United States
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**Forest
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Survey of Existing Performance Requirements in Codes and Standards for Light-Frame Construction

Abstract

Present building codes and standards are a combination of specifications and performance criteria. Where specifications prevail, the introduction of new materials or methods can be a long, cumbersome process. To facilitate the introduction of new technology, performance requirements are becoming more prevalent. In some areas, there is a lack of information on which to base acceptable performance. As background information, existing major codes and standards were surveyed. Existing criteria are listed for each aspect of construction under major headings of structural and environmental. A brief discussion of agreement, differences, and deficiencies is also given. Selected references include publications that should be useful in establishing performance requirements. This information should be useful to building researchers and others concerned with development of performance requirements for buildings.

CREDITS

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NOTE

Building codes and standards are complex documents, with many interrelated requirements. This survey was necessarily limited in scope and actually does not identify such relationships or their effects. For example, most codes provide design rules for combinations of design loads that may occur simultaneously. The codes also normally contain several structural criteria for each building element, such as deflection limits, minimum loads for design analysis, and required load factors for ultimate capacity or proof testing. The relationships between such rules and criteria are generally not contained herein; the reader is strongly advised to consult the code in question.

Contents

Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BBC	Basic Building Code (Building Officials and Code Administrators of America)
Btu	British thermal units
CNEL	Community Noise Equivalent Level
dB	decibels
EPA	Environmental Protection Agency
HUD-MPS	Housing and Urban Development-Minimum Property Standards
IIC	Impact Insulation Class
NIC	Noise Isolation Class
NFPA	National Forest Products Association
SSBC	Southern Standard Building Code (Southern Building Code Congress)
STC	Sound Transmission Class
UBC	Uniform Building Code (International Conference of Building Officials)

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Survey of Existing Performance Requirements in Codes and Standards for Light-Frame Construction

By
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Introduction

The concept of performance requirements for light-frame construction increases in importance as new technology becomes more prevalent in building construction. Codes and standards that require specific materials and techniques restrict the introduction of new technology because of the extremely long, cumbersome process for obtaining acceptance. Codes and standards generally are classified under two categories—specification or performance. A specification code or standard lists material type, quality, size, and spacing to perform a certain function. Whereas, a performance code or standard states how a building element must perform under a specific loading. The choice of materials and techniques may be selected from anything the designer conceives that will perform as required.

Attempts have been made in the past to establish performance standards. In 1947, the National Housing Agency prepared a publication, "Performance Standards—Structural and Insulation Requirements for Houses." It was based on the best available information at the time, and had some impact on the building industry, but codes continued to include specifications. In 1965, the Building Research Advisory Board held a symposium on the "Performance Concept in Building." The symposium was held primarily to stimulate and develop thoughts and ideas. Participation indicated a high degree of interest in the subject, and a similar symposium was held in 1974.

When Operation Breakthrough was started by HUD in 1969, design requirements were established in terms of performance criteria. The Department of Housing and Urban Development-Minimum Property Standards (HUD-MPS) that became effective in 1973 were also presented in terms of performance wherever feasible. Major model codes, including Basic Building Code (BBC), Southern Standard Building Code (SSBC), and Uniform Building Code (UBC), have also moved toward performance requirements, but many specifications still remain. The American National Standards Institute (ANSI) has developed standards for structural performance of buildings that are widely recognized by the design profession. Test methods are generally consensus standards developed by the American Society for Testing and Materials (ASTM). With the advent of energy shortages, conservation standards were developed by the American Society for Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).

All the preceding codes and standards have a common goal of satisfying needs for safety and comfort of occupants as well as durability of the building. In order to establish uniformity, these need to be considered as background material. We also know that present light-frame construction performs satisfactorily, but we cannot always provide an analytical reason. Light-frame construction has developed over many years, largely by a trial-and-error method. Techniques that worked were adopted and often became the basis of comparison for

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

judging new techniques. This technique has been used in some cases to develop performance requirements employed by the major model building codes. However, such requirements often differ among various code-writing bodies.

This paper surveys major codes and standards for existing performance requirements for light-frame construction to provide background for further work in establishing performance-based design information. Only those codes or standards that include performance requirements are listed for each element of construction. The survey is presented under two major headings: (1) structural, and (2) environmental. Selected references are presented at the end of this report.

Structural Performance

Structural requirements of codes and standards are generally stated in terms of allowable deflection and/or minimum strength. Loads include dead load, wind, snow, earthquake, and occupancy. These requirements are discussed under each building component and type of loading.

Floors

Floor loadings may be either concentrated or uniformly distributed. A concentrated load is applied to a small area such as by the leg of a heavy item of furniture or by an appliance. Uniform load could best be illustrated by a large number of occupants distributed over the floor space of a room.

Concentrated Load

(1) BBC 707.1, 702.2, and 803.0.

Load–200 pounds on an area of 1 square inch.

Requirement–The deflection is limited to 11360 of the span for plaster construction or 11240 of the span if there is no plaster. The floor must sustain 2½ times design load without failure.

(2) SSBC 1203.1(d) and 1203.5.

Load–Probable concentrated load expected.

Requirement–The floor must sustain at least twice the design load and recover at least 75 percent of its maximum deflection within 24 hours after the load is removed.

(3) UBC 2517(h) and 2518(d).

Load–300 pounds on 3-inch or smaller diameter.

Requirement–Deflect ion limit for sheathing, 1/360 of the span between supporting joists or beams.

Load–200 pounds on a 1-inch diameter.

Requirement–Sheathing deflection limit 0.125 inch when loaded midway between supporting joists or beams not over 24 inches on center and 1/360 of the span for spans over 24 inches.

(4) Guide Criteria for Operation Breakthrough, D.1.4. 1(b).

Load–400 pounds on 5/8-inch diameter.

Requirement–No residual indentation of the structural surface in excess of 1/16 inch after 1 hour.

Load–280 pounds on 5/8-inch diameter.

Requirement–No residual indentation of the structural surface in excess of 1116 inch under long-term loading .

(5) ANSI A58.1, 3.2.

Load–200 pounds on an area of 1 square inch.

Requirement–Safe support.

Uniform Load

(1) BBC 706.0, 702.2, and 803.0.

Load–First floor 40 lb/ft^2. Second floor 30 lb/ft^2. Uninhabited attic 20 lb/ft^2.

Requirement–Deflection limit is 1/360 of span for plaster construction and 1/240 of span if there is no plaster. The floor must sustain 2½ times design load without failure.

(2) SSBC 1203.1(a) and 1203.5.

Load–Sleeping rooms, attic, and storage, 30 lb/ft^2. All other rooms, 40 lb/ft^2.

Requirement–The floor must sustain at least twice the design load and recover at least 75 percent of its maximum deflection within 24 hours after the load is removed.

(3) UBC 2517(h) and 2518(d).

Load–40 lb/ft^2.

Requirement–Deflection limit for sheathing is 1/360 of the span between supporting joists or beams. Joists must be in accordance with NFPA span tables (deflection limit is 11360 of the span; strength limit is allowable fiber stress).

(4) One- and two-family dwelling code R602.3.

Load–Sleeping rooms and attic, 30 lb/ft^2. All other rooms, 40 lb/ft^2.

Requirement–Deflection is limited to 1/360 of the span.

(5) HUD-MPS 601-4.2.

Load–Dwelling rooms other than sleeping, 40 lb/ft^2. Sleeping rooms and attic floor, 30 lb/ft^2. Attic with limited storage, 20 lb/ft^2.

Requirement–Joists must be in accordance with NFPA span tables (deflection limit is 1/360 of the span; strength limit is allowable fiber stress).

(6) Guide Criteria for Operation Breakthrough A(3)(b) and A.1.1.1(b).

Load–As required by ANSI A58.1 (see below).

Requirement–The extreme limit of deflection under dead load plus live load should not exceed 11360 of the span. The extreme limit of long-term sustained load should not exceed 11240 of the span.

(7) ANSI A58.1, 3.1.1.

Load–First floor, 40 lb/ft^2. Second floor, 30 lb/ft^2. Uninhabitable attic, 20 lb/ft^2.

Requirement–Safe support.

Discussion

Performance requirements for floors are generally stated as deflection limits and are not explicit on length of time the load is applied. A deflection limit of 1/360 of the span is used in a majority of cases; however, 1/240 of the span is permitted by BOCA where there is no plaster ceiling under the floor. The SSBC does not state deflection limits, but states percent of recovery of deflection after the load is removed. Guide Criteria for Operation Breakthrough has an indentation limitation for concentrated loads. The usual strength requirement is 2½ times design load. However, SSBC requires 2 times design load. In some cases requirements are more stringent than necessary because of concerns for new use if the building is rehabilitated.

There is no general agreement on concentrated loads to be applied or their area of application. Loads vary from 200 to 400 pounds and the area of application varies from a 5/8-inch diameter to a 3-inch diameter. Uniformity of concentrated load should be developed based on realistic loads in light-frame construction. A new ASTM standard is presently being developed that may satisfy this requirement. Uniform load is fairly consistent in following ANSI requirements; however, UBC requires a design load of 40 lb/ft^2 for all floors regardless of intended use. The ANSI loading of 40 lb/ft^2 for all first floors of residences has often been criticized as unrealistic since about 40 people would have to crowd into a 12- by 14-foot room to achieve such a uniform loading. However, 40 lb/ft^2 may be a realistic load for the 1/360 of the span deflection limit.

None of the codes or standards address vibration of floors which appears to be a major criterion for acceptance. There also is little consideration given to load sharing or performance of the floor as a system. The NFPA span tables for joists do consider some load sharing by allowing a 15-percent increase for extreme fiber stress in bending where repetitive members are no more than 24 inches apart.

Load-Bearing Walls

Walls are loaded in bending, racking, and bearing. Bending load is generally due to wind perpendicular to the surface of the wall. Wind also produces a racking load on walls oriented parallel to the wind direction. Bearing load is produced by the dead load of the roof plus snow load. All of these live loads are dependent on geographic location.

Bending Load

(1) BBC 713.2.1, 803.2, and 854.2.1.

Load–Wind pressure, 15 lb/ft^2 (two-thirds on windward side and one-third as suction on leeward side).

Requirement–The wall must sustain, without failure, superimposed loads equal to 2½ times the design live load. It must also provide adequate support for materials used to enclose the building and provide for transfer of all lateral loads to the foundation.

(2) SSBC 1205.1 and 1203.5.

Load–10 lb/ft^2 inland. 25 lb/ft^2 coastal (within 25 miles of the coast).

Requirement–The wall must sustain a superimposed load equal to twice the design live load and recover at least 75 percent of its maximum deflection within 24 hours after the load is removed.

(3) UBC 2311 (a and b) and 2303(b).

Load–See table 1 and figure 1.

Requirement–Design of the wall must admit to rational analysis in accordance with well-established principles of mechanics.

(4) One- and Two-Family Dwelling Code R-202, R-401, and S-26,401.

Load–To be established by local authorities.

Requirement–Design must conform with applicable grading, material, test, construction, and design standards.

