Developing a New Temporary Lighting System: From Identification of the Problem to the Design of the Solution

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Recent studies have shown that many buildings under construction are not adequately illuminated to meet the minimum OSHA standard for general construction illumination. The purpose of temporary lighting is to give workers a safe and productive environment in which to work. Contractors and owners use various techniques to provide temporary lighting for buildings under construction, but are not always successful in meeting minimum requirements. The reasons for the inadequate lighting can be viewed as a consequence of the construction process. Buildings under construction are an ever changing environment, which require an ever changing lighting solution. Previous studies have shown that adequate lighting can be provided through planning and proper placement of fixtures to avoid constant movement of fixtures. One problem is that the presently available light strings were not flexible enough to adapt to different requirements. The following goes through the process of analysis of the problem, the first design for a solution, the development of the design, the validation of the solution, and the first step to bringing a product to market.

Key Words: Temporary lighting, construction, safety, light strings

Introduction

Adequate lighting on construction sites is necessary for the safety of the workers, productivity of the workers, and the quality of the completed work. Natural light may need to be supplemented by temporary lighting due to the size or design of the building, working hours, time of year, and weather conditions. The method or requirement for temporary lighting is often ill defined in the construction documents and inadequate in performance (Smith, April 2006). The result is that many jobsites have poor illumination. Although there are many aspects to lighting, such as quantity, contrast, brightness, glare, and reflection (Lechner, 2001), only quantity of light is measurable and used by OSHA in defining the minimum requirement of illumination.

Buildings under construction challenge contractors to provide adequate lighting because of the changing environment. After the building frame is in place, lighting can be installed that meets OSHA guidelines. As components of the building are installed, including ductwork, piping, and wall framing, lights are covered up or blocked from the work area. Through preplanning the temporary lighting, the lights can be placed to avoid being blocked. Placing lights at irregular intervals to avoid being blocked and being located to provide adequate lighting does not lend itself to standard lighting strings that space lights at ten foot intervals. There can be many solutions to the problem and the following show the development of one solution.

Background

OSHA Standard 29 CFR 1929.56 is entitled “Illumination”, and 29 CFR 1926.56(a) General, states, “Construction areas, runways, corridors, offices, shops, and storage areas shall be lighted to not less than the minimum illumination listed in Table 1 while any work is in progress” (OSHA, 2006). General construction areas require a minimum of 5 foot-candles of illumination. The OSHA standard uses foot-candles as the measure of illumination, so foot-candles were used throughout this paper. Another current measurement is the metric “lux”, where 1 foot-candle = 10.764 lux.

Table 1 - OSHA standard for minimum illumination intensities in foot-candles (fc)

Foot-Candles	Area of Operation
5	General construction area lighting
3	General construction area, concrete placement, excavation and waste areas, access ways, active storage areas, loading platforms, refueling, and field maintenance.
5	Indoor warehouses, corridors, hallways, and exit ways
5	Tunnels, shafts, and general underground work areas. (Exception: minimum of 10 foot-candles is required at tunnel and shaft headings during drilling, mucking, and scaling. Bureau of Mines approved cap lights shall be acceptable for use in the tunnel heading.)
10	General construction plant shops (e. g. batch plants, mechanical and electrical equipment rooms, carpenter shops, rigging lofts and active storerooms, barracks or living quarters, locker or dressing rooms, mess halls, and indoor toilets and workrooms.)
30	First aid stations, infirmaries , and offices

Building project specifications often address temporary lighting in Division 1, General Requirements. The construction manager or general contractor can place the duty to provide temporary lighting under the scope of work for the electrical contractor. The typical specification or scope of work could be as simple as "provide temporary lighting". The Dade County Schools in Florida have a specification for construction that requires one 100-watt lamp for each 250 square feet of area, but not less than one per area (Dade County, 2005). New Brunswick, NJ has a recommended lighting level of 10 foot candles (fc) for general construction, with an example of 150 watt lamps eight feet off the floor and thirteen feet apart (New Brunswick, 2000). The Pittsburgh AIA has set guidelines at 100 watt lamps thirty feet on center for corridors and one lamp per 300 square feet or part thereof, with a minimum of one lamp in each space (Pittsburgh, 1987).

