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THE IMPACT OF DAYLIGHTING-ARTIFICIAL LIGHTING INTEGRATION ON BUILDING OCCUPANTS' HEALTH AND PERFORMANCE

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ABSTRACT

Natural lighting was the primary light source in buildings prior to the invention of the electrical lighting in 1879. After that, artificial lighting was mainly utilized to supplement natural lighting. Artificial lighting has nowadays become the major source to illuminate working spaces. However, due to the growing concern of passive design, energy efficiency and environmental issues, daylighting is integrated with artificial lighting to reduce energy consumption. The benefits obtained from the efficient utilization of daylight are not limited to architecture and energy aspects only. Rather, natural lighting affects building occupants in various aspects. This includes occupants' preferences, health, performance, and productivity. This paper aims to review the previous literature to highlight the impact of daylighting on building occupants, particularly in schools and office buildings. Many studies have proven that a large number of students and office workers (60-85%) prefer daylighting as a source of illumination. It was found that proper daylighting designs help maintain good health, reduce stress levels of office workers and alleviate headaches. Internal lighting conditions have had a noticeable effect on building occupants' performance and productivity. An increase of about (5-15%) in the productivity of office workers was reported when daylight was efficiently integrated with artificial lighting in their working places. The reviewed studies showed an increase in students and teachers' attendance in classes, which were mainly illuminated by daylight. In addition, students' progress was faster in math and reading tests (20-26%) compared with those, who occupied a classroom with less daylighting.

1. INTRODUCTION

For many years throughout the human history, natural lighting was the only efficient source of light, and thus it was difficult to perform visual tasks during night-time or cloudy days. This

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indicates that basic lighting condition is required to do various visual tasks. Human beings, therefore, searched for alternatives to light sources other than natural lighting to fulfill the required lighting conditions. Nowadays, daylight is not the only source of light. The electric lighting fixtures were significantly developed and working hours have become longer.

Before the existence of artificial lighting, it was important to properly design for daylighting. Because of the shortage of daylight in northern Europe, especially in winter, large windows and high ceilings were used to provide sufficient natural lighting into the interior space. Different window designs were found in the southern countries due to the need to minimize heat gain during summer along with providing adequate natural lighting. Studies have found that incorporating a courtyard into a building design provided acceptable solutions to provide daylight into internal spaces (Phillips, 2004).

In the 20th century, architectural styles have been developed and at the same time maintaining the traditional design for daylight. However, the environmental aspects and energy conservation were not considered during the design process. Daylighting design was noticeably disregarded due to the wide use of low-cost fluorescent lamps. Many buildings were found to be poorly designed for daylighting, particularly between 1945 and 1975, when compared with historical buildings (Baker et al., 2013).

Around the turn of the 20th century, awareness towards daylight designs has been increased with the great influence of remarkable architects such as Frank Lloyd Wright, le Corbusier, Louis Kahn, and Louis Sullivan. These architects tried to integrate daylighting designs with the buildings' aesthetic values and functional requirements (Mazharuddin, 2000). Currently, many books, articles, and methods have been produced concerning the efficient utilization of natural light from the visual and aesthetic aspects, as well as energy efficiency views (Phillips, 2004).

It has become obvious from observations based on human behaviors that working and living space arrangement and research studies indicated that natural lighting is desirable by building occupants. Windows are important in buildings not only to provide adequate natural lighting but also to maintain a connection with the outside view. The quality, variability and spectral composition are additional important factors to illuminate spaces with daylight. Building occupants' reactions to indoor environments were reviewed and recorded. Occupants pointed out that natural lighting is preferred to fulfill two basic human visual needs. The first is the ability to perform a visual task and see the space well, whereas the second is to gain some environmental stimulation. People admitted that health is highly affected by the long-term working under artificial lighting. They believed that less stress and discomfort are major advantages of working in a space illuminated mainly with natural lighting (Hwang & Kim, 2011).

Good conditions to perform various visual tasks can be provided by daylight as high

illumination levels are delivered and excellent color rendering and discrimination are allowed. However, poor daylight designs can create reflections due to the very high luminance and discomfort glare interfering with good vision. Therefore, efficient daylight designs need to be taken into careful consideration at an early stage of the building design to get the full advantage of daylight while minimizing the problems associated with excessive daylight (Egan & Olgyay, 2002).

The main objective of this paper is to highlight the impact of daylighting on building occupants, particularly with regard to health, performance, productivity, and financial effect. Therefore, this study focuses on the influence of the utilization of available daylight in office buildings and schools because these types of facilities are mostly occupied during the daytime. Accordingly, this can provide a high potential to take the natural lighting benefits and advantages along with the reduction in the energy consumption.

