Direct Visual Signaling as a Means for Occupant Notification in Large Spaces
Research Project

Technical report

Prepared by

Robert P. Schifiliti, P.E.

R.P. Schifiliti Associates, Inc.

THE FIRE PROTECTION RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION
RESEARCH FOUNDATION

ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02269
E-MAIL: Foundation@NFPA.org

FOREWORD

In April of 2005, the Fire Protection Research Foundation's Detection and Alarm Research Council identified the need for a study of direct visual signaling as a means for occupant notification in large spaces. This need was based on the promise shown by some previous limited testing that demonstrated the potential for direct signaling for notification and a request from the NFPA 72 Technical Committee on Notification Appliances for Fire Alarm Systems for additional data to substantiate the addition of text to the Annex explaining possible direct signaling effects in large spaces. The project was initiated in July of 2005.

The Research Foundation expresses gratitude to the report author, Robert Schifiliti, P.E., the Project Technical Panel: Bob Boyer, Dan Grosch, Dave Lowrey, Harry Massey, Jeff Klein, Lee Richardson, Paul Patty, Ray Grill, and Rein Haus, and the project sponsors: GE Security, Honeywell, Siemens Building Technologies, SimplexGrinnell, Wheelock Inc., National Electrical Manufacturers Association, and the Automatic Fire Alarm Association for their support.

The content, opinions and conclusions contained in this report are solely those of the author.

Direct Visual Signaling as a Means for Occupant Notification in Large Spaces Research Project

Technical Panel

J. Robert Boyer, GE Security

Raymond Grill, ArupFire

Daniel Grosch, Underwriters Laboratories Inc.

Rein Haus, Wheelock, Inc.

Jeffrey Klein, System Sensor

David Lowrey, Boulder Fire Department

Harry Massey, National Electrical Manufacturers Association

Paul Patty, Underwriters Laboratories Inc.

Lee Richardson, National Fire Protection Association

Sponsors

Automatic Fire Alarm Association

GE Security

Honeywell Fire Group

National Electrical Manufacturers Association

Siemens Building Technologies

SimplexGrinnell

Wheelock, Inc.

rpsa

FIRE PROTECTION ENGINEERS
www.rpsa-fire.com

R.P. SCHIFILITI ASSOCIATES, INC.
P.O. Box 297
Reading, MA 01867 - 0497
USA
781.944.9300 Fax / Data
781.942.7500 Telephone

Direct Visual Signaling as a Means for Occupant Notification in Large Spaces

An Engineering Study Sponsored by the Fire Protection Research Foundation

Principle Investigator:
R.P. Schifiliti Associates, Inc.,
Robert P. Schifiliti, P.E.

**Report Issued:
12 January 2006**

Table of Contents

rpsa
FIRE PROTECTION ENGINEERS
www.rpsa-fire.com

R.P. SCHIFILITI ASSOCIATES, INC.
P.O. Box 297
Reading, MA 01867 - 0497
USA
781.944.9300 Fax / Data
781.942.7500 Telephone

1. EXECUTIVE SUMMARY

The requirements for the installation and performance of visible signaling in NFPA 72, the *National Fire Alarm Code*, are based on occupants being alerted by indirect signaling effects[1]. That is, they are alerted by the illumination of their surroundings, not necessarily by direct viewing of the signaling appliance.

The testing that led to the requirements in NFPA 72 was limited to classroom and office type spaces[2]. The methodology was never tested in large, well lit spaces such as warehouses, large "super stores", etc. Nevertheless, because strobes are required by other codes in these spaces, the installation and performance requirements of NFPA 72 are being enforced despite the lack of any technical foundation. In some cases, authorities are imposing their own requirements such as not allowing ceiling mounted appliances. The Annex of NFPA 72 states that there may be more efficient methods of visible signaling in large spaces such as warehouses and distribution centers.

NFPA 72 permits a performance based design approach that actually exceeds the prescriptive requirements for visible signaling[3]. Ad hoc testing in a large home supply store showed that such an approach may be effective, but not necessarily for the same reasons that it works in smaller spaces. The tests showed that high ambient light levels resulted in little or no *indirect* signaling effect in some parts of the space. The signal-to-noise ratio produced by the operating strobes was low in many locations. However, with strobes located over the aisles or unobstructed by stock, *direct* signaling and some indirect signaling was achieved.

As a result of that test, a proposal was submitted to the NFPA 72 Technical Committee on Notification Appliances for Fire Alarm Systems to add text to the Annex explaining possible direct signaling effects in large spaces. The committee accepted the proposal but requested that additional data be gathered and added in the form of a Comment on the Report on Proposals[4]. A proposal for limited research and testing was submitted to the Fire Protection Research Foundation. The proposal was accepted and the project was funded.

Tests were conducted in three different warehouse type stores. The results show that it is possible to have effective occupant notification by strobes installed per the requirements of the performance-based section of NFPA 72. Occupant alerting is achieved by a combination of direct and indirect signaling. The tests highlighted additional factors that designers, installers and owners should consider in order to increase the effectiveness of systems in large spaces. As a direct result of this project, the NFPA 72 Technical Committee on Notification Appliances drafted a Committee Comment revising the Annex text regarding visible signaling in large spaces to incorporate ideas and concepts found in the testing.

2. INTRODUCTION

The NFPA 72 Technical Committee on Notification Appliances recognized that the effectiveness of the prescriptive and the performance based requirements for visible appliances had not been tested in large volume spaces. The Fire Protection Research Foundation was asked to consider sponsoring a project to address some of the committee's concerns[5].

A two-phased research initiative was proposed. This project represents only Phase 1. In Phase 1, testing was done in large warehouse stores to test the hypothesis that the current performance based approach provides sufficient direct alerting of occupants. The principle goal of this project was to test the effectiveness of strobe systems in large volume spaces designed and installed using the performance based approach of NFPA 72, 2002. A secondary goal was to understand if occupant alerting was the result of direct or indirect signaling. The main objective was to draft text for inclusion in the Annex of the 2007 edition of NFPA 72 that would provide designers, installers and authorities some guidance on how to configure systems to provide effective alerting in these challenging spaces.

Phase 2, if approved and funded, will be a separate project. Phase 2 will extend testing to other large spaces such as malls and atria. The principle goal of Phase 2 is to test the performance based methods in more challenging visual environments. A second goal is to gather sufficient data to permit drafting of code text permitting or limiting the performance based approach as an acceptable method of occupant notification in large volume spaces. This may potentially move Annex text on suggested design and installation issues into the body of the code. Phase 2 may also consider other visible signaling methods or performance criteria.

This project (Phase 1) was intentionally designed for quick, but meaningful results. The project began in mid July 2005 and needed to be substantially complete by the end of October to provide feedback to the code committee. The project did not seek to define all variables and their required parameters for success. Instead, the systems were studied as a whole to determine if they were effective. Engineering analysis of the tests resulted in the identification of several variables that affect the success of the systems in alerting occupants. This allowed some information on design and installation practices to be proposed for inclusion in NFPA 72.

The Fire Protection Research Foundation formed a Project Technical Panel to monitor project progress, review and comment on any interim or draft reports and to release the final project report. The Project Technical Panel consisted of:

Robert Boyer	GE Security
Ray Grill	Arup Fire (Chair of the NFPA 72 NAS TC)
Dan Grosch	Underwriters Laboratories, Inc.
Rein Haus	Wheelock, Inc.
Jeffrey Klein	System Sensor, Inc.
David Lowry	Boulder Fire Department
Issac Papier	Honeywell Life Safety
Jack Poole	Poole Consulting Services, Inc.
Lee Richardson	National Fire Protection Association, NFPA 72 Liaison

3. PROJECT PARTNERS

The Fire Protection Research Foundation is the principle sponsor for this project. They have provided a grant to R.P. Schifiliti Associates, Inc. to conduct tests, draft code language and write a report.