A study published in 2008 (Smith, 2008) tested four commonly used temporary lighting methods to measure the illumination and compare with the OSHA requirements. The four methods were 400 watt metal halide lamps spaced 30 foot on center, 100 watt incandescent bulbs, 150 watt incandescent bulbs, and 23 watt compact florescent bulbs, all spaced 10 foot on center each way.

The results of the testing have given valuable data on the four lighting methods.

- Metal halide lights (400 watts) eleven feet off the floor and spaced thirty feet apart, provide enough light to meet OSHA standards. These lights are very bright and cause glare problems. The bright lights also resulted in deep shadows and high contrast within the test area during the shadow testing. Tests could be conducted to see if the metal halide lamps perform better in rooms with higher ceilings, where brighter lights are required and the impact of the glare may be diminished.
- The 100 watt lights, eleven feet off the ground and spaced ten feet on center did not test well. There was no point in the test area that met the minimum OSHA requirements. Tests could be conducted to see if 100 watt lamps provide enough light to be used in smaller rooms that already have gyp on the walls. There may be enough light surfaces and reflection to meet the minimum requirements.
- The 150 watt lamp test was successful in meeting the OSHA requirements in the center of the test area. It is possible that if a third row of lights was installed, and the rows were still ten feet apart, the entire room may meet the OSHA requirements. The key may be to specify one lamp per 100 square feet. The lights did not have a strong glare problem. The shadow tests showed that the shadows were not deep, except in very small areas of multiple shadows, and did not appear to pose significant problems.
- The 23 watt florescent lamps tested well. The overall lighting was comparable to the 150 watt lamps, and met the OSHA guidelines in the central area like the 150 watt lamps. As with the 150 watt lamps, an additional row may have brought the entire room up to OSHA standards. The impact of the shadows was slightly less than the 150 watt lamps (Smith, 2008).

The conclusion of the study was 150 watt incandescent bulbs or 23 wall compact florescent bulbs placed 10 feet on center and eleven feet above the floor, provide OSHA compliant illumination. Light strings are commercially available that have lights placed at ten foot intervals and are designed for 150 watt bulbs. Compact florescent bulbs with a medium screw in base can be placed in the same strings.

Most buildings have irregular floor plans that do not readily adapt to lights placed ten feet on center. The challenge of installing and maintaining lighting during construction, which meets OSHA requirements and workers' needs, can be addressed by designing temporary lighting specifically for a project.

An analysis of the building plans can be employed to design the temporary lighting by identifying the lighting requirement in each area, specifying the type and location of fixtures, and supplying the necessary illumination. The location of the lights needs to be predetermined so the lights do not conflict with the piping, HVAC, electrical, or other building components. The location of the light fixtures can be drawn on existing drawings or determined through the use of AutoCAD and/or 3-D modeling. The temporary lighting can be installed soon after the structure is put in place, and remain in one location throughout the project. Without AutoCAD, construction drawings can be used to locate the areas without obstructions in each room. The following example of a lighting analysis shows the methodology used in creating a lighting layout, which in turn creates the parameters for the lighting system. The desired result is the installation of temporary lighting that will fulfill the illumination requirements for all phases of construction from mechanical and electrical rough-in through final finishes.

Figure 1 shows a section of a medical building. The drawing is 6500 square feet of a 45,000 square foot, three-story building. The budget for the building was $9.5 million. There are many small rooms and corridors. There are no windows in this area. The exterior walls on the top part of the drawing are below grade, and the exterior walls on the lower part of the drawing are blocked by an enclosed stairwell and a conference room. There are two mall windows in the conference room, but the illumination from natural light above 3 fc did not extend beyond the proposed walls of the room. To the right and left are other parts of the interior. Required lighting is one light per 100 square feet, with a minimum of one light per room.

