

IMPROVED TEMPORARY CONSTRUCTION LIGHTING AS A METHOD OF IMPROVING PRODUCTIVITY AND QUALITY

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ABSTRACT

Lean construction, in part, speaks to the maximisation of value and the minimization of waste. Increasing productivity increases the value of labour. Increasing quality by decreasing defects lowers wasted resources. Studies have shown that many buildings under construction are not illuminated to the minimum standards required by OSHA. Could it follow that poor illumination impacts productivity and quality? The question of proper illumination is both qualitative and quantitative. The study starts by looking at the effectiveness and cost of current temporary lighting systems. The effectiveness of current temporary lighting systems is based quantitatively on the minimum OSHA illumination standard. The quality of temporary lighting is discussed as a basis for the evaluation of the total system. The second part of the study looks at techniques which provide temporary lighting meeting OSHA requirements and providing the quantity and quality of illumination that could promote a higher level of productivity and quality. The final part of the study performs a cost/value analysis of improved temporary lighting. This analysis is based on installation, maintenance, and energy costs, which are compared to potential benefits in productivity and quality.

KEY WORDS

Temporary lighting, construction, productivity, safety, lean construction.

INTRODUCTION

The core of lean construction is the maximisation of value and the minimization of waste. The relationship of illumination in the workplace to quality and productivity is not a new concern for employers. The Hawthorne Experiments from 1924 to 1927 included illumination studies. The hypothesis was that greater illumination would generate higher productivity. Unfortunately, the studies were inconclusive because of the construction of the experiment (Ballantyne 2000), but the study was a milestone by influencing future studies of productivity and environment.

More recently, the Light Right Consortium released the results of a field simulation that indicated a causal relationship between lighting quality and worker satisfaction and motivation (Dilouie 2003). Although the simulation was conducted in an office environment, the relationship between lighting environment and worker motivation could possibly be applied to the construction process.

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In 2006, Juslen, Wouters and Tenner studied the effects of task-lighting on productivity in a factory setting. This study indicated a increase of productivity of 4.5% for a group that was provided high lighting levels as a base working environment. Although outside the construction realm, the mechanisms of improved visual performance, biological effects of light, and/or psychological effects remain similar. Productivity factors measured in this report included speed, quality (failure), delivery performance, and absenteeism.

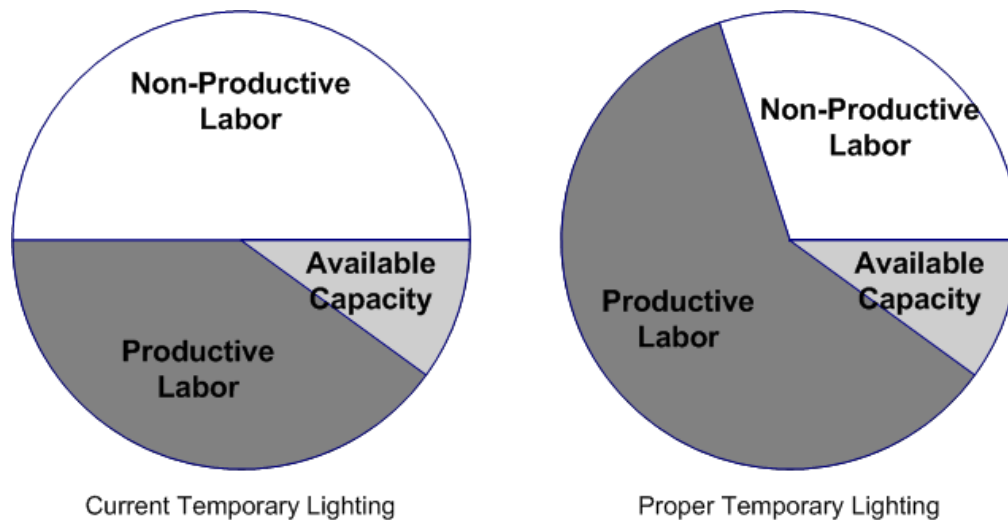
The link between illumination, quality of work, safety, and productivity provides the motivation to examine current conditions and the opportunity to look at methods of improving temporary lighting. This link is important, as any improvement in illumination would require the allocation of resources. The general contractor or owner would need to believe that the cost of the changes was returned in higher quality work and/or more productivity. The Light Right study identified the barriers to improved lighting as the initial cost and the lack of evidence that there is a link to performance. The study also found that 87% of the companies interviewed would spend the money if the return on investment could be demonstrated (Dilouie 2003).

In the lean system, work is focused on human movement. Essentially, improved lighting on a job site hopes to develop a people-centred process that flows smoothly and safely in each required operation. One measure of labour efficiency is work/motion, or labour density. Market demand controls the numerator. Improved lighting on the job site helps control the denominator.