(5) HUD-MPS 600,401-2.1, 601-6.1, and 601-6.2C.

Load–For wind speeds up to and including 80 miles per hour, minimum of 15 lb/ft^2 inward or outward. Local pressure at corners shall be not less than 30 lb/ft^2 outward. Minimum for overturning, racking, or sliding, 20 lb/ft^2. Where higher wind loadings exist, use ANSI A58.1.

Requirement–Assure adequate strength and rigidity based on

Table 1.–Wind pressures

	Wind-pressure-map areas (fig.1)						
	20	25	30	35	40	45	50
	Lb/ft^2						
Less than 30 Ft	15	20	25	25	30	35	40

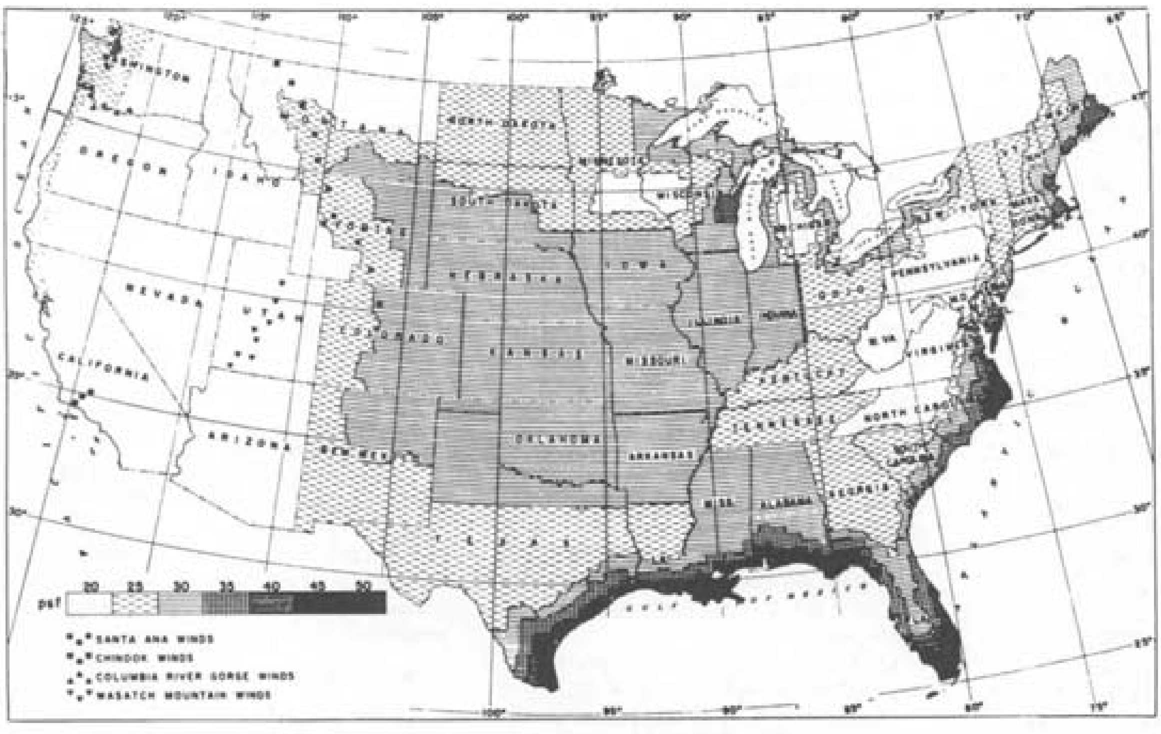

Figure 1.—Allowable resultant wind pressures. Combined inward and outward pressures on exterior surfaces of ordinary square buildings at 30 feet above ground.

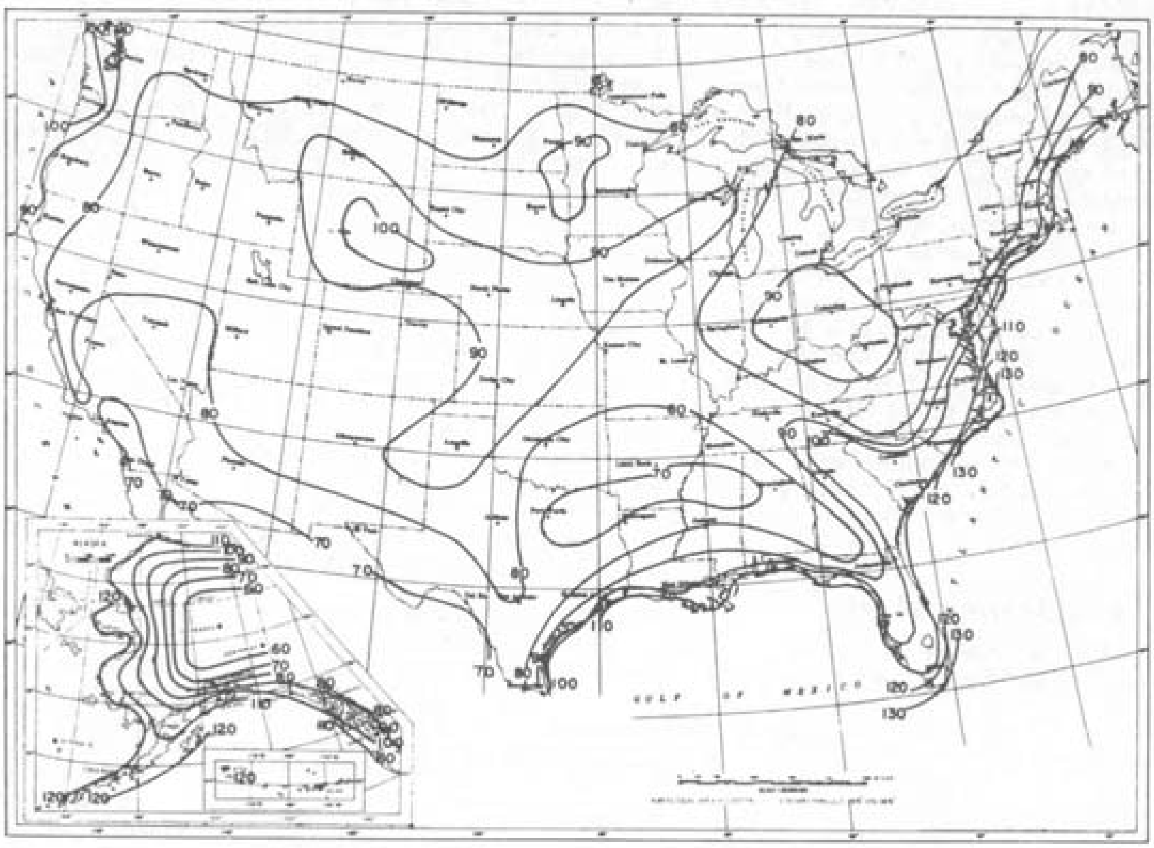

Figure 2.–Basic wind speed in miles per hour annual extreme fastest-mile speed 30 feet above ground, 100-year mean recurrence interval.

generally accepted engineering practice.

(6) Guide Criteria for Operation Breakthrough A.1.3(b).

Load–Wind load given in ANSI A58.1. Wind load or live load plus 0.8 wind load.

Requirement –Recommended deflection limit 1/480 of the span, Extreme deflection limit 1/240 of the span.

(7) ANSI A58.1, 6.3.4.1.

Load–In accordance with table 2 and figure 2.

Requirement –No requirement stated.

Table 2.–Effective velocity pressures for ordinary buildings and structures

	Height	Basic wind speed								
		50	60	70	80	90	100	110	120	130
	Ft					*Mph*				
Exposure A, centers of large cities and rough, hilly terrain	*Less than 30*	*3*	*4*	*5*	*6*	*7*	*9*	*10*	*12*	*14*
Exposure B, suburban areas, towns, city outskirts, and rolling terrain	*Less than 30*	5	6	*8*	*10*	*13*	*16*	*20*	*23*	*27*
Exposure C, flat open country, open flat coastal belts, and grassland	*Less than 30*	6	*7*	*11*	*15*	*20*	*26*	*32*	*39*	*45*

Racking Load

(1) HUD-MPS Appendix D (500).

Load–ASTM E-72 test method. Maximum load dry, 5,200 pounds. Maximum load wet, 4,000 pounds.

Requirement– No failure.

Load–Dry, 1,200 pounds.

Requirement –Average total deflection 0.2 inch. Residual deflection 0.1 inch.

Load–Dry, 2,400 pounds.

Requirement –Average total deflection 0.6 inch. Residual deflection 0.3 inch.

Load –Wet, 1,200 pounds.

Requirement –Average total deflection 0.28 inch. Residual deflection 0.14 inch.

Load –Wet, 2,400 pounds.

Requirement –Average total deflection 0.8 inch. Residual deflection 0.4 inch.

(2) Guide Criteria for Operation Breakthrough A.1.2.1 and A.1.2.2.

Load–0.9 dead load plus wind load from ANSI A58.1. Also, dead load plus gravity live load plus 0.8 wind load.

Requirement –Drift (horizon tal movement) should not exceed 0.002 of the height.

(3) ANSI A58.1, 8.4.

Load–In accordance with table 2 and figure 2 as shown under wall bending load, item (7).

Requirement –Lateral deflections or drift considered in accordance with accepted engineering practice.

Bearing Load

(1) BBC 854.1.

Load–Dead and live loads.

Requirement –Adequate strength to resist all vertical forces.

(2) HUD-MPS 606-4.1 and 601-2.1.

