Chapter C4
LIVE LOADS

C4.2 UNIFORMLY DISTRIBUTED LOADS

C4.2.1 Required Live Loads. A selected list of loads for occupancies and uses more commonly encountered is given in Section 4.2.1, and the authority having jurisdiction should approve on occupancies not mentioned. Tables C4-1 and C4-2 are offered as a guide in the exercise of such authority.

In selecting the occupancy and use for the design of a building or a structure, the building owner should consider the possibility of later changes of occupancy involving loads heavier than originally contemplated. The lighter loading appropriate to the first occupancy should not necessarily be selected. The building owner should ensure that a live load greater than that for which a floor or roof is approved by the authority having jurisdiction is not placed, or caused or permitted to be placed, on any floor or roof of a building or other structure.

To solicit specific informed opinion regarding the design loads in Table 4-1, a panel of 25 distinguished structural engineers was selected. A Delphi [Ref. C4-1] was conducted with this panel in which design values and supporting reasons were requested for each occupancy type. The information was summarized and recirculated back to the panel members for a second round of responses. Those occupancies, for which previous design loads were reaffirmed, as well as those for which there was consensus for change, were included.

It is well known that the floor loads measured in a live-load survey usually are well below present design values [Refs. C4-2, C4-3, C4-4, C4-5]. However, buildings must be designed to resist the maximum loads they are likely to be subjected to during some reference period T, frequently taken as 50 years. Table C4-2 briefly summarizes how load survey data are combined with a theoretical analysis of the load process for some common occupancy types and illustrates how a design load might be selected for an occupancy not specified in Table 4-1 [Ref. C4-6]. The floor load normally present for the intended functions of a given occupancy is referred to as the sustained load. This load is modeled as constant until a change in tenant or occupancy type occurs. A live-load survey provides the statistics of the sustained load. Table C4-2 gives the mean, m_s, and standard deviation, σ_x, for particular reference areas. In addition to the sustained load, a building is likely to be subjected to a number of relatively short-duration, high-intensity, extraordinary, or transient loading events (due to crowding in special or emergency circumstances, concentrations during remodeling, and the like). Limited survey information and theoretical considerations lead to the means, m_t, and standard deviations, σ_t, of single transient loads shown in Table C4-2.

Combination of the sustained load and transient load processes, with due regard for the probabilities of occurrence, leads to statistics of the maximum total load during a specified reference period T. The statistics of the maximum total load depend on the average duration of an individual tenancy, τ, the mean rate of occurrence of the transient load, v_e, and the reference period, T. Mean values are given in Table C4-2. The mean of the maximum load is similar, in most cases, to the Table 4-1 values of minimum uniformly distributed live loads and, in general, is a suitable design value.

For library stack rooms, the 150 psf (7.18 kN/m) uniform live load specified in Table 4-1 is intended to cover the range of ordinary library shelving. The most important variables that affect the floor loading are the book stack unit height and the ratio of the shelf depth to the aisle width. Common book stack units have a nominal height of 90 in. (2,290 mm) or less, with shelf depths in the range of 8 in. (203 mm) to 12 in. (305 mm). Book weights vary, depending on their size and paper density, but there are practical limits to what can be stored in any given space. Book stack weights also vary, but not by enough to significantly affect the overall loading. Considering the practical combinations of the relevant dimensions, weights, and other parameters, if parallel rows of ordinary double-faced book stacks are separated by aisles that are at least 36 in. (914 mm) wide, then the average floor loading is unlikely to exceed the specified 150 psf (7.18 kN/m^2), even after allowing for a nominal aisle floor loading of 20 to 40 psf (0.96 to 1.92 kN/m^2).

The 150 psf floor loading is also applicable to typical file cabinet installations, provided that the 36-in. minimum aisle width is maintained. Five-drawer lateral or conventional file cabinets, even with two levels of book shelves stacked above them, are unlikely to exceed the 150 psf average floor loading unless all drawers and shelves are filled to capacity with maximum density paper. Such a condition is essentially an upper-bound for which the normal load factors and safety factors applied to the 150 psf criterion should still provide a safe design.

If a library shelving installation does not fall within the parameter limits that are specified in footnote *c* of Table 4-1, then the design should account for the actual conditions. For example, the floor loading for storage of medical X-ray film may easily exceed 200 psf (2.92 kN/m^2), mainly because of the increased depth of the shelves. Mobile library shelving that rolls on rails should also be designed to meet the actual requirements of the specific installation, which may easily exceed 300 psf (14.4 kN/m^2). The rail support locations and deflection limits should be considered in the design, and the engineer should work closely with the system manufacturer to provide a serviceable structure.

