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The Dilemma of Emergency Lighting: Theory vs Reality

M.J. Ouellette (1), B.W. Tansley (2), and I. Pasini (3)

THIS PAPER IS AN IESNA TRANSACTION.
IT WAS ORIGINALLY PRESENTED AT
THE 1992 IESNA ANNUAL CONFERENCE.

Introduction

One of the greatest responsibilities of building maintenance is the safety of occupants. There must always be enough illumination to enable orderly, accident-free evacuation from buildings. Webber,¹ then Ouellette and Rea² consolidated several studies from around the world³⁻⁶ that show that under reduced emergency lighting, performance is reduced and evacuees move more hesitantly and slowly.³ For example, at a mean of 0.16 lx, Boyce³ observed hesitant movement and collisions with furniture, jeopardizing the efficiency and possibly the safety of building evacuation. At yet lower levels of illumination, Boyce³ observed confusion, reversals in direction of movement, and dependence upon tactile cues for wayfinding.

North American occupation, building, and fire codes and standards provide specifications for emergency lighting practice and maintenance. Canadian Occupational Safety and Health (COSH) regulations,⁷ for example, specify that principal exit routes and other designated spaces require a mean* lighting level of at least 10 lx, as determined "by making four measurements at different places representative of the level of lighting 1 m above the floor of the area and; by dividing the aggregate of the result of those measurements by four." Additionally, COSH regulations specify that in buildings constructed after October 31, 1990, no point in the designated spaces shall be illuminated at less than 0.25 lx. The 1990 National Building Code of Canada⁸ recommends that principal exit routes and other designated spaces should have no less than 10 lx of emergency lighting on average at floor level. The US National Fire Protection Association also calls for 10 lx of emergency illumination.⁹ The National Fire Code of Canada¹⁰ provides guidance on the maintenance and testing of emergency lighting equipment. Where emergency lighting is powered by backup generators, it recommends that the generators be tested monthly and that a log of test results be maintained. Likewise, it recommends that

individual battery-powered units should be tested on a regular basis. The IESNA¹¹ now recommends no less than an average of 5 lx along the centerlines of the floors of principal exit routes and designated spaces. It is anticipated¹² that the next edition of the *IES Lighting Handbook* will recommend no less than 10 lx on average, with no point less than 0.5 lx, and with a uniformity ratio (E_{mean} to E_{min}) not to exceed 100 to one.

Thus, in North America, recommendations seem to converge on an average level of 10 lx. But how common is 10 lx in practice? How meaningful is it, and how practical is it to measure? Most importantly, how suitable are these regulations, standards, and recommendations for specifying an intended minimal level of safety in buildings? This paper presents the results and conclusions drawn from a comprehensive survey conducted in seven randomly selected buildings in Ottawa, Ontario, Canada, in an attempt to answer these questions.

Sample size effect

Foremost, it was necessary to determine the number of measurements needed to obtain a reasonable degree of confidence in the calculated mean illuminances. Pilot work revealed the following statistics for the floor of a typical evacuation route illuminated by two-lamp, 4-ft, recessed, overhead, fluorescent troffers on 45-ft centers: mean (E_{mean}) = 6.47 lx, and standard deviation (SD) = 6.39 lx. If the illuminances were distributed normally, then the percent critical significant difference, d , for E_{mean} would have been¹³

$$d = 100 \frac{2 \text{ SD}}{E_{\text{mean}} \sqrt{n}}$$

at the 95 percent confidence level (i.e., 19 times out of 20). For the $n = 58$ measurements in the given space, d is 26 percent. Thus, one could expect E_{mean} to be accurate to within 26 percent, 19 times out of 20. Table 1 displays values of d for other sample sizes, n . More than 1500 measurements were required to obtain an accuracy within 5 percent, 19 times out of 20. One should not treat these findings in a strict quantitative manner, however, because the observed illuminance measurements were not distributed normally. Skewed distributions of the type observed would require even

*The word mean in this paper refers to arithmetic mean, the most common and often misleading type of average. The word average is a generic term for any of arithmetic mean, geometric mean, harmonic mean, mode, and median—all different estimators of central tendency.

