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In Situ Case Studies of Two Operation-Critical Control Rooms at the Same Facility: With Comparison to Industry Recommendations

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Abstract

There is a dearth of case studies relative to Control Room lighting, however, Control Rooms are important work environments which must ensure the safety of critical processes. As an indicator of their importance to organizations, Control Rooms have been referred to as the "brains" or "nerve centers" of facilities. Generally, lighting has been found to influence work performance, alertness and safety within a very wide range of facility types. The Illuminating Engineering Society (IES) makes recommendations for light levels for various types of applications, including Control Rooms. Researchers conducted in situ case studies in two Control Rooms of different vintages at the same facility in an effort to determine how well one transportation and storage company's older and newer Control Rooms' lighting levels met current recommendations. An Extech LT300 light meter was used to empirically measure horizontal footcandles (lux) on task surfaces and AutoCAD software was employed to document existing conditions and associated light levels. The findings revealed empirically that the older Control Room illuminated with "static" lighting did not meet industry standards for light levels while the newer Control Room illuminated with "dynamic" lighting met the industry standards and also allowed for user adjustments now and in the future.

Keywords

Lighting, Control Room, Shift Worker

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1. Introduction

Control rooms are important work environments where critical systems are monitored, 24 hours/day, and seven days per week and are typically staffed by shift workers. Control Room workers' performance, alertness and situational awareness support safe operations (Nye 2010; Ergonomics & Employee Productivity 2016; Revel & Eastman 2005; U.S. Department of Transportation 2012; Lerman et al. 2012). Lighting may contribute to successful work operations in Control Rooms if the quantity of light meets industry recommendations. Currently, there is a dearth of in situ case studies regarding the lighting of Control Rooms. However, Control Rooms have been referred to as the "brains" (U.S. Department of Transportation 2012) of facilities and therefore warrant additional research. The current study aims to fill this gap in the literature by providing lighting case studies of two Control Rooms which have been recently operational.

2. Literature Review

2.1. Control Room Design and Management

Control Room workers are responsible for continually monitoring and reacting to critical processes in many industries including the transportation and utilities sectors.

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The heightened vigilance and adaptability required of Control Room workers may be supported by well-designed Control Rooms which facilitate worker alertness. (Baker, Campbell, Linder & Moore-Ede 1990).

Tewel (2007) emphasized the need for good aesthetics in control rooms and suggests they can be "showcase environments". He advocated the use of ergonomic workstations and good lighting. A white paper entitled "*Ergonomics and Employee productivity"* on the SitOnIt Seating website (2016) emphasized that the incorporation of ergonomic seating can generally affect worker productivity.

According to Revell and Eastman (2005) the safety of workers in some professions, as well as the safety of their stakeholders, may be adversely affected by a lack of alertness which could contribute to errors. According to the U.S. Department of Transportation (2012), fatigue can also be an important factor affecting worker performance. Control Room management may seek to reduce the risks associated with on-the-job worker fatigue.

2.2. Lighting and Performance

Researchers have shown that workers who were exposed to higher light levels in the workplace demonstrated higher levels of alertness and performance than those workers experiencing lower light levels (Lerman et al. 2012) The researchers also noted, "Over the past 20 years, as computer display screens have become progressively more common in the workplace, the tendency has been for nocturnal workplaces to become progressively darker, because the visual display is sharper in dimmer room light, and the computer screens may reflect bright room light sources in a distracting and stressful way…This especially occurs when night workers have control of the dimmer switch. The research on the effects of light on alertness and performance has led to recommendations to reverse this trend and to make nocturnal workplaces well lit." (Lerman et al 2012, 246). The website of CineMassive, a Control Room design consulting firm, recommends "proper…ambient environment lighting…(to) reduce fatigue" in Control Rooms (Cinemassive 2014, 1).

Lighting is critical to the process of vision and in the completion of visual tasks. These tasks include those performed on the computer as well as non-computer tasks. Pencil, pen and paper tasks (such as completing checklists and reports) continue to exist in modern Control Rooms. It is generally accepted that lighting influences visual tasks in a wide range of industries and applications. (Dilaura et al. 2011; Rea 2000; Pacifico & Wilsted 2009, editors, *Archival and special collections facilities*. The Illuminating Engineering Society is considered to be "the lighting authority in North America" and many other countries and they have made specific lighting recommendations regarding the quantity of light for control rooms (Dilaura et al. 2011). Generally, as people age they require more light to see visual tasks and the IES lighting recommendations for Control Rooms are designed to address the needs of an aging workforce (Rea 2000). Richman (No Date), recommends that "Central Plant: Control Rooms" should be illuminated to 500 lux. Additionally, indirect lighting and the addition of supplemental task lights were recommended by other experts (Tewel 2007; Nye 2010).