The lateral loads of Table 4-1, footnote *d*, applies to “stadiums and arenas,” and to “reviewing stands, grandstands, and bleachers.” However, it does not apply to “gymnasiums—main floors and balconies.” Consideration should be given to treating gymnasium balconies that have stepped floors for seating as arenas, and requiring the appropriate swaying forces.

C4.2.2 Provision for Partitions. The 2005 version of the standard provides the minimum partition load for the first time, although the requirement for the load has been included for many years. Historically a value of 20 psf has been required by building codes. This load, however, has sometimes been treated as a dead load.

If we assume that a normal partition would be a stud wall with 1/2-in. gypsum board on each side (8 psf per Table C3-1), 10 ft high, we end up with a wall load on the floor of 80 lb/ft. If the partitions are spaced throughout the floor area creating rooms on a grid 10 ft on center, which would be an extremely dense spacing over a whole bay, the average distributed load would be 16 psf. A design value of 15 psf is judged to be reasonable in that the partitions are not likely to be spaced this closely over large areas. Designers should consider a larger design load for partitions if a high density of partitions is anticipated.

C4.3 CONCENTRATED LOADS

The provision in Table 4-1 regarding concentrated loads supported by roof trusses or other primary roof members is intended to provide for a common situation for which specific requirements are generally lacking.

Primary roof members are main structural members such as roof trusses, girders, and frames, which are exposed to a work floor below, where the failure of such a primary member resulting from their use as attachment points for lifting or hoisting loads could lead to the collapse of the roof. Single roof purlins or rafters (where there are multiple such members placed side by side at some reasonably small center-to-center spacing, and where the failure of a single such member would not lead to the collapse of the roof), are not considered to be primary roof members.

C4.4 LOADS ON HANDRAILS, GUARDRAIL SYSTEMS, GRAB BAR SYSTEMS, VEHICLE BARRIER SYSTEMS, AND FIXED LADDERS

C4.4.1 Loads on Handrails and Guardrail Systems. Loads that can be expected to occur on handrail and guardrail systems are highly dependent on the use and occupancy of the protected area. For cases in which extreme loads can be anticipated, such as long straight runs of guardrail systems against which crowds can surge, appropriate increases in loading shall be considered.

C4.4.2 Loads on Grab Bar Systems. When grab bars are provided for use by persons with physical disabilities the design is governed by CABO A117 Accessible and Usable Buildings and Facilities.

C4.4.3 Loads on Vehicle Barrier Systems. Vehicle barrier systems may be subjected to horizontal loads from moving vehicles. These horizontal loads may be applied normal to the plane of the barrier system, parallel to the plane of the barrier system, or at any intermediate angle. Loads in garages accommodating trucks and buses may be obtained from the provisions contained in Standard Specifications for Highway Bridges, 1989, The American Association of State Highway and Transportation Officials.

C4.4.4 Loads on Fixed Ladders. This provision was introduced to the standard in 1998 and is consistent with the provisions for stairs.

Side rail extensions of fixed ladders are often flexible and weak in the lateral direction. OSHA (CFR 1910) requires side rail extensions, with specific geometric requirements only. The load provided was introduced to the standard in 1998, and has been determined on the basis of a 250 lb person standing on a rung of the ladder, and accounting for reasonable angles of pull on the rail extension.

C4.6 PARTIAL LOADING

It is intended that the full intensity of the appropriately reduced live load over portions of the structure or member be considered, as well as a live load of the same intensity over the full length of the structure or member.

Partial-length loads on a simple beam or truss will produce higher shear on a portion of the span than a full-length load. "Checkerboard" loadings on multistoried, multipanel bents will produce higher positive moments than full loads, while loads on either side of a support will produce greater negative moments. Loads on the half span of arches and domes or on the two central quarters can be critical.

For roofs, all probable load patterns should be considered uniform for roof live loads that are reduced to less than 20 lb/ft^2 (0.96 kN/m^2) using Section 4.9.1. Where the full value of the roof live load (L_r) is used without reduction, it is considered that there is a low probability that the live load created by maintenance workers, equipment, and material could occur in a patterned arrangement. Where a uniform roof live load is caused by an occupancy, partial or pattern loading should be considered regardless of the magnitude of the uniform load. Cantilevers must not rely on a possible live load on the anchor span for equilibrium.