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Table 1—Effect of sample size (n) on accuracy represented as percent significant difference (d)

n	d	n	d
1	198	128	18
2	140	256	12
4	99	512	8.7
8	70	1561	5.0
16	49	2048	4.4
32	35	4086	3.1
58	26	8172	2.2
64	25	16344	1.5

more measurements to obtain the same level of confidence in the mean. Nevertheless, the findings reinforced the need to collect a very large number of measurements. Most certainly, a random sample of size $n = 4$, as specified in the COSH regulation,⁷ could not provide an accurate estimation of mean illuminance in spaces comparable to the one described in this example. In the present survey, 4540 measurements were collected in an unbiased manner within the 7 buildings sampled.

The buildings

Building 1 is a three-story building constructed in the 1970s. It has offices along the periphery and laboratory facilities within the central core. The offices are illuminated by a combination of daylight and ceiling-mounted fluorescent fixtures. The inner core doesn't require emergency lighting because of its simplicity and smallness. Emergency lighting is provided primarily in the corridors, stairwells, and washrooms by ceiling-recessed fluorescent 1-by-4-ft fixtures.

Building 2 is a 25-yr-old high-rise tower. The layout of each floor surveyed was similar, consisting of a central core of elevators, opening to a central foyer, leading through short access hallways to the surrounding open-plan office space reaching to the building periphery. On some floors private offices were found in parts of the open-plan space, typically located on an outer wall. On all floors the corridors or walkways in the open-plan areas that would serve as emergency exit routes were defined by portable office dividers. Emergency lighting in this building consisted of a subset of the 1-by-4-ft ceiling-recessed fluorescent fixtures used during regular operations. An exception was the cafeteria, a place of employee congregation, which had a combination of U-tube fluorescent lamps and mercury halide lamps in surface-mounted fixtures.

Building 3, a high-rise tower, was built in 1975 and consisted mostly of offices designed on open-plan grids leading from a central elevator core. Emergency lighting consisted of ceiling-mounted fluorescent luminaires spaced in a rectangular array. Principal ex-

it routes in the open-plan areas were defined by portable office dividers.

Building 4 is similar to Building 3 except that it was built in 1978. Floor spaces varies; the lower floors are substantially greater than those higher up.

Buildings 5 and 6, office towers constructed in 1978, have impressive architectural features including large atria, which provide daylight to elevator foyer areas and pedestrian walkways in publicly accessible spaces. Surface-mounted luminaires doubled as emergency lighting in the elevator foyers. The rest of these buildings are primarily open-plan offices with emergency lighting consisting of recessed fluorescent luminaires arranged in a manner similar to Building 2.

Building 7 is 33 yrs old and comprises five interconnected buildings ranging from five to seven stories in height. It houses a mixture of open-plan and private offices. Its hallways are spacious and contained few obstructions.

Emergency lighting in all buildings was powered by central backup generators, except for Building 7. Building 7 was equipped with dual-head, wall-mounted, incandescent floodlights powered by local rechargeable batteries.

Procedure

The buildings were all surveyed at night. Three of them (2, 5, and 6) were studied during complete building power shutdowns with emergency lighting powered by central generators. In Buildings 1, 3, and 4 normal lighting circuits were switched off by maintenance personnel floor by floor to simulate power failure. Battery-powered units in Building 7 were evaluated by shutting off electrical circuits within the area under study and completing illuminance measurements within 20 min.

Both visual inspection and illuminance measurements were performed. Three general features of the emergency lighting were assessed during visual inspection:

1. the fit of the ceiling luminaire plan to the floor plan, including emergency routes and furniture layout
2. the logic of the emergency route layout, including the prevalence and visibility of obstructions
3. the level of maintenance of the emergency lighting system as evidenced by the ease by which building operators could locate and identify the emergency lighting, the number of luminaires in need of service, and the area of evacuation routes where no emergency lighting was operational

In multistory buildings, visual inspection identified floors that appeared typical of the entire building.

These floors were targeted for illuminance survey.

Illuminance surveys in the targeted floors exhaustively* covered areas identified in Part 6.10 of the COSH regulations: "(a) exits and corridors; (b) principal routes providing access to exits in open floor areas; and (c) floor areas where employees normally congregate." Horizontal illuminance was measured photopically at 1 m above the floor along the centerline of the evacuation routes at 1-m intervals. Care was taken to avoid shadowing the illuminance meter speciously. Measurements along level surfaces were collected with a Topcon Model IM-3 illuminance meter. Stairwells were sampled using a Hagner model EC1-ES illuminance meter. Both instruments were cosine corrected and had been recently calibrated. In many floors, there were numerous areas where emergency illumination was below the limits of sensitivity of the illuminance meters (0.1 lx). Values below 0.1 lx were recorded as 0.1. In some local areas where illuminance did not vary by more than approximately 30 percent, data collection was expedited by recording, for each 1-m interval, the most common illuminance value observed within that local area. While this technique has drawbacks, it increased the amount of data the survey team could collect within the time that the buildings were available.

