Minimum Stair Width for Evacuation, Overtaking Movement and Counterflow – Technical Bases and Suggestions for the Past, Present and Future

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Traditional lane models such as the 560 mm (22-in.) unit of exit width are examined as historical artifacts and, when studied empirically, as flawed bases for minimum stair width determination. Criticisms of this lane model were presented separately by the authors as early as about 1970 and improved bases for minimum width determination were also presented. Currently, even the improved bases for minimum stair width—based on the authors' early work—need to be updated for stair user demographics and other factors that have changed in recent decades. Three types of crowd flow are considered; coherent flow, overtaking movement, and counterflow. All of these occurred in the evacuations of the World Trade Center in 1993 and 2001. Partly as a result of the latter incident, counterflow has recently received particular attention in some US standards and building code-change deliberations that led to a minor increase—from 1120 mm to 1422 mm (44 in. to 56 in.) in minimum, nominal exit stair width requirements for certain occupancy conditions. Completing an examination of past, current and future criteria for setting minimum stair width, the authors provide suggestions for studies that will help provide significantly improved bases for such widths in the future.

1. Objectives and Issues

The purpose or objective of this collaboration—of three North American pioneers in modern pedestrian studies(1-3)—is to develop recommendations for long overdue empirical study that will lead to a more substantial reconsideration of traditional lane models such as the 560 mm (22-in.) unit of exit width. This model, although largely eliminated from national building code requirements in North America over the last two decades, still is the most widely used basis for regulating minimum exit (escape) stair width for building evacuation. To what extent was a minimum width of 1120 mm (44 in.) ever appropriate for coherent crowd flow, for overtaking movement, and for counterflow? What factors were ignored or misunderstood in setting this minimum? What factors have changed over time that make this a more dubious minimum today, especially within a US context where there are significant changes in people's body size and fitness? What are the implications for modeling pedestrian movement on stairs? What are the implications for building or facility design and construction? What are the implications for research?

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2. Traditional Bases and Justifications for the Lane Model

A 560 mm (22-in.) lane model for pedestrian movement, at least within the context of US requirements for means of egress (escape), apparently has its origins in the early part of the 20th century. This was related to the creation, in 1905, of the first US model building code—the National Building Code, by the National Board of Fire Underwriters, and, in 1913, of the National Fire Protection Association, NFPA, Committee on Safety to Life which developed the Building Exits Code, now the Life Safety Code.

As part of a review by Pauls (4), the views about exit width presented in two committee reports—from the US, 1935, and from Britain, 1952 (5, 6)—were critically discussed. While both reports concluded that there was not definitive empirical evidence for a lane model for egress flow, the building codes (regulations) that followed for a few decades after these reports maintained a traditional lane or unit-width model (22 in. or 560 mm in the US and 21 in. or 550 mm in Britain). Reflecting the overwhelming influence of tradition, the US report asserted, "In the opinion of many who have studied the matter, 22 inches can be taken as the width of a file of people in motion. Its origin is said to be in experience gained in the Army. A stairway width of 44 inches will permit 2 files of people to move freely down the stairs at the same time." No scientific reference was provided for these assertions.

Notably, the British report, considering both the US work from 1935 and subsequent French work, stated: "The tests do not give any reliable evidence on the effect of small differences in width, say 6 in. increments," and "Before this question can be definitively settled it will be necessary to get experimental conditions where reasonably consistent results can be obtained for each particular width." As one example of the weight given to the traditional lane model—even after the 1952 report, the NFPA Building Exits Code, 1963 edition, stated:

> "Measurement of exit width in terms of units representing the width occupied by one person, rather than measurement in feet and inches is an important concept of the Building Exits Code. Measurement in feet may in some cases involve additional expense in building construction without corresponding increase in safety. For example, a 44-in. stairway comfortably accommodates two files of people; adding 4 in. to make a 4-ft. stairway does not increase the capacity of the stairway. However, it has been shown by count of stairway flows that adding 12 in. to a 44-in. stairway does increase the flow of people, in effect permitting an intermediate staggered file."

The NFPA Building Exits Code did not provide a specific citation to the study having this conclusion which, according to the work of Pauls among others, is partly correct and mostly incorrect; both a 100 mm (4-in.) width increase and a 305 mm (12-in.) width increase result in higher flows—in proportion to effective width or, respectively, about

13 percent and 38 percent (3, 7). Here it should be noted that flow capacity varies directly—and linearly— with effective width (the nominal width less 300 mm or 12 in.), not with the nominal width.