C4.7 IMPACT LOADS

Grandstands, stadiums, and similar assembly structures may be subjected to loads caused by crowds swaying in unison, jumping to its feet, or stomping. Designers are cautioned that the possibility of such loads should be considered.

C4.8 REDUCTION IN LIVE LOADS

C4.8.1 General. The concept of, and methods for, determining member live load reductions as a function of a loaded member's influence area, A_I, was first introduced into this standard in 1982 and was the first such change since the concept of live load reduction was introduced over 40 years ago. The revised formula is a result of more extensive survey data and theoretical analysis [Ref. C4-7]. The change in format to a reduction multiplier results in a formula that is simple and more convenient to use. The use of influence area, now defined as a function of the tributary area, A_T, in a single equation has been shown to give more consistent reliability for the various structural effects. The influence area is defined as that floor area over which the influence surface for structural effects is significantly different from zero.

The factor K_{LL} is the ratio of the influence area (A_I) of a member to its tributary area (A_T), that is, $K_{LL} = A_I/A_T$, and is used to better define the influence area of a member as a function of its tributary area. Figure C4-1 illustrates typical influence areas and tributary areas for a structure with regular bay spacings. Table 4-2 has established K_{LL} values (derived from calculated K_{LL} values) to be used in Eq. 4-1 for a variety of structural members and configurations. Calculated K_{LL} values vary for column and beam members having adjacent cantilever construction, as is shown in Fig. C4-1, and the Table 4-2 values have been set for these cases to result in live load reductions that are slightly conservative. For unusual shapes, the concept of significant influence effect should be applied.

An example of a member without provisions for continuous shear transfer normal to its span would be a precast T-beam or double-T beam that may have an expansion joint along one or both flanges, or that may have only intermittent weld tabs along the edges of the flanges. Such members do not have the ability to share loads located within their tributary areas with adjacent members, thus resulting in $K_{LL}, = 1$ for these types of members. Reductions are permissible for two-way slabs and for beams, but care should be taken in defining the appropriate influence area. For multiple floors, areas for members supporting more than one floor are summed.

The formula provides a continuous transition from unreduced to reduced loads. The smallest allowed value of the reduction multiplier is 0.4 (providing a maximum 60 percent reduction), but there is a minimum of 0.5 (providing a 50 percent reduction) for members with a contributory load from just one floor.

C4.8.2 Heavy Live Loads. In the case of occupancies involving relatively heavy basic live loads, such as storage buildings, several adjacent floor panels may be fully loaded. However, data obtained in actual buildings indicate that rarely is any story loaded with an average actual live load of more than 80 percent of the average rated live load. It appears that the basic live load should not be reduced for the floor-and-beam design, but that it could be reduced a flat 20 percent for the design of members supporting more than one floor. Accordingly, this principle has been incorporated in the recommended requirement.

C4.8.3 Passenger Car Garages. Unlike live loads in office and residential buildings, which are generally spatially random, parking garage loads are due to vehicles parked in regular patterns and the garages are often full. The rationale behind the reduction according to area for other live loads, therefore, does not apply. A load survey of vehicle weights was conducted at nine commercial parking garages in four cities of different sizes [Ref. C4-8]. Statistical analyses of the maximum load effects on beams and columns due to vehicle loads over the garage's life were carried out using the survey results. Dynamic effects on the deck due to vehicle motions and on the ramp due to impact were investigated. The equivalent uniformly distributed loads (EUDL) that would produce the lifetime maximum column axial force and midspan beam bending moment are conservatively estimated at 34.8 psf. The EUDL is not sensitive to bay-size variation. In view of the possible impact of very heavy vehicles in the future such as sport-utility vehicles, however, a design load of 40 psf is recommended with no allowance for reduction according to bay area.

Compared with the design live load of 50 psf given in previous editions of the standard, the design load contained herein represents a 20 percent reduction, but is still 33 percent higher than the 30 psf one would obtain were an area-based reduction to be applied to the 50 psf value for large bays as allowed in most standards. Also the variability of the maximum parking garage load effect is found to be small with a coefficient of variation less than 5 percent in comparison with 20 percent to 30 percent for most other live loads. The implication is that when a live load factor of 1.6 is used in design, additional conservatism is built into it such that the recommended value would also be sufficiently conservative for special purpose parking (e.g., valet parking) where vehicles may be more densely parked causing a higher load effect. Therefore, the 50 psf design value was felt to be overly conservative, and it can be reduced to 40 psf without sacrificing structural integrity.

