Publication XI

Juslén H. 2006. Lighting and Productivity in the Industrial Working Place. Proceedings of Fifteenth international symposium, Lighting Engineering Society of Slovenia. Lighting of work places. Slovenia, Bled. 53-62.

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LIGHTING AND PRODUCTIVITY IN THE INDUSTRIAL WORKING PLACE

Abstract

Lighting-related parameters like visual performance and alertness, together with motivation, are assumed to influence productivity, wherever productivity is related to human performance. To test the impact of lighting level on productivity five case studies were started in 2003 and 2004. Studies have been finalized and a number of conclusions can be drawn. Lighting influences productivity if productivity is related to human performance. Productivity increases as illuminance levels rise. This paper considers also the question: "What happens if we change and improve the lighting in an industrial workplace?" Installing a new system of illumination in the workplace can affect the individual's performance level in a variety of ways. The following mechanisms are described and discussed: visual performance, visual comfort, visual ambience, interpersonal relationships, biological clock, stimulation, job satisfaction, problem solving, the halo effect and change process.

Povzetek

***Razsvetljava in produktivnost na industrijskih delovnih mestih**; Za parametre, povezane z razsvetljavo, kot sta na primer vidna sposobnost in budnost oziroma motivacija, velja da vplivajo na produktivnost v kolikor je le-ta povezana z človeškim delom. Da bi preverili povezavo med nivojem osvetljenosti in produktivnostjo, smo v letih 2003 in 2004 izvedli pet študij. Iz rezultatov študij lahko zaključimo: razsvetljava vpliva produktivnost, če je le-ta povezana s človeškim delom ter produktivnost se poveča s povečano osvetljenostjo. Članek pa obravnava tudi vprašanje: »Kaj se zgodi če spremenimo oziroma izboljšamo razsvetljavo industrijskega delovnega mesta?« namestitev nove razsvetljavne naprave na delovnem mestu lahko vpliva na delavčevo delovno sposobnost na različne načine. V članku so opisani sledeči mehanizmi: vidna sposobnost, vidno udobje, vidno okolje, medčloveški odnosi, biološka ura, stimulacija, zadovoljstvo ob delu, reševanje problemov, odmevni učinek in proces sprememb.*

1 Mechanisms in the description of the effect of changing the lighting

In order to determine the size of the effect that a lighting change might have on productivity and viability, particular attention can be drawn to the possible reasons for an increase in productivity. Previous field studies (Ruffer, 1925 and 1927; Schneider, 1938; Goldstern and Pudnoky, 1931; Bitterli, 1955; Stenzel, 1962a and 1962b; Crouch, 1967; Lindner, 1975; Carlton, 1980; Buchanan et al, 1991; Völker, 1999) have indicated an increase in productivity levels following an improvement in the system of illumination. Of course the reason for this increase is not necessarily only to be found in the improvement in visual performance levels.

On the basis of a literature search with the focus on light, biology and psychology, it has been possible to develop a model to describe the effect of a lighting change on profitability (Juslén and Tenner, 2005).

The model is illustrated in Figure 1. Light can affect human performance levels through visual and psycho-biological channels. In addition, changing the lighting affects the performance level when emotional and psychological reaction is taken into account. Just how much effect the mechanisms have on performance levels may be different for different people. In industrial work environments human performance level is linked directly to profitability. The costs for the installation and the effect on visiting customers will also influence the profitability of the lighting change.