3. Research from the 1960s and 1970s in North America

Both the nature of the lane model and its dimensions were challenged by researchers who, for perhaps the first time, examined and documented—in detail—crowd movement in the contexts of urban-scale movement (including mass transportation systems) and intra-building egress in evacuation drills. The work of Fruin and of Pushkarev and Zupan in the New York City area, circa 1970, has been especially influential in traffic engineering (1, 2). Fruin recommended a minimum 1524 mm (60-in.) nominal stair width based on a 560 mm (22-in) shoulder width and body sway of 100 mm (4 in.) to each side. For building design and regulation contexts, there was extensive documentation in Canada by Pauls of, first, high-rise building evacuation drills and, later, crowd movement at large events like the Olympic Games, mostly in the 1970s. Pauls' studies, both in tall office buildings and in large buildings with assembly occupancies, covered extensively used stairs in the nominal width range of 914 mm to 2235 mm (36 to 88 in.), a range of widths and use conditions allowing Pauls to develop the Effective Width Model which was included in a chapter of the SFPE Handbook of Fire Protection Engineering in 1988 (7).

Especially notable for its intensive focus on one particular stair width was Pauls' field study, in 1978, of aisle stair use in the Edmonton Commonwealth Stadium which, as well as leading to some detailed data analysis (of particularly intensive film and video documentation), resulted in the unique documentary film, The Stair Event (8-9). Notably, that study was done with intensively used stairs having a nominal width effectively about 1422 mm (56 in.) by virtue of the fact that the clear width between seats, on either side of the aisle, was approximately1200 mm (48 in.).

During the 1980s, as a result of Pauls' aisle stair study and a widely used report by the US-based Board for the Coordination of the Model Codes (BCMC) in 1985, this 1200 mm (48-in.) clear width became the standard minimum requirement for aisle stair width regulated by US model building codes and standards, beginning with the BOCA National Building Code in 1987 and the NFPA Life Safety Code in 1988. Notably, a center handrail (with gaps every three to five seat rows) is usually provided for such aisle stairs as the preferred option to providing handrails on each side. Thus two lanes of nearly 600 mm (24 in.) clear width—actually about 590 mm (23 in.)—were created on each such subdivided aisle stair which are used for coherent egress flow, overtaking movement and counterflow. In addition to its use in the Edmonton stadium, there has been extensive use of this aisle stair width in new aisle stairs constructed in the USA since approximately 1990. The widespread existence and extensive use of such stair widths offer significant research possibilities on the minimum stair width issue (as discussed below).

Empirically based recommendations from the authors, for minimum stair width, were in the range of 1370 mm to 1525 mm (54 in. to 60 in.)—significantly greater than the traditional 1120 mm (44 in.) minimum nominal width enshrined in building codes. Notably, the authors took careful account of lateral body sway in their work; lateral body sway had not been taken into account in the development and use of the traditional unit exit width approach using the 560 mm (22-in.) lane width. Other ergonomics-oriented authors, Panero and Templer, have also opined on significantly wider minimum widths—1422 mm (56 in.)—and preferred widths—about 1753 mm (69 in.) based on two 95th percentile men side-by-side, in their books in 1979 and 1992 respectively (10, 11). For all the foregoing dimensions, the nominal width is used (e.g., wall-to-wall clearance in those cases where a stair flight is bounded by walls on each side). Handrails (and everything below handrail height) are typically permitted, by US building code requirements, to project up to about 100 mm (4 in.) into required minimum, nominal stair width.

4. Current Situation regarding Minimum Stair Width Rules

Not until the World Trade Center (WTC) disaster in 2001 was there a major push to reconsider minimum exit stair width requirements in building codes and safety standards, especially given some limited but influential photographic evidence as well as research survey data indicating a major problem with counter flow of evacuees and firefighters. Preliminary evidence on evacuee speed and flow during the 2001 evacuation of the WTC also has raised questions about appropriate stair geometry. Although there are three major studies currently being done on the evacuation of the World Trade Center, most of the currently published work is that of the US National Institute of Standards and Technology (NIST) which has posted all of its 10,000 pages of comprehensive findings and presentations (heavily focused on structural collapse) on a special web site, http://wtc.nist.gov. The two other studies—which are more focused on human behavior and evacuation issues—are being done by Columbia University and by a three-university consortium in the UK. Information on at least two of these studies is found in other papers given at the PED2005 conference.

