A Review of Current and Historical Occupant Load Factors for Mercantile Occupancies

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ABSTRACT

The determination of the occupant load of a building is often necessary as part of a fire engineering design assessment. Designers often use occupant load factors (or other equivalent terminology) to carry out this calculation typically using values taken from various published guidance or deemed-to-satisfy documents. This paper examines past and current values for mercantile occupancies that are specified in documents that are used in various jurisdictions around the world. In general three approaches are used; the occupant load factors are defined by the floor level of the building, by the type of mercantile activity within the spaces or through the application of uniform values throughout the occupancy. A simple six-storey exemplar building is used to illustrate the differences in the total occupant load and the relative number of occupants per floor when the different occupant load factor approaches are employed. Even for this simple building the occupant load differs by a factor of 4.1 and the distribution of the occupants varies noticeably between upper and lower levels depending on the particular document selected for the calculation.

KEYWORDS

occupant density; mercantile; occupant load.
INTRODUCTION

Background
In doing an egress calculation for a fire engineering design assessment it is necessary to determine the occupant load of a building and the distribution of the people throughout the building’s spaces. The definition of occupant load is not universal. In NFPA 1 [1] it is described as “the total number of persons that might occupy a building or portion thereof at any one time”. The New Zealand Acceptable Solutions [2] defines it as “The greatest number of people likely to occupy a particular space within a building”. The Scottish Technical Handbook [3] states “…the appropriate number of occupants in each space for normal circumstances”.

Typically occupant loads are calculated from occupant load factors (or other equivalent terminology) specified in various ‘prescriptive documents’. In some cases these documents are deemed-to-satisfy methods to meet a regulatory requirement and other cases they are provided as a form of guidance. However, Authorities Having Jurisdiction “…might specify a higher occupant load than calculated using occupant load factors… to provide an additional safety margin” [4] or occupant loads can be derived from measured values.

This paper examines the adopted occupant load factors for mercantile spaces given in a number of internationally available documents, although it is beyond the scope of this work to attempt to review every jurisdiction around the world and trace their development.

Measuring Occupant Density

It would be expected that occupant load factors used in design are based on historical data from measured occupant densities. Although measuring occupant density appears to be a straight-forward process it does come with temporal, dimensional and cultural complexities. The traditional method is to count the number of occupants at a given instant in time and then relate that to the footprint of the space in question. In these instances, the density depends heavily on the time and placement of the measuring area. To reduce the impact of these factors, more complex methods can be adopted, such as by using Voronoi diagrams [5]. Videographic methods can also be employed although these are not always precise. By taking such measurements in buildings of the same type, at different times of the day and year, gives an indication of the variation in occupant density and what might be expected as the maximum density.

Occupant density and occupant load factors are both quoted either in terms of the number of people per unit area or the area taken up per person (pp). One dimensional aspect is that these areas may depend on the body size of the individuals across the sampled population, the type of clothing worn, whether people are carrying items etc. [6]. The issues of what footprint should be used, whether a gross or net area be adopted and if a net area, then what elements are discounted from the calculation, are subject to interpretation.

In terms of temporal factors, the Post-War Building Studies in the UK [7] notes the difficulty of counting people in shops and department stores as well as changes that occur during seasonal sales. There could be changes in society over longer time scales in the way that mercantile occupancies are configured and used by people. Finally, there may be variations in social and cultural practices that mean the way in which mercantile spaces are used vary in different societies. The application of occupant load factors from one country or region may not be applicable to other parts of the world.

BASIS OF PUBLISHED OCCUPANT LOAD FACTORS

Notwithstanding the previous definitions of occupant density, a rational expectation is that published occupant load factors represent reasonable worst-case scenarios to allow for an acceptable level of conservatism, such that they correspond to some upper percentile related to a distribution of actual values that occur over the life of the space. However, the original underlying data used to determine the basis of the factors is difficult if not impossible to find in many cases. Clearly the maximum number of people a space can hold is related to an ultimate packing density and is not practical in real-world occupancy situations. Aside from record breaking attempts to try to fit as many people in a space that is physically possible, occupant density values up to 9 pers/m² [8] (0.11 m² pp) have been reported although ref. [4] notes that at an occupant density of 0.28 m² pp movement generally reaches a virtual stop.