Additionally, to assess the effects of measurement height, illuminance readings were obtained at both the floor level and at a height of 1 m at one of the sites. In this way, it was possible to later relate floor level measurements (e.g., as recommended in the National Building Code of Canada⁸) to measurements collected at 1 m as specified in the COSH regulations.⁷

Results

Visual inspection

Building 1, the smallest building studied, had good emergency lighting with recessed, ceiling-mounted fixtures centered every 45 ft. No areas were in near darkness, and the survey team had no difficulty maneuvering throughout the exit routes of this building.

Inspection of the office towers (Buildings 2-6) revealed that emergency lighting followed the same design on all floors: typically, eight luminaires were located at the corner of two concentric rectangles, with supplemental emergency lighting in the elevator lobbies and central core areas. This design provided

*One exception is the survey of Building 1, which covered only one of the four similarly designed corridors.

**This point became apparent to one member of the survey team who, in spite of precautions, fell over a potted fern while conducting measurements.

noticeably excellent lighting in the central areas, but a severe reduction of emergency lighting the farther one proceeded from the central core.

In a significant number of open-plan areas, discrepancies were found between the emergency luminaire locations on the ceiling and the emergency exit routes on the floor. Changes in the architectural layout and the furniture arrangements likely account for these inconsistencies. Quite commonly, a small private office or conference room enveloped a sole emergency fixture designed to service a much larger floor area. Consequently, emergency lighting was limited to the newly partitioned room while the larger zone remained in near darkness, typically an estimated 10-30 percent of the total floor area.

Wall-mounted battery units were found to be inconsistently positioned for some open-plan office layouts, probably for similar reasons. High privacy panels in some open-plan areas severely shaded exit routes from emergency illumination.

Emergency exit signs and exit routes in many of the open-plan areas were inconsistent. In extreme examples, exit signs led to locked doors or cul-de-sacs. Here, the need for security and the need for emergency egress appeared to conflict. In some buildings with complex open-plan layouts, there was no apparent principal exit route. Where one was apparent, it was sometimes overly complex. In some office areas, especially at night, it would be difficult for people to find their way to safety with the emergency lighting systems now in place.**

The building operations and maintenance personnel were quite aware of the requirements to inspect, test, and maintain emergency generators. Typically, the personnel were not aware of the actual state of maintenance of the emergency luminaires, of the location of the emergency power panels, and of the appropriateness of the present emergency lighting layout. Many of the battery-powered units in Building 7 were connected to general-purpose circuits rather than to lighting circuits. Thus, if lighting failed independently of the general-purpose circuits, the exit routes would not be lighted. There is considerable room for improvement regarding the maintenance of emergency lighting systems for ensuring safety during real emergency situations.

Illuminance measurements

Emergency lighting at all points in stairwells and stair landings consistently exceeded 10 lx, except for Building 7 in which electric emergency lighting was not provided in the stairwells. Emergency illumination was generally at its maximum near the elevator lobbies and central cores of all buildings; diminishing as distance from the core increased.

Figure 1 shows that illuminance data are highly skewed and variable. Similar distributions were observed in each surveyed floor of each building. For distributions of this kind where values differ so greatly among themselves, a mean is paradoxically almost

Figure 1—Linear and logarithmic (inset) frequency distributions from all buildings combined ($n=4540$)

meaningless,¹⁴ and may lead one to the wrong conclusions.

For example, the mean illuminance in six of the seven buildings exceeds or approaches 10 lx (Table 2). The remaining building provides a mean of only 2.1 lx. These results alone might lead to the conclusion that the emergency lighting systems in most of the buildings performed well. In fact, most of the evacuation routes were well below 10 lx, and the mean was strongly influenced by the few brightly illuminated areas near and directly below the sparsely spaced luminaires. From the median of the combined data (Table 2), exactly half of the measurements were at or below 1.0 lx. Therefore, when surveyed sparsely (e.g., only four random measurements), there is a high probability that the mean would be below 10 lx in these buildings.