All of this background, but most explicitly the need for emergency responder counterflow, led committees of the National Fire Protection Association (NFPA) to introduce a wider 56-inch, 1425 mm minimum exit stair width requirement to NFPA codes and standards for certain high-occupancy contexts (2,000 occupants per stair). This was in response to proposals to NFPA from Pauls, first in 2001 and then more successfully in 2003, for incorporation in the Life Safety Code (NFPA 101) and Building Construction and Safety Code (NFPA 5000), both ANSI documents being finalized during 2005. Not yet well addressed are clear indications, from public health data, of significant increases in body mass and size as well as significant reductions in fitness for the US population. Increased body mass/size and reduced fitness—resulting in slower speed on stairs—influence lateral body sway, for example, which also affects needed stair width. All of these factors underline the urgent need for new empirical studies and improved modeling, preferably of an international and cross-cultural nature, of pedestrian movement on stairs in a variety of contexts. Detailed recommendations are offered below on planning, conducting and applying such studies which have major implications for evacuation and pedestrian dynamics plus the design and operation of buildings in which evacuation is anticipated.

Summing up the current situation, where are we now with the three-decade old recommendations coming especially from the work and analyses of Fruin and Pauls, the two North American investigators of human movement who have thought the most about minimum stair width in relation to coherent crowd movement, overtaking movement and counterflow? Given traditional requirements and the demographics of North American adults—studied about three decades ago, we can assume a base clear width of about 560 mm (22 in.). To this we need to add an allowance for body projections and lateral sway of 100 mm (4 in.) to each side. This results in a nominal minimum stair width—with two channels or lanes—of 1320 mm (52 in.) to 1520 mm (60 in.). Where one selects a width within this 200 mm (8-in.) range depends on whether the 100 mm (4 in.) of body sway toward the center of the stair is ignored (assuming side-by-side individuals are swaying laterally in the same direction or in phase, and thus not interfering) or is fully accounted for (assuming side-by-side individuals are swaying toward each other, out of phase).

A width in the middle of the range—specifically 1400 mm (56 in.) has been the recommendation from Pauls' work, while the wider option—1520 mm (60 in.) has been advanced by Fruin. Incidentally, the 1400 mm (56-in.) width, with handrails approximately 1200 mm (48 in.) apart allows an adult—with a 5th percentile female to 95th percentile male stature—in the middle of the stair to simultaneously grasp handrails on each side. While not adopted generally for minimum exit stair width, Pauls' recommended minimum has had relatively wide acceptance in US model building codes and standards for two contexts. The first accepted of these contexts is aisle stairs in assembly seating facilities. The second is exit stairs where an occupied wheelchair will have to be carried—by three persons—on the stair (as opposed to using a one-person-operated, gravity-powered, stair descent, evacuation device transporting the person otherwise unable to use stairs). As this paper is being prepared a third context, for the 1400 mm (56 in.) nominal minimum width, is being adopted for NFPA model codes and standards for new exit stairs used by more than 2,000 persons per stair. Otherwise, the minimum nominal stair width required by model building codes and safety standards in North America is 1120 mm (44 in.).

Again, the foregoing recommendations date from three decades ago and relate to demographics that are significantly different from those becoming increasingly pervasive in the USA due to increased body mass and reduced fitness generally. Development of new minimum stair width recommendations should not be based merely on anthropometric changes over the last three decades (or, for that matter, even projections of such changes over the coming decades when buildings constructed today will still be in use). More basic (re)examination, taking into account public health and ergonomics, is warranted. This is addressed in the next section.

5. Research Suggestions and Future Design Requirements

The underlying assumption behind the following recommendations is that information about people's use of stairs, in relation to establishing justified criteria for minimum stair width, should be based on field observations of actual stair use. The authors' early work from a few decades ago demonstrates the value of this approach as contrasted to a literature-based approach or use of computer models—both of which may be flawed by out-of-date or otherwise incorrect information or methods.

Moreover, while this paper is based on predominantly North American experience, it is recommended that more than one cultural or demographic context be examined. One way to do this, which will have other advantages (listed in Section 5.1), is to conduct detailed field studies of crowd movement on aisle stairs of large buildings used for public assembly; i.e., arenas and stadia. Thus, even though the contexts for most urgent application might be exit stairs in multistory buildings (dealt with in Section 5.2), with office or residential occupancy, the best study possibilities appear to occur with assembly occupancy aisle stairs. Effectively, much of the following set of recommendations is for a second, albeit more sophisticated iteration of the studies headed by Pauls in the 1970s, especially in the context of the Edmonton Commonwealth Stadium which led to the documentary film, The Stair Event (8, 9).