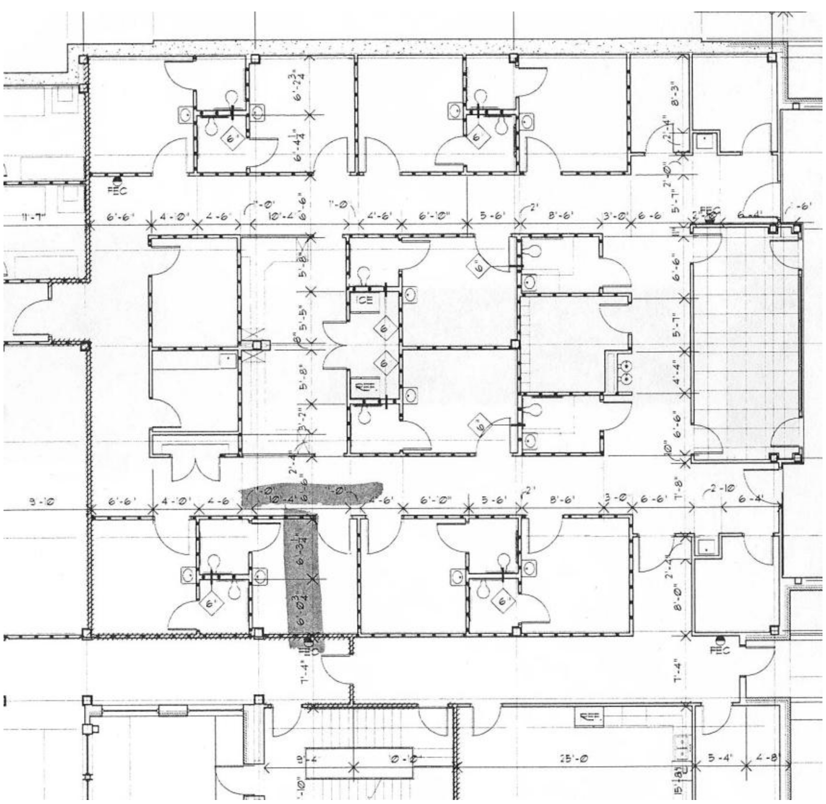

Figure 1 – Medical Building – Plan View of One Section

Figure 2 shows the location of the HVAC system. Other drawings, which are not included, give the location of the plumbing system, lights, major conduit and cable trays. The dark circles on the drawing are the locations of the temporary lighting fixtures.

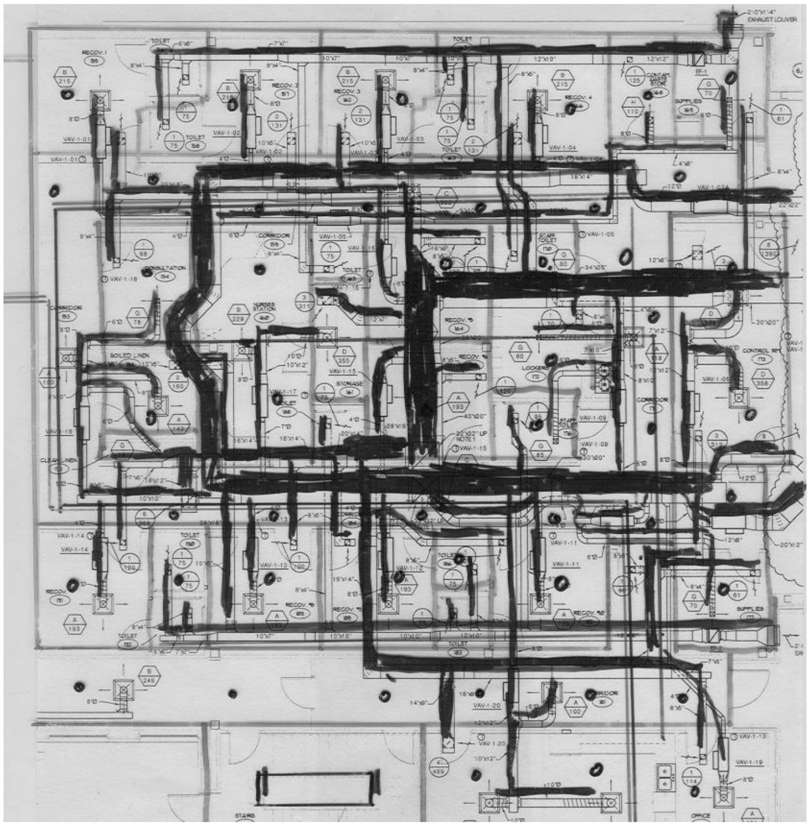

Figure 2 – Medical Building – Location of Temporary Lighting

The Problem

Current light strings have five or ten lights spaced 10 feet on center. The ideal locations for lights, in the example shown in Figure 2, are not ten feet on center throughout the area. Also, the light strings go from room to room, which may cause problems when removing the lights that penetrate gypsum walls. Pipes, conduit, and ductwork will be placed below the temporary light strings and may not permit the easy removal of the lights. The installation of the building materials and systems would result in cutting cords to remove the lights.