Table 3 represents the proportion of observations within the given illuminance ranges and can be used to predict the probability of any single measurement being within the given ranges. It shows, for example, that 66 percent of the combined measurements were

below 10 lx. It also shows that 15 percent of the measurements were below the COSH minimum of 0.25 lx for new buildings.

Discussion

The survey reveals several problems with the implementation of the current standards and regulations. Quite obviously, the presumed intended level of safety was not met in six of the seven buildings. More disturbing, however, is the realization that the buildings' shortcomings are not reflected in the comprehensive illuminance measurements summarized in Table 2. The survey demonstrates that we should not assume that the emergency lighting is sufficient simply because it provides a mean illuminance of 10 lx. We should not assume that emergency luminaires are now serving the exit routes simply because they did so at the time a building was commissioned. We should not assume that battery-powered units will start simply because they did so the last time their test buttons were pressed. They might not be triggered by lighting circuits. During routine power shutdowns, we should not assume that the exit routes are properly illuminated simply because the diesel generator started.

This survey, then, reveals more about the ambiguities and limitations of current emergency lighting regulations. Perhaps the most serious problem is the futility of attempting to characterize emergency illumination in terms of a small number of "representative" measurements. The reasons for this are threefold.

First, because of the high variability in illuminances, it is virtually impossible to pick four representative locations without first having exhaustively sampled the entire space. This is an important consideration because the resulting mean can be distorted by the inclusion of a disproportionate number of exceptionally bright or exceptionally dark regions. This problem can only be resolved by sampling a very much larger number of points in an unbiased manner.

Second, large variances introduce large uncertainties in the accuracy of derived means. As calculated above, a sample size of four can give an uncertainty of 99 percent in the calculated mean illuminance of a typical exit route under emergency lighting.

Third, averaging is not meaningful for the highly skewed distributions typical of emergency lighting. Where the sources of illumination are few, illuminance measurements tend to distribute by the inverse square law and do not cluster about a central value. In these cases, arithmetic means can give grossly misleading estimates of central tendency. One solution is to transform the observed data into a distribu-

Table 2—Summary of illuminance measurements expressed as number of measurements (n), arithmetic mean (Mean), median (Md), standard deviation of the mean (SD), minimum (Min), maximum (Max), and uniformity ratios (Max/Min and Mean/Min)

Building	n	Mean	Md	SD	Min	Max	Max/Min	Mean/Min
1								
Floor 3	57	89	27	115	6	396	66	15
2								
Floor 12	82	20	2.6	35	0.2	140	700	100
Floor 11	180	9.3	0.1	26	0.1	140	1400	93
Cafeteria	42	10	6.2	9.9	0.8	51	64	13
Combined	304	12	1.2	28	0.1	140	1400	124
3								
Floor 8	248	19	0.5	53	0.4	336	840	48
Floor 4	220	3.9	1	5.7	1	15	15	4
Floor 5	121	7.9	1	7	1	15	15	8
Floor 7	320	7.1	1	7	1	15	15	7
Combined	909	9.6	1	29	0.4	336	840	24
4								
Floor 12	203	28	5	50	0.1	258	2580	280
Floor 10	189	32	12	43	2	233	117	16
Floor 6	297	24	15	38	0.18	283	1572	133
Floor 3	397	17	4.3	39	0.1	258	2580	170
Combined	1086	24	10	42	0.1	283	2830	240
5								
Floor 10	393	23	1	57	0.1	548	5480	230
Floor 4	340	5.9	0.5	21	0.5	190	380	12
Combined	733	15	0.5	45	0.1	548	5480	150
6								
Floor 11	143	14	0.5	50	0.4	325	813	35
Floor 6	357	8.1	0.5	20	0.1	190	1900	81
Floor 4	275	14	0.5	38	0.1	260	2600	140
Floor 1	289	11	0.1	37	0.1	263	2630	110
Combined	1064	11	0.5	35	0.1	325	3250	110
7								
Floor 4	387	2.1	0.3	3.3	0.1	18	180	21
Combined	4540	15	1	39	0.1	548	5480	150

Table 3—Cumulative percent frequencies for the distribution of all illuminance measurements (n=4540)

Illuminance range (lx)	Cumulative frequency (percent)
0.1	14
<0.25	15
<0.5	19
<0.6	38
<1	40
<2	54
<5	59
<10	66
<15	73
<20	88
<100	96
548	100

tion appropriate for description by the arithmetic mean. An alternative solution is to abandon the statistic of mean in favor of one less sensitive to

distribution shape. One such statistic is the median, a more representative measure of central tendency under these circumstances. Another preferred statistic is the one introduced in 6.11(4) of the COSH regulation—the minimum. The Commission Internationale de l'Eclairage,¹⁵ the United Kingdom,¹⁶ and other countries quantify emergency lighting primarily in this manner.