From a regulatory and practical perspective, typically buildings are divided into different occupant uses with their own occupant load factors although this is not universally true and the approach to determine occupant load in the Republic of Korea does not follow a building use classification system [9], for example. Occupant uses are generally divided into assembly, mercantile etc. with sub-classifications. Modern retail developments are often complex multi-use buildings containing shops plus food halls; circulation areas, ancillary spaces;
storage; back-of-house administration etc. This paper only considers the specific mercantile activities generally referred to as ‘shops’ that are accessible to the public. However, shops themselves can be classified by various types including department stores selling clothes and homewares; showrooms for bulky items such as furniture; food supermarkets; specialised traders and/or mixed sales areas. The application of such definitions can be subject to interpretation.

Of the aforementioned general space use classifications, those for offices have been documented in some detail regarding the level of apparent conservatism. Schulte [10] quotes the proceedings of the 26th Annual [NFPA] meeting in 1922 discusses the use of applying 100 sq. ft pp (9.3 m² pp) for offices from surveys conducted by the Building Exits Code Committee. It is noted that there is the statement “…the Committee felt that this figure of 100 square feet was conservative” although there is no further comment on to what extent it is considered conservative. However, when it comes to mercantile space there are less comments on the level of conservatism noted in the historical literature. Nevertheless, in the recent work by De Sanctis et al. [11] the probability of exceedance of design occupant load densities in NFPA 101 [12], Approved Document B (ADB) [13] and New Zealand Acceptable Solutions, C/AS [2] compared to their measurements ranged between 5.9% and 0.01%. In the work of Angerd and Frantzich [14] the maximum occupant density from their analysis of mercantile spaces in Sweden did not exceed 0.28 pers./m² net area (3.6 m² pp) and their best-fit log-normal distribution has an average value of 12.5 m² pp such that the ADB value of 2 m² pp would be at the 99.9% upper limit. The occupant load factors used in the various documents are discussed in the next section.

PUBLISHED VALUES

Uniformly Applied Values

The simplest method to specify an occupant load factor is to use a single value throughout an occupancy type and this approach is used in documents for several occupancy classifications. Specifically for mercantile occupancies it appears that the occupant load factor used in Japan and Switzerland is 2 m² pp according to Youn et al. [9] and De Sanctis et al. [11] respectively whereas in the International Building Code (IBC) [15] 2015 edition, a gross mercantile occupant load factor of 60 sq. ft pp (5.6 m² pp) is given. The IBC also provides an ‘occupant formula’ to determine the occupant load factor that increases between 2.8 and 4.6 m² pp for malls with a specified range of gross leasable areas. BS 5588 [16] Part 11 suggests a floor space factor of 4 m² pp for retail premises where the occupancy is not known but notes that this could be 2 to 10 m² pp where the occupancy is known and the value can be ascertained by reference to similar premises.

Based on Floor Level

As an alternative to using a single occupant load factor for mercantile spaces some documents vary their factors as a function of floor level. Historically for department stores in the US Schulte [10] quotes the 22nd Annual (NFPA) meeting in 1918 in which “… an average of one person for each thirty-two square feet of floor space (irrespective of counters, etc.) on the upper floors, and one person for each twenty-five square feet on the ground floor and basement” (i.e. 3.0 m² pp and 2.3 m² pp respectively). In 1935 NBS M151 [17] gives 30 sq. ft pp (2.8 m² pp) for street floors and basements and 60 sq. ft pp (5.6 m² pp) for the other floors for the gross area of store (retail) spaces. The 2012 edition of the IBC followed NBS M151 whereas NFPA 101 [12] provides gross mercantile sales area values of 2.8 and 5.6 m² pp depending on the relationship of the floor to street level corresponding to NBS M151 but with an additional factor of 3.7 m² pp for sales areas on two or more street floors. NFPA 101 also includes a method for calculating the occupant load factor that increases between 2.8 and 5.1 m² pp over a range of gross leasable areas. The New York Building Code [18] in 1938 gave net values that slightly differ from NBS M151 / NFPA 101 with 25 sq. ft pp (2.3 m² pp) for first floors and basements and 60 sq. ft pp (5.6 m² pp) for the other floors. However, the 1968 edition gave 50 sq. ft pp (4.6 m² pp) for other floors and by 2008 gross areas values of 30 sq. ft pp (2.8 m² pp) for first floors and basements and 60 sq. ft pp (5.6 m² pp) for the other floors are specified, matching NBS M151.