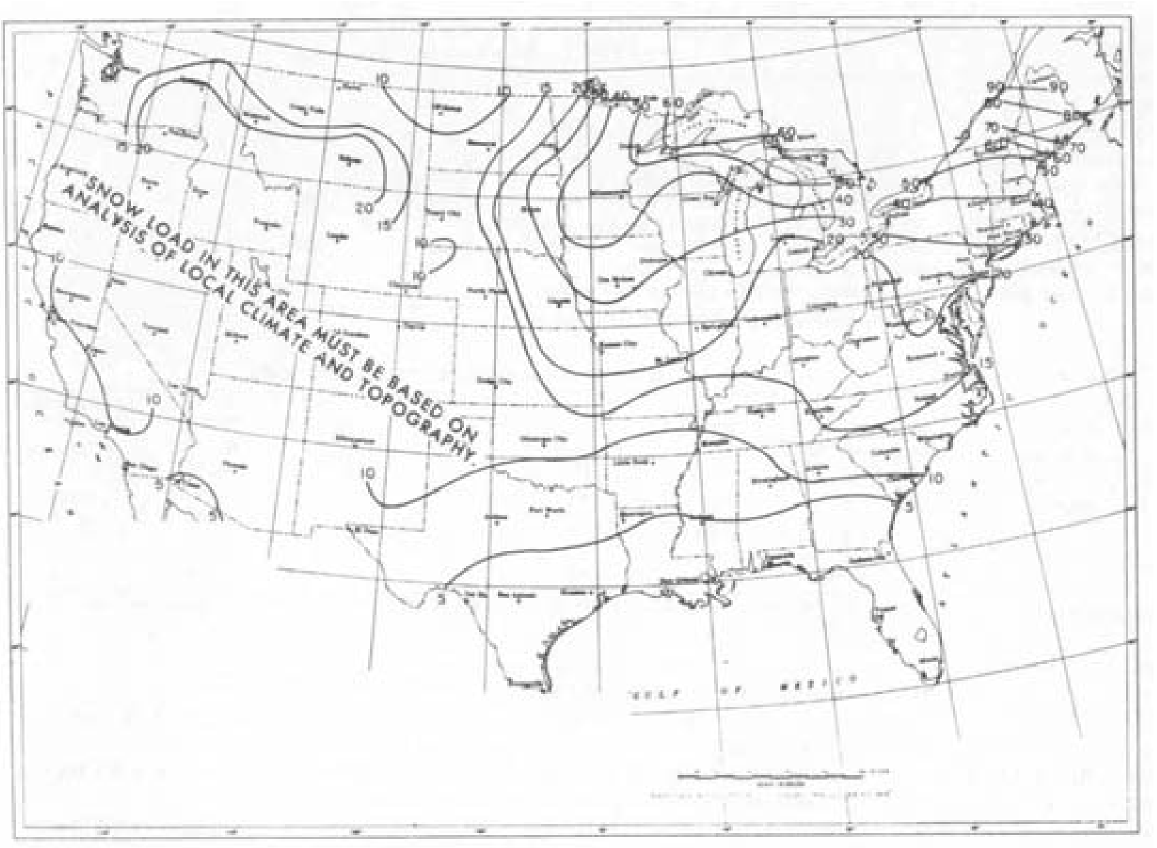

Figure 3.–Snow load in pound-force per square foot on the ground, 100-year mean recurrence interval.

Load –In accordance with ANSI A58.1.

Requirement –Design by generally accepted engineering practice. The wall must support all design loads without exceeding the allowable stresses and deflections (NFPA National Design Specification for Stress-Grade Lumber and Its Fastenings).

(3) Guide Criteria for Operation Breakthrough C.1.3.1(d).

Load–1.3 dead load plus 1.7 live load. In addition, an eccentric load of 40 pounds per lineal foot or 1.5 times the maximum load likely to be exerted by attached and modular furniture, whichever is greater applied at an eccentricity of one-half the wall thickness plus 6 inches.

Requirement –No damage.

(4) ANSI A58.1, 1.3.

Load–Dead load plus snow load from map (fig. 3). For first floor walls, add 30 lb/ft^2 load from second floor.

Requirement –The wall must support all design loads without exceeding the allowable stresses for the materials of construction in the structural members and connections.

Discussion

Code requirements for walls are generally specifications rather than performance related. Wind loads are given for bending load, and these are usually consistent with ANSI A58.1. For bending, BBC requires that the wall support 2½ times the load while SSBC requires a 75-percent recovery of maximum deflection resulting from twice the design load. Guide Criteria for Operation Breakthrough requires a deflection limit of 1/240 of the span, but no failure criteria is listed.

Racking resistance is generally determined by the ASTM E-72 test method which is applied to a wall section 8 feet long. Requirements usually do not include consideration for the overall length of wall resisting the racking load. In most cases, construction is specified that will provide a certain resistance at each corner. Interior covering is not considered as contributing to racking resistance, although there is indication that it makes a major contribution. Interaction of walls with partitions, floor, and roof also adds to racking resistance. There is a need to define requirements for racking resistance as it relates to the entire structure.

Bearing load on walls is commonly a combination of dead and live loads transferred from the roof. The Guide Criteria for Operation Breakthrough includes a requirement for an eccentric load such as modular furniture hanging on the wall. Design procedures accepted by the codes for walls to support bearing loads are quite direct and the performance requirement is simply support of the load without failure of the structural materials used. In reality, there is composite action with vertical and horizontal loads acting together. There is no particular disagreement concerning bearing load; however, most codes specify properties of structural members rather than stating performance standards.

Nonload-Bearing Partitions

While this term may not be accurate since partitions often carry racking forces and roof loads, it is

Table 3.–Minimum roof live loads[1]

Roof slope	Tributary loaded area for any structural member: 0 to 200	201 to 600	Over 600
	Ft²		
Flat or rise less than 4 inches per foot Arch or dome with rise less than 1/8 of span	20	16	12
Rise 4 inches per foot to less than 12 inches per foot Arch or dome with rise 1/8 of span to less than 3/8 of span	16	14	12
Rise 12 inches per foot and greater Arch or dome with rise 3/8 of span or greater	12	12	12

[1] In pound-force per ft² of horizontal projection.

Table 4.–External wind Pressure on roofs

Ratio of side wall height to building width	Flat roofs	Windward slope of roofs: Less than 1:12	1:12 to 4.05:12	4.05:12 to 6:12	612 to 1212[1]	Leeward slope: All slopes
0.2	- 0.60	- 0.60	- 0.06	0.12	0.19	- 0.50
.4	- .60	- .60	- .33	.01	.09	- .50
.6	- .60	- .60	- .49	- .20	- .06	- .50
.8	- .60	- .60	- .57	- .30	- .18	- .50
1.0 or more	- .60	- .60	- .60	- .39	- .28	- .50

[1] For all roof surfaces having a slope greater than 12:12 the same wind force as for vertical surfaces shall be assumed.

common terminology in codes and standards. Partitions are not normally exposed to the same loads from the elements as the exterior envelope of a building is; however, if windows or doors are open, some wind load can be exerted on partitions. They must also take the load of people leaning or the impact of people or objects hitting the partition. Loads may also be hung on partitions.

(1) BBC 713.4.2.

Load–10 lb/ft² acting perpendicular to the partition.

Requirement–Safe support without exceeding the allowable stresses for the materials of construction in the structural members and connections.

(2) HUD-MPS 6 or 6.2d.

Load–10 lb/ft².

Requirement –Adequate strength and rigidity.

(3) Operation Breakthrough Guide Criteria C.1.1.2 and C.1.3.1.

Load –5 lb/ft².

Requirement –The recommended limit of deflection should not exceed 1/240; the extreme limit should not exceed 1/120.

Load–

a. A concentrated horizontal load of 150 pounds, applied at any location to a bearing area not to exceed 5 square inches.

b. A concentrated horizontal load of 22 pounds, applied to a bearing area not to exceed 5 square inches and centered 3 inches above finished floor level.

c. A load of 10 lb/ft² applied horizontally over the entire vertical surface of one side of the wall.

d. In addition to 1.3 dead plus 1.7 live, an eccentric vertical load, equal to 40 lb/ft² or 1.5 times the maximum load likely to be exerted by attached shelves and modular furniture, whichever is greater, at an eccentricity with respect to the centerline of the partition of one-half the partition thickness plus 6 inches. Partitions to which shelves or furniture cannot be attached are exempt from this requirement.

e. An impact of 60 foot-pounds, applied horizontally at any location five consecutive times, except in the case where the wall consists of stiffening elements supporting a surface cover. In the latter case, the wall should resist the 60 foot-pound impact energy delivered five consecutive times to the surface cover coincident with the axis of the stiffening element and a 30 foot-pound impact energy delivered five consecutive times to the surface cover at any location.

Requirement–Resist the loads with a maximum residual deflection not exceeding 10 percent of total maximum net deflection or 1/4000 of the span, whichever is greater, measured 24 hours after removal of the superimposed load, and with no damage to surfaces, finishes, supports, or subsystems.

Discussion

The performance required of nonload-bearing walls is more a matter of acceptance than of health and safety. Support of modular furniture is considered only by Operation Breakthrough, and this requirement is considered unnecessary where furniture cannot be attached to walls. The function of partitions needs to be defined. Rigid partitions have generally been required in wood-frame construction out much more deflection has been allowed in mobile home partitions, and occupants have accepted the fact that heavy objects cannot be hung from walls.

Roofs

Major roof loads are those exerted by wind and snow, sometimes acting together to varying degrees. Performance required under these loads is usually expressed in terms of strength and stiffness.

Snow and Wind Loads

(1) BBC 710, 711, 714, 719, and 701.1.

Load–In accordance with tables 3 and 4.

Requirement–Support all loads safely.

(2) SSBC 1203.2(a) and 1205.3.

Load–For a rise less than 30 degrees, vertical live load shall not be less than 20 lb/ft² of horizontal projection. For a rise greater than 30 degrees, wind load acts inward normal to the surface on the windward slope only. Outward load normal to all surfaces is 1¼ times the wind load. Wind load on overhanging eaves and cornices is twice the usual upward load.

Requirement –Sufficient strength to support the imposed loads without exceeding, in any of its structural elements, the stresses prescribed. Adequate anchorage of roof to walls and columns, and of walls and columns to the foundation.

(3) UBC 2305(a)(d) and 2311(a)(b)(c)(d).

Load–Snow load vertically upon the area projected on a horizontal plane. Loads in excess of 20 lb/ft² may be reduced for each degree of pitch over 20 degrees by $\left(\frac{\text{load}}{40}\right) - 1/2$.

Wind pressure on the vertical projection is shown in table 5. For enclosed buildings, uplift pressure acting normal to the surface is 3/4 the values in table 5. For unenclosed buildings, roof overhangs, etc., uplift pressure is 1¼ times the values in table 5. For slopes greater than 30 degrees, pressures act inward normal to the surface on the windward slope only.

Requirement–Sustain all loads within stress limitations. Provide adequate anchorage of the roof to walls and columns, and walls and columns to foundation to resist overturning, uplift, and sliding.

(4) HUD-MPS 601-6.2, 601-4.4, and 601-5.

Load–Wind load 20 Ib/ft² inward or outward. For overhanging eaves, etc., 40 lb/ft² upward normal to roof surface. For slopes greater than 6 in 12, pressures normal to the surface shall be equal to design wind pressure on exterior walls.

For snow load, refer to ANSI A58.1 if greater than 20 Ib/ft² for a slope of 3 in 12 or less, and 15 Ib/ft² for a slope over 3 in 12.

Requirement –All structural design shall be based on generally accepted engineering practices.

(5) Guide Criteria for Operation Breakthrough A(3)(c) and (e), A.1.1.1(b).

Load–Based on ANSI A58.1.

Requirement–Deflection due to superimposed load should not exceed: Recommended 1/240; Extreme limit 1/180. Deflection due to long-term sustained load plus superimposed load should not exceed: Recommended 11240; Extreme limit 1/150.

(6) ANSI A58.1, 3.8.1, 6.5.3.2, and 6.5.1.

Load–Minimum loads shown in table 7. For a ratio of wall height to least width less than 2.5, external suction coefficient on the roof is - 0.7. For a ratio of 2.5 or greater, the suction coefficient for the entire roof area is –0.8.

Requirement–Withstand sliding and overturning effects of wind. Support safely all loads without exceeding allowable stresses, for materials of construction, in the structural members and connectors.