2. BUILDINGS OCCUPANTS' PREFERENCES

Several studies have reported that the use of daylight to illuminate the indoor space is better than artificial lighting with relation to its impact on buildings' occupants. A study on the perceived attributes of windows was conducted in England and New Zealand using a survey questionnaire (Cuttle, 1983). Office workers responded to questions related to the importance of windows in the workplace and, if so, why windows are important for them and how. It was reported that almost all respondents (99%) prefer to have windows in their offices. At the same time, 86% of the surveyed respondents indicated that the most desirable source of light is daylight. They believe that health is highly affected by long-term working hours under artificial lighting. In addition, less stress and discomfort were found to be two major advantages of working in a space illuminated mainly with natural lighting (Cuttle, 1983).

In another related study, Heerwagen et al (1998) conducted a survey in an office building in Seattle in the USA in 1984 to investigate the occupants' reaction to daylight. The survey results indicated that more than 50% of the respondents believed that natural light is the best source of light owing to many factors such as psychological relief, visual comfort, general health, the appearance of the space, and color appearance of finishing and furniture. Respondents whose offices were not provided with windows strongly supported such views and perceptions than those with windows in their offices (Veitch & Newsham, 1998).

Similar data were obtained from a study on university students in Canada to investigate their preferences, beliefs, and knowledge about space illumination (Veitch et al., 1993). The study findings revealed that beliefs and perceptions about lighting influence on health were recognized by the majority of students (65-78%). Students confirmed that natural light has, in fact, many advantages over other light sources as 52% of the surveyed students mentioned that they did their work better in places, which were mainly illuminated by daylight.

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Back in 2006, another study was conducted to investigate the subjective problems and advantages related to the use of daylighting in office buildings (Galasiu & Veitch, 2006). The results are summarized as follows:

- Office workers strongly prefer daylight in their workplaces, associated mainly with the belief that better health can be supported by the use of natural lighting.
- Office workers overestimate daylight contribution to the overall illumination when both electric light and daylight are used.
- In general, people prefer larger windows in their offices.

Studies have proven that both students and teachers preferred classrooms filled with daylight and attractive views to the outside, which improves the students and the teachers' attendance and performance (Lechner, 2014).

3. THE IMPACT OF DAYLIGHTING ON BUILDING OCCUPANTS' HEALTH

Many studies indicated that building occupants' health can be maintained by the proper use of daylight. The U.S. Department of Energy conducted a study in 2000 to investigate the effect of daylight on office workers. The study found that staff with windows near their working spaces experienced fewer symptoms related to "sick buildings" by 20% compared with windowless offices (Franta & Anstead, 1994). It was reported that the appropriate use of daylighting can reduce the occurrence of eyestrain, headaches and Seasonal Affective Disorder (SAD). SAD and headaches can happen as a result of insufficient illumination levels. Therefore, the use of proper spectral light can improve the illumination level. Nevertheless, eye strain is regarded as a major health problem, which is associated with lighting conditions. Eye strain can be reduced by implementing the proper design and integration of daylight to provide the human eye with the best light spectrum (Heerwagen et al., 1998).

Another important influence of the efficient use of daylight is the improvement of office building occupants' positive moods. This can result in lowered absenteeism, work motivation, work involvement, and can increase job satisfaction as well. It was also found that discomfort and distraction were consequences of workers' negative moods, while their positive moods resulted in more daily activities such as social interaction among staff members and better physical setting at work (Plympton et al., 2000).

A report, which was published in 'The Management Review' in 1999, indicated that many health problems can result from the lack of light and particularly natural light. Health problems include, for example, maladjustment of our body clock (circadian rhythms), Seasonal Affective Disorder (winter depression or winter blues) and consistent periods of reduced productivity (Singh et al., 2010).

Many studies have suggested that the overall health and physical development of students and

teachers in classrooms can be promoted by proper utilization of natural lighting. In Sweden, a study on students of 90 elementary schools was carried out to evaluate the students' health, behavior, and cortisol (stress hormone) levels in four classrooms with a variation in levels of daylight over the period of one year. The results indicated that the absence or low level of daylight directly affected basic hormone pattern. Consequently, the students' ability to concentrate or cooperate was affected and eventually resulted in a negative impact on their body growth (Nicklas & Bailey, 1995).

A comparative study between students in classrooms with full spectrum light and students in classrooms with conventional lighting was conducted in elementary schools in Alberta, Canada. Fewer days of absence per year were recorded in the classrooms with natural lighting and the overall students' health was enhanced. The findings also indicated that lower cooling load and lower capacity of heating, ventilation, and air conditioning (HVAC) system were achieved with the efficient integration of artificial lighting with daylight. This resulted in a better learning environment due to the minimization of the noise levels in both the library and classrooms (Nicklas & Bailey, 1997).

4. THE IMPACT OF DAYLIGHTING ON BUILDING OCCUPANTS' PRODUCTIVITY

Office workers hold strong beliefs on the importance of lighting conditions in their working space environment. Workers' productivity can be negatively affected by unfavorable lighting conditions. However, it is quite challenging to accurately define productivity as a dependent variable in human performance studies. Productivity improvement takes place when people are able to perform their tasks faster, more properly, for longer periods, and without getting tired (Abdou, 1997). The results of the previous research in indoor spaces without windows vary according to the space function. In schools, an increase has been reported in students' absenteeism and lack of interest in windowless classrooms. People, in general, strongly prefer to have windows in their working places in office buildings (Edwards & Torcellini, 2002).