In New Zealand, NZS 1900 [19] gave values for the ground floor of shops as 20 sq. ft pp net or 30 sq. ft pp gross (1.9 m² pp and 2.8 m² pp respectively) and for other floors 40 sq. ft pp and 60 sq. ft pp (3.7 m² pp and 5.6 m² pp respectively) where the gross values correspond to those given in NBS M151. As discussed in the next section, New Zealand no longer uses this approach.

Qatar [20] has three classes of occupancy that depend on the number of storeys and building area but mercantile occupant load factors are the same in each case and follow NFPA 101. Similarly, the 2007 edition Saudi Building Code [21] gives gross occupant load factors of 2.8 m² pp for basement and grade floor areas and 5.6 m² pp for areas on other floors but no occupant load factor for areas on two or more street floors.
Canada has had a National Building Code [22] since 1941 but it has not been possible to access early editions. Some provinces and municipalities implement the code exactly as is, while others use a slightly modified version. Occupant load factors for mercantile uses in Ontario are 3.7 m$^2$ pp for basements, first storeys and second storeys having a principal entrance from a pedestrian thoroughfare or parking area. For other storeys, a value of 5.6 m$^2$ pp is used. These values have been used from at least 1997. The 1998 edition of the British Columbia Fire Code adopts the same values as with Ontario. In either case it is not clear whether values are net or gross. Comparing with M151 it would appear that the ‘other storey’ value is a gross value. However, the basement, first floor etc. does not correspond to the M151 gross value of 2.8 m$^2$ pp but does match the net value given in NZS 1900 [19] for other floors. Whether this match is coincidental is unknown to the authors.

Occupant load factors in Hong Kong, Australia and India all follow a similar procedure. In the 2011 edition (and the 1996 edition) of the Hong Kong Code of Practice for Fire Safety in Buildings [23], basement, ground, first and second floors of retail shops and department stores are specified as 3 m$^2$ pp. For the third floor and higher the value is 4.5 m$^2$ pp. The Australian National Construction Code [24] specifies 3 m$^2$ pp levels entered direct from the open air or any lower level. A value of 5 m$^2$ pp is then given for all other levels. The Indian National Building Code, along with the Delhi building bye-laws [25], specifies 3 m$^2$ pp for the street floor and sales basement and a value of 6 m$^2$ pp is then given for upper sales floors.

In the UK, occupant load factors are discussed in ref. [6] in which an occupant load factor of 75 sq. ft pp for retail shops and upper floors of department stores and 10 sq. ft pp for department store “sales basements, ground floor and any upper floor used for bazaars or special sales displays” are recommended. These equate to 6.7 m$^2$ pp and 0.9 m$^2$ pp respectively and are at the upper and lower extremes of similar environments found elsewhere. While ref. [6] distinguished occupant load factors between floor levels, no existing UK document referred to in this paper has adopted this approach.

**Based on Occupancy Type**

Rather than defining mercantile occupant load factors with regard to building storey an alternative (or supplementary) method is to give occupant load factors for specific mercantile activities.

In the UK, the 2013 edition (consistent back to 2000) of ADB [13] in England and Wales, the 2017 edition (consistent back to 2005) of the Scottish Technical Handbook [3] and the 2005 edition of Technical Handbook E for Northern Ireland recommend a floor space factor of 0.7 m$^2$ pp for a queuing area or shopping mall, 2 m$^2$ pp for shop sales areas including supermarkets and department stores and 7 m$^2$ pp for shop sales areas trading in furniture and other ‘bulky goods’. For shopping malls, ADB also makes reference to BS 5588 [16] Part 10, which recommends an occupant load calculation based on mall widths, with 0.75 m$^2$ pp applied for mall widths up to 8 m, and 2 m$^2$ pp for any additional mall width beyond 8 m. This approach is also described in annexes in both the BS 9999:2008 and BS 9999:2017 editions.

The now superseded BS 9999:2008 [26] listed 63 different occupancy types in which 7 m$^2$ pp for showrooms, 2 m$^2$ pp for shops and bazaars were given. In comparison BS 9999:2017 has streamlined floor space factors and gives 2.4 and 7 m$^2$ pp for normal (clothing store), medium (supermarket) and low (furniture showroom) density conditions respectively. The generic term ‘shops’ in BS 9999:2008 no longer exists in BS 9999:2017 but could be represented by the ‘normal’ or ‘medium’ categories and also that the value for supermarkets here does not correspond to other UK guidance discussed above.