5.1. Why Study Stair Use in Assembly Aisle Stairs?

Among the reasons for conducting new research within the context of assembly aisle stairs are the following.

1. The buildings, containing an abundance of such stairs, are found in virtually all countries.
2. Such buildings typically have very limited use and are thus available frequently and for long periods without disrupting their normal use for spectator events. This provides two documentation options: observations during normal events with thousands of spectators and observations during other times, including observations with experimental modifications to the stairs and with controlled tests of counterflow and overtaking movement for example.
3. The stairs, especially for outdoor facilities, have relatively good lighting which will facilitate detailed photographic and video documentation.
4. The stairs can be observed and documented from numerous vantage points, including especially overhead ones (for example, from lighting catwalks and towers), that are needed to best document critical aspects of people's movement.

5. Camera positions can be set up at great distance from the observed activity thus satisfying two important criteria. First, the camera activity will be unobtrusive to those using the stairs. Secondly, there will be minimal problems with parallax as long-focal length lenses can be used at distances of up to 200 metres (700 ft.), a very good approximation of infinity. This was, for example, a much-used setup for the study leading to the film, The Stair Event, as high-quality (Beaulieu) Super-8 film cameras were used with high-quality (Hasselblad) lenses, of up to 500 mm focal length, so that a person's image nearly filled a frame—shot in vertical format—at a distance of 200 metres! At the left side of Figure 1 is a single frame from one of the research films; it depicts aisle stair ascent by a girl with a stature of about 1500 mm (60 in.). There is a central handrail, the aisle stair has a width of 1200 mm (48 in.) measured at the treads; and this is effectively similar to a non-aisle stair with a nominal width of about 1400 mm (56 in.). At the right side of Figure 1 is the camera setup on the other side of the stadium about 200 metres (700 feet) distant from the girl on the aisle stair.

Figure 1: Film documentation 200 metres (700 ft.) distant from aisle stair

Such facilities often have a variety of aisle stair widths, although for newer facilities in the US, there will be a preponderance of aisle stairs with a clear width of 1200 mm (48 in.) which, fortunately, is the single width warranting the most intensive study given current understanding of minimum width and recent code requirement practice.

6. Current aisle facilities, depending to some extent on the country, seat deck pitch, and the age of the facilities, have various approaches to provision of handrails. Outside the US and with older facilities generally, many aisles have no handrails at all. Within the US, especially with facilities built in the last decade or so, all of some aisle stairs will have handrails, usually installed at the centerline of the aisle, with gaps every three to five rows. Some facilities have handrails at the side of aisle stairs, with gaps at each row. For experimental purposes—with aisles not already equipped with handrails, temporary handrails could be installed at, or near, the sides of aisles to test effectiveness of various clear stair widths.

7. Such facilities typically have various seat deck slopes which leads to different step geometries including, especially in the US, the 180 mm (7-in.) maximum rise by 280 mm (11-in) minimum run/going geometry that is a commonly required for enclosed exit stairs in multistory buildings. In chapter 3 of his book, Pedestrian Planning and Design, Fruin (1) first reported—quantitatively—that better step geometries would be associated with higher speeds, especially in descent. His data cover only two rise-run/going step geometries: 180 mm (7 in.) by 285 mm (11.25 in.) and 150 mm (6 in.) by 305 mm (12 in.) with the former being on an indoor stair and the latter on an outdoor stair. Subsequent studies by Templer (12) and Roys and Wright (13, 14), among others, have provided information on usability and safety differences among various step geometries but there remains a relative dearth of studies that specifically address the benefits—to crowd egress flow—of various step geometries. Thus studies in the context of aisle stairs, with their range of step geometries in otherwise comparable conditions, can be useful.