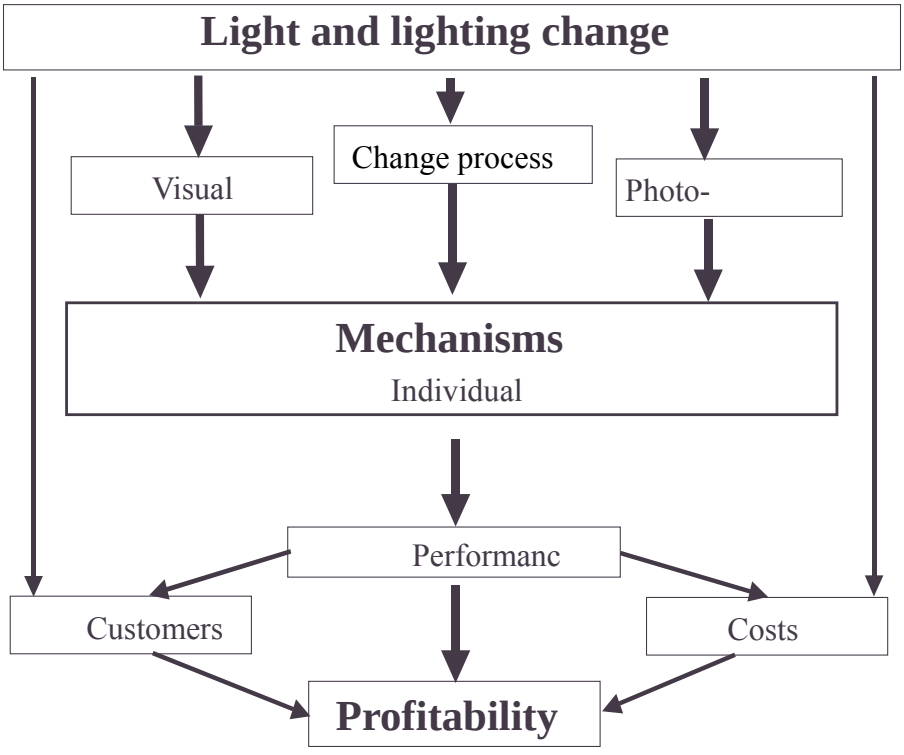

Figure 1. Model showing the effect of a change of the lighting on the profitability in a work environment. (Juslén and Tenner 2005)

A change in the lighting can be effected by modifying the artificial light as well as the quality of natural daylight. Many previous studies show the effect on worker performance level of a change of illumination. This effect is the combination of a variety of mechanisms. When lighting is changed (improved), increased performance level can be achieved using the mechanisms described below. Using the above-illustrated model these can be categorised as visual and photo-biological mechanisms and mechanisms related to the process of change. However, this categorization is conceptual and the origin of mechanisms might vary. For example, stimulation might be sometimes resulted via the visual channel, not biological.

Visual

1. Visual performance
   People are more productive when they can better see what they are doing

2. Visual comfort
   Reduced glare improves performance level through higher levels of concentration

3. Visual ambience
   Illumination has an effect on visual surroundings which are part of the work environment. In turn this affects performance level.

4. Interpersonal relationships
   The way people physically see each other will influence their opinions of each other and this can impact teamwork and therefore productivity.

Photo-biological

5. Biological clock
   Light has an effect on the biological clock, which controls the circadian rhythm and thus at particular periods of time performance levels.

6. Stimulation
   Light stimulates psychological and physiological processes which will affect performance levels.

Process of change

7. Job satisfaction
   Improving the illumination as a means of recognising someone's work can in some circumstances improve work satisfaction. Further more, improvement can result by providing individual control of the system of illumination ("autonomy"). Job satisfaction affects productivity.

8. Problem solving
   By solving problems which have led to complaints improves the feeling of wellbeing and helps motivation. These feelings are directly linked to performance levels.

9. The halo effect
   The halo effect derives from a belief in the superiority of new technologies or products resulting in improved productivity.

10. The change process
    Good change management supports the positive effects of a lighting change.

If improving the lighting situation has an effect on productivity, as demonstrated by most studies, how long does this effect last? The mechanism model can provide a first approximation. If the reason for an increase in performance levels is the visual or photo-biological aspect or a combination of these mechanisms, it can be concluded that the effect will be long-term, assuming that no other variables reduce the performance levels in this time period.

It is more likely that psychological effects resulting from the process of change will decrease with time, depending also of course on other influences on the person. The "autonomy" aspect (see point 7 – job satisfaction), i.e. the individual's ability to control the lighting in the workplace, is more likely to have a lasting effect. If more positive steps are to be taken by an industrial business, these changes can be a link in the extended chain.

2 Case studies in an industrial environment

Five field studies were carried out in various European countries in order to determine the effect of the lighting change on productivity. Table 1 gives an overview of the study methodology and the results.