In 1991 the Republic of Ireland’s Building Regulations [27] gives an approach equivalent to BS 9999:2008 however in the 1997 and 2006 editions BS 5588 [16] parts 10 and 11 are adopted and no specific factors are listed for mercantile occupancies.

The 2006 edition of the New Zealand Acceptable Solution C/AS1 [2] specified gross area mercantile occupant load factors as 0.3 pers./m$^2$ for shop spaces, malls and circulation areas, 0.1 pers./m$^2$ for furniture and large appliance stores or similar and 0.2 pers./m$^2$ for showrooms (equivalent to 3.3, 10 and 5 m$^2$ pp respectively). In the equivalent 2012, C/AS4 document these values were given as 3, 10 and 5 m$^2$ pp respectively where the value for shop spaces etc. has been modified to 3.5 m$^2$ pp in the 2017 edition. The New Zealand Verification Method C/VM2 [28] adopts the same values as C/AS4, 2017 although C/VM2 does not explicitly state whether these are for gross or net area.

The 2000 edition of the Russian Construction Standards and Regulations [29] is the only reference reviewed in which the occupant load factor varies between urban and rural locations. A value of 1.35 m$^2$ pp is given for sales areas of shops in towns and urban settlements; 2.0 m$^2$ pp for rural shops and 1.6 m$^2$ pp for sales areas.
Finally, some published documents give occupant load factors for specific mercantile activities in addition to those as a function of building storey. In Hong Kong [23] markets, supermarkets, showrooms, jewellery and goldsmith shops, pawn shops and money changers are specifically identified with a value of 2 m² pp. In Australia, ref. [24] specifies 5 m² pp for showrooms which are described as display areas, covered malls or arcades. In Ontario, dining, alcoholic beverages and cafeteria areas are specified within the mercantile category as 1.1 m² pp however British Columbia does not list these within its mercantile use category.

APPLYING THE PUBLISHED VALUES TO DESIGN

To illustrate the variation between recommendations, occupant load factors have been applied to a simplified hypothetical retail design to determine an overall building occupant load. This is not intended to encapsulate all possible variations in published values, but only to provide a single example. The building is assumed to have six storeys including a ground level, two basement levels and three upper levels each with a gross area of 1000 m². The ground and first storey (Level 1) are assumed to be accessible from a street. In cases where it is not clearly specified whether a gross or net floor area factor should be assumed then the gross has been applied. Where there is a ‘choice’ of occupant load factors, the value which results in the greatest occupant load has been selected for conservatism – an approach often adopted by designers.

(1) BS 9999:2008 only has shops at 2 m² pp whereas 2017 edition distinguishes between supermarkets and clothing stores. (2) C/AS4 and C/VM2 separate ’showrooms’ from areas with furniture using factors of 5 m² pp and 10 m² pp respectively. (3) Occupant load changes from 1629 to 1867 if the 3.5 m² pp or 3 m² pp factors using 2017 or 2012 editions of C/AS4 respectively.

Fig. 1. Total calculated occupant loads using published occupant load factors (numbers in m² pp).

Fig. 1 shows the number of occupants per level using the indicated occupant load factors. Values for BS 9999:2008, ADB and Scottish Technical Handbook have been consolidated as have NBS M151, NYC (2008), Qatar and gross values from NZS 1900. The variation in the proportion of the occupant load in the basement, for example comparing the Post-War Building Studies with BS 9999 is illustrated. For the exemplar building the occupant load varies from 1074 to 4444 but clearly larger and more complex retail buildings are being designed, where for these designs variations between occupant loads could be even greater.

CONCLUSION

In general there are three approaches for determining the occupant load in mercantile spaces; by floor level, by occupancy type or as uniform values. In all of the documents reviewed only BS 5588 allows for a calculation that considers the circulation areas rather than the shop areas. In addition, occupant load factors for mercantile spaces not only differ by jurisdiction but also over time within some jurisdictions.

