	.90	6) .042	.038
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.044

JOIST OR RAFTER SPACING	12"	16"	24"
RATIO	0.13	0.10	0.06

TABLE A - JOIST OR RAFTER FRAMING RATIO

ROOF - CEILING HEATING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE	.17	.17
2 OUTER SURFACE	—	—
3 OUTER SHEATHING	—	—
4 FRAMING	9.38	—
5 CAVITY a) INSULATION	—	19.00
6 b) AIR SPACE	—	—
7 INSIDE SURFACE	.45	.45
8 AIR FILM INSIDE	.61	.61
9) OTHER a)	—	—
10 (Specify) b)	—	—
11 R _T = TOTAL LINES 1-10	10.61	20.23
12 U = 1/R TOTAL	.094	.049

ROOF - CEILING HEATING	AREA (s.f.)	GROSS AREA RATIO 1)	U VALUE	UxRATIO
13 GROSS ROOF-CEIL.	900	—	—	—
14 SKYLIGHT	—	—	—	—
15 ROOF SCUPPER	—	—	—	—
16 OTHER (Specify)	—	—	—	—
17 OTHER (Specify)	—	—	—	—
18 OPAQUE ROOF-CEIL.	2) 900	—	—	—
19 FRAMING	3) 90	.10	5) .094	.009
20 CAVITY	4) 810	.90	6) .049	.044
21 U ₀ = TOTAL LINES 14, 15, 16, 17, 19, 20				.053

COMBINING COMPONENTS

ALLOWED	AREA	GROSS AREA RATIO 7)	U VALUE ALLOWED 8)	UxRATIO
22 WALL	960	.348	.20	.070
23 FLOOR	900	.326	.08	.026
24 CEILING- ROOF	900	.326	.05	.016
25 TOTAL	2760	U_T ALLOWED =		.112

U ACTUAL $\leq$ U ALLOWED

ACTUAL	AREA	GROSS AREA RATIO 7)	U VALUE ACTUAL 8)	UxRATIO
22 WALL	960	.348	.161 9)	.056
23 FLOOR	900	.326	.044 10)	.014
24 CEILING- ROOF	900	.326	.053 11)	.017
25 TOTAL	2760	U_T ACTUAL =		.087

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

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WALLS COOLING	R VALUES FRAMING	R VALUES CAVITY
1 AIR FILM OUTSIDE		
2 OUTER SURFACE		
3 OUTER SHEATHING		
4 FRAMING		
5 CAVITY a) INSULATION		
6 b) AIR SPACE		
7 INSIDE SURFACE		
8 AIR FILM INSIDE		
9 OTHER a)		
10 (Specify) b)		
11 R_T = TOTAL LINES 1-10		
12 U = 1/R TOTAL		

WALLS COOLING	AREA (s.f.)	OPAQUE 1) AREA RATIO	U VALUE	UxRATIO
13 GROSS WALL				
14 WINDOW				
15 DOOR				
16 OTHER (Specify)				
17 OTHER (Specify)				
18 OPAQUE WALL	2)			
19 FRAMING	3)	13)	5)	
20 CAVITY	4)	14)	6)	
21 U_o = TOTAL LINES 19, 20				