One of the principle goals for this project was a quick turn-around and a second was low cost. To achieve these goals the help of other organizations was solicited. Project Partners were solicited to provide facilities for testing, technicians to assist in the tests and other services necessary to move the project forward. Several Project Partners have provided in-kind donations of time, facilities and services. In addition to the corporate support, several individuals within these companies have been instrumental in setting up and conducting the strobe tests.

TVA Fire & Life Safety, Inc. offers comprehensive fire protection, life safety, security, engineering, risk management, and loss control services to Fortune 500 companies including Home Depot and Wal*Mart stores. They donated time and assisted in setting up tests at Home Depot locations. In addition, they provided engineering information about the installed systems and coordinated technicians from FMG for conducting the tests at the Home Depot test sites.

The Home Depot is the world's largest home improvement retailer and second largest retailer in the United States. They donated the use of their stores as test sites.

Fire Materials Group (FMG) provides professionally managed fire and life safety services. They provide fire alarm inspection, testing and maintenance services for the Home Depot. FMG donated the services of their technicians for conducting tests at Home Depot locations.

Wal-Mart Stores, Inc. is the world's largest retailer. They have donated time and permitted testing in their stores. Wal-Mart Security Services donated time and assisted in setting up testing at the Kissimmee, FL test location. They have also provided Wal-Mart fire alarm technicians for conducting tests.

American Sign Language Interpreting Services (ASL Services) is a nationwide company dedicated to providing the highest quality of professional and ethical Sign Language services at reasonable prices to the community in accordance with the communication preferences of the Deaf and Hard of Hearing persons they serve. ASL provided the services of an interpreter during the testing in Kissimmee, Fl.

4. TEST PLAN

The test plan began with the development of a detailed *Test Protocol*. A copy of the protocol is reproduced in Section 14 to this report. The protocol was used as a checklist for each test. In summary, participants were solicited and asked to walk around the store. The fire alarm system was then activated. Pre and post test surveys were used to gather data.

For each site, information was gathered concerning the design and installation of the strobe alerting system. Ceiling heights were either obtained from plans or measured. The mounting height of strobes, relative to the floor, the ceiling and lighting fixtures was measured. Stock heights, aisle widths and rack widths were measured in several locations. Ambient light measurements were taken throughout the stores.

At each test location a reception/gathering point for participants was established outside, in front of the main entrance to the store. Refreshments were provided for the participants. Because the project used human test subjects, an Informed Consent Form was required. Section 15 contains a copy of the *Participant Information Sheet & Consent Form*. As each person arrived, they were given a numbered nametag. Their participant number was used on all forms as the means of tracking the participant. Each person was asked to read, initial and sign a consent form. The form was checked for completeness and the person was asked if the had any questions, which were then answered.

A tool was developed to gather pertinent information about the test participants. A blank copy of the *Participant Survey – Pre-Test* is included as Section 16. After completing the Consent Form, they were given the Pre-Test Survey to complete. Each survey form was checked to determine if there were any conditions that might be cause for a person to not participate. (None were noted for any of the tests.)

Test participants were each given a small note card with instructions and reminders about what they were to do during the tests. A copy of the card is reproduced in Section 17. The group was given verbal instructions and asked to enter the store and go "shopping".

The store's paging systems were used to make verbal announcements that a test was in progress. After participants had been in the store for 10 to 20 minutes, the fire alarm system was activated. The group returned to the gathering point where they were given a Post-Test survey (*Participant Survey – Post-Test*, Section 18). Each Post-Test Survey was checked for completeness and, if necessary, questions were asked and the form marked for clarity or completeness.

After all forms had been gathered a group discussion was initiated to gather addition feedback and information. The group discussions were valuable in getting qualitative information about the pros and cons for each test scenario. This was particularly valuable for participants that took part in more than one test.

5. TEST LOCATIONS

The first two test sites were Home Depot stores located in Reading, MA and Danvers, MA. Invitations to participate were sent to members of the NFPA Technical Committee, NFPA staff, members and affiliates of the New England Chapter of the Society of Fire Protection Engineers and several deaf and hard-of-hearing organizations, including Self Help for the Hard of Hearing (SHHH).

A third test was planned for a Home Depot in Plaistow, NH and a fourth was planned for a Wal*Mart in Plymouth, MA. Both tests were cancelled after receiving only a few responses from persons invited to participate. A test was then scheduled to coincide with the NFPA 72 Report on Comments meeting taking place in Orlando, Fl.

Because the tests were taking place in businesses that were already occupied and open for business, the owners required testing to be done during early morning hours (6:30 – 7:30 AM) when there were few public customers in the stores. While this limited the ability to include "walk-in" participants, it did minimize the "Cry Wolf Syndrome" impact of the testing[6]. The early test time also affected the ability to get participants. In some cases it helped to get persons to come before or on their way to work. However, the time probably caused some people to decline participation.

Lighting in each of the locations was provided by fluorescent lamps. The Wal*Mart store also had skylights. The Illuminating Engineering Society of North America (IESNA) defines these spaces as "High Activity Spaces" with minimal sales assistance and products that are easily recognizable[7]. The recommended lighting level varies with the specific use of the space. IESNA recommends the following levels:

Area	Level	
	lux	ft-candles
Circulation	323	30
Merchandise	1,076	100
Feature displays	5,382	500

Lighting levels for all three locations were within the range for general circulation and merchandise areas. The highest levels were found in the carpet and lighting displays of the two Home Depot stores. Ranges were on the order of 431 – 1937 lux (40 – 180 ft-candles).

5.1. Home Depot, Reading, MA

The test at this location took place on August 24, 2005. There were 13 participants. The fire alarm system at this location was designed and installed to permit the audible signal to be disabled separate from the visible signals. This allowed the strobe lights to be activated without any audible signal.

Table 1 is a summary of relevant building and environmental information. Table 2 summarizes information about the strobe light system.

Nominal ceiling height:	27 ft
Nominal height to top of storage:	16 ft
Range of ambient light level:	538 – 1,937 lux 50 – 180 ft-candles
Ceiling configuration:	Metal deck (white/gray) on I beams. All utilities exposed.

Table 1 - Building Information

Strobe location:	Mounted below the ceiling, 23 ft above the floor at the same level as the fluorescent light fixtures.
Strobe spacing:	Varies. Nominal 45 - 48 ft spacing in open areas and in aisles.
Strobe intensity:	75 cd. eff. per drawings (one unit found to be only 15 cd eff.)

Table 2 - System Information

The strobes at this location are located below the ceiling, at about the same level of the hanging fluorescent lights. The original design called for the strobes to be located over the aisles, between racks. Within each aisle, the strobes are spaced approximately 45 to 48 ft. Rack spacing varies with most 16 ft on center and some as much as 30 ft on center. Thus, strobe coverage might be 45 ft x 16 ft in order to provide a line of strobes in each rack aisle. However, after the system was installed, the rack layout was altered resulting in many lines of strobes not falling directly over an aisle.

The strobes at this location are the multi-candela type that is field adjustable. After the test it was found that at least one strobe was never changed from the nominal 15 cd eff. out-of-the-box setting.