Some researchers have assessed the effects of *dynamic* light on Control Room shift workers (Lowden & Akerstedt 2012, 648) and have suggested that workers' alertness and health could be improved through proper *dynamic* lighting. They define *dynamic* lighting as that which changes in spectral content and light intensity". The inspiration for some dynamic electric lighting systems is natural daylight since daylight exhibits continual light level and light color changes. Some experts advocate an increase in dynamic electric lighting systems for interior applications (Lowden & Åkerstedt 2012; Gertner 2014). Dynamic lighting may influence employees in ways that are currently not well understood in addition to proposed benefits of simulating natural light cycles with electric lights. One proposed benefit of dynamic lighting systems is that employees may feel that the workplace is more amenable to their personal preferences and physical needs throughout the work shift. It is anticipated that in the future there may be color "light recipes" for particular work environments, work shifts, and worker preferences (Gertner 2014). However, research has not yet resulted in specific industry recommendations for the dynamic lighting in Control Rooms.

3. Purpose

The purpose of this study was to produce case studies which 1). examine and document two Control Rooms (one older and one newer) at a transportation and storage facility with different lighting systems; 2). determine compliance of the two control rooms with current industry recommendations for light levels.

4. Method

The researchers measured and analyzed two Control Rooms operating at the same large transportation and storage facility in a Southern Mid-Western location of the USA during a six-month study period. Control Room "A" had been in operation since the 1950's and had received a fluorescent lighting retrofit in 2005. Control Room "B" was located nearby in an historic

building for which the interior had been recently repurposed, via a major renovation in 2015. The renovation of the latter included all new furniture, new room finishes, and new Light Emitting Diode (LED) lighting system. The transportation and storage facility intended to move its workers from Control Room "A" to Control Room "B" when the latter's renovation was complete. However, Control Room "A" would remain ready to serve as the back-up in the event of an emergency disabling Control Room "B".

For Case Study #1, which investigated the older Control Room "A", and for Case Study #2, which investigated the newer Control Room "B", the researchers field-photographed and field-measured the overall spaces. The researchers examined the respective lighting systems. They examined the furniture and developed a furniture floor plan. These findings were converted into scaled drawings employing AutoCAD software. Researchers utilized an Extech LT300 light meter to empirically measure horizontal footcandles (lux) on task surfaces. The electric light contributions were measured only. (All computer monitors were turned off during the study period.) The field data was inserted into the plan drawings. Refer to Figures 3 for Control Room "A" and Figure 4 for Control Room "B" plans with furniture layouts and light levels.

The researchers utilized the current Illuminating Engineering Society (IES) recommendations which they compared to the measured results from the two case studies. Indications of compliance or non-compliance of light levels in Control Room "A" and "B" with industry recommendations were developed.

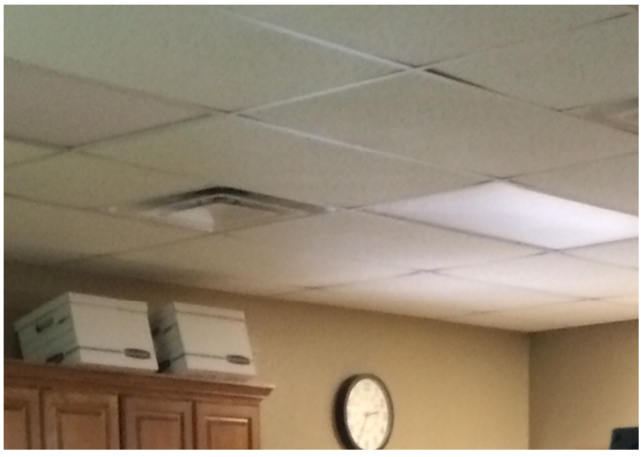

Figure 1. Photograph of lighting in Control Room "A".

5. Findings

Case Study #1 – Control Room "A" Lighting System Description

Control Room "A" featured standard, 2'-0" x 4'-0" (0.61 meters x 1.22 meters) recessed-in-the-ceiling, *fluorescent* troffers with acrylic prismatic lenses as the only electric lighting in the room. Refer to Figure 1 for photograph of lighting in Control Room "A". These luminaires (light fixtures) were *static* (turned "on" or "off" only) and were controlled by wall box toggle switches. Some of the overhead fluorescent fixtures had been disabled by operators but remained in place. Control Room "A" had no task lights. This Control Room had six windows which were fully shielded (e.g. black out shades) with negligible daylight intrusion. The furniture consisted of a custom-built desk with two workstations. The desk was "fixed" and therefore not adjustable in height. Standard desk chairs were used.