There are three types of waste: conveyance, delay, and motion. Conveyance waste is waste caused by inefficient workplace layout or set-up. Delay waste is also applicable as employees may stand around or require movement of correct lighting. Finally, motion waste as poor workplace design negatively affects productivity and quality as well as safety. Productivity suffers when there is unnecessary movement or relocation to obtain the proper lighting. Quality suffers when the worker does not have quality lighting.

Table 1 illustrates the impact of proper lighting applied to the concept of lean construction. The increase in productive labour can result from increased productivity and the reduction quality issues that require additional labour to correct.

Table 1 Productive vs. Non-productive Labour



The study of the impact of temporary construction lighting on productivity and quality is intrinsically subjective in nature. Each jobsite is unique and the workforce is always changing. The current study attempts to minimize the variables and look at temporary lighting objectively. The study starts with an examination of current site conditions regarding temporary lighting. Next, there is an examination of four lighting systems for quantity and quality. Third, there is a cost comparison of the four lighting systems. Finally, there is a brief discussion of the possible cost/benefit relationship of temporary lighting to productivity.

REQUIREMENTS AND CURRENT CONDITIONS

Temporary lighting is necessary for the construction process. When OSHA developed standards for the construction industry, lighting was one of the safety aspects of construction projects addressed. The writers of the standard realized that some level of lighting was necessary to provide workers with a safe environment. OSHA standard 29 CFR 1929.56 is entitled "Illumination", and 29 CFR 1926.56(a), states that the illumination for "general construction areas" must meet a minimum of 5 foot-candles (fc) (OSHA 2004). The OSHA minimum of 5 fc was used throughout the study as the minimum standard for the quantity of illumination.

Building project specifications often address temporary lighting in Division 1, General Requirements. The CM or GC 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 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). New Brunswick has a recommended lighting level of 10 fc for general construction, with an example of 150 watt bulbs eight feet off the floor and thirteen feet apart (New Brunswick 2000). The Pittsburgh AIA has set guidelines at 100 watt bulbs thirty feet on centre for corridors and one lamp per 300 square feet or part thereof, with a minimum of one bulb in each space (Pittsburgh 1987).

The United States Department of Energy recognizes the lack of specific guidelines for temporary lighting, and in reference to the topic states, "Construction design documents define the contractor's responsibilities during construction, but they typically focus on the design elements of the finished product. They rarely set environmental guidelines to be followed during the construction phase. The design team should work with the construction contractor to adopt environmental guidelines to be followed during construction." (U.S. DOE 2004)

A recent study of temporary lighting on three projects showed all three projects were substantially non-compliant to the minimum OSHA standard. The first project was a hospital addition, eight stories tall, with a cast-in-place concrete structure. The temporary lighting system was comprised of 400 watt metal halide fixtures 60 feet on centre. The surfaces were dark and non-reflective, and there was little natural light. The light meter readings showed that 78% of the building was under 5 fc (Smith August 2006).

The second building was a two-story school addition. The structure was steel frame with CMU interior walls and CMU back-up block on the exterior walls. The ceilings were corrugated steel in the first floor and white gyp on the second floor. There was some natural light on the perimeter of the building. The temporary lighting was 100 watt bulbs spaced unevenly throughout the building. The only area in the building that had sufficient

light was near the windows on a sunny day. The interior areas were all below 5 *fc* (Smith August 2006).

The third building was engineered steel on steel building. The temporary lighting consisted of 150 watt bulbs, about 20 feet off the floor, and 20 feet on centre. Other than natural light through the windows and openings, the temporary lighting was inadequate to meet OSHA standards in all interior areas (Smith August 2006).

The three buildings examined identified the problem, but did not give a broad enough view of temporary lighting. Buildings vary in shape, size, materials and a multitude of other factors. More buildings were examined and the results summarized.

Several other sites were also investigated during this study. It was found that most of the smaller projects, such as multifamily residential units and small retail, had no temporary lighting. Observations indicated that eleven investigated sites did not have any temporary lighting, one used metal halide fixtures, one used clusters of four halogen bulbs, and the remainder used 100 watt incandescent bulbs. Where temporary lighting was provided, only the 400 watt metal halide bulbs and the halogen bulbs provided enough illumination to meet the OSHA guidelines. There was no area in any building that, without natural light, met OSHA standards with only 100 watt incandescent lighting (Smith Azhar 2007).

The buildings were all located in Alabama and Tennessee, and all locations were examined in May and June on sunny days. The results showed that natural lighting was heavily relied on at many of the locations. It was estimated that 41% of the building area examined did not meet the minimum of 5 *fc* with the natural light. Without sufficient natural light, such as early morning starts, short daylight hours in the winter, and cloudy days, the non-compliant area of the combined buildings would exceed 75% (Smith Azhar 2007).