Photo 1 shows a picture of a typical rack aisle with a strobe located directly overhead. A close-up of the strobe in Photo 2 shows the ceiling configuration and the location of the strobe relative to the building lights and structural steel.

Photo 1 - Strobe Over Aisle (Reading, MA)

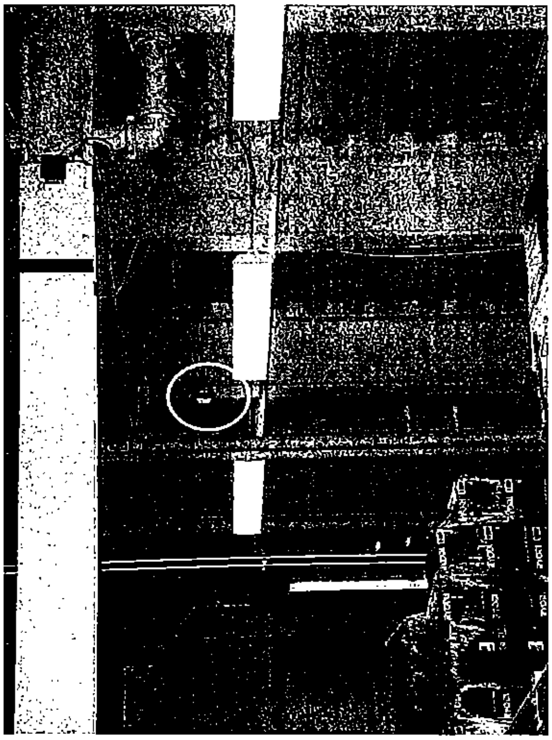

Photo 2 - Close-up of Strobe (Reading, MA)

5.2. Home Depot, Danvers, MA

The test at this location took place on August 25, 2005. There were 12 participants, eight of whom also participated in the Reading test. The fire alarm system at this location did not permit the audible signal to be disabled separate from the visible signals.

Table 3 is a summary of relevant building and environmental information. Table 4 summarizes information about the strobe light system.

Nominal ceiling height:	21.5 ft
Nominal height to top of storage:	16 ft
Range of ambient light level:	431 – 1,722 lux 40 – 160 ft-candles
Ceiling configuration:	Suspended acoustical tiles (white) with recessed fluorescent light fixtures. Most utilities hidden above the suspended ceiling.

Table 3 - Building Information

Strobe location:	Mounted on the ceiling, 21.5 ft above the floor.
Strobe spacing:	48 ft spacing in open areas and in aisles.
Strobe intensity:	115 cd. eff.

Table 4 - System Information

The strobes at this location are located on a suspended acoustical tile ceiling at the same level of the building's fluorescent lights. The design and installation resulted in most strobes being located over the aisles, between racks. Within each aisle, the strobes are spaced approximately 48 ft. Rack spacing varies with most 16 ft on center and some as much as 30 ft on center. Thus, strobe coverage might be as low as 48 ft x 16 ft in order to provide a line of strobes in each rack aisle.

Photo 3 shows lines of strobes on the ceiling. Photo 4 shows an aisle with strobes directly overhead. Photo 5 is a close-up of a strobe on the suspended ceiling.

Photo 3 - Lines of Strobes

Photo 4 - Strobes Over Aisle

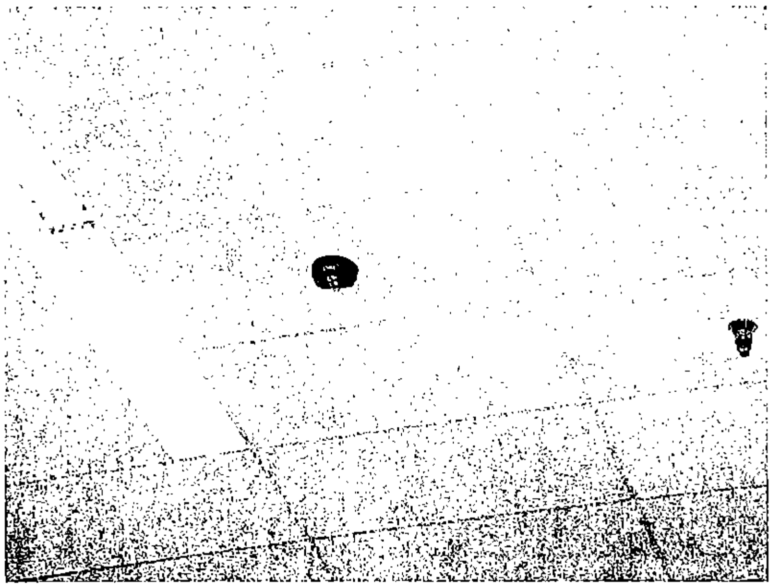

Photo 5 - Close-up of Strobe (Danvers, MA)

5.3. Wal*Mart, Kissimmee, FL

The test at this location took place on October 28, 2005. There were 22 participants. Two participants had also taken part in both the Reading and Danvers tests. This test coincided with the Report on Proposals meetings of the NFPA 72 Technical Committees. The participants were all Technical Committee members and included almost all members of the Notification Appliances Committee.

The fire alarm system at this location was designed and installed to permit the audible signal to be disabled separate from the visible signals. However, the manner in which this is effected results in a single audible chirp when the system was activated. After that first chirp, the audible signals stop and the strobes continued to operate.

Table 5 is a summary of relevant building and environmental information. Table 6 summarizes information about the strobe light system.

Nominal ceiling height:	16 – 21 ft
Nominal height to top of storage:	9 ft
Range of ambient light level:	510 – 1,265 lux (47 – 114 ft-candles)
Ceiling configuration:	Metal deck (white) on bar joist on trusses. All utilities exposed.

Table 5 - Building Information

Strobe location:	Mounted below the ceiling on the bottom chord of the bar joists, approximately 15 – 20 ft above the floor.
Strobe spacing:	45 ft x 45 ft
Strobe intensity:	115 cd. eff.

Table 6 - System Information

The strobes at this location are located on the bottom of the bar joists supporting the ceiling/roof. The florescent light fixtures are approximately 8 - 12 in. below the bar joists. The design and installation resulted in strobes being located over most of the main aisle and circulation areas. However, not every merchandise aisle has a row of strobes overhead. Typically, the strobes are over the main aisles and over every third to fifth stock aisle.

Photo 6 shows the ceiling configuration with strobe lights located on the bottoms of the bar joists.

Photo 6 - Strobes Located on Bottoms of Bar Joists (Kissimmee, FL)

6. TEST PARTICIPANTS

There were 13 participants in the Reading test, 12 at Danvers and 22 at Kissimmee. Most participants were from the fire protection and fire service communities. Despite several contacts with deaf and hard-of-hearing organizations, only one (Danvers) participant was drawn from those communities. For the Kissimmee test, three different local deaf and hard-of-hearing organizations contacted their members and gave them information and an invitation to the test. The state of Florida sent the project information and invitation by email to over 8,000 persons – twice.

In Reading, three participants identified themselves as having hearing impairments. Two indicated their impairment was mild and one said it was severe. Two of these participants (one severe and one mild) wore corrective devices.

In Danvers, two participants identified themselves as having hearing impairments. One indicated their impairment was mild and one said it was severe (participant from a hard-of-hearing organization). One of these participants (severe) wore corrective devices.

In speaking with participants and with persons from the deaf and hard-of-hearing communities, it appears the early morning test times had the greatest negative impact on drawing participants. Other factors such as transportation and motivation may also have impacted participation.