The studies are based on the mechanism model (Juslén and Tenner 2005). By selecting a variety of field studies, the mechanism to describe the effects of a change in illumination on productivity could be investigated in real industrial environments.

As already stated, the visual and photo-biological mechanisms which lead to an improvement in performance levels have a long-term effect. The effects from mechanisms associated with the process of change can decrease over time. For this reason long-term studys were carried out such that the effect of the "change process" (mechanisms 7 to 10) would be minimised. As a result the studys are focussed on the visual and photo-biological mechanisms.

The case studies treated communication with other people as a subordinate task, so that the point "interpersonal relationships" (4) was not investigated and is not included in the evaluation.

In each of the working environments investigated, normal industrial activities were carried out and no special arrangements were made. The methods of study and techniques for measurement of productivity were adapted to meet local conditions. For example productivity was measured by assembly time or number of errors. Fundamentally the results show an improvement in productivity with increased levels of illumination.

It is necessary to conduct long-term studys in order to obtain reliable practical data. In each study the productivity measurements were made under varying conditions of illumination and over a long period of time using a fixed group of employees. In 4 of the 5 studies ANOVA (Analysis of variance $r<0.05$) was used in order to determine the significance of the change in productivity. In the final field study (see E below), a before and after study, no statistical method was employed. A reference group was used in 3 of the 5 studies.

A. In study A the workstation of the employees in a Finnish luminaire factory were fitted with a new overhead controllable lighting system (task lighting). The old task lighting was not controllable. Each user could freely choose the level of illumination within the range 100 lx to 3000 lx. The productivity (in this case assembly time) of the test group was compared with the productivity of a reference group provided with a workplace illumination level of 700 lx (Juslén et al, 2006). The productivity of the test group was significantly increased (4.6%) when measured against the reference group. There was a weak statistically significant correlation between the level of illumination and the productivity of the test group.

B. Study B was carried out in a German luminaire manufacturing company. A section of the employees was provided with a new, controllable lighting system for their workplaces (task lighting), allowing them to adjust the illumination level in the range 100 lx to 900 lx in addition to the general illumination level of 250 lx. The illumination was selectable as a colour temperature of 3500 K or 4400 K. The lighting situation at switch-on was varied at intervals of several weeks using the following combinations: high level of illuminance with low colour temperature, high level of illuminance with higher colour temperature, low level of illuminance with higher colour temperature and low levels of illuminnce with low colour temperature. The users could modify the level of illuminance but not the colour temperature. The result was that the illuminance levels chosen by the users were set 5% higher at higher colour temperatures. Productivity (assembly time) was recorded for each preset switch-on value. In this study the higher colour temperature had a positive effect on productivity (5.7%), the illuminance did not.

C. Study C was carried out in a Dutch electronics company (assembly of electronic components). Work was done in shifts. The illumination levels at the assembly desks came from the general illumination and were re-set for each shift to a level of 800 lx or 1,200 lx. Productivity (assembly time and number of errors) was measured on scanners, which recorded production time and errors (Juslén and Fassian, 2005). On both shifts productivity increased with increased illumination (3% and during night shift 7%).

D. Study D was carried out at the packing line of a Dutch food manufacturing company. The general illumination level before and during the study was approximately 300 lx. An additional, local lighting was installed and the level of local lighting set alternately to 50 lx or 1,700 lx on a weekly basis. The rate of absenteeism of the test group was compared with that of the reference group (no additional workplace lighting). The rates of absenteeism of the test group were 17% lower than that of the reference group. In order to measure productivity the repair time on the machines was recorded as representative of the productivity levels of the employees. The test group increased productivity by 3%, although it should be noted that the difference was only significant for one particular type of error and for one of the shifts only.

E. In study E the lighting conditions in a Dutch luminaire factory were modified. Local illumination was introduced and the level increased from 500 lx to 1,050 lx. Productivity and absenteeism were measured for the test group and compared with the reference group before and after the change (Juslén und Kremer, 2005). In this study, carried out before and after the change, productivity increased by 5.5%.