Regarding the question of measurement height, we found that mean illuminance at the 1-m height generally exceeded that at floor level by a factor of 1.2. More important, however, illuminance measurements at 1 m were nearly twice as variable as measurements collected at floor level. These measurements are thus more vulnerable to the three problems discussed above. For this reason, measurements at floor level provide more reliable estimates of average illuminance. Regardless, human vision responds to considerably more than average illuminance in a given horizontal plane: we view objects in three

dimensions. Therefore, both the vertical and the horizontal components of illumination should be considered when characterizing illuminated environments. This is of particular concern for spaces equipped with wall-mounted incandescent flood luminaires, which project a large portion of their illumination onto vertical planes. Resolving this problem is a subject for further research. Emerging improvements in image photometry and computational modeling offer promising areas of exploration.

Recommendations

It is impossible, from this survey of only seven buildings, to draw conclusions about the general state of emergency lighting across North America. Nevertheless, the findings call attention to some important aspects of building safety that may be overlooked. They suggest that a suitable result cannot necessarily be obtained by relying on such common rules of thumb as dedicating every tenth luminaire to emergency lighting. Rather, emergency lighting must be carefully designed, redesigned, inspected, and reinspected to ensure that the specific requirements of dynamically changing building interiors are met. In addition, this study highlights the futility of attempting to accurately characterize emergency illumination in terms of the arithmetic mean of a small number of "representative" measurements. The following recommendations are proposed based on the results of this study:

- Codes and standards based on average illuminance should be revised in favor of more appropriate and less ambiguous guidelines for specifying emergency lighting.
- Entire emergency lighting systems (including individual fixtures) should be routinely tested and inspected.
- Emergency lighting fixtures should be discernible from the normal lighting fixtures (e.g., by a colored sticker on one corner of each unit).
- Operations policy should ensure that these fixtures receive maintenance priority and that floor plan changes, such as the erection of partitions, do not defeat the effectiveness of these fixtures.
- Local battery-powered units should be triggered on lighting circuits rather than general-purpose circuits.

Current North American codes, standards, and regulations on emergency lighting are based on the assumption that lighting distributions can be accurately characterized in terms of mean illuminances in a horizontal plane. To test this assumption, a comprehensive survey of emergency lighting was conducted in the exit routes of seven randomly selected

buildings in Ottawa. Six of the seven buildings had mean illuminances meeting the recommendations of codes and standards. Nevertheless, some areas of evacuation were completely dark. Other areas were sufficiently dim to jeopardize the efficiency of building evacuation. It was concluded that arithmetic means cannot accurately describe the severely skewed and variable distributions of emergency lighting data found in typical office buildings. Implications on building safety were discussed, and recommendations for improvement were provided.

Acknowledgements

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Discussion

I would like to congratulate the authors on the excellent work they did. They have backed up what engineers and designers have theorized for years. Their field of study shows that emergency lighting levels, placement, and maintenance are inadequate, and that stricter attention should be paid by enforcement officials, maintenance personnel, designers, architects, and engineers.

This paper has shown that average levels of 10 lx are not normally achieved if the median is used to determine the illuminance average, which is the proper method in this case. More often, the mean is used to determine the average illuminance, which could leave areas in total darkness, causing unsafe egress paths as demonstrated in this paper.

Moreover, due to lack of actual measurement of illuminance by the enforcement community, it is hard to expect emergency lighting levels to comply with code. It's even harder to imagine that required levels will be maintained as a building's interiors change over the life of the building.

In Building 7, which contained battery-operated emergency lighting equipment, the length of time over which 387 measurements were taken may have been too long. Canada only requires a 30-min duration for emergency lighting. The 20 min required to take the measurements may have permitted the emergency illumination level to drop by up to 30 percent of the initial level, which code requires to be 10 lx and only 6 lx at the end of the emergency lighting period.