7. TEST RESULTS AND ANALYSIS

This section of the report presents the results of the Post-Test Survey with some discussion of the results for each question. In section 8, Discussion, many factors are discussed relatively along with possible causes and consequences.

7.1. How were you first alerted?

As noted in the test descriptions, the test in Reading was the only one where the audible signals could be completely silenced. The system at the Wal*Mart in Kissimmee allowed the horns to be disabled separately from the strobes, but only after a single "chirp" of the audible signal. Figure 1 shows that where audible signals operate along with visible appliances, the audible signals are generally the first means of occupant notification. This is as expected due to the ability for audible signals to penetrate and fill a space. Because visible signaling relies upon a system of distributed point type "line-of-sight" appliances, the coverage volume will almost always be significantly less than audible signaling.

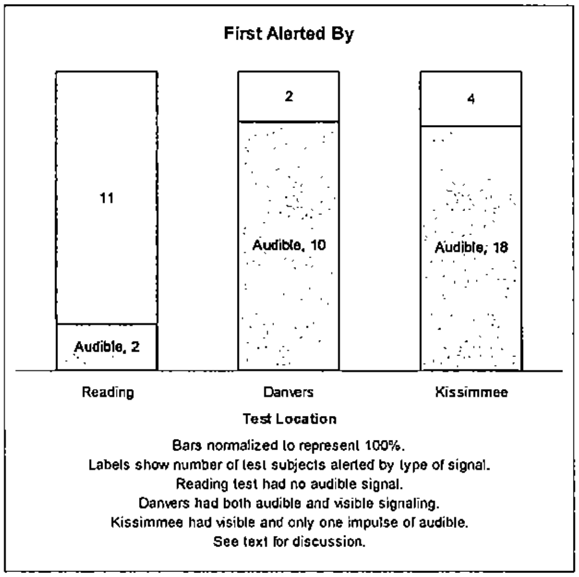

Figure 1 - First Alerted By

Interestingly, even though audible signals did not operate in the Reading Home Depot test, two participants indicated that they were first alerted by audible, not visible signals. Both indicated in their Post-Test Survey that the sound was very faint. It is possible they were alerted by the control panel audible indicator. However, the panel was located in a separate room within an enclosed vestibule and both participants were quite a distance from that room.

7.2. Indirect Strobe Effects

Participants were asked if they could see the flash of the strobes reflecting off of the floor, stock or other surface without actually seeing a strobe light directly. The results summarized in

Figure 2 show that the Danvers system was the most effective system and the Reading system was the least effective system for indirect signaling.

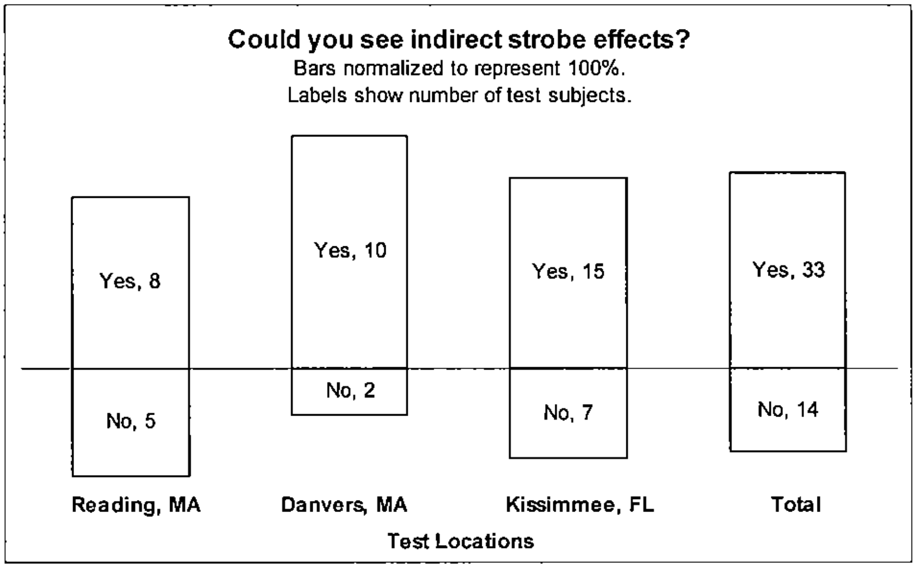

Figure 2 - Indirect Signaling Effectiveness

The variables and methods for calculating strobe illumination are presented in detail in Section 13. The discussion in the Annex notes that designers differ on whether calculations are done for a simple square or for an overlapping pattern of circular coverage areas. In addition, for each assumed area, calculations can be done for the basic distance from the strobe or corrected for the angle at which the light ray strikes a surface. Calculations for all four possibilities are included for each of the test sites for nominal heights and spacings.

Although there are many other factors involved in the actual effects of the systems (versus a strobe in an imaginary square) the calculations show the Reading system provides the lowest levels of illumination. Based on the industry standard for performance based calculations, the systems for Danvers and Kissimmee were over-designed while the Reading system most closely met the minimum requirements of the code.

In addition to strobe intensity and the resulting level of illumination, the clearance between the top of the stock/storage and the strobe lights affected indirect signaling in both the Reading and Kissimmee stores. In these stores, there were many aisles where strobes were not located directly overhead. This light had to come over the racks/shelves from adjacent lines of strobes. See Section 13.1 for more detailed discussion. In Danvers, in addition to a higher calculated level of illumination, strobes were located directly over almost all aisles. This resulted in greater indirect coverage on the surface of stock. Similarly, the greater clearance from the top of the stock to the strobes in Kissimmee versus Reading permitted greater penetration into aisles that did not have strobes directly over them. Figure 3 shows a typical warehouse store with strobe coverage providing both direct and indirect signaling to the occupants. Figure 4 is the same diagram highlighted to show the surfaces where one of the strobes provides indirect signaling by illuminating the surface of the floor and the stock on the racks or shelves. The highlighted surfaces in Figure 4 show that as the clearance between the top of the storage and the strobe is decreased, or as strobe spacing is increased, light penetration to adjacent aisles is decreased.