5.2. The Case for Studies of Stair Use in Tall Building Exit Stairways

The fact that tall building stairs are, geometrically, different from typical aisle stairs underlines the need to conduct systematic studies there as well. For example, there might be particular step geometries that are more typical in office buildings—older ones especially—than are found in aisle stairs. Also, there are important differences in provision of walls, enclosing the stairs, and provision of landings—one, two or four per building floor so that crowd movement on exit stairs consists of a combination of steps and level walkways with the latter providing, on the one hand, places of lower energy expenditure or even rest while, on the other hand, they require frequent transitions from one type of gait to another that is very different biomechanically and in terms of safety. Indeed, the mere fact that there are such frequent transitions—onto and from steps—significantly affects safety as well as the degree of attention people need to pay to their own movement while coping with the movement of others nearby.

Thus, even given this incomplete discussion of differences, there are very good reasons for research to be done within the context of typical tall buildings. However, enclosed stairs with frequent landings pose difficult challenges in terms of detailed documentation. Cameras cannot be placed so distant and fewer options are available for type of view. Some of these difficulties can be partly mitigated if mirrors are used—for example on soffits and ceilings—to provide greater flexibility with camera placement while doubling (or tripling) distances between cameras and observed action to reduce parallax. Lighting will be a problem in actual exit stairs and, given the need to document evacuation movement under emergency lighting and lights-out, photoluminescent marking conditions, infrared cameras may be needed.

Generally, to provide data also from actual evacuations, use should be made of permanently installed cameras so that some key data are available from real-world conditions as opposed to tests. At a minimum, such cameras should be set up at the discharge levels of exits, directed toward the final stair flights.

5.3. Other Study Contexts

Only brief of mention will be made of two other options for studying crowd movement. One is transit system stairways—where there are no problems getting extensive usage. The second, where setting up crowd usage may be a challenge, is laboratory settings. This offers better precision and instrumentation possibilities.

5.4. What Data Should Be Collected?

Regardless of the crowd movement context, standard measures of pedestrian movement—speed, flow and density—should be determined for each observation. Other data to be collected include the following.

1. Traditionally, body width (as it affects width of circulation facilities) has been measured at shoulders. A more meaningful dimension may be body width at a person's elbows. In any event, measurements should be made of the maximum lateral dimension of people's bodies (with clothing) at both elbows and shoulders to establish which governs and for what kind of movement conditions.
2. Regarding the space required by special stair users—notably emergency responders who might need to ascend stairs carrying bulky firefighter turnout gear and other equipment, data need to be collected on the resulting counterflow with descending evacuees.
3. Other special users and use conditions, as part of evacuation flow, include persons with mobility disabilities using walking aids such as crutches or canes, persons being carried in wheelchairs (either by two persons or by three persons), and persons being transported on one of the several commercially available evacuation chairs or gravity-powered stair descent devices.
4. A potentially important factor is whether the predominant evacuation flow is downward—the usual case for high-rise buildings—or upward, as would be the case for underground facilities. How does the width required change as a function of predominant travel direction?
5. Regarding precision for all such measurements, it is suggested that (with better quality digital documentation methods now available) measurement to the closest 10 mm (0.4 in.) should be the goal. This is approximately a factor of ten better than achieved in studies done some three decades ago by Pauls, based on relatively poor video resolution then available. With higher-resolution motion picture film (of Super-8 format and low-grain, 40 ISO speed) used for the Edmonton Commonwealth Stadium study in 1978, the subsequent analysis achieved a precision of about 40 mm or 1.5 in. (10), for example to code individual foot placement

across the stair width. Precision with video was only slightly better than Pauls achieved with video nearly a decade earlier.

6. In general, the analysis of Edmonton records (performed under contract for Pauls) could be one starting point for future studies although modern human movement study technologies should permit less dependence on manual data take off from visual records. For example, data acquisition technologies such as employed in the recent stair use studies at the UK Building Research Establishment laboratory by Mike Roys and Michael Wright should also be exploited where possible (13, 14) as should other studies of human movement being performed in other laboratories. (No literature research of such general human movement study methods has been performed for this paper; however it should be one of the first steps taken in a subsequent study.)
7. The extent of lateral body sway should be assessed in an absolute sense (relative to a fixed line) and relative to the person's average walking line taken as the center point between ones feet or ones center of gravity projected vertically to the walking surface. How lateral body sway varies as a function of anthropometrics, walking speed, gender, and other factors should be investigated. An important factor also to assessed, relative to body sway, is the lateral spacing of ones feet. Use or nonuse of a handrail (or of handrails) should also be assessed as it might affect lateral body sway.
8. The lateral clearance between people, when side by side, should be measured for the three conditions—coherent flow, overtaking movement and counterflow. For coherent flow, the extent to which adjacent persons are using the same weight-bearing foot—and thus swaying—in phase or in unison should be investigated. This may be a prime reason that people marching with military precision might be able to achieve high flow with relatively small inter-person spacing and with lane widths as small as the traditionally assumed 560 mm (22 in.).