A Solution

One solution shorter strings with only one light, so that many short cords are connected together to illuminate the entire area. The individual lights would have a male plug on one end of the cord and a light, similar to individual work lights. There would also be multiple female plugs on the other end to allow multiple lights to be attached. Installing the individual lights in a continuous string would require linear attachment, which may become awkward in many applications. Placing a double female end to replace the single female end makes the arrangement of lights much more flexible, as shown in Figure 3. From sampling the requirements for several different building layouts, the maximum distance between lights should be 14 feet. So the distance from the male end of the light cord to the light was 14 feet.

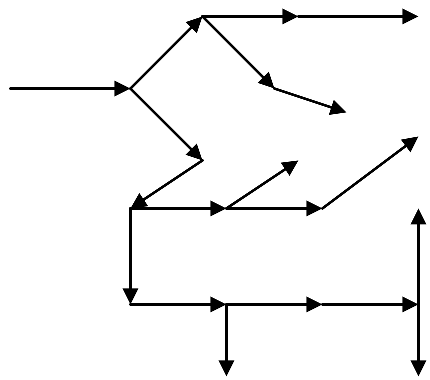

Figure 3 - A configuration of several single-light cords

Temporary lighting systems need to be installed before any interior systems to have the greatest benefit to the workers. As the systems, such as ductwork, are placed, the materials begin to block the light. Being able to drop the lights at a future time would bring the lights below the mechanical systems, providing proper lighting without excess shadows. Placing the lights on the end of a three foot tail, as shown in Figure 4, would allow the lights to hang below the mechanical systems. A grommet attached to the cord just above the light would allow the height to be adjusted, based on needs. Grommets would also be placed near the male end, the female end, and the center, to make the light strings easier to install.

Figure 4 – Single Light Temporary Light

The electrical cord to be used in the lighting system is 12/3 SJTW. The National Electrical Code, ANSI/NFPA 70, in Article 400, Table 400-4, lists SJTW as acceptable flexible junior hard service cord for construction application. All temporary lighting needs to meet the same applicable electrical code as the building (OSHA 2006). SJTW flexible cords comply with OSHA §1926.405(a) (2) (ii) (J) for their use on construction site (OSHA Interpretation).

The current commercial light strings for construction are designed to accept 150 watt bulbs. Previous studies have shown that florescent bulbs are more efficient in that they consume less energy, and they do not need to be replaced as often (Smith, 2007). Only ten 150 watt bulbs (120 volt) can be safely placed on a 100 feet of 12/3 SJTW cord on a 20 amp circuit. Using compact florescent bulbs increases the number of lights to around 64, depending on the wattage used (23 watt to 26 watt provide approximately the same lumens as the 150 watt incandescent bulb). Using 23 watt compact florescent bulbs would allow 6500 square feet to be illuminated by one 20 amp circuit. The calculations are as follows:

- Amps = watts/ volts
- Ten 150 watt bulbs = 1500 watts
- Voltage = 120 volts
- 1500 watts / 120 volts = 12.5 amps (which is below the capacity of 15 amps for a 12/3 SJTW cord.
- The same 1500 watts, using 23 watt compact florescent bulbs, would support 65 bulbs

The move to compact florescent bulbs makes the temporary lighting system easier to install, and the compact florescent bulbs are more economical to operate. In addition to less energy use, the compact florescent bulbs have a rated life of 10,000 hours as compared to 800 hours on 150 watt incandescent bulbs. With temporary lighting on 24 hours a day, as is the case on many sites, the savings are significant. Table 2 shows a cost comparison using a larger compact florescent bulb of 26 watts.

Table 2 - Cost Comparison of Compact Florescent vs. Incandescent

	26 watt CP	150 watt Incandescent
Energy Cost per Year	$25	$144
Replacement cost	0	$120
Cost per light	$25	$264
Cost per 100 lights	$2,500	$26,400

Assuming:

- Energy cost at $.11 per kilowatt hour
- Continuous operation 24/7 for one year
- Replacement cost of $10 per light – labor and material
- Expected life of 150 watt incandescent of 800 hours
- Expected life of 26 watt compact florescent 10,000 hours

Using light strings in areas where over 12 lights would be connected on the same circuit, precautions would be necessary to prevent the substitution of the compact fluorescents with incandescent bulbs. The substitution would cause overloading of the circuit. The use of a “bi-pin” base would eliminate the problem. Incandescent bulbs cannot be inserted into a “bi-pin” base. There are several base configurations available along with appropriate bulbs.