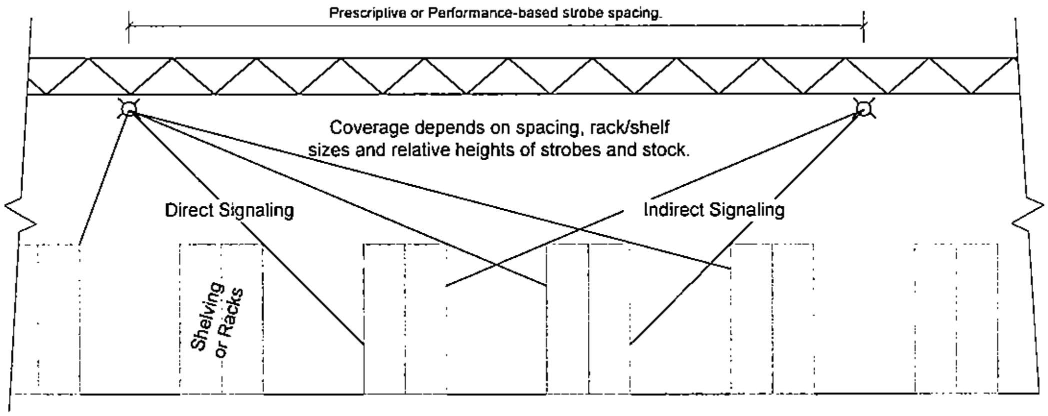

Figure 3 - Direct and Indirect Strobe Coverage in Racks

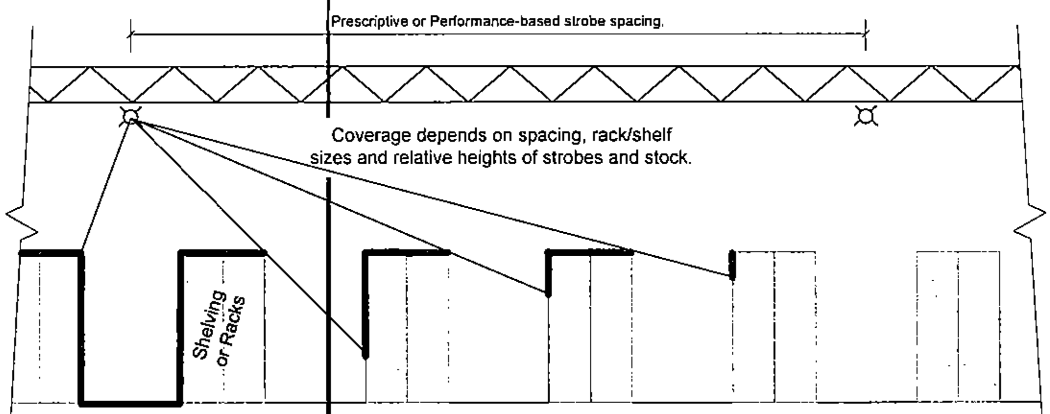

Figure 4 - Actual Strobe Penetration in Racks

7.3. Direct Signaling Effects

These types of stores have large volumes and long viewing paths. In many places, the aisles, racks and shelves focus the occupants' vision in a way similar to corridors in schools and offices. In those spaces, the National Fire Alarm code permits the use of lower intensity strobes at greater distances since occupants are likely to directly view at least one appliance as they transit the corridor. Presently, most authorities require strobe system design in warehouses and superstores to be based on NFPA 72 room coverage requirements. They do not permit the use of corridor rules.

Participants were asked if they were able to actually see (directly view) one or more strobe lights flashing without intentionally looking up at the ceiling. The results, summarized in Figure 5, show that the Kissimmee system was the most effective at direct signaling to occupants.

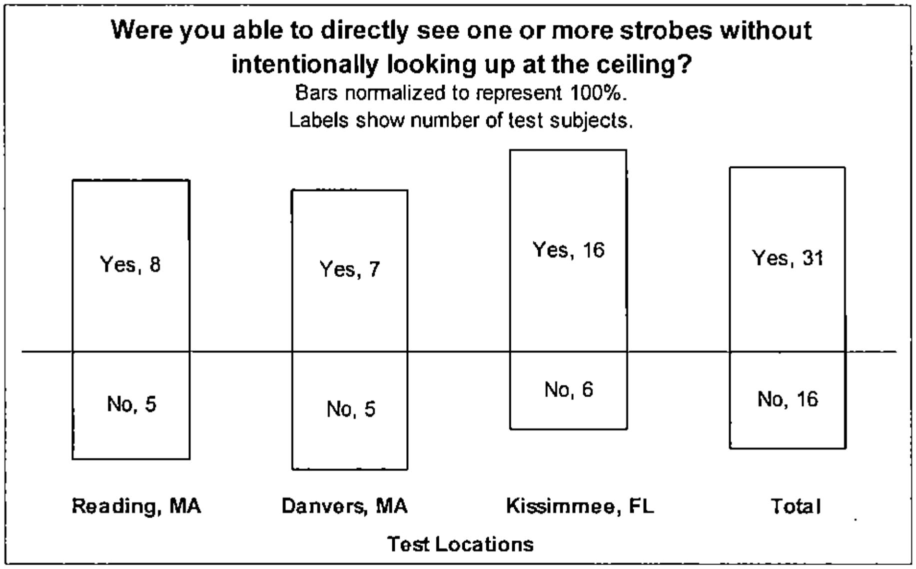

Figure 5 - Direct Signaling Effectiveness

The better outcome in the Kissimmee Wal*Mart is probably the result of a greater clearance between the top of stock/storage and the strobe lights than either of the two Home depot stores. As a result, occupants could see more of the ceiling and, hence, more strobes from most vantage points. This is discussed in more detail in Section 8. Also, there may still have been locations where strobes or their effects were not viewable – see Blind Spots.

7.4. Number of Strobes Visible

Participants were asked if as they could see more than one strobe light flashing as they moved about, and if so, how many. Figure 6 through Figure 8 show the number of strobes viewed by participants for each test location. Figure 9 sums the data for all three locations.