In 1996, renovation works were completed to improve the indoor lighting conditions' quality in the Reno Post Office in Nevada. The renovation was accomplished by the installation of better artificial lighting fixtures and the enhancement of delivered daylight into the indoor space. The findings revealed that an increase of about 8% in productivity was recorded in the first 20 weeks in the renovated building compared with the previous year (Romm & Browning, 1994).

Pennsylvania Power and Light found a drop of 25% in absenteeism rates, an increase of 13.2% in productivity and a decline of 69% in energy costs after upgrading the building to integrate more daylight than before (Franta & Anstead, 1994). In 1983, Lockheed Martin designers changed the layout of their offices in Sunnyvale, California to open offices' layout and install a lighting control system to integrate daylighting with artificial lighting. This has successfully improved the

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interaction among the staff and reduced levels of lighting energy consumption. An increase of about 15% in the contract productivity was recorded. This happened because of the effective integration of daylighting with artificial lighting. In the same vein, VeriFone Incorporation constructed a new Worldwide Distribution Center near Los Angeles, California with a better daylighting design. An increase of more than 5% in productivity was recorded for the first year and a half after moving to the new building in addition to an increase of 25-28% in the total product output (Edwards & Torcellini, 2002). In the early 1990s, West Bend Mutual Insurance built a new building for their employees. The constructed building was designed so that almost all spaces have windows for natural lighting with personal control over task lighting and indoor temperature. Accordingly, it was reported that productivity was increased by 2.8% as a result of the new workstations with personal control (Romm & Browning, 1994).

Another study, which includes four case studies, was conducted to investigate the effectiveness of students' performance due to daylight integration in their buildings. The results showed an increase in both students and teachers' attendance compared with schools with traditional illumination systems. It was reported that students progressed 26% faster in reading tests and 20% faster in math tests when their classrooms were mainly illuminated with daylighting (Plympton et al., 2000). In North Carolina, test scores of students in three schools with daylight integration were compared with scores in the region school system in general and other new schools within the region. The main results revealed that students, who have a daylighting system in their schools, performed better than those in non-daylight schools (Nicklas & Bailey, 1997).

5. THE FINANCIAL EFFECT OF DAYLIGHTING INTEGRATION WITH ARTIFICIAL LIGHTING

The cost of the initial construction of a building and employees' recruitment is large compared with the cost of operation, maintenance, and energy. The implementation of daylighting does not add much cost to the construction cost, operation or maintenance. However, it significantly reduces lighting energy consumption and associated cooling load. When the work environment in West Bend Mutual Insurance building was improved, an increase in profit levels was reported due to the improved productivity. It was reported that moving some of Lockheed Martin offices to a building with daylight integration has led to an increase in productivity and consequently financial savings were obtained. It was also reported that electricity bills were reduced and lower absenteeism was achieved (Romm & Browning, 1994).

The report, which was published in EPRI Journal in 1998, stated that buildings with better daylighting designs can have up to 20% higher rental income than buildings that use electric lights only. The Environmental Design and Construction (2001) mentioned that the value of a property can be significantly increased when energy-efficient building designs are incorporated. This can be attributed to lower operation and maintenance costs (Franta & Anstead, 1994).

Furthermore, it was found that the improvement of daylighting in schools did not essentially result in an increase in the construction cost of the school or operation. The initial capital cost can be reduced when daylight is properly integrated using a suitable lighting control system, and improving electrical and mechanical systems due to the decrease in lighting and cooling loads. In addition, lower electrical load and less number of lighting fixtures will reduce the costs of operation and maintenance (Nicklas & Bailey, 1995).

6. CONCLUSION

Great importance is placed on construction and maintenance costs when designing buildings. These buildings will be occupied by real people, and therefore, their psychological and physiological needs should be given priority. The occupants' performance will be improved as a result of their health improvement, which benefits employers and building owners.

It was concluded that natural light has a positive impact on the building occupants' performance, productivity, and their health as well when daylighting systems are properly designed, installed and maintained. Good health can be maintained and some medical disorders can be remedied through the effective use of natural light. Natural light creates a pleasant environment, which can result in lower stress levels of office workers. The better health employees have, the higher their productivity rates will be. The financial benefits for the employers are considered as direct results of a better work productivity. In addition, the performance of students will surely be better in classrooms with natural light. Studies have shown that students scored higher in natural-lighting-illuminated classrooms compared with students in poorly daylight-designed classrooms. In addition, students' health can be enhanced with better daylighting designs due to an increase in vitamin D intake. Students will grow stronger bones and they will have fewer dental cavities under full-spectrum lighting. Studies have shown that indoor lighting conditions have a strong influence on people in different environments from different aspects. Therefore, the effects of natural lighting on building occupants should be carefully considered at an early stage of the building design. Eventually, satisfaction for both building occupants and owners can be fulfilled through more efficient designs of daylighting.

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