The final design has the following characteristics:

- A 12/3 SJWT 14 foot electrical cord with a male cord plug on one end and a double female pug on the other end.
- Next to the female end there is a “Y” connection that leads to a three foot length of cord that terminates in a “bi-pin” bulb base for a 23 to 26 watt compact florescent bulb with a protective cage.
- There will be a grommet attached to the cord at the light, the male end, the female end, and half way between the female and male end to facilitate installation of the light string and limit damage to the cord.

Cost Benefit Analysis

The cost of each section of the lighting system and the number of sections required is significant. It is estimated that the cost of each section at $50, which compares to $250 for a string of 10 lights and $ 180 for a string of five lights now available (Woods Industries).

There are some areas of analysis that are difficult to quantify, but need to be part of the decision process.

- The number of circuits can be decreased using compact florescent lights.
- The layout for the lights can be placed on the floor and the lights placed exactly where they are required, then attached to a nearby light (within 14 feet).

- Individual shorter strings are easier to work with.
- The shorter strings would be easier to remove at the end of the job (Anticipated salvage 75%)
- Longer strings could incur more losses (damaged or destroyed) when removing because the lights strings pierce walls and are behind or above equipment. (Anticipated salvage 60%)
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A cost comparison of 1, 5, and 10 light strings is provided in Table 3. The current products can use compact fluorescents, so energy cost has not been considered in the table. The result shows that there is little difference in the cost of the different lighting systems, or components, based on the stated assumptions.

Table 3 – A cost comparison of 1, 5, and 10 light strings

Type of Light	# Strings	$/String	Total Cost	$ per light	Salvage %	Salvage $	Net Cost	Cost per light
100 ft String (10 Lights)	10	$278	$2780	$27.80	60%	$1,668	$1,112	$11.12
50 ft String (5 Lights)	20	$160	$3200	$32.00	60%	$1,920	$1,280	$12.80
14 ft String (1 Light)	100	$50	$5000	$50.00	80%	$3,750	$1,250	$12.50

100 Foot String – Woods Industries 2481 – 12/3 SJTW cord (Woods Industries)
50 Foot String – Woods Industries 2480 – 12/3 STW cord (Woods Industries)

Patent Process

The product development has gone through the several steps. The final step is the patent process. The process can be drawn out and expensive. Faculty members at most universities have a resource that can help, not only with the patent process, but bringing the product to market. A university "technology transfer", or similar department, has the mission to help faculty members patent a product and find an industry partner that is interested in producing and marketing the product.

The process starts with a "provisional patent". The provisional patent is filed to protect the design for one year, while research is conducted for existing patents and industry partners are solicited. The provisional patent can be renewed.

The contractual agreement between the university, industry partners, and the inventor will vary, but there is a general format. The industry partner will pay a fee or royalty to the university. The university, the technology transfer department, the college, and the inventor's department will all get a slice. The inventor will also get a slice. The size of the payments to the university from industry and the percentages to each of the entities at the university will vary and may be negotiable.

The advantage to the academic inventor is that they do not need to deal with the contracts, auditing, collecting money, manufacturing, or marketing. The university protects the inventor's interests as well as that of the university.

Conclusions

One of the services that construction management programs and academic professionals can provide to the industry is the analysis of current problems or issues and the proposal of a product or process to help resolve the issue. Academics perform these services on a regular basis in the form of research papers and grants. Taking products to market may not be the intent of faculty member when entering academia. But solutions that need to go back to industry need to have a vehicle. Manufacturers of products used by the construction industry are the vehicles. Manufacturers provide products that help make the construction industry and their projects safer, more cost effective, and provide many other benefits.

The "Short Cord, Temporary Lighting System" was result of an industry need. Previous research had identified a problem with temporary lighting in buildings under construction. An examination of the current products showed that there was a need for another solution. The process of development provided a solution. Further analysis showed the cost comparison with current products to establish whether the product would become marketable. The university provided a method to bring the product to market.

The described product has a provisional patent. Whether the process continues depends on the result of the next steps, including the interest of a manufacturer and the marketability. The future of the product is not important. The intent of the author was to provide a roadmap for those in our industry who want to spread their ideas, but have been unsure of the path.

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