STUDY OF FOUR TEMPORARY LIGHTING SYSTEMS

The examination of jobsites indicated that illumination was generally inadequate, but did not allow any meaningful conclusions because the sites had different lighting methods and the physical environment varied (Smith April 2006). The variables include:

- Types of lights – sites use different types of light fixtures and different wattages of light bulbs in the fixtures.
- Natural light – different sites have different amounts of natural light due to the orientation of the building, size of the openings, size of the building, time of day, and weather conditions.
- Construction material – different materials have different light reflection attributes due to colour, texture, and material. Slick finish concrete decks have higher reflection qualities than rough or dark concrete.
- Materials in place – as more material is put in place, there are more shadows and a greater contrast between dark and light areas.

In order to compare lighting systems, variables need to be controlled. An empty warehouse was chosen for the study that was 28 feet wide and 61 feet long. The walls were unpainted CMU and the ceiling (roof) was pre-cast slabs on steel bar joists. The

ceiling was lighter than concrete but not as light as white paint. The floor was concrete with a smooth finish. A grid was laid out on the floor 5 feet on centre each way. The nine-foot wide overhead door on one wall was solid, with no appreciable light entering the space (based on light readings). There were three small windows (32 inches x 16 inches) high on one wall, and these windows were completely covered.

The walls, floors, and ceiling all have light reflection qualities that impact light readings at any one point. The impact of the environment is shown in the results of the light readings during the testing. Readings at different locations, but the same distance from a light source, had a variation in the light readings. The variation due to the surrounding surfaces has been accepted for this experiment because the purpose of the experiment is to compare different lighting schemes. Since the environment is the same for all tests, comparisons have merit.

The warehouse location can also have a benefit to the study. The materials used in the building and the size of the test area are common to many projects. The results of the light readings can be viewed as typical for industry practice.

The purpose of the grid points was to define the location of the lights and define the locations where the light readings were taken. The process was designed to eliminate as many variables as possible. The five-foot on centre each way grid, with 5 rows and 11 columns, gave fifty-five data points for each test, and each point was numbered. The five-foot grid was chosen because some of the lighting schemes used fixtures on a ten foot grid. Light meter readings were taken at floor level at each of the 55 points in the grid. Having light readings between fixtures was found to give important information (Smith April 2006). All light readings were taken on the floor with a "Centre 337 Mini Light Meter" calibrated in foot candles.

Four types of lighting systems were tested. All the light fixtures were about 11 feet above the floor. The lighting systems were 400 metal halide fixtures, 100 watt incandescent bulbs-10 feet on centre each way, 150 watt bulbs-10 feet on centre each way, and 24 watt compact florescent bulbs-10 feet on centre.

The first lighting fixture tested was the 400 watt metal halide fixture. The spacing found on jobsites was closer to 60 feet on centre, but light readings showed that this was inadequate. Preliminary test showed that 30 feet on centre would provide the minimum required lighting (5 fc) on the majority of the area. The test on the 400 watt system showed that the illumination ranged from 23 fc to 11 fc . All points in the test area were above the 5 fc minimum. The fixtures could have been spaced further apart. The test area was too small for a complete test at different spacing, but an examination of the light levels with one fixture showed that the light levels drop significantly after 15 feet from the fixture, so 35 to 40 feet on centre would be the maximum spacing. The downside of the lighting was the deep shadows that resulted from few, very bright lights. When there was an obstacle in the test area blocking one of the lights, the point was under the 5 fc minimum. On the qualitative aspects for the lights, there was a lot of glare, deep contrast, and brightness issues. The lights were not comfortable to work in for long periods.

The second test used 100 watt incandescent light bulbs. The Dade County requirement was one 100 watt bulb for 250 square feet. Pre-built light strings are 10 feet on centre, so 10 feet on centre each way (100 square feet) was chosen for testing. The 100 watt lights, 10 feet on centre, had a maximum reading of 3.2 fc and a minimum of 1.2 fc . There was no point in the tested area that met the OSHA standard of 5 fc . The Dade County requirement, which requires less than half the fixtures, would not meet the

minimum OSHA requirement. The lights were not so bright as to be uncomfortable, and although the light was dim, the area was relatively uniform visually in illumination. Shadows were not a problem.

The third light tested was the 150 watt incandescent lights. The same fixture arrangement was used as for the 100 watt bulbs. New Brunswick required 150 watt bulbs 8 feet off the floor and 13 feet on centre. Since most buildings have ceiling heights over 8 feet, the height remained at 11 feet, and the spacing was 10 feet on centre. The 150 watt lights, 10 feet on centre, had a maximum reading of 6.1 *fc* and a minimum of 2.5. The area under the 5 *fc* was on the perimeter of the test area. Interpolating the results over a larger area, the majority of the points would be in compliance with the OSHA standards. With some additional lighting on the perimeter, the entire area could become compliant. The shadows were not a problem. The lights were brighter than the 100 watt, but not so much to cause the eye discomfort as experienced with the metal halide bulbs.