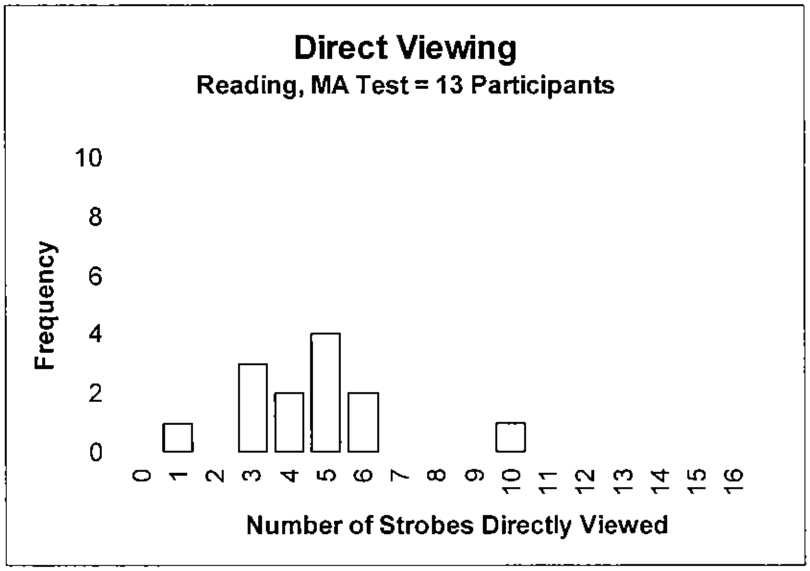

Figure 6 - Number of Strobes Directly Viewed – Reading

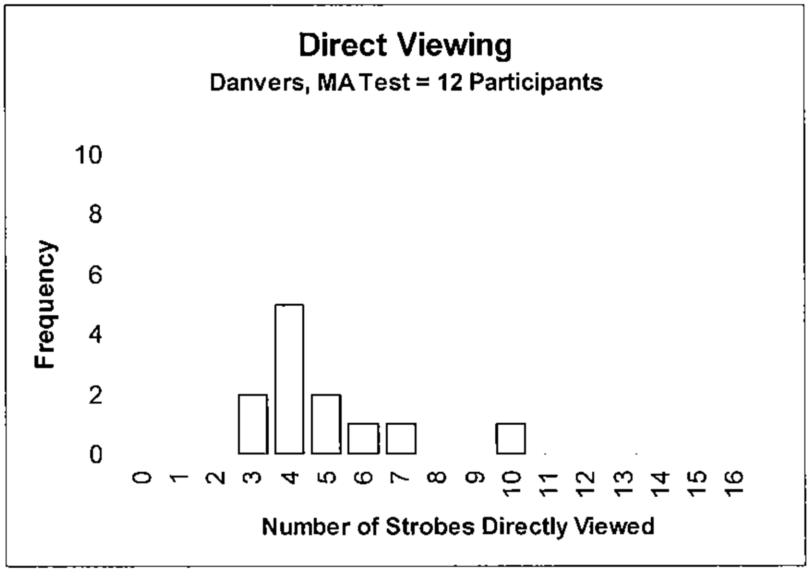

Figure 7 - Number of Strobes Directly Viewed – Danvers

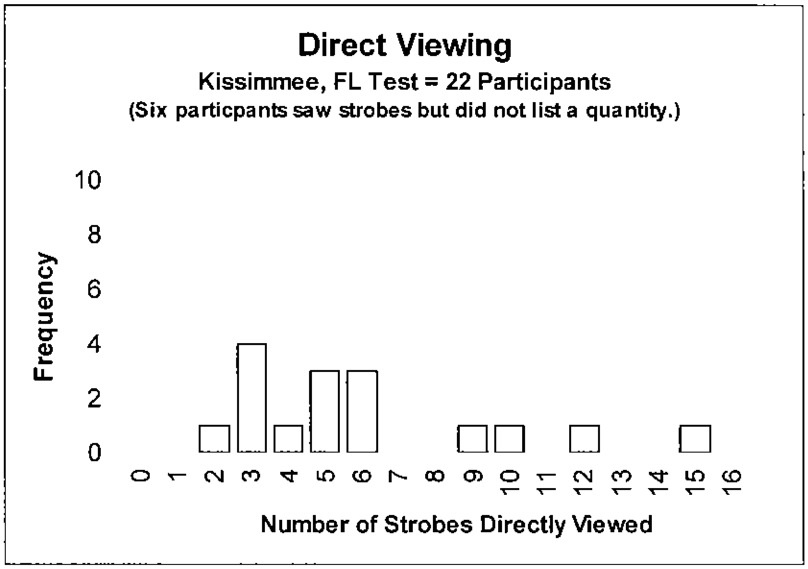

Figure 8 - Number of Strobes Directly Viewed – Kissimmee

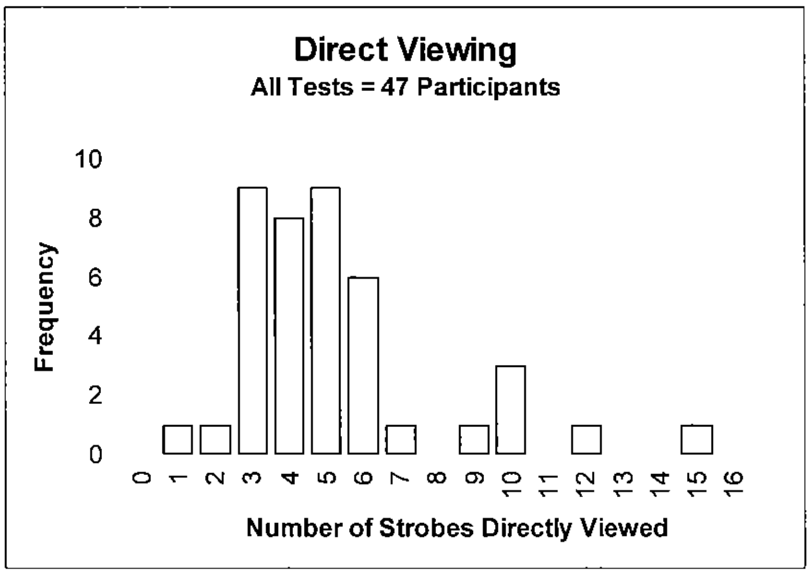

Figure 9 - Number of Strobes Directly Viewed – All Stores Combined

The data show that for these test conditions, all participants could see at least one strobe as they walked through aisles. The majority of responses indicate that three to six strobes were generally visible as the participants moved about the space.

7.5. Blind Spots

Despite there generally being three to six strobes directly visible as participants walked around the stores, there still were locations where they did not directly see a strobe or its indirect reflection. Participants were asked if there were there any locations where they could not see a strobe light or its reflection. The results are summarized for all locations in Figure 10.

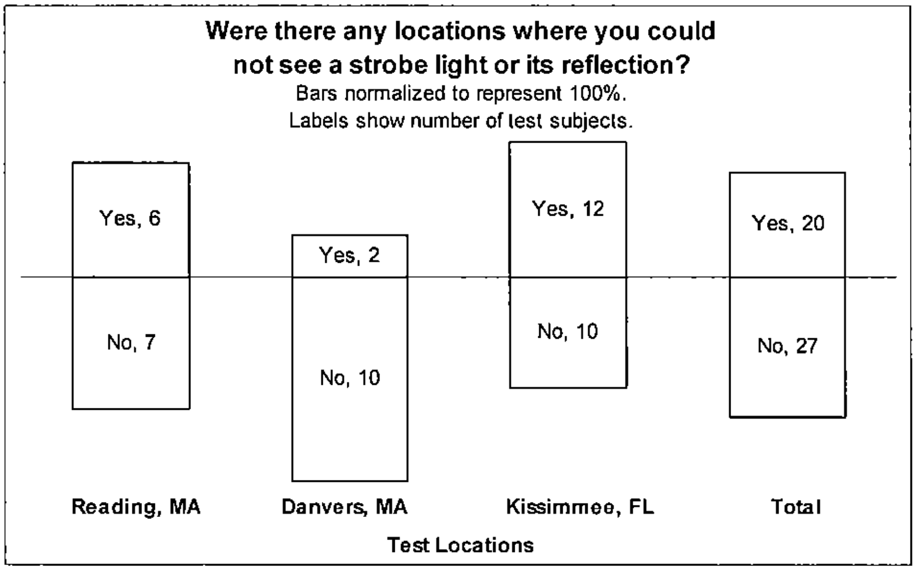

Figure 10 - Blind Spots

At the Kissimmee location, the greater clearance between stock and strobe lights increased the likelihood of direct signaling. Nevertheless, this location also had the greatest number of reported blind spots where a strobe or its effect was not visible. By most accepted standards, the system was over-designed with respect to strobe intensity for a given height and spacing. However, even with a larger strobe clearance, the aisle spacing versus the strobe spacing resulted in a single row of strobes for three to five aisles. Participants found that the strobes did not penetrate when they were more than two or three aisles away. This is discussed in more detail in Section 8.

In Reading, the ceiling was an open plan type with all structural members and utilities exposed. The strobes were located below almost all obstructions except air handling ductwork. There were several locations noted where ductwork blocked the strobes.

7.6. System Rating

For each location, participants were asked to rate the effectiveness of the fire alarm strobe light system. The results for the three test locations are shown in Figure 11 through Figure 13 and combined for all locations in Figure 14.