Did the authors evaluate the time necessary for eye adaptation from the areas of high luminous intensity to the low areas? If so, did this condition hinder the speed of egress the occupants would move? Did the authors observe any discomfort or disability glare from the luminaires during their observations?

I would like to additionally indicate that in the United States Building 7 would be in violation of the National Electrical Code (NFPA 70) because the battery-operated units were not triggered by lighting circuits.

Besides these questions, I completely concur with the authors' recommendations and findings as stated, and that engineers, designers, maintenance personnel, and the enforcement community need to pay more attention to emergency illuminance levels and maintenance thereof: proper emergency lighting provides proper life safety of the building occupants.

S. Altamura
Dual-Lite Inc.

The authors are to be commended for their insightful research into the realities of emergency lighting. Emergency lighting codes and standards are written under the assumption that what is specified is what is provided. Ouellette, et al. have provided information that this is not necessarily so. They have successfully documented that emergency lighting levels in Canada, and presumably the rest of North America, do not come close to meeting IESNA or COSH specifications. Their paper is unique in documenting the levels of emergency lighting that actually prevail in real buildings. It suggests that there is some real cause for alarm when considering the actual implementation and maintenance of emergency lighting systems.

The paper also provides very useful suggestions for more realistic specifications for emergency lighting conditions. The authors provide excellent information about the statistical treatment of emergency lighting. Could they address their reasons for preferring the minimum luminance over the median or modal luminance? Use of the modal illuminance appears to give reasonable information about the frequency of occurrence of a particular luminance value. What about the geometric mean? Would the authors care to speculate on the relationship between illuminance (mean, median, or minimum) in ensuring safe egress? Certainly, specifying a mean of 10 lx is nonsense if that value is only obtained at one place in a 30-m corridor with much of the corridor left in darkness. If levels of illuminance were low enough that researchers fell over potted plants, that suggests that building occupants would have trouble making their way out successfully during a building emergency. Can the authors speculate that if minimum and median luminance were used this problem would have been avoided? Could they also address the issue of photometer accuracy at such low illuminances?

B. Collins
National Institute of
Standards and Technology

Authors' response

To S. Altamura and B. Collins

We appreciate the kind and thoughtful comments

of the two discussers, especially since they have both elaborated on a key theme of our study—the use and misuse of popular estimators of central tendency. This is especially important in the case of emergency lighting distributions, which as we have seen, are governed more by the inverse square law than by central limit theory. There are a number of alternative techniques for estimating central tendency, and the discussers have touched on some of them.

The choice of technique depends upon the types of measurement collected, as discussed by Reichmann.¹⁴ For example, the geometric mean is suited mostly to measurements of rates of growth (e.g., the growth of national population statistics) in which one measurement is dependent upon the former. The harmonic mean is suited to simple ratios (e.g., speed). The mode, or modal value, is useful when most of the measurements cluster around a single value. Perhaps the most promising one for our purposes is the median, which gives us the dividing line separating the lowest from the highest sets of measurements.

The median is invaluable when the upper or lower boundaries are unknown, as was the case when illuminance values fell below the limits of sensitivity of our photometers. Equally important, it is useful when the distribution of measurements is skewed, as we observed in our study. Nevertheless, the median alone does not give the entire picture, but rather a view from a keyhole, as Reichmann puts it. Furthermore, a laborious sorting procedure is required to determine it. The arithmetic mean, as we discussed, is perhaps the least appropriate for emergency lighting because it is meaningful only when the distribution of measurements is not severely skewed. One might perhaps attempt to transform the data to a more normal distribution, then report the arithmetic mean of the transformed data. From our preliminary work, log transforms appear promising. Nevertheless, this approach depends upon distribution shape and involves additional calculation.

Taking a step back, we ask, If there is no central tendency, why try to measure it? The measure might be meaningless at best, and misleading at worst. We believe the solution to the problem is to question why we provide emergency lighting in the first place. One would agree, to some extent, that it is to provide a minimum degree of safety for evacuation and other activities deemed essential. As Dr. Collins points out, an especially bright area at one end of the route does not compensate for dark areas elsewhere, where one might perhaps encounter a potted fern or other hazard in a most unfortunate manner. No form of average (e.g., arithmetic mean, median, geometric mean, harmonic mean, or mode) could be specified to

ensure that all areas of the evacuation route are sufficiently illuminated. An estimate of dispersion is required. Variance and standard deviation are both estimators of dispersion, as is the range, a measure derived from the minimum and the maximum. For the purposes of emergency lighting, the minimum is the most important component of the range, but the maximum does have importance, especially in regards to adaptation issues, as implied by S. Altamura. If one must adopt a single-number specification system, we recommend the use of the minimum.