Figure 2. Photograph of lighting in Control Room "B".

Case Study #2 – Control Room "B" Lighting System Description

Control Room "B" featured indirect, cove-mounted, Light Emitting Diode (LED) luminaires producing the majority of the lighting. The cove lights were supplemented by LED lensed suspended "ring" luminaires and LED task lights. Refer to Figure 2 for photograph of lighting in Control Room "B". The overall dimensions of the two coves in the Control Room were 14'– 0" x 26'-0" (4.27 meters x 7.92 meters) each. The LED coves were *dynamic* with infinite dimming and color temperature tuning capabilities. The LED coves were controlled by a programmable computer system. The LED rings were controlled by the pre-programmed computer system, however, and end-user override, via dimming, was possible. Two LED task lights were installed at each workstation. Each task light was operator-controlled by integral dimming and switching. This Control Room had no windows and no daylight intrusion. The furniture consisted of (3) workstations. The three independent, ergonomic control consoles were accompanied by ergonomic chairs. The console desktops were fitted with pneumatically-controlled raise/lower mechanisms which could be cooperator-adjusted as desired by each operator during his/her shift.

Recommendations for Control Rooms

The Illuminating Engineering Society (IES) (DiLaura et al. 2011) recommendations for Control Room light levels which were used as the standard for comparison in this study were: 13.94 fc (150 lux) (when the "Visual Ages of Observers (years) where at least half are < 25", (p. 30-28); 27.87 fc (300 lux) (when the "Visual Ages of Observers (years) where at least half are 25 - 65"(p. 30-28); and 55.74 fc (600 lux (when the "Visual Ages of Observers (years) where at least half are > 65, (p. 30-28).

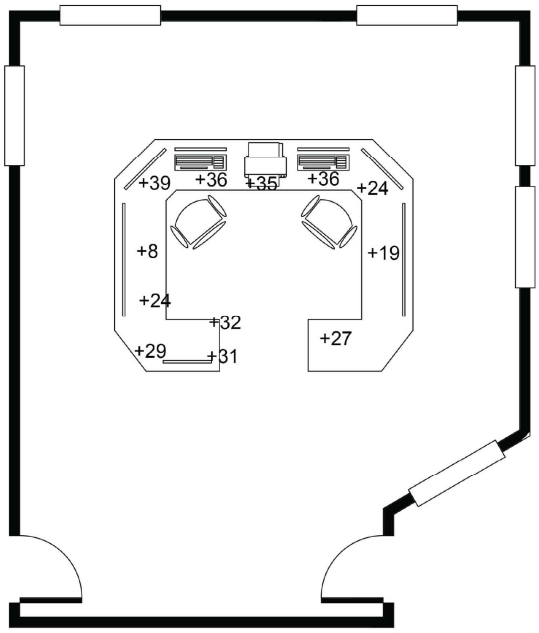

Figure 3. Control Room "A" plan with furniture layouts and light levels.

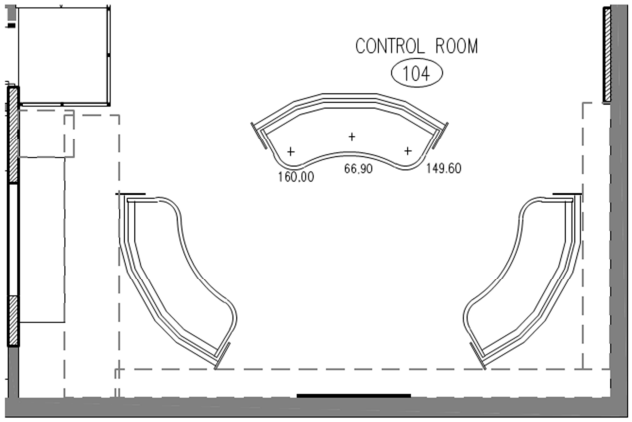

Figure 4. Control Room "B" plan with furniture layouts and light levels.

Case Study #1 – Control Room "A" Lighting Levels

In Control Room "A", the in-situ light levels at the typical work plane height (2'-6" above finished floor (0.76 meters)) were found to range from 8 to 39 footcandles (fc) (86.11 to 419.79 Lux). The researchers were informed by the facility that 100% of the current controllers in Control Room "A" were 25-65 years old and therefore researchers utilized the middle IES range for Control Room recommendations, for when the "Visual Ages of Observers (years) where at least half are 25 - 65", (p. 30-28), 27.87 fc (300 lux). Researchers therefore concluded that, in Control Room "A", with the lighting system in its current state (2 x 4 fluorescent troffers with some of these luminaires disabled) the light levels in some parts of the Control Room "A" did not comply with industry standards.