A fourth system was tested that used 24 watt florescent bulbs in the same fixtures as were used for the incandescent bulbs. The fixtures were placed 10 feet on centre. The results showed the same illumination as the 150 watt bulbs with the visual brightness of the 100 watt bulbs. The 24 watt florescent lighting system met OSHA minimums, provided quality illumination, and was considered the best lighting solution of the four tested.

COST COMPARISON OF THE FOUR LIGHTING SYSTEMS

The quality of illumination is one factor in analyzing the temporary lighting in regard to lean construction. Another aspect of temporary lighting is cost. The least expensive solution for the electrical contractor is to do nothing. Doing nothing on most projects would result in poor working conditions, and poor working conditions could lead to poor productivity. The assumption necessary for cost comparison is that all four systems are fully utilized and the costs compared.

There are four components needed to calculate the cost of temporary lighting: installation material, installation labour, energy cost, and maintenance. Maintenance includes material and labour. Maintenance was only considered burn-out replacement. Incandescent light bulbs last 750 hours and need to be replaced 12 times. Metal halide and compact florescent bulbs have a life of over 10,000 hours and would not need replacing during the year due to burn-out. Energy cost is based on lights on 24/7 for one year and energy costs of \$.08 per kilowatt hour. Material costs are based on OSHA compliant fixtures, and installation labour based on prevailing wage rates for Alabama. Table 2 shows that the compact florescent has the lowest per square foot cost at \$.47.

Table 2: Cost comparison of lights for one year

	100w.	150w.	400w	24w.
Installation Labour	\$10	\$10	\$30	\$10
Installation Material	\$10	\$10	\$100	\$20
Energy for 1 year	\$70	\$105	\$280	\$17
Replace bulbs at \$10 each for labour and material	\$120	\$120	0	0
Total \$ per light	\$210	\$245	\$410	\$47
Cost per Sq. Ft.	\$2.10	\$2.45	\$1.00	\$.47

COST/BENEFIT RELATIONSHIP OF TEMPORARY LIGHTING TO PRODUCTIVITY

The final part of the question is whether good quality lighting with OSHA compliant quantity of illumination would benefit productivity. An experiment to accurately evaluate productivity would be difficult for most, if not all construction projects. But deductive reasoning could give some indication of the possibility. Such an exercise requires the acceptance of assumptions and deductions from the assumptions and previous data.

1. A commercial building, such as a low rise office or school, with medium range finishes cost about \$180 per square foot to build.
2. 60% of the cost of the building is in mechanical systems and interior systems and finishes that would require temporary lighting to perform the work, or \$108 per square foot.
3. 50% of the cost of interior work would be labour, or \$54 per square foot.
4. Quality lighting will cost about \$.50 per square foot. The \$.50 is the cost of the lighting, not just the difference from some other lighting system.
5. The \$.50 lighting cost would result in an increase in cost that would need to be recovered in the form of increased productivity.
6. Productivity would need to increase by .9% to offset the lighting cost.
7. .9% equates to 4.4 minutes per day per worker.

The question becomes whether a worker would be at least .9% more productive if adequate lighting was provided throughout the construction process. Industrial studies referenced previously indicate that productivity in controlled factory settings increases 4.5% (Juslen et al 2007). Assuming correlation between the factory numbers and a temporary construction working environment, it appears reasonable to surmise that at least the required productivity would be achieved.

CONCLUSION

The implementation of proper lighting on jobsites can contribute to lean construction by increasing productive labour through higher productivity and reduced waste. The current contractual language is often not adequate to insure proper illumination on the jobsite, even though OSHA has set minimum requirements, as was shown by the study of 30 jobsites. There are ways to illuminate jobsites that are economical and OSHA compliant, and the 24 watt compact florescent bulb tested better among the four systems tested for illumination and cost.

The ability to realize higher portion of productive labour on a construction site is one of the goals of lean construction. It is the goal of most construction. Improving the work environment for the trade workers on construction sites is a substantial method of encouraging an increase in productive labour. Improving the temporary lighting on the jobsite is a very cost effective method of improving the work environment. The measurement of changes in productivity is highly subjective due to the number of variables involved. Low quality issues are easy to track, but good quality issues are difficult to document. The impact of improved lighting cannot be easily measured, but managers can evaluate conditions and costs, and make decisions based all information available. Workers, in general, want to be productive on the jobsite, and managers need to provide the working environment required for the success of the workers.

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