Table 5–Wind pressures[1]

	Wind-pressure-map areas (fig. 1)						
	20	25	30	35	40	45	50
	Lb/ft²						
Less than 30 *Ft*	15	20	25	25	30	35	40

[1] See figure 1. Wind pressure column in the table should be selected which is headed by a value corresponding to the minimum permissible, resultant wind pressure Indicated for the particular locality. The figures given are recommended as minimum. These requirements do not provide for tornadoes. Minimum live loads are shown in table 6.

Table 6.–Minimum roof live loads[1]

Roof slope	Method 1: Tributary loaded area in square feet for any structural member			Method 2		
	0 to 200	201 to 600	Over 600	Uniform load	Rate of reduction R	Maximum reduction R
					Pct	*Pct*
Flat or rise less than 4 inches per foot	20	16	12	20	0.08	40
Rise 4 Inches per foot to less than 12 Inches per foot	16	14	12	16	.06	25
Rise 12 Inches per foot and greater	12	12	12	12	No reductions permitted	
Awnings except cloth covered	5	5	5	5	No reductions permitted	
Greenhouses, lath houses, and agricultural buildings	10	10	10	10	No reductions permitted	

[1]Where snow loads occur, the roof structure shall be designed for such loads as determined by the Building Official.

Table 7.–Minimum roof live loads[1]

Roof slope	Tributary loaded area in square feet for any structural member		
	0 to 200	201 to 600	Over 600
	Ft²		
Fiat or rise less than 4 inches per foot	20	16	12
Rise 4 inches per foot to less than 12 inches per foot	16	14	12
Rise 12 inches per foot and greater	12	12	12

[1] In pound-force per square foot of horizontal projection.

Discussion

There are no particular discrepancies in the loadings and performance requirements for roofs. Requirements are stated in very general terms. The NFPA span tables are normally used. These permit a deflection of 1/180 of the span in a concealed attic. Where the ceiling is applied directly to the bottom of roof joists, the deflection limit is 1/240 of the span if the ceiling is not plastered, or 1/360 of the span where the ceiling is plastered.

Earthquake

Requirements for earthquake design are generally based on frequency of occurrence as shown in maps for codes or standards.

Engineering calculations for earthquake resistance are essentially the same for all the codes and standards. Method of calculation is shown in ANSI A58.1.

(1) BBC 718.0.

In regions where local experience or the records of the National Ocean Survey show loss of life or damage of buildings resulting from earthquakes, buildings and structures shall be designed to withstand lateral forces, except where building: (1) is located in zone 0 (fig.4); (2) is located where local experience or the records of the National Ocean Survey do not show loss of life or damage to property, regardless of zone; (3) is a one- or two-family dwelling; or (4) is a minor accessory building.

(2) UBC 2312.

Every building or structure and every portion thereof shall be designed and constructed to resist stresses produced by lateral forces. Stresses shall be calculated as the effect of a force applied horizontally at each floor or roof level above the base. The force shall be assumed to come from any horizontal direction. Structural concepts other than set forth in section 2312 may be approved by the Building Official when evidence is submitted showing that equivalent ductility and energy absorption are provided.

(3) HUD-MPS 601-2.2 and 601-9.

Seismic design shall be in accordance with ANSI A58.1 except as noted: In regions where local experience shows loss of life or damage resulting from earthquakes, and in regions located in zones 1, 2,

Figure 4.–Risk zones and damaging earthquakes of the United States through 1968.

or 3 (fig. 4), buildings and components, or structures shall be designed to withstand the lateral forces provided for in the 1970 issue of the UBC.

(4) Operation Breakthrough Guide Criteria A.2.1.1.

Loads should account for earthquake forces acting in alternating directions on any part of the structure. Such forces should not cause failure of any part of the structure or of the connection between any part of the structure and the rest of the structure.

(5) ANSI A58.1, 8.1.1.

Every building or structure and every portion thereof, and minor accessory buildings, shall be designed and constructed to resist stresses produced by lateral forces as provided herein. Stresses shall be calculated as the effect of a force applied horizontally at each floor or roof level above the foundation. The force shall be assumed to come from any horizontal direction.

In those zones where wind, snow, or other loads impose a greater load than those provided herein, such other loads shall be provided for. It may be assumed that wind and earthquake loads will not occur simultaneously.

Discussion

Performance under earthquake loads is quite complex, and cannot be stated in simple terms of limitations for a specific load. The basic requirement is to tie all elements of the structure together and provide sufficient shear resistance so the entire building will move as a unit when the foundation moves. The wood-frame house usually has adequate resistance and resilience without special design (foundation anchors and racking resistance are required). The more complex high-rise buildings are beyond the scope of this study. Most of the codes and standards are in general agreement since they have been based on work by the Seismology Committee of the Structural Engineers Association of California.

Environmental Performance

Environmental requirements include heat transfer limitations, moisture control, and acoustical restrictions. Requirements for these items cannot be established on the same basis as structural aspects because life safety is not at stake. They do affect energy usage, maintenance and life of buildings, and privacy or freedom from nuisances.

Heat Transfer

Heat loss or gain for a building from exterior sources occurs primarily by conduction through the building envelope (wall, floor, and roof) and by air leakage and consequent replacement by infiltration of outside air. These losses are controlled by insulation and reduction of cracks or installation of draft stops. Requirements of this type are just beginning to appear in codes. They have not appeared in the past because they did not affect life safety. The major reference document for energy conservation in buildings is ASHRAE Standard 90-75.

Roof/Ceiling

(1) HUD-MPS 6-7.1.

"U" values shall not exceed those shown in table 8. ASHRAE 90-75 may be used as an alternative.

(2) ASHRAE 90-75, 4.3.2.2.

For 8,000 degree days or less, transmittance value shall not exceed 0.05 Btu/h/ft[2] °F. For more than 8,000 degree days, transmittance shall not exceed 0.04 Btu/h/ft[2] °F. An exception is that for all degree-day areas, roof-deck ceiling combinations shall have a transmittance value not to exceed 0.08 Btu/h/ft[2] °F.

(3) Davis, California Energy Code Resolution No. 1833, 4.B.

Minimum resistance of R-19 for insulation. If unshaded roof is darker than No. 6 on Munsell chart for multifamily dwellings or No. 4 for single-family, insulation must be increased to R-25.

Table 8.–Maximum "U" values of ceilings, walls, and openings

Building component	Winter Degree Days (65° F Base) 2500 or less	2501 to 4500	4501 to 8000	8000 or more
Roof deck[1]	[2]0.14	0.08	0.08	0.08
Ceiling	.05	.05	.05	.04

[1] Roof/ceiling assemblies, in which the finished ceiling surface is the underside of the roof deck.
When mechanical cooling is proposed, use 0.08.

Table 9.–Maximum allowable "Uo" values for gross exterior wall assemblies (residential buildings)

Annual heating degree days	Detached one- and two-family	All other residential	Annual heating degree days	Detached one- and two-family	All other residential
500	0.30	0.38	6000	0.22	0.27
1000	.29	.37	7000	.20	.26
2000	.28	.35	8000	.19	.24
3000	.26	.33	9000	.17	.22
4000	.25	.31	10,000 or more	.16	.20
5000	.23	.29			

Table 10.–Maximum allowable "U" values for above-grade exterior wall sections and corresponding maximum allowable glazed opening areas

Yearly degree days	Glazed openings	Required "U" opaque walls Btuh per square foot per degree F (three stories or less) — Use group R-3 percent glazed opening: 10	15	20	25	All other residential percent glazed opening: 15	20	25	30
2500 or less	Single	0.21	0.15	0.09	0.03	0.25	0.19	0.13	0.07
	Double	.26	.24	.21	.18	.33	.31	.29	.27
2501 to 4500	Single	.17	.12	.06	.02	.20	.14	.06	.03
	Double	.23	.20	.18	.14	.29	.26	.24	.21
4501 to 6000	Single	.14	.08	.02	NP	.15	.09	.03	NP
	Rouble	.19	.17	.14	.10	.24	.21	.18	.15
6001 to 8000	Single	.12	.06	.01	NP	.13	.07	.01	NP
	Double	.17	.14	.11	.08	.21	.19	.16	.13
8001 to 10,000	Single	.09	.02	NP	NP	.08	.02	NP	NP
	Double	.14	.11	.08	.04	.17	.14	.10	.06
10,000 or more	Single	.05	NP	NP	NP	.04	NP	NP	NP
	Double	.11	.07	.04	NP	.12	.09	.05	NP

[1] NP—not permitted.
[2] For glazed opening percentages other than those specified above, linear interpolation may be utilized.
[3] For combinations of single and double glazing, the "U" values above may be interpolated in proportion to the single and double glazed areas utilized.
[4] Interpolation between given "U" values and between degree days is not permitted.

Table 11.–Maximum allowable "Uo" values for gross exterior wall assemblies

Annual heating degree days	Three stories or 40 feet or less	More than three stories or 40 feet	Annual heating degree days	Three stories or 40 feet or less	More than three stories or 40 feet
500	0.38	0.47	6000	0.27	0.33
1000	.37	.46	7000	.26	.31
2000	.35	.43	8000	.24	.28
3000	.33	.41	9000	22	28
4000	.31	.38	10,00 or more	.20	.28
5000	.29	.36			

Table 12.–Maximum overall thermal transfer values (U) for gross exterior walls (cooling requirement)

Degrees north latitude	Maximum overall thermal transfer value Btuh per square foot	Degrees north latitude	Maximum overal thermal transfer balue Btuh per square foot
24	29.0	48	35.7
32	31.3	56	38.0
40	33.5		

Wall

(1) BBC 301.2.1, 301.3.1, and 301.3.5.

In accordance with tables 9 through 12.

(2) HUD-MPS 6-7.1.

"U" values shall not exceed those shown in table 13.

(3) Operation Breakthrough Guide Criteria E.7.1.1, E.7.1.2, and E.7.1.3.

For winter conditions, the average heat loss for walls including doors should not exceed 15 Btu/h/ft^2 when the temperature difference is 75° F minus design outdoor temperature. Total heat loss through windows should not exceed heat loss through walls. Average heat gain through nonwindow area should not exceed 4 Btu/h/ft^2 with a temperature difference of outdoor design temperature minus 75° F.

(4) ASHRAE 90-75 4.3.2.1.

In accordance with figure 5.

(5) Davis, California Energy Code, Resolution No. 1833, 4.A and 4.D.

All exterior walls shall use R-11 batt insulation between studs. Multifamily dwellings must have light-colored or shaded walls. Fifteen percent of wall area may be dark colored to allow for trim and color accents. For dark-colored walls, insulation requirement is increased by 20 percent.

In multifamily dwellings, single glazing may not exceed 12½ percent of floor area; double glazing may not exceed 17½ percent of floor area. In single-family dwellings, a constant of 20 square feet in single glazing and 28 square feet in double glazing may be added to the percentages above.

Table 13.–Maximum "U" values of walls and openings

Building component	Winter degree days (65° F base) 2500 or less	2501 to 4500	4501 to 800	8001 or more
Masonry walls	0.10	0.10	0.10	0.10
Frame walls	.08	.08	.08	.08
Doors and windows[1]	1.13	1.13	.69	.69

[1] Maximum glass area shall not exceed 15 pct of the gross area of all exterior walls enclosing heated spaces, except when demonstrated that the winter dally solar heat gain exceeds the 24-h heat loss.