In view of the large load effect produced by a single heavy vehicle (up to 10,000 lb), the current concentrated load of 2,000 lb should be increased to 3,000 lb acting on an area of 4.5 in. × 4.5 in., which represents the load caused by a jack in changing tires.

C4.8.5 Limitations on One-Way Slabs. One-way slabs behave in a manner similar to two-way slabs, but do not benefit from having a higher redundancy that results from two-way action. For this reason, it is appropriate to allow a live load reduction for one-way slabs, but restrict the tributary area, A_T, to an area that is the product of the slab span times a width normal to the span not greater than 1.5 times the span (thus resulting in an area with an aspect ratio of 1.5). For one-way slabs with aspect ratios greater than 1.5, the effect will be to give a somewhat higher live load (where a reduction has been allowed) than for two-way slabs with the same ratio.

Members, such as hollow-core slabs, that have grouted continuous shear keys along their edges and span in one direction only, are considered as one-way slabs for live load reduction even though they may have continuous shear transfer normal to their span.

C4.9 REDUCTION IN ROOF LIVE LOADS

C4.9.1 Flat, Pitched, and Curved Roofs. The values specified in Eq. 4-2 that act vertically upon the projected area have been selected as minimum roof live loads, even in localities where little or no snowfall occurs. This is because it is considered necessary to provide for occasional loading due to the presence of workers and materials during repair operations.

C4.9.2 Special Purpose Roofs. Designers should consider any additional dead loads that may be imposed by saturated landscaping materials in addition to the live load required in Table 4-1. Occupancy related loads on roofs are live loads (L) normally associated with the design of floors rather than roof live loads (L_r), and are permitted to be reduced in accordance with the provisions for live loads in Section 4.8 rather than Section 4.9.

C4.10 CRANE LOADS

All support components of moving bridge cranes and monorail cranes, including runway beams, brackets, bracing, and connections, shall be designed to support the maximum wheel load of the crane and the vertical impact, lateral, and longitudinal forces induced by the moving crane. Also, the runway beams shall be designed for crane stop forces. The methods for determining these loads vary depending on the type of crane system and support. References C4-9 through C4-12 describe types of bridge cranes and monorail cranes. Cranes described in these references include top running bridge cranes with top running trolley, underhung bridge cranes, and underhung monorail cranes. Reference C4-13 gives more stringent requirements for crane runway designs that are more appropriate for higher capacity or higher speed crane systems.

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[Ref. C4-6] Chalk, P.L., and Corotis, R.B. (Oct. 1980). "A probability model for design live loads." *J. Struct. Div. (ASCE)*, 106(ST10), 2017–2030.

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[Ref. C4-8] Wen, Y.K., and Yeo, G.L. (Mar. 2001). "Design live loads for passenger cars parking garages." *J. Struct. Engrg. (ASCE)*, 27(3). Based on a report titled "Design live loads for parking garages." ASCE Structural Engineering Institute, Dec. 31, 1999.