Case Study #2 – Control Room "B" Lighting Levels and Industry Compliance

In Control Room "B", when all electric light sources were illuminated to their maximum levels, in-situ light readings at the typical work plane height (2'-6" above finished floor (0.76 meters)) were found to range from 66.90 to 161.00 footcandles (fc) (720.11 to 1732.99 Lux). The researchers were informed by the facility that 100% of the current controllers in Control Room "B" were also 25-65 years old and therefore again utilized the middle IES range for Control Room recommendations, for when the "Visual Ages of Observers (years) where at least half are 25 - 65", (p. 30-28), 27.87 fc (300 lux). Researchers therefore concluded that when fully illuminated, the lighting system (indirect LED cove lights, LED pendant ring lights and LED task lights) in Control Room "B" currently exceeds industry standards.

6. Limitations

Many of the visual tasks in Control Rooms require operators to look at computer screens. Computer screen tasks were not considered in the current study. The light level contributions from computer monitors were not considered. The number of Control Room workers in the current study was relatively small and therefore the results of this study may not be generalized to the greater population of Control Room workers.

7. Discussion

In Control Room "A", it was reported that end-users had disconnected some of the overhead fluorescent lights. This may be in reaction to any or all of the following: the "on" or "off" nature of static lighting might not have offered an intermediate light level preferred by the workers; the positioning of the institutional fluorescent lighting overhead may have not been preferred by the workers, the workers may have perceived unwelcome brightness from the lensed fluorescent fixtures; the workers may have perceived flicker from the fluorescent lamps (light bulbs); and/or they may have perceived fluorescent ballast "hum".

Although the maximum light level reported for Control Room "B" was measured with all electric light layers (cove,

rings and task lights) "on" and measurements complied with/exceeded industry standards, the actual light levels during workers' shifts is anticipated to vary. This is due to the dynamic nature of the programmable lighting system and also the built-in end-user override capacity. The dynamic lighting may be re-programmed to lower the light levels produced by the LED cove or rings. The workers in Control Room "B" may choose to dim or turn "off" the overhead LED suspended rings during some or all of their shifts. Additionally, controllers may also choose to individually dim or even turn "off" their LED task lights during some or all of their shifts. Any of these three latter scenarios would result in lower light levels than the "all on" light level measured during the study. The horizontal footcandle (lux) level in Control Room B's consoles with only the cove lighting "on" only was measured to be 18 footcandles (193.75 lux) average when the consoles were in their lower (2'-6" above finished floor (0.76 meters)) positions. Also, if the consoles' positions are raised, the light level would be higher since the consoles would then be closer to the light source above.

Older workers may be hired in the Control Rooms of the future. The population of older adults in the United States is projected to increase from 48 to 88 million persons by 2050 and labor force participation rates for men and women over the age of 65 are increasing as well (He, Goodkind & Kowal 2015). Older workers' "visual age" and their respective need for more light and associated higher industry recommendations must be considered for best results and industry recommendation compliance.

8. Conclusion

This Control Room study provides two, in situ case studies that begin to fill a gap in the literature in the areas of lighting and work environments. These case studies provide measured ranges of illuminance from an older Control Room illuminated by a static fluorescent system and a newer Control Room illuminated by a dynamic LED lighting system. The former does not meet current industry standards for light levels in Control Rooms. The later exceeds current industry standards for light levels in Control Rooms when all of the lighting "layers" are illuminated at maximum. However, the installed task lights, dimming and programmable controls can vary the light levels of the three light layers over the course of workers' shifts and to meet the needs of individual workers. The effects of dynamic lighting systems on workers present an exciting direction for further research. Future planned studies will measure variability of the light quantity (fc/lux), composition (NM wavelength) and changes over the work shift (lux time) on a per worker basis using spectrum actigraphy watches.

Recommendations

It is recommended that Control Room "A" be outfitted with LED task lights which could be independently controlled by users as needed to illuminate visual tasks. This intervention could raise light levels to comply with current, lighting industry recommendations. It is recommended that Control Room "B" be analyzed via a temporary installation of data loggers to unobtrusively monitor and record light levels over a typical one –week or more period. A data logging study would capture any potential interventions by Control Room end-users, such as whether and when Control Room workers dim or turn "off" the LED cove lights; rings or task lights.

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