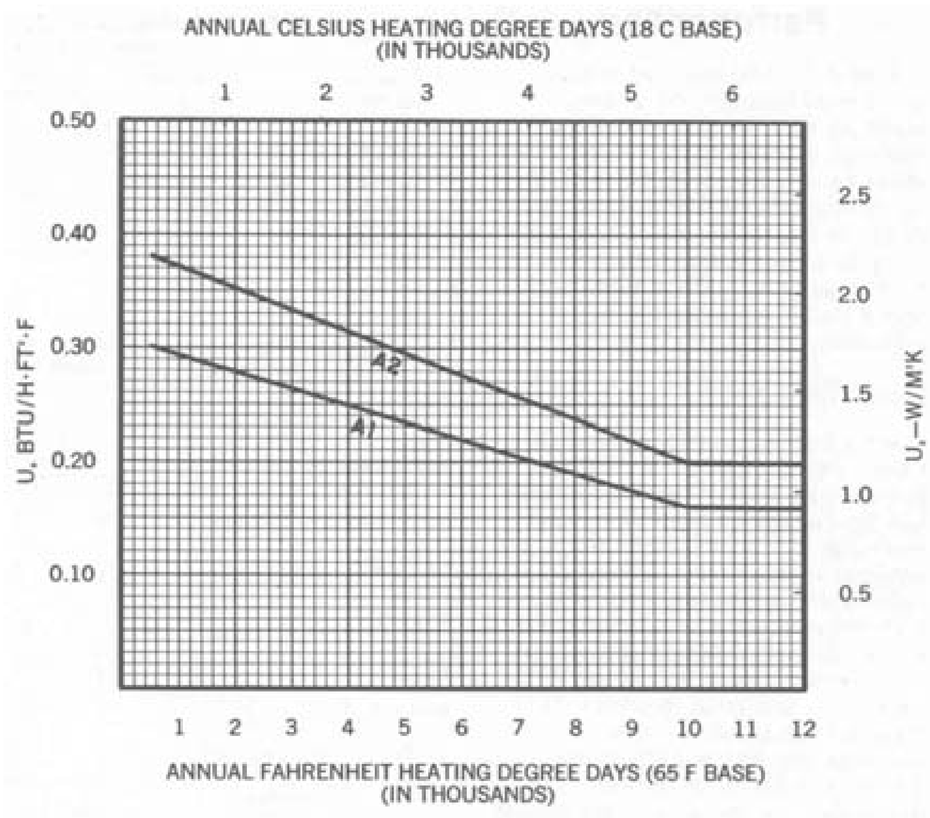

Figure 5.–"U" walls—type "A" buildings. Type "A" buildings shall include: A 1—detachedone- and two-family dwellings. A2–all other residential buildings, three stories or less, including but not limited to: multifamily dwellings, hotels, and motels.

Floor

(1) BBC 301.3.3 and 301.3.4.

In accordance with tables 14 and 15.

(2) HUD-MPS 6-7.2 and 6-7.4.

In accordance with tables 16 and 17. ASHRAE 90-75 may be used as an alternative.

(3) Operation Breakthrough Guide Criteria F.7.7.1.

Heat loss should not exceed 15 Btu/h/ft^2 over an unheated crawl space. Heat loss from a slab on grade should not exceed 40 Btu/h/lineal foot of perimeter.

(4) ASHRAE 90-75 4.3.2.3 and 4.3.2.4.

For floors over unheated spaces, "U" value shall be no greater than

Table 14.–Maximum allowable "Uo" values for floor assemblies over unheated spaces

Annual heating degree days	Maximum Uo	Annual heating degree days	Maximum Uo
[1] 500	0.36	3000	0.18
1000	.32	4000	.11
2000	.25	4500 or more	.08

[1]Table values may be Interpolated.

Table 15.–Minimum allowable "R" values of perimeter insulation for slab-on-arade floors

Annual heating degree days	Heated slab	Unheated slab	Annual heating degree days	Heated slab	Unheated slab
[1]500	2.9	-	6000	7.0	4.9
1000	3.3	-	7000	7.8	5.5
2000	4.0	-	8000	8.5	6.2
3000	4.8	2.8	9000	9.3	6.8
4000	5.5	3.5	10,000 or more	10.0	7.5
5000	6.3	4.2			

[1]Table values may be interpolated.

Table 16.–Maximum "U" value of floor sections over unheated basements, unheated garages, or crawl spaces[1]

Winter degree days (65° F base)	Maximum U value[2]	Winter degree days (65° F base)	Maximum U value[2]
500 or less	0.36	3000	0.19
1000	.32	4000	.12
2000	.26	4501 or more	.08

[1] A basement, crawl space, or garage shall be considered unheated unless it is provided with a positive heat supply to maintain a minimum temperature of 50° F. Positive heat supply is defined by ASHRAE as "heat supplied to a space by design or by heat losses occurring from energy-consuming systems or components associated with that space."

[2] For increments between degree days shown, "U" values may be interpolated, or the values shown in Figure 6 (Fig. 5 of ASHRAE 90-75) may be substituted.

Table 17.–Minimum R values of perimeter insulation for slabs-on-grade

Winter degree days (65° F base)	Minimum R values[1]		Winter degree days (65° F base)	Minimum R values[1]	
	Heated slab	Unheated slab		Heated	Unheated slab
500 or less	2.8	-	5000	6.3	4.2
1000	3.5	-	6000	7.0	4.8
2000	4.0	-	7000	7.8	5.5
2500	4.4	2.5	8000	8.5	6.2
3000	4.8	2.8	9000	9.2	6.8
4000	5.5	3.5	10,000 or more	10.0	7.5

[1] For increments between degree days shown, U values may be interpolated, or the values shown in figure 7 (fig. 2 of ASHRAE 90-75) may be substituted.

shown in figure 6, "R" values for slabs on grade shall be not less than shown in figure 7.

(5) Davis, California Energy code, Resolution No. 1833, 4.C.

Suspended floors over ventilated crawl space or other unheated space shall have insulation with a minimum resistance of R-11. No requirement for concrete slabs.

Total Envelope

(1) BBC 301.1.1.

The required transmittance value (U) of roof/ceiling, wall, or floor may be increased and transmittance of other components decreased if overall transmittance does not exceed the total resulting from the required component transmittance value.

(2) HUD-MPS 607-3.2.b.

The "U" value for one component may be increased and the "U" value of other components decreased if overall heat gain or loss does not exceed the total from conformance to the stated "U" value.

(3) ASHRAE 90-75 4.2.4.1.

The "U" value for one component may be increased and the "U" value of other components decreased if overall heat gain or loss does not exceed the total from conformance to the stated "U" values.

(4) Davis, California Energy Code, Resolution No. 1833, 5.

Buildings that do not meet individual component criteria must be calculated by a registered architect, engineer, building designer, or other qualified person to show that the proposed building will not exceed standards set forth in section 4. Solar heat gain may be used for winter calculations, and must be used for summer calculations.

Discussion

The codes and standards that have insulation requirements are generally performance oriented in that resistance or transmittance values are presented rather than a material requirement.

Even greater flexibility is allowed by permitting trade-offs with various components as long as the overall heat-loss limitation is not exceeded. All codes and standards are not in total agreement, but the present activity directed toward Federal standards may bring uniformity.

Air Leakage

(1) Operation Breakthrough Guide Criteria E.7.3.1.

With a simulated wind load not less than 1.567 lb/ft^2, the flow of air shall be limited to 0.06 ft/min/ft^2 of fixed glass and fixed window areas plus 0.5 ft^3/min/ft^2 of operable sash perimeter.

(2) ASHRAE 90-75, 4.5.

Air leakage limitations shall be satisfied at a pressure differential of 1.567 lb/ft^2, which is equivalent to the effect of a 25-mile-per-hour wind (test method ASTM E283-73). Air infiltration at windows shall not exceed 0.5 ft^3/min/ft of sash crack. Air infiltration at sliding glass doors shall not exceed 0.5 ft^3/min/ft^2 of door area. At residential entrance swinging doors, air infiltration shall not exceed 1.25 ft^3/min/ft^2 of door area. Air leakage at all doors for other than residential use shall not exceed 11 ft^3/min/lineal foot of door crack.

(3) Davis, California Energy Code, Resolution No. 1833, 3.6.(1).

Exterior swinging doors and windows shall be fully weather-stripped, gasketed, or otherwise treated to limit infiltration. All manufactured windows and sliding glass doors shall meet ANSI A134.2, A134.3, and A134.4 when tested in accordance with ASTM E283-73 with a positive differential of 1.57 lb/in.^{2} and shall be certified and labeled.

Discussion

Air leakage is much more difficult to control than heat transfer and so far all attempts have been directed specifically at doors or windows. Draft stops in walls, floors, and ceilings can also be effective measures. Performance criteria should be stated as a total rate of air exchange for the building.

Solar Concepts

(1) Davis, California Energy Code, Resolution 1833 E.

All glazing not oriented north must be shaded from direct solar radiation at 8 a.m., 12 p.m., and 4 p.m. on August 21. Total unshaded glazing may not exceed 1.5 percent of multifamily dwelling floor area or 3 percent of single-family dwelling floor area.

Discussion

Although the rate of heat transfer and air leakage is critical for energy efficiency, many other elements of design that could greatly influence energy usage seldom appear in codes and standards. These include building size, shape, and orientation; window location; location of garage and porches for protection from wind; and landscape for shading and wind protection. All of these elements are difficult to control without excessively restricting architectural and landscape design. The shading requirements in the Davis Energy Code are unique in requiring one of the above design features.

Energy Budget

(1) Davis, California Energy Code, Ordinance No. 784, 3.A and 3.B.

For single-family, see table 18. For multifamily, winter total day's heat loss shall not exceed 120 Btu/ft^2 of floor area. Summer total day's heat gain shall not exceed 40 Btu/ft^2 of floor area.

Discussion

One approach to energy conservation is the energy budget concept. This allows the designer and building occupant to choose among various alternatives as long as the actual energy usage is kept below a specified level. The designer alone could not control the level of energy use. The occupant would play a major role by controlling temperature levels, closing and opening drapes, maintaining mechanical equipment, limiting hot water usage, using lights only where needed, and generally planning all activities for energy conservation. Such an energy budget is a true performance requirement.

The ordinance adopted by Davis, California includes an optional energy budget standard and other authorities are considering similar requirements.

Table 18.–Detached dwelling unit thermal standards

Floor area	Winter heat loss	Summer heat gain	Floor area	Winter heat loss	Summer heat gain
Ft²	*Btu/ft²/d*	*Btu/ft²/d*	*Ft²*	*Btu/ft²/d*	*Btu/ft²/d*
[1] 500	363	118	2000	192	95
1000	239	103	2500	182	93
1500	208	98	3000	176	91

[1] Direct interpolation shall be used for floor areas not shown.