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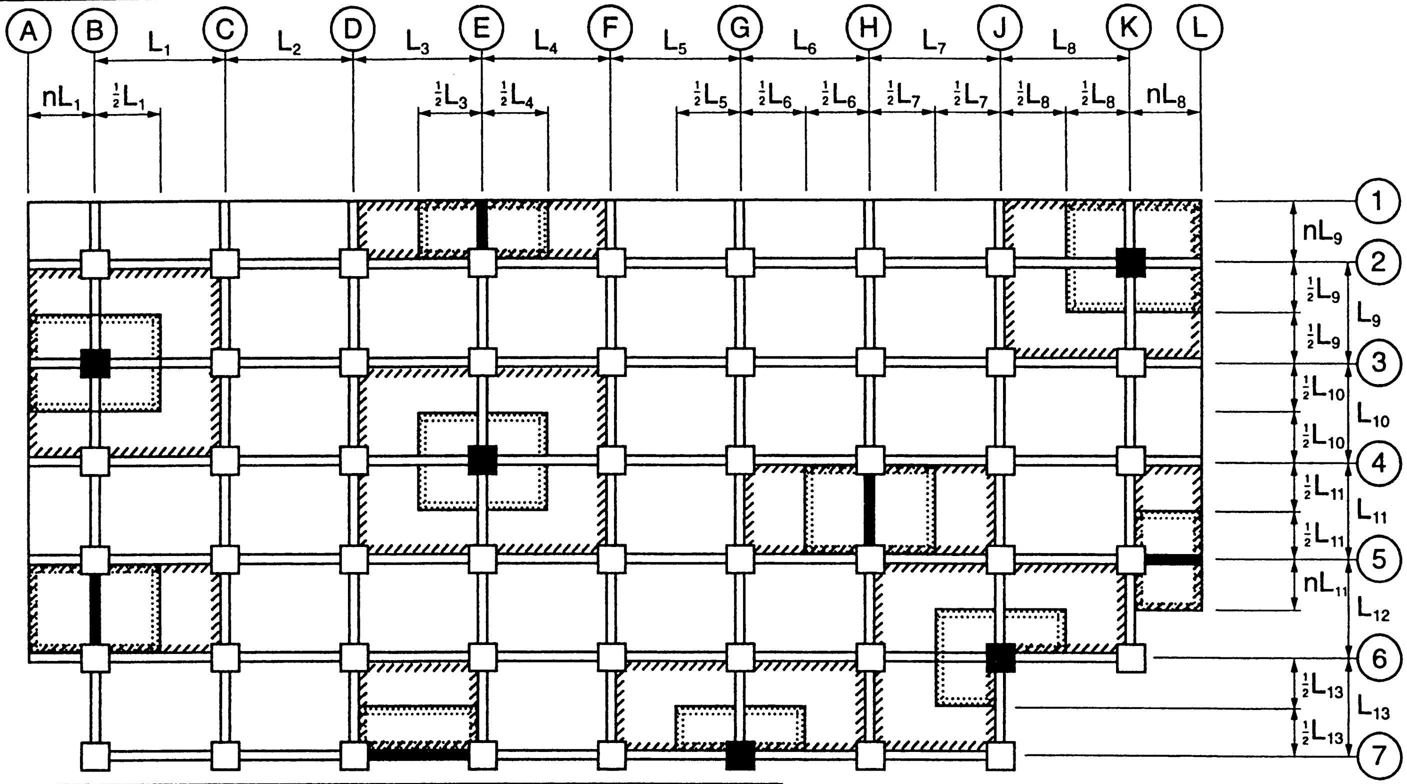
[Ref. C4-12] Metal Building Manufacturers Association. (1986). "Low rise building systems manual." MBMA, Inc., Cleveland, OH.

[Ref. C4-13] Association of Iron and Steel Engineers. (1979). *Technical Rep. No. 13*, Pittsburgh, PA.



Element	Actual K_{LL} Members w/o Cantilevers	Actual K_{LL} Members w/ Cantilevers			K_{LL}	Example Member
		n = 0	n = 0.5	n = 1.0	(Table 4-2)	(Fig. C-4)
Interior Columns	4	-	-	-	4	E4
Exterior Columns w/o cantilevers	4	-	-	-	4	G7, J6
Edge Columns w/ cantilevers	-	4	3	2.67	3	B3
Corner Columns w/ cantilevers	-	4	2.25	1.78	2	K2
Edge Beams w/o cantilever slabs	2	-	-	-	2	D7 - E7
Interior Beams	2	-	-	-	2	H4 - H5
Edge Beams w/ cantilever slabs	-	2	1.5	1.33	1	B5 - B6
Cantilever Beams w/o cantilever slabs	2	-	-	-	1	E1 - E2
Cantilever Beams w/ cantilever slabs	-	2*	1.5*	1.33*	1	K5 - L5