The authors have not been able to source the original data used to select the occupant load factors, and therefore have been unable to identify the basis for these factors and to what distribution percentile they correspond. The difficulty in obtaining this information can make it hard for designers to determine the relevance of occupant load factors when applied to modern design and why there can be large disparities between jurisdictions. Whether these variations are solely down to cultural differences is not clear but it would seem the basis of current occupant load factors have origins that go back more than 60 years. By performing this review, a need to revisit mercantile floor space factors for new data has been highlighted. Future work should take into consideration the different cultural practices between jurisdictions.
REFERENCES

[1] NFPA 1, Fire Code, National Fire Protection Association, Quincy, MA, USA, 2012.
[2] MBIE, Acceptable Solutions, Wellington, New Zealand, 2006 through to 2017.
[3] Technical Handbook – Non-domestic. Scottish Government, 2005 and 2017.
[4] Cote, R. and Harrington, G., (eds.), NFPA 101 Life Safety Code Handbook, 12th ed., National Fire Protection Association, Quincy, MA, USA, 2006.
[5] Steffen, B., Seyfried, A. (2010) Methods for measuring pedestrian density, flow, speed and direction with minimal scatter, Physica A, 389(9): 1902-1910, 10.1016/j.physa.2009.12.015
[6] Predtechenskii, V.M. and Milinskii, A.I., Planning for Foot Traffic Flow in Buildings. Amerind Publishing Company, Inc, New Delhi, 1978.
[7] Fire grading of buildings, Post-War Building Studies, No. 29, HMSO, London, 1952.
[8] Xiaoping, Z., Jiahui, S. and Yuan, C. (2010) Analysis of crowd jam in public buildings based on cusp-catastrophe theory, Building and Environment, 45(8): 1755-1761, 10.1016/j.buildenv.2010.01.027
[9] Youn, H., Hwang Y. and Kwon, Y. (2011) A study of density of the person in a classroom for building evacuation safety regulations in Korea. In: Peacock R., Kuligowski E., Averill J. (eds) Pedestrian and Evacuation Dynamics. Springer, Boston, MA
[10] Schulte, R.C., Fire protection history – Part 250: 1918, (Design occupant factors - Department stores), Building Code Resource Library, 2014.
[11] De Sanctis, G., Kohler, J. and Fontana, M. (2014) Probabilistic assessment of the occupant load density in retail buildings. Fire Safety Journal, 69:1-11, 10.1016/j.firesaf.2014.07.002
[12] NFPA 101, Life Safety Code, National Fire Protection Association, Quincy, MA, USA, 2015.
[13] Fire Safety Approved Document B, Buildings Other than Dwellinghouses, 2000 through to 2013, UK.
[14] Angerd. M. and Frantzich, H. The use of uncertainty analysis in performance based design. 4th Int. Conference on Performance-based Codes and Fire Safety Design Methods, 2002, pp.179-189.
[15] International Building Code (IBC), International Code Council (ICC), 2015.
[16] BS 5588. Fire Precautions in the Design, Construction and Use of Buildings – Part 10 and Part 11. British Standards Institution, 1991 and 1997 respectively.
[17] Courtney, J., Houghton, H. and Thompson G., Design and construction of building exits. NBS Publication M151, National Bureau of Standards, Washington, 1935.
[18] New York Building (Construction) Code, New York City, 1938, 1968 and 2008 editions.
[19] NZS 1900. Model Building Bylaw, Chapter 5, Fire Resisting Construction and Means of Egress, New Zealand Standards Institute, 1963.
[20] Civil Defence Regulation, Ministry of Interior, State of Qatar, 2012.
[21] Saudi Building Code, Kingdom of Saudi Arabia, 2007.
[22] The National Building Code of Canada (NBC), National Research Council Canada, 2015.
[23] Code of Practice for Fire Safety in Buildings, Buildings Dept., Hong Kong, 1996 and 2011.
[24] The Building Code of Australia, Class 2 to Class 9 Buildings, Volume one, Australian Building Codes Board, Canberra, ACT, Australia, 2007.
[25] Puri, V., Compendium of Delhi building bye-laws and development regulations. JBA Pub., 2007.
[26] BS 9999, Fire safety in the design, management and use of buildings – Code of practice, The British Standards Institution, 2008 and 2017 editions.
[27] Building Regulations, Technical Guidance Document B – Fire Safety, Dublin, Republic of Ireland, 1991, 1997 and 2006.
[28] C/VVM2 Ministry of Business, Innovation and Employment, Verification method: Framework for fire safety design, Wellington, New Zealand, 2014.
[29] Construction Standards & Regulations, SNiP 2.08.02-89, Moscow, Russian Federation, 2000.