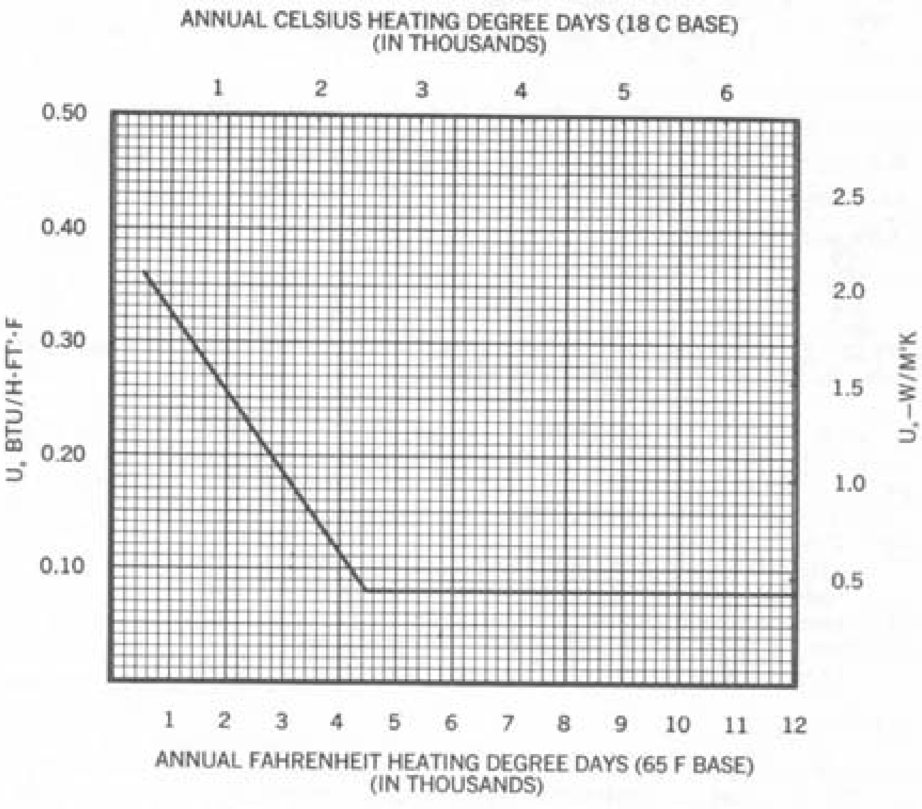

Figure 6.–"U" values—floors over unheated spaces.

Moisture Control

Any effort to conserve energy by added insulation or reduction of air leakage, increases the potential for moisture condensation in the building components. Some codes and standards for energy conservation have been developed without consideration for moisture control. Where condensation occurs it reduces the value of insulation, increases maintenance requirements for the building, and may shorten the life of the building. Usual control measures are the installation of vapor barriers and ventilation of structural spaces.

Vapor Barriers

(1) HUD-MPS 607-2.4.

A vapor barrier with a perm rating not exceeding 1 is required on the warm side of all walls having a "U" value of less than 0.25. For ceilings under a ventilated roof or attic space, no vapor barrier is required when 11150 of the ceiling area is provided for ventilation, or when 50 percent of the otherwise required 1/300 of ceiling area is at least 3 feet above the eaves and the remaining ventilation required is at the eaves. For all other conditions a vapor barrier with a perm not exceeding 1 is required on the warm side of the ceiling. Roof decks shall have a perm rating of not more than 1/2 near the warm face.

(2) Operation Breakthrough Guide Criteria E.7.6.2.

Where cold weather condensation is probable, a vapor barrier having a perm rating not exceeding 1 shall be provided on the winter warm side of walls. Where condensation is probable and the exterior siding has a low permeance, in addition to a vapor barrier, provide ventilation between the insulation and the outside wall covering. Provide adequate ground cover so that condensation will not occur, or so humidities will not build up in living areas above a crawl space.

Attic Ventilation

(1) BBC 5072

Not less than two opposite windows. louvers. or vents with a total clear area of opening not less than 113 of 1 percent of the horizontally projected roof area

(2) SSBC 1707.8.

Furnish cross ventilation for gable and hip roofs. Free ventilating area shall be not less than 11150 of the ceiling area. Area may be reduced to 11300 where a vapor barrier with a perm not exceeding 1 is placed on the warm side of the ceiling; or at least 50 percent of the vent area is in the upper portion of the space with the balance at eave or cornice at

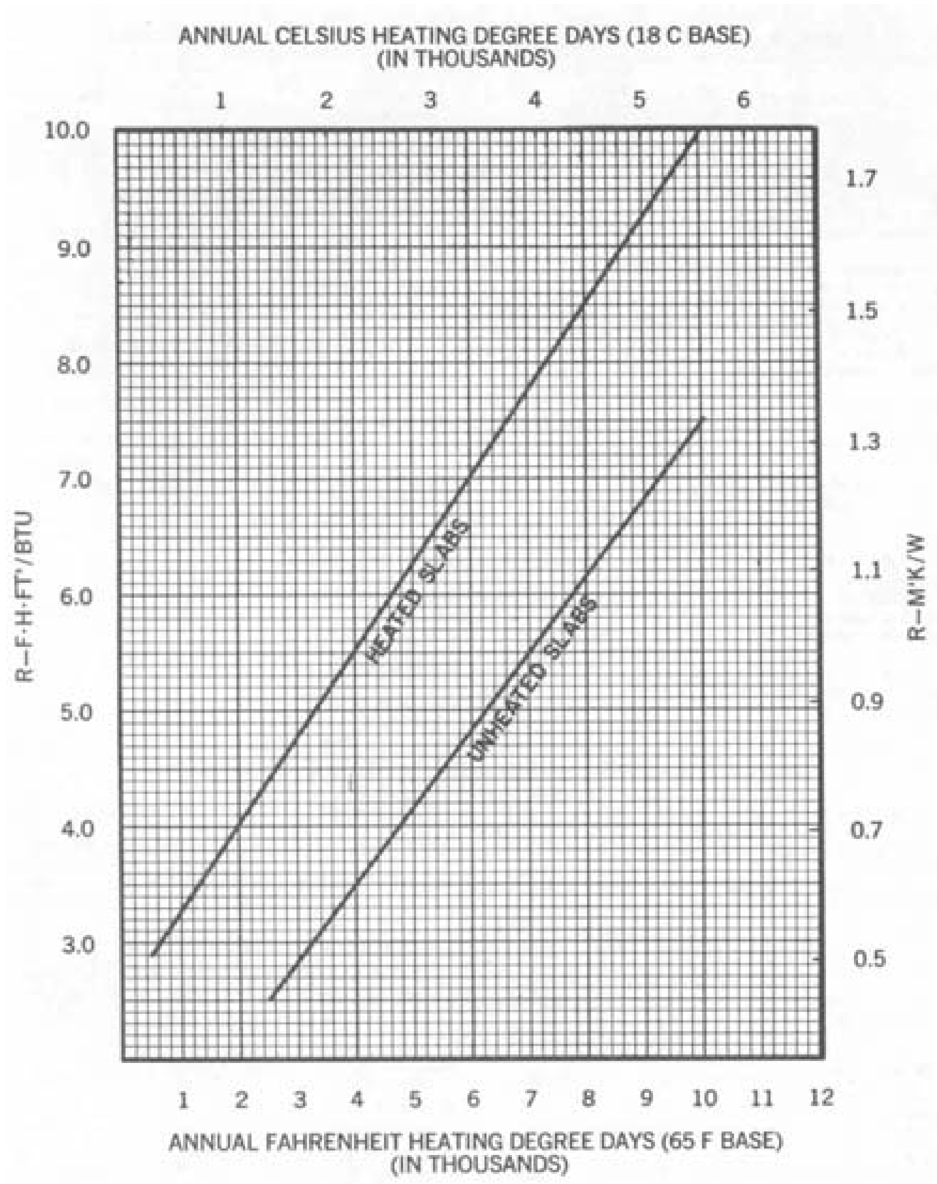

Figure 7.–"R" values–slab on grade.

least 3 feet lower.

(3) UBC 3205 (c).

Cross ventilate each space. Net free area shall be not less than 11150 of the area ventilated except where 50 percent of the vent area is in the upper portion of the space and the remaining vents are in eave or cornice located at least 3 feet lower.

(4) HUD-MPS.

Provide a net free area 11150 of the area ventilated except 11300 may be used when; (a) a vapor barrier with a perm less than 1 is used in the ceiling, or (b) at least 50 percent of the required area is provided with fixed louvers in the upper portion of the space at least 3 feet above an eave containing the remaining required ventilation. Mechanical ventilation as an alternate must provide 10 air changes per hour or 0.9 ft^3/min/ft^2 of attic floor area, plus 15 percent for dark roofs. Provide an air intake of 1 square foot of free opening per 300 ft^3/min of fan capacity.

Crawl Space ventilation

(1) BBC 507.3.

The crawl space shall have screened openings not less than 113 of 1 percent of the enclosed building area, or shall be provided with other means of ventilation approved by the building official.

(2) SSBC 1302.5(e).

Ventilate by approved mechanical means or by openings in foundtion walls. Openings shall be arranged for ventilation and covered with corrosion-resistant wire mesh 114 to 112 inch in any dimension. Openings shall be not less than 2 square feet for each 100 linear feet of wall, plus 113 square foot for each 100 square feet of crawl space. Where an approved vapor barrier is placed over the ground, the opening area may be reduced by 50 percent.

(3) UBC 2517(c) b.

Ventilate by approved mechanical means or by at least two vents located at corners on approximately opposite sides. Net area shall be 1112 square foot for each 25 linear feet of exterior wall. All vents shall be covered with corrosion-resistant wire mesh one-fourth to one-half in any direction.

(4) HUD-MPS 403-3.

Net free area shall be at least 11800 of the area ventilated, and include cross ventilation.

(5) Operation Breakthrough Guide Criteria F.7.6.1.

Provide at least two ventilators located on opposite sides of the structure, having a total net free area not less than 11800 of the crawl space area.

Discussion

None of the major model codes have vapor barrier requirements, however, some recognize their significance in reduced ventilation requirements. ASHRAE 90-75, which is being used as a basis for new energy conservation codes, also has no vapor barrier requirements. This lack of requirements may partly be due to the absence of information on which to base requirements. There may also be a general disregard for the importance of vapor barriers. In either case, a major national effort is needed to determine vapor barrier requirements for variables such as climate, interior humidity conditions, and type of construction.

Ventilation requirements. for attics and crawl spaces are recognized by codes and are in general agreement. However, there has been a recent move to base crawl space ventilation on the perimeter length rather than area enclosed. All ventilation requirements have been selected on the basis of what has been found to work. Development into a more exact science is needed.

None of the codes or standards include any requirement for controlling indoor humidity; but, that appears to be the most critical item for limiting moisture in structural spaces. Without humidity control and adequate ventilation, vapor barriers may not be sufficient to prevent moisture problems.