* The value of n for member K5-L5 is used to calculate the distance nL_{11}

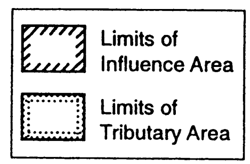


FIGURE C4 TYPICAL TRIBUTARY AND INFLUENCE AREAS

TABLE C4-1 MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS

Occupancy or use	Live Load lb/ft^2 (kN/m^2)	Occupancy or use	Live Load lb/ft^2 (kN/m^2)
Air-conditioning (machine space)	200[a] (9.58)	Laboratories, scientific	100 (4.79)
Amusement park structure	100[a] (4.79)	Laundries	150[a] (7.18)
Attic, nonresidential		Libraries, corridors	80[a] (3.83)
Nonstorage	25 (1.20)	Manufacturing, ice	300 (14.36)
Storage	80[a] (3.83)	Morgue	125 (6.00)
Bakery	150 (7.18)	Office Buildings	
Exterior	100 (4.79)	Business machine equipment	100[a] (4.79)
Interior (fixed seats)	60 (2.87)	Files (see file room)	
Interior (movable seats)	100 (4.79)	Printing Plants	
Boathouse, floors	100[a] (4.79)	Composing rooms	100 (4.79)
Boiler room, framed	300[a] (14.36)	Linotype rooms	100 (4.79)
Broadcasting studio	100 (4.79)	Paper storage	[c]
Catwalks	25 (1.20)	Press rooms	150[a] (7.18)
Ceiling, accessible furred	10[f] (0.48)	Public rooms	100 (4.79)
Cold storage		Railroad tracks	[d]
No overhead system	250[b] (11.97)	Ramps	
Overhead system		Driveway (see garages)	
Floor	150 (7.18)	Pedestrian (see sidewalks and corridors in Table 4-1)	
Roof	250 (11.97)	Seaplane (see hangars)	
Computer equipment	150[a] (7.18)	Rest rooms	60 (2.87)
Courtrooms	50–100 (2.40–4.79)	Rinks	
Dormitories		Ice skating	250 (11.97)
Nonpartitioned	80 (3.83)	Roller skating	100 (4.79)
Partitioned	40 (1.92)	Storage, hay or grain	300[a] (14.36)
Elevator machine room	150[a] (7.18)	Telephone exchange	150[a] (7.18)
Fan room	150[a] (7.18)	Theaters:	
File room		Dressing rooms	40 (1.92)
Duplicating equipment	150[a] (7.18)	Grid-iron floor or fly gallery:	
Card	125[a] (6.00)	Grating	60 (2.87)
Letter	80[a] (3.83)	Well beams, 250 lb/ft per pair	
Foundries	600[a] (28.73)	Header beams, 1,000 lb/ft	
Fuel rooms, framed	400 (19.15)	Pin rail, 250 lb/ft	
Garages—trucks	[c]	Projection room	100 (4.79)
Greenhouses	150 (7.18)	Toilet rooms	60 (2.87)
Hangars	150[c] (7.18)	Transformer rooms	200[a] (9.58)
Incinerator charging floor	100 (4.79)	Vaults, in offices	250[a] (11.97)
Kitchens, other than domestic	150[a] (7.18)		

[a] Use weight of actual equipment or stored material when greater.
[b] Plus 150 lb/ft^2 (7.18 kN/m^2) for trucks.
[c] Use American Association of State Highway and Transportation Officials lane loads. Also subject to not less than 100% maximum axle load.
[d] Paper storage 50 lb/ft^2 per foot of clear story height.
[e] As required by railroad company.
[f] Accessible ceilings normally are not designed to support persons. The value in this table is intended to account for occasional light storage or suspension of items. If it may be necessary to support the weight of maintenance personnel, this shall be provided for.

TABLE C4-2 TYPICAL LIVE LOAD STATISTICS

	Survey Load		Transient Load		Temporal Constants			Mean maximum
Occupancy or use	m_s lb/ft^2 (kN/m^2)	σ_s[a] lb/ft^2 (kN/m^2)	m_t[a] lb/ft^2 (kN/m^2)	σ_t[a] lb/ft^2 (kN/m^2)	τ_s[b] (years)	v_e[c] (per year)	T[d] (years)	load[a] lb/ft^2 (kN/m^2)
Office buildings								
offices	10.9 (0.52)	5.9 (0.28)	8.0 (0.38)	8.2 (0.39)	8	1	50	55 (2.63)
Residential								
renter occupied	6.0 (0.29)	2.6 (0.12)	6.0 (0.29)	6.6 (0.32)	2	1	50	36 (1.72)
owner occupied	6.0 (0.29)	2.6 (0.12)	6.0 (0.29)	6.6 (0.32)	10	1	50	38 (1.82)
Hotels								
guest rooms	4.5 (0.22)	1.2 (0.06)	6.0 (0.29)	5.8 (0.28)	5	20	50	46 (2.2)
Schools								
classrooms	12.0 (0.57)	2.7 (0.13)	6.9 (0.33)	3.4 (0.16)	1	1	100	34 (1.63)

[a] For 200 ft^2 (18.58 m^2) area, except 1000 ft^2 (92.9 m^2) for schools.
[b] Duration of average sustained load occupancy.
[c] Mean rate of occurrence of transient load.
[d] Reference period.