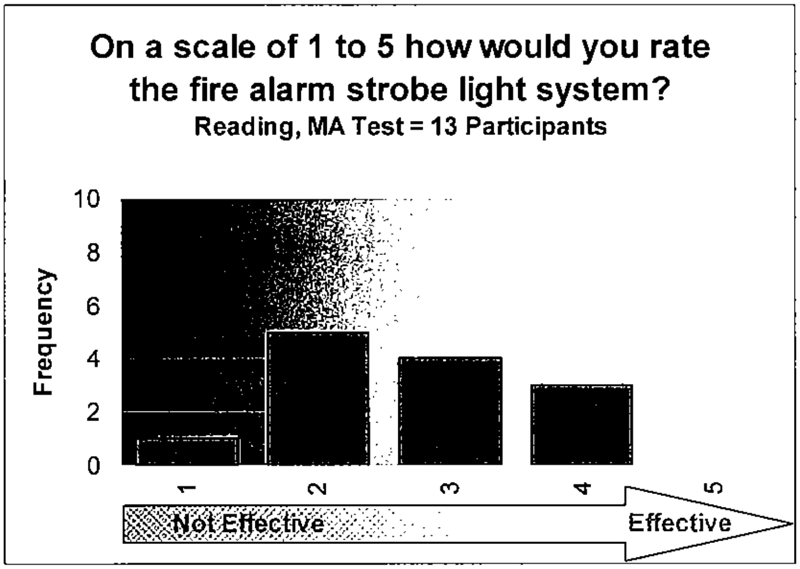

Figure 11 - Strobe Effectiveness - Reading

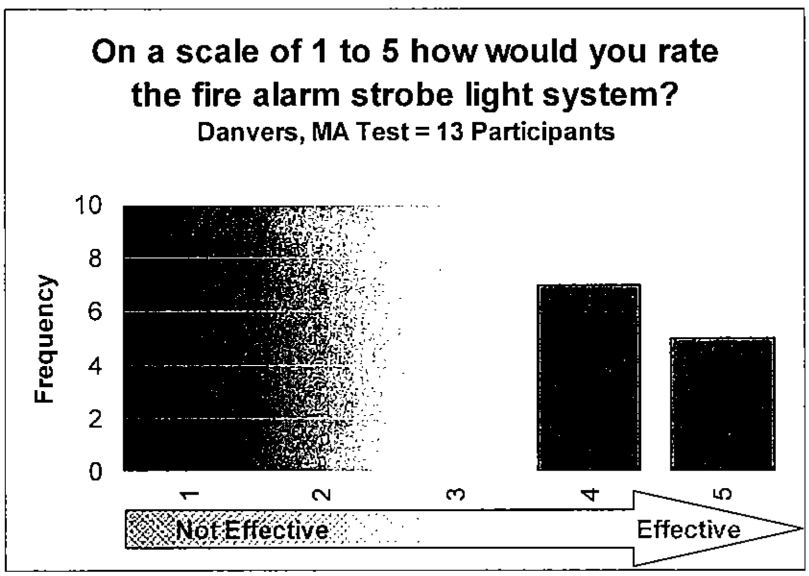

Figure 12 - Strobe Effectiveness - Danvers

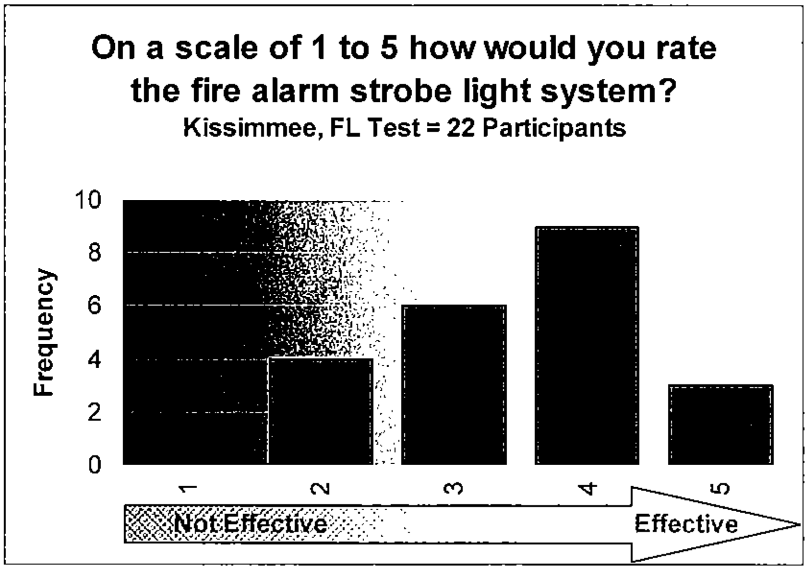

Figure 13 - Strobe Effectiveness - Kissimmee

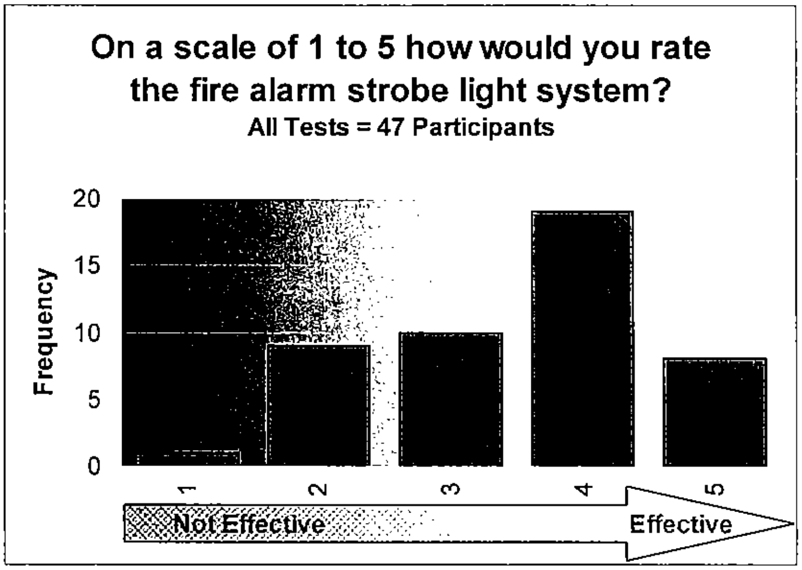

Figure 14 - Strobe Effectiveness - All Locations

In general, the systems were effective. However, clearly there were differences that made the Danvers system stand out as the most effective and the Reading system as the least effective system. The Danvers system used higher intensity strobes, on a reduced spacing and located over almost all aisles between racks. In Reading, the strobes locations were designed to be over aisles. Before completion, the rack layout changed resulting in most aisles not having a row of strobes directly overhead. In Kissimmee, most respondents felt the system was effective. Based on strobe intensity, ceiling height and strobe spacing, the system was over-designed. Nevertheless, when superimposed on aisle/stock layout, there were aisles where coverage was minimal or non-existent. This is discussed in more detail in Section 8.

For the Reading test, the three hearing impaired persons gave ratings of 1, 2 and 3 out of 5. In Danvers, both hearing impaired persons rated the system 4 out of 5. In Kissimmee the hearing impaired all rated the system at 3 or higher (3, 3, 4, 5 and 5). Thus, the hearing impaired persons rated the system effectiveness approximately the same as other participants.

7.7. Universal Effectiveness of Strobe Light Systems

Participants were asked if, in their opinion, strobe lights are an effective method for alerting deaf or hearing impaired persons. See Figure 15.

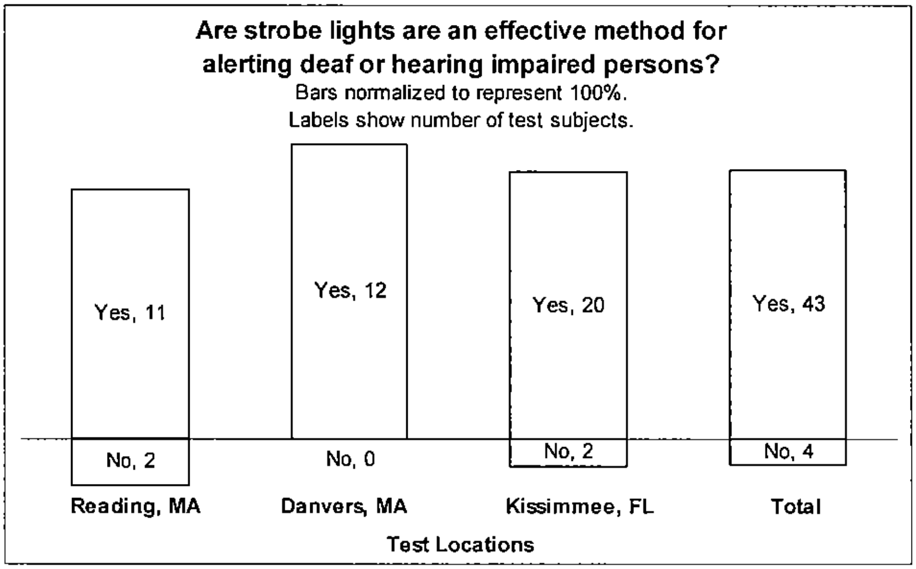

Figure 15 - Universal Effectiveness of Strobe Systems

There was general agreement among participants that strobe lights were an effective means for alerting the deaf and hearing impaired. The survey results show that the experience of the participants on that day, with a particular system, affected their opinions. Their opinions on universal effectiveness correlated with their opinions of the particular systems they just experienced. Nevertheless, they gave higher effectiveness-ratings when generalizing. Even though they may have seen faults with the system they just witnessed, they still felt that strobes were an effective method for alerting.