Noise Control

Acoustical requirements in light-frame construction apply to wall and floor/ceiling assemblies separating dwelling units and to exterior walls. Although some noise control is desirable between rooms within a living unit, the occupants usually have some control over the noise sources within their own residence. Performance requirements are stated in terms of Sound Transmission Class (STC) for airborne sound and Impact Insulation Class (IIC) for impact sound. Standard laboratory tests for STC are presented in ASTM E 90 and ASTM E 413. The IIC is determined by ASTM E 492-73T.

Noise Isolation Class (NIC) is a field measurement based on noise reduction between two spaces. It is generally based upon a furnished space having some level of background noise. Community Noise Equivalent level (CNEL) is an average of hourly A-weighted sound levels resulting from outdoor noise. It is determined by placing a 10-point penalty on evening and nighttime sound levels and averaging these, along with the daytime noise, to achieve a 24-hour average sound level.

Between Dwelling Units

(1) UBC Appendix Chapter 3501

Wall and floor/ceiling assemblies separating dwelling units or guest rooms from each other and from public space such as interior corridors and service areas shall provide airborne sound insulation for walls, and both airborne and impact sound insulation for floor/ceiling assemblies. All such assemblies shall have an STC of 50 (45 if field tested). Penetrations or openings in construction assemblies for piping, electrical devices, recessed cabinets, bathtubs, soffits, or heating, ven-

Table 19.–Sound transmission limitations–one- and two-family dwellings

Location of partition	Sound trans-mission class (STC)	Location of floor/ceiling	Sound trans-mission class (STC)	Impact Insulation class (IIC)
Separating living unit from other living units, common service areas, or public spaces (average noise)[1]	45	Separating living units from other living units, public spaces, or common service areas[1]	45	45
Separating living unit from public spaces or common service areas (high noise)[2]	50	Separating living unit from public spaces or common service areas (high noise)[2]	50	50

[1] Public spaces of average noise include entries, stairways, etc.
[2] Areas of high noise include boiler rooms, mechanical equipment rooms, central laundries, and most commercial uses.

Table 20.–Sound transmission limitations—multifamily dwellings

Location of partion	Sound trans-mission class (STC)	Location of floor/ceiling	Sound trans-mission class (STC)	Impact insulation class (IIC)
Living unit to living unit, corridor[1] or public space (average noise)[2]	45	Floor/ceiling separating living units from other living units, public space,[4] or service areas[2]	45	45
Living unit to public space and service areas (high noise)[3,5]	50	Floor/ceiling separating living units from public space and service areas (high noise)[3] includlng corridor floors over living units	50	50

[1] These values assume floors in corridors are carpeted; otherwise increase STC by 5.
[2] Public space of average noise includes lobbies, storage rooms, stairways, etc.
[3] Areas of high noise include boiler rooms, mechanical equipment rooms, elevator shafts, laundries, incinerator shafts, garages, and most commercial uses
[4] Does not apply to floor above storage rooms where noise from living units would not be objectionable.
[5] Increase STC by 5 when over or under mechanical equipment which operates at high noise levels.

Table 21.–Criteria for airborne sound insulation within a dwelling unit[1]

Partition function between rooms	Minimum desir-able STC	Minimum accept-able STC	Partition function between rooms	Minimum desir-able STC	Minimum accept-able STC
Bedroom to bedroom	40	36	Kitchen to bedroom	45	36
Living room to bedroom	42	36	Bathroom to living room	45	36
Bathroom to bedroom	45	36	Bathroom to bathroom	45	36

[1] Noise Isolation Class shall be 8 less than the corresponding STC values.

Table 22.—Criteria for airborne sound insulation of wall partitions between dwelling units

Partition function between dwellings			Grade II[1]
Apartment A		Apartment B	STC
Bedroom	to	Bedroom	52
Living room	to	Bedroom	54
Kitchen	to	Bedroom	55
Bathroom	to	Bedroom	56
Corridor	to	Bedroom	52
Living room	to	Living room	52
Kitchen	to	Living room	52
Bathroom	to	Living room	54
Corridor	to	Living room	52
Kitchen	to	Kitchen	50
Bathroom	to	Kitchen	52
Corridor	to	Kitchen	52
Bathroom	to	Bathroom	50
Corridor	to	Bathroom	48

[1] Grade II is residential urban and suburban areas considered to have “average” noise environment. Nighttime exterior noise levels might be about 40-45 dB (A-weighted); and permissible interior noise environment should not exceed NC 25-30 characteristics.

tilating, or exhaust ducts shall be sealed, lined, insulated, or otherwise treated to maintain the required ratings. Entrance doors from interior corridors together with their perimeter seals shall have a laboratory tested STC rating of not less than 26 and such perimeter seals shall be maintained in good operating condition.

All separating floor/ceiling assemblies between separate units or guest rooms shall have an IIC of 50 (45 if field tested). Floor coverings may be included in the assembly to obtain the required ratings.

(2) HUD-MPS 404-1 and 404-2

Living units shall be designed to provide an acoustically controlled environment in relation to noise from adjacent living units and public spaces. Living units shall be provided with acoustic separation in accordance with table 19 for detached one- and two-family, or table 20 for multifamily.

Within Dwelling Units

(1) HUD-MPS 404-1, 404-2, and 615-1.6.

Living units shall be designed to provide an acoustically controlled .environment. Mechanical equipment shall be located and installed to minimize transmission of objectional sound.

(2) Operation Breakthrough Guide Criteria B.5.1, C.5.1, and D.5.2.1.

There should be acoustical privacy within the dwelling unit to create and allow for development of personal and family relationships. The STC of intradwelling space dividers should be equal to or greater than shown in table 21.

For multilevel dwelling units, floor/ceiling between levels of the unit shall have an STC of 40 and IIC of 40.

(3) Operation Breakthrough Guide Criteria 8.5.1.

The STC of interdwelling space dividers should be equal to or greater than Grade II criteria of table 22. The NIC may be up to 4 less than corresponding STC values.

(4) California Noise Insulation Standards.

For sound transmission control, wall and floor/lceiling assemblies separating dwelling units shall meet an STC of 50 (45 if field tested), and an IIC of 50 (45 if field tested). Entrance doors from interior corridors shall have an STC rating of not less than 30. Laboratory tests of walls and floor/ceiling designs may be used to establish an acceptable design. Field testing, if required to prove compliance with the code, shall include all flanking paths.

Between Dwelling and Exterior

(1) HUD-MPS 303-4, Circular 1390.2.

Through the use of site design techniques such as building location and orientation, window placement and the use of barriers, predictable undesirable site noise shall be moderated to as close to clearly acceptable levels as practicable. External noise sites are limited to those shown in table 23.

(2) California Noise Insulation Standards.

Table 23.–External noise exposure standards for new construction sites (measurements and projections of noise exposures are to be made at appropriate heights above site boundaries)

General external exposures dB(A)	Airport environs CNR zone[1]	Airport environs NEF zone[2]	General external exposures dB(A)	Airport environs CNR zone[1]	Airport environs NEF zone[2]
Unacceptable Exceeds 80 dB(A) 60 minutes per 24 hours	3	C	Discretionary—normally unacceptable Exceeds 65 dB(A) 8 hours per 24 hours	2	B
Exceeds 75 dB(A) 8 hours per 24 hours			Loud repetitive sounds on site		
(Exceptions are strongly discouraged and require a 102(2)C environmental statement and the Secretary's approval.)			(Approvals require noise attenuation measures, the Regional Administrator's concurrence, and a 102(2)C environmental statement.)		
Discretionary– normally acceptable Does not exceed 65 dB(A) more than 8 hours per 24 hours			Acceptable Does not exceed 45 dB(A) more than 30 minutes per 24 hours	1	A

[1] *Composite Noise Rating* (CNR). The CNR is a calculated rating for aircraft noise based on maximum sound pressure levels during a flyover, frequency of occurrence, time of day and other variables. It has been adopted by the Federal Aviation Administration (FAA) to describe the noise produced by aircraft operations in the vicinity of airports. In FAA usage, the CNR takes into account the magnitude of the sounds of individual aircraft types, the number of operations of each type on each runway, and the time of day. The numerical value of CNR is related to an expected range of community response.

The FAA has calculated CNR's for a number of domestic airports, and has divided CNR's into three zones—corresponding to our acceptable, discretionary, and unacceptable, respectively—according to the expected community response, as shown in the following chart:

Chart for estimating response of residential communities from composite noise rating

Composite noise rating: Takeoffs and landings	Composite noise rating: Runups	Zone	Description of expected response
Less than 100	Less than 80	1	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
100 to 115	80 to 95	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Greater than 115	Greater than 95	3	Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

When advice and guidance are required in the analysis of property sites in the vicinity of military airports the request for existing data and projections should be made Initially to the Commander of the military base and subsequently to his designee

[2] *Noise Exposure Forecasts* (NEF). The NEF is a calculated environmental rating which refines and replaces the CNR calculations for aircraft by Including corrections for the presence of pure tone and duration of peak levels within the composite of Intermittent noise. As currently used, it has validity only for airports.

The Department of Transportation (DOT) is converting from CNR to Noise Exposure Forecasts (NEF's). DOT has a contact for the calculation of NEF's at some 29 commercial and general aviation airports, and will soon have an Intramural capability for producing NEF's for any aviation airport. The new NEF ratings for areas around commercial airports should be sought through FAA Airport Regional Offices.

The following categories correspond roughly to the categories of community response calculated originally for CNR's (see above).

Noise exposure forecasts

Category	*Rating*	*Disposition in HUD*
A	less than 30	Acceptable
B	30 to 40	Discretionary
C	more than 40	Unacceptable

For data on anticipated noise levels in the vicinity of military airports, the request should be made initially to the Commander of the base and subsequently with his designee.

Interior CNEL shall not exceed 45 decibels (dB) in any habitable room with all doors and windows closed. Residential locations having a CNEL greater than 60 dB require an acoustical analysis showing that the structure has been designed to meet the interior CNEL of 45 dB. The CNEL shall be determined by local jurisdictions as part of its general plan (noise element). Exception—railroads with only four daytime and no nighttime operations.

Acceptable Noise Exposure for Sleeping Quarters

(1) HUD-MPS Circular 1390.2.

Noise levels resulting from exterior sources and interior building sources such as heating, plumbing, and air conditioning are acceptable if they do not exceed:

55 dB(A) for more than an accumulation of 60 minutes in any 24-hour period.

45 dB(A) for more than 30 minutes during nighttime sleeping hours from 11 p.m. to 7 a.m.

45 dB(A) for more than an accumulation of 8 hours in any 24-hour day.

Discussion

The UBC is the only one of the major model codes that has requirements for sound transmission control. The UBC chapter on sound transmission control has been made mandatory by the State of Minnesota. Most code jurisdictions have not included that chapter as a requirement. Only HUD-MPS and Operation Breakthrough include detached, single-family dwellings in standards even though it is recognized that noise insulation from exterior sources would be desirable for all types of dwellings. Also, sound transmission control within dwelling units might make smaller units more liveable.