Ultimately, the suggested studies should provide useful data and models that can help describe the dynamic space requirements for crowd movement on stairs taking into account user demographics, nature of the movement, and stairway geometry. These data and models should then be employed to help set minimum stair width criteria that can be implemented in model codes and standards for building design. A goal here should be to develop models that can address changing demographics—for example, even larger and less fit people than is currently typical in the US. The movement models should also be used to improve the quality of evacuation and crowd movement models generally, in terms of both the analysis or simulation and the graphic output.

6. Concluding Remarks

Moving beyond the current, tradition-based criteria for minimum exit stair width will require substantial research to address adequately coherent flow, overtaking movement and counterflow plus to take into account changing demographics. The demographic changes, especially in the US, have led to larger, heavier people with fitness levels lower than was the case when the authors first began documenting pedestrian movement a few decades ago.

The traditional 1120 mm (44-in.) nominal minimum width for exit stairs was flawed, and known to be flawed a few decades ago. Even with knowledge available around 1970, it was clear to the authors that a minimum nominal width of between 1400 mm (56 in.) and 1520 mm (60 in.) should be used for design of stairs where two-abreast movement could occur reliably. Preferred widths, facilitating more efficient crowd movement were approximately 1730 mm to 1750 mm (68 in. to 69 in.) measured nominally, or about 1520 mm (60 in.) measured as the clear width between handrails on each side. Indeed the 1520 mm (60 in.) clear width between handrails has been the maximum permitted clear distance between stair handrails if all of the stair width is to be credited for egress capacity in US model building codes, based on Pauls' analyses of adult anthropometrics and of field data (3, 15). With this width, everyone on the stair is within reach of one handrail. Moreover, according to the Effective Width Model developed by Pauls, based on field studies of tall building evacuation and crowd movement in large assembly facilities (3, 7, 15), this preferred 1730 mm (68-in.) nominal width has an effectiveness for evacuation flow that is 75 percent greater than the traditional 1120 mm (44-in.) nominal stair width even though its nominal width is only 55 percent greater.

But the foregoing recommendations are based on observations made a few decades ago. Today, user demographics have changed significantly. Moreover, some of the applications are very tall buildings where a total evacuation by stairs will be a lengthy, arduous experience—even more so now with typical occupants having lower fitness levels than was the case a few decades ago. New research must be done. Also, with the much improved video documentation methods available now, much higher quality data can be collected. We cannot afford to ignore both the research needs and the research opportunities. For these reasons, several suggestions have been made for conducting such new research. Given that these recommendations come from three senior pedestrian movement researchers, we should not be surprised that today's younger, highly skilled and (we hope) more motivated researchers will accept the challenge. After all, new, better founded criteria for minimum exit stair width will affect the design of buildings that will still be in use long after the authors—and, indeed, even today's younger researchers—have passed on.

The life safety implications of getting critical features for building evacuation designed correctly are too great to ignore. Thus we hope that our account of how we got to where we are today and our suggestions about preparing sensibly for the future will find an audience among pedestrian researchers and building safety policy makers among others.

Moreover, to all responsible for developing the increasingly sophisticated and sometimes visually compelling models of pedestrian movement, we request that human movement be better represented in your models. If body sway, for example, is as important in crowd movement as we believe it to be—especially for larger, heavier, slower-moving people—then pedestrian and evacuation models should take it into account and depict it realistically.

7. Postscript

Within hours of this paper being finalized, the US National Bureau of Standards and Technology, NIST, released its draft final reports, totaling some 10,000 pages (accessible at http://wtc.nist.gov/pubs/reports_june05.htm) with 30 recommendations including recommendations 4, 16-20 on evacuation of tall buildings. These recommendations, for code changes and (indirectly) future research, along with findings reported especially on project 8 (Emergency Response Operations), clearly identify counterflow—of emergency responders and evacuees—as a phenomenon to be addressed in relation to exit stair width. Most important, NIST recommendation 4 calls for tall building design facilitating full evacuation of occupants within time limits set by the capability of the building to withstand burnout without collapse. Thus stair width and effectiveness of crowd movement now have renewed importance. «

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