Although the sample size is too small to draw conclusions, it is interesting to note that in the Reading test, the two persons that felt that strobe light systems were not effective were both hearing impaired (one severe, one mild). The third person with a hearing impairment thought that the systems, in general, were effective.

In Danvers, the two hearing impaired persons thought that strobes were an effective alerting system. In Kissimmee, four of the five hearing impaired persons thought that strobes were an effective alerting system. The fifth hearing impaired person qualified their response by writing “in this case”, rather than making a general evaluation. When asked, they were non-committal with respect to general strobe effectiveness.

8. DISCUSSION

To better understand the possible causes of the results of this project it is helpful to understand the existing performance based requirements of NFPA 72 and the light distribution requirements of UL 1972. The requirements, different variables and four possible ways of doing the calculations are discussed in detail in Section 13.1.

The Danvers system was generally rated higher because strobes were located over almost all aisles. The Kissimmee system showed that good performance does not require strobes over every aisle. Similarly, the Reading test showed that where aisles are moved, resulting in not having strobes directly overhead, adequate performance is still possible.

When all three tests are reviewed and compared, several significant points emerge:

1. Strobe lights are effective for both direct and direct viewing even if not located directly over an aisle, provided there is sufficient penetration to the aisle.
2. A design with strobe lights over every aisle is more effective than one where strobes serve several aisles.
3. Aisles focused the occupant's vision and improved direct signaling effects.

In Reading one strobe was found to be rated at 15 cd eff., not the intended 75 cd eff. It was not possible to inspect all the strobes as part of this test/survey. It is possible that more, or even all, of the strobes were installed at a setting of 15 cd. eff. This, combined with the outstanding results for the Danvers test, warrant investigation into the use of corridor rules for strobe selection and layout in aisles. Where strobes are located directly over aisles, it may be possible that the aisle width could be used to determine the required intensity. This might reduce the required intensity of most strobes. The coverage area would then be a long rectangle rather than a square. The distance to the far corner of the rectangle could be used as the worst case distance. Using the aisle width to determine the required intensity would mean that the resulting illumination on the floor at the far ends of the rectangle would be less than the 0.0375 lm/ft^2 currently required. Nevertheless, in that direction, it appears that corridor effects result in occupant notification by direct viewing of the strobes. Figure 16 shows this effect.

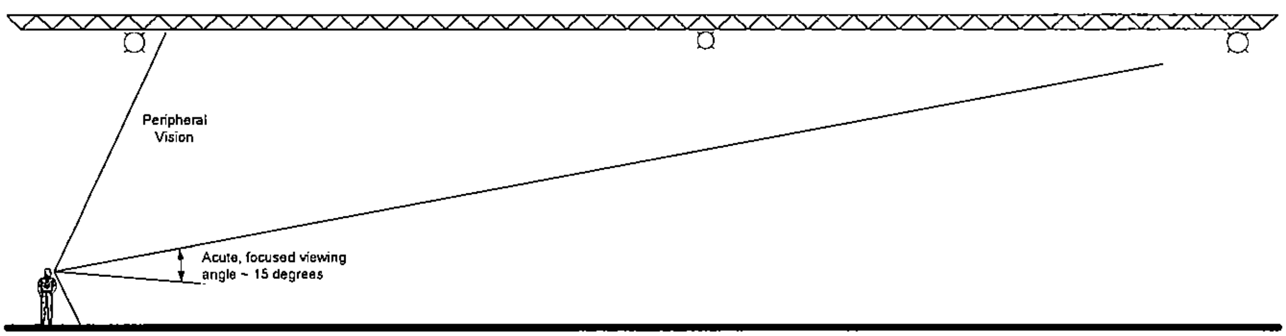

Figure 16 - Direct Viewing of Strobes

However, it must be recognized that some stores regularly change rack/shelf locations and spacings. Any reduction in strobe intensity or spacing for corridor effects would be negated if a new rack layout resulted in strobes not directly over each aisle. For those situations, the data suggest that a design based on the current requirements for performance based designs in NFPA 72 will be adequate. However, the calculated strobe spacing must be compared to the aisle spacing, rack height, rack width, stock height and strobe height to determine if there is adequate penetration into all aisles. This project did not attempt to determine what "adequate penetration" means. For example, many people shopping in an aisle may see the indirect illumination if it "paints" the stock from six to seven feet and up. This places the light in the direct or peripheral vision of most people. It may be that an even higher penetration line is acceptable, or that a lower one is required.

In the testing that led to the requirements in NFPA 72 ambient light measurements were taken in classrooms, a test room and in a typical hotel/motel room[2]. However, actual testing with human subjects was limited to the classroom environment and a fabricated test room. Lighting levels in the classroom tests varied from about 129 – 807 lux (12 – 75 foot-candles). Lighting levels in the test room varied from 29.6 – 105 lux (2.75 to 9.75 foot-candles). Thus, ambient lighting for the tests used to generate the requirements in NFPA 72 were considerably less than those in the large stores used in this project. This resulted in lower signal-to-noise ratios and reduced visibility of the strobe's effects. Nevertheless, except where strobes did not penetrate into aisles, the strobes were found to be effective on average. However, participants felt that the more brightly lit areas were marginal. This project did not attempt to determine a threshold signal-to-noise ration that would reliably alert occupants.

Since the test could not be "blind" or "double blind", the inclusion of participants that were active in the fire prevention and protection industry could have affected the data. After initial alerting, they tended to provide a more critical "inspection" of the operating systems. This more critical review was noted in the general discussions after the tests. However, the limited number of participants makes it impossible to tell if the participant's involvement in the fire industry affected their answers on the post-test with any degree of statistical significance.

The post test survey indicated that test locations had "blind" spots where a strobe or its effects were not visible. Obviously, designs should endeavor to eliminate or reduce blind spots. These blind spots occurred more frequently in the Kissimmee test where some aisles were three to five aisles away from a row of strobes. The angle and stock height combined to block direct and indirect strobe viewing in those remote aisles. Blind spots were also common in the Reading test where strobes were sometimes blocked by other utilities at the ceiling. The open ceiling plan in the Reading store differed from the uncluttered suspended ceiling in Danvers and open, but less cluttered ceiling in Kissimmee. Installing technicians need to understand the spacing rules and field modify the installation to prevent appliances from being blocked.

Similarly, it was noted that in central areas there is an opportunity for an occupant to see direct or indirect strobe coverage in all directions – 360 degrees. Closer to the outside walls of the