The Environmental Protection Agency (EPA) has prepared a draft dated January 1978, of "Model Noise Control Provisions for Building Codes." It does include detached, single-family dwellings in provisions for noise insulation from exterior sources. The EPA is concerned about sound control because noise can affect physical, mental, and social well-being. "Health and Welfare," also includes personal comfort and well-being, and the absence of mental anguish and annoyance. In the draft, EPA recognizes that many sound transmission control measures also result in energy conservation. Examples are double glazing and elimination of air leaks.

Summary

Performance requirements do exist for most structural and environmental aspects of light-frame construction. However, these differ among the various codes and standards. It is helpful that each aspect has a primary reference document: (1) ANSI A58.1 for all structural considerations; (2) ASHRAE 90-75 for energy conservation; and (3) an EPA draft of a model document for noise control.

While performance is well identified in some areas, certain essential items are overlooked. These include vibration of floors, overall rigidity (racking resistance) of buildings, shape and orientation for energy conservation, and condensation control. Research is still required in many areas to identify acceptable performance levels. Coordination of all aspects of performance is also necessary since structural and environmental aspects interact, and compromise is often required. This paper does not address specific research needs, but summarizes performance requirements in existing codes and standards as background for those concerned with the development of a knowledgeable basis for performance of light-frame construction.

Selected References

Codes and Standards Cited

1. American Insurance Association, Building Officials and Code Administrators International Inc., International Conference of Building Officials, and Southern Building Code Congress.
   1975. One- and two-family dwelling code. 252 p.
2. American National Standards Institute, Inc. (ANSI).
   1972. Building code requirements for minimum design loads in buildings and other structures. ANSI A58.1 60 p.
3. American Society of Heating , Refrigerating , and Air-Conditioning Engineers, Inc. (ASHRAE).
   1975. Energy conservation in new building design. ASHRAE Standard 90-75. 53 p.
4. American Society for Testing and Materials (ASTM).
   1977. Annual book of ASTM standards, part 18. 1024 p.
5. Building Officials and Code Administrators International, Inc.
   1975. The BOCA basic building code (BBC). 497 p.
6. International Conference of Building Officials.
   1976. Uniform building code (UBC). 728 p.
7. Southern Building Code Congress.
   1973. Southern standard building code (SSBC).
8. U.S. Department of Housing and Urban Development (HUD).
   1970. Guide criteria for the design and evaluation of Operation Breakthrough Housing Systems. Vol. II, Ill, and IV.
9. U.S. Department of Housing and Urban Development (HUD).
   1973. HUD minimum property standards. Vol. I, II, and Ill.

Publications Relating to Performance Criteria in Codes and Standards

1. American Society for Testing and Materials (ASTM).
   1967. ASTM standards in building codes. 1674 p.
2. Carroll, M. N.
   1977. Use of performance specifications in wood products standards. For. Prod. J. 27(8):46-52.
3. National Bureau of Standards (NBS).
   1971. Index of U.S. voluntary engineering standards. 984 p.
4. National Bureau of Standards (NBS).
   1972. Performance concept in buildings. 808 p.
5. National Bureau of Standards (NBS).
   1975. Index of U.S. voluntary engineering standards. Supl. 2. 467 p.
6. National Bureau of Standards (NBS).
   1977. Performance criteria resource document for innovative construction. 155 p.
7. National Research Council of Canada (NRC).
   1974. The development of a knowledge-based building code. 33 p.
8. National Research Council of Canada (NRC).
   1975. List of standards referenced in the National Building Code. 42 p.

Floors

1. McCutcheon, W. J.
   1977. Method for predicting the stiffness of wood-joist floor systems with partial composite action. USDA For. Serv. Res. Pap. FPL 289. For. Prod. Lab., Madison, Wis.
2. Onysko, D. M.
   1970. Performance of wood-joist floor system: A literature review. Inf. Rep. OP-X24. Can. For. Prod. Lab., Ottawa, Ont., Canada.
3. Thompson, E. G., J. R. Goodman, and M. D. Vanderbilt.
   1,975. Finite element analysis of layered wood systems. J. of Struct. Div., ASCE.
4. Vanderbilt, M. D., J. R. Goodman, and M. E. Criswell.
   1974. Service and overload behavior of wood-joist floor systems. J. of Struct. Div., ASCE.

Load-Bearing Walls

1. Adams, N. R.
Undated. Plywood shear walls. Am. Plywood Assoc. Lab. Rep. 105. Am. Plywood Assoc., Tacoma, Wash.
2. Carney, J. M.
1975. Bibliography on wood and plywood diaphragms. J. of the Struct. Div., Nov. 1975. Am. Soc. of Civ. Eng., New York, N.Y.
3. NAHB Research Foundation Inc.
1971. Racking strengths and stiffness of exterior and interior frame wall constructions. Report CR-486, NAHB Res. Found. Inc., Rockville, Md.
4. Polensek, A.
1976. Rational design procedure for wood-stud walls under bending and compression loads. Wood Sci., Vol. 9, No. 1, July 1976.
5. Tuomi, R. L., and W. J. McCutcheon.
1974. Testing a full-scale house under simulated snowload and windloads. USDA For. Serv. Res. Pap. FPL 234. For. Prod. Lab., Madison, Wis.
6. Yancy, C.W.E.
1976. The development of an improved test for evaluating the racking re sistance of wall panels. NBS Build. Sci. Ser. 91. U.S. Dep. of Commerce, Nat. Bur. of Stand., Washington, D.C.

Nonload-Bearing Walls

1. NAHB Research Foundation Inc.
1971. Racking strengths and stiffnesses of exterior and interior frame wall construction. Rep. CR-486, NAHB Res. Found. Inc., Rockville, Md.

Roofs

1. Midwest Plans Service.
1975. Designs for glued trusses. Midwest Plans Serv., Iowa State University, Ames, Iowa.
2. National Association of Home Builders.
1975. Load-sharing in roof assemblies utilizing roof trusses with plywood sheathing and spaced-board sheathing. NAHB Res. Found. Inc., Rockville, Md.
3. Suddarth, S. K., F. E. Woeste, and W. L. Galligan.
1978. Differential reliability: Probabilistic engineering applied to wood members in bending/tension. USDA For. Serv. Res. Pap. FPL 302, For. Prod. Lab., Madison, Wis.
4. Wilkinson, T. L.
1973. Longtime performance of trussed rafters with different connection systems: Five-year evaluation. USDA For. Serv. Res. Pap. FPL 204. For. Prod. Lab., Madison, Wis.

Earthquake

1. American Plywood Association.
1971. San Fernando earthquake of February 9, 1971.
2. Lew, H. S.
1971. Performance of building structures during the 1971 San Fernando earthquake. U.S. Dep. of Commerce, Nat. Bur. of Stand. Washington, D.C.
3. Lew, H. S. (editor).
1976. Wind and seismic effects–proceedings of the U.S.-Japan cooperative program in natural resources. NBS Special Publ. 444. U.S. Dep. of Commerce, Nat. Bur. of Stand., Washington, D.C.

Heat Transfer

1. Burch, D. M., and C. M. Hunt.
1977. Retrofitting on existing wood frame residence for energy conservation—an experimental study. NBSIR 77-1274. U.S. Dep. of Commerce, Nat. Bur. of Stand., Washington, D.C.
2. National Association of Homebuilders.
1977. Thermal performance guidelines. Nat. Assoc. of Homebuilders, Washington, D.C.
3. Tennessee Valley Authority.
1977. Energy conservation ideas for housing. Tennessee Valley Authority, Knoxville, Tenn.
4. U.S. Department of Commerce.
1975.. Making the most of your energy dollars. U.S. Dep. of Commerce, Nat. Bur. of Stand:, Washington, D.C.

Air Leakage

1. Harrje, D. T.
1976. Retrofitting: Plan, action, and early results using the townhouses at Gwin Rivers. Center for Environmental Studies Report 29, Princeton Univ., Princeton, N.J.
2. Mattingly, G., and E. Peters.
1975. Wind and trees–air infiltration effects on energy in housing. Center for Environmental Studies Report 20, Princeton Univ., Princeton, N.J.
3. Tamura, G. T., and A. G. Wilson.
1964. Air leakage and pressure measurements on two occupied houses. ASHRAE Transactions Refrigerating and Air-conditioning Engineers, New York, N.Y.

Solar Concepts

1. AIA Research Corporation.
   1976. Solar dwelling design concepts. Dep. of Housing and Urban Dev., Washington, D.C.
2. Crowther, R.
   1976. Sun/earth: How to apply free energy sources to our homes and buildings. Crowther/Solar Group, Denver, Colo.
3. Hastings, R. S., and R. W. Crenshaw.
   1977. Window design strategies to conserve energy. NBS Building Sci. Series 104. U.S. Dep. of Commerce, Nat. Bur. of Stand., Washington, D.C.
4. Olgyay, V.
   1963. Design with climate. Princeton Univ. Press.

Energy Budget

1. Federal Energy Administration.
   1975. Lighting and thermal operations guidelines. Conserv. Pap. No. 3. Federal Energy Admin., Washington, D.C.
2. Forrest Coile and Associates, and Charles W. Moore Associates.
   1975. NASA project tech—technology utilization house study report. NASA/Langley Res. Center, Hampton, Va.

Moisture Control

1. Anderson, L. O., and G. E. Sherwood.
   1974. Condensation problems in your house: Prevention and solution. Agric. Inf. Bull. No. 373. USDA, Washington, D.C.
2. Duff, J. E.
   1968. Moisture distribution in wood-frame walls in winter. For. Prod. J. 18(1):60-64.
3. Duff, J. E.
   1972. Vapor barrier decreases moisture conditions in wood walls exposed to air-conditioning and heating. USDA For. Serv. Res. Pap. SE-98. SE For. Exp. Stn., Ashville, N.C.
4. Sherwood, G. E.
   1977. Moisture conditions in walls and ceilings of a simulated older home during winter. USDA For. Serv. Res. Pap. FPL 290. For. Prod. Lab., Madison, Wis.

Noise Control

1. Heebink, T. B.
   1977. Upgrading the sound-insulating efficiency of wood-joist floor-ceiling systems. Sound and Vibration 11(6):16-18.
2. Jones, R. E.
   1973. Improved acoustical privacy in multifamily dwellings. Sound and Vibration 7(9):30-37.
3. Jones. R. E.
   1975. Field sound insulation evaluations for two auxiliary walls. USDA For. Serv. Res. Pap. FPL 244. For. Prod. Lab., Madison, Wis.
4. Jones, R. E.
   1976. How to accurately predict the sound insulation of partitions. Sound and Vibration 10(6):14-25.
5. Jones, R. E.
   1978. Sound insulation evaluation of high-performance wood-frame party partitions under laboratory and field conditions. USDA For. Serv. Res. Pap. FPL 309. For. Prod. Lab., Madison, Wis.
6. Sabine, H. J., M. B. Lacker, D. R. Flynn, and T. L. Quindry.
   1975. Acoustical and thermal performance of exterior residential walls, doors, and windows. NBS Build. Sci. Series 77. U.S. Dep. of Commerce, Nat. Bur. of Stand., Washington, D.C.
7. U.S. Environmental Protection Agency.
   1974. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. Washington, D.C.

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