Compliance to a minimum illuminance ensures that all hazards, not just some of them, receive sufficient illumination to minimize the risk of mishap from insufficient lighting. As a convenient bonus to the enforcement community, the minimum is perhaps the most convenient parameter to measure and analyze. One needn't collect, record, and sort exhaustive measurements in the obviously well lighted areas. It would suffice to use one's own visual system to lead one to the dimmest areas, then simply measure the illuminance value there. Of course, the approach necessitates the use of common sense to find the dimmer areas, and common sense alone cannot be quantified. However, the immediate alternative is to abandon common sense in favor of measures that don't work. We believe the method we propose, a convenient balance between the two approaches, is appropriate and stands the greatest chance of acceptance by enforcement and other communities. It is perhaps the lack of convenient measurement procedures of this kind that hinders the enforcement community from measuring emergency illumination as extensively as S. Altamura and others might prefer. For all these reasons, the IESNA Emergency Lighting Committee has recently proposed revising the *IES Lighting Handbook* to include a recommendation for a minimum level of emergency illumination. They have also proposed that their recommended average should remain in the next edition of the Handbook, as a transitional precaution.

Dr. Collins asked us to recommend a minimum illuminance value. We agree that the value of 0.5 lx now proposed by the IESNA Emergency Lighting Committee is reasonable as discussed in Ouellette and Rea.²

S. Altamura is concerned that battery-serviced spaces should be surveyed in less than 20 min because of possible luminous decay during that period. We admit that this is always a problem with battery-serviced spaces, but it is the only practical method available. He is reminded that occupancy can be expected throughout the 20 minute period, so our measurements are not atypical of the time-and space-averaged illuminances that occupants would ex-

perience throughout their evacuation. Nevertheless, S. Altamura's comment highlights another fundamental weakness in the central tendency approach to characterizing emergency lighting—the difficulties and potential biases introduced while collecting time-consuming measurements in dynamically changing environments. The minimum is the easiest and quickest statistic to collect, and is therefore the best suited for these types of environments.

Regarding the question of light and dark adaptation in emergency evacuation, its effects are addressed in the literature.^a The subject is a complex one, and the need for additional research in this area remains.

Regarding the question of glare, it was not a serious problem in the first six buildings. There, the emergency lighting was a subset of the normal lighting. Glare was more of an issue for the seventh building, which was serviced by wall-mounted floods. Very few units in this building were aimed against the direction of evacuation, into the eyes of evacuees. In fact, some units were perhaps inappropriately aimed high up the nearest wall in hallways. This practice reduced glare, but also the magnitude of illumination on the floor. Nevertheless, the reviewer's comment is well taken and provides the opportunity to emphasize the importance of good aiming practices and the potential glare problems associated with certain forms of emergency lighting.

Regarding the use of nonlighting circuits for triggering battery-operated equipment, we are assured that the current COSH standard requires that emergency lighting need only activate during total building power failures, not necessarily during local lighting failures. It is encouraging that the issue is well addressed in the US code referred to by the discussor.

Regarding the question of photometer accuracy, it is understood that high-quality, suitably calibrated instruments are required for accurate measurement of low levels of illumination. The emphasis of the present paper is in the procedures for obtaining these kinds of measurements and in the appropriateness of the application of conventional statistical descriptors.

Before concluding, we should repeat that although both discussors credit us for having successfully documented the emergency lighting levels in Canada and presumably the rest of North America, the survey was conducted in only seven buildings of one city. Although we have every reason to believe that some of the emergency lighting practices employed in the surveyed buildings are commonly employed elsewhere in North America, one is cautioned in extrapolating beyond the scope of the present study.

In conclusion, we thank both discussors for sharing their thoughts. Quite frankly, this paper

was written to provoke insightful discussion of this kind; not only in this forum but in the sectors of building management, design, standards, codes, and regulation. Regarding the 1992 IES Annual Conference, where this paper was first presented, it would seem that we are well on our way. Elsewhere, our success remains to be determined.

Reference

- a. Boyce, P. 1986. Movement under emergency lighting: The effects of changeover from normal lighting. *Ltg Res & Tech* 18(no. 1):1-18.