	A	B	C	D	E
Type of work	Luminaire assembly	Luminaire assembly	Electronics assembly	Machine maintenance	Luminaire assembly
Location	Finland	Germany	the Netherlands	the Netherlands	the Netherlands
Number of people in test group	21	25	35	26	42
Local Illumination levels	100 – 3,000 lx	100 – 900 lx	-	50 – 1,700 lx	700 lx
General Illumination levels	250 lx	250 lx	800 lx / 1,200 lx	300 lx	350 lx
Reference group	Yes	No	No	Yes	Yes
Reference group illumination	700 lx	-	-	300 lx	500 lx
Changes on local illumination	User selection	User selection	-	Regular changes	Increased once
Changes on general illumination	-	-	Regular changes	-	Decreased once
Shifts	Day	Day	Day/eve/night	Day/eve/night	Day
Length of study	1 year	8 months	2 x 2 months	5 months	Before/after
Change in productivity as a result of changing illumination	4.6 %	Not significant	Morning: 3 % Evening: 3 % Night 3%	3 %	5.5 %
Change in productivity as a result of colour temperature	Not measured	5.7 %	Not measured	Not measured	Not measured
Change in error rate	Not measured	Not measured	Not significant	Not measured	Not measured
Change in absenteeism	Not measured	Not measured	Not measured	-17 %	-2.5 %

Table1. Overview of the methodology and the results of the productivity studies

3 Discussion

The variations in the studies were designed so that the mechanisms for defining the effects of changes in illumination on productivity could be investigated in real industrial environments. However, it appears difficult in practice to determine the effects of different mechanisms on worker productivity independently of one another.

Nonetheless, the effect of some mechanisms can be evaluated on an approximated basis or rejected. The evaluation for each study is considered individually below.

The test subjects in study A were provided with a new system of illumination for their workplaces and according to the questionnaire (Juslén et al 2005) expressed themselves as satisfied with it. Although the lighting installation was changed, and the initial increase in productivity could be related to the “process of change” or the “halo effect”, these effects could not be long term and would become ineffective during the study time of 1 year.

The employees were able to set their own levels of illumination and thus the “autonomy“ aspect (work satisfaction) could have an influence on productivity.

It is also possible that the photo-biological mechanisms, “biological clock” and “stimulation”, could have an effect in this case. The effect of using higher levels of illumination during daytime could strengthen the circadian rhythm thus improving sleep and thereby performance levels during the day.

In study B productivity increased when the colour temperature was increased. The “change process” mechanism within the framework of various test situations is discussed below. Since the illumination levels set by the users for different colour temperatures were almost the same, we can conclude that the “visual” mechanisms most probably did not have strong effect. This study therefore concentrates on the “photo-biological” mechanisms. This is in agreement with the results of previous studies, which indicate that a higher colour temperature increases the attention span of the worker (Fleischer 2001).

The results of study C are relatively clear. The increase in productivity at higher illumination levels (1,200 lx as against 800 lx) was observed on all shifts. Since the general level of illumination was only changed between shifts, it is very unlikely that the “visual surroundings” and the “visual comfort” have had any influence. For the same reasons (varying levels per shift), and because the test persons were unaware of the studies and the methodologies, the “process of change” can also be eliminated. The most likely effective mechanisms in this study are “visual performance levels” and “stimulation”.

The work carried out in study D deviates considerably from the work carried out at the other locations. Small reduction in repair time was observed. In retrospect it has been established that the repair time – the only possible measure of productivity – is not necessarily a representative yardstick for performance.

However a large decrease in absenteeism was observed. This would suggest some effect from the mechanisms “job satisfaction” and “stimulation”. Both have an indirect effect on the total performance of the department.

Study E is a typical “before and after” study. The illumination was changed once and the measurements made before and then after the change. The reasons for the increase in productivity in this study is not discussed here, since not all aspects could be brought under complete control, even by bringing in a reference group.

4 Conclusions and recommendations

From the evidence of the studies described above, it can be concluded that a change and improvement in lighting can have an effect on productivity. By increasing illumination levels it is possible to increase a person’s productivity. It is difficult to predict the extent of this effect since the starting conditions, the final installation, the people involved, the nature of the work and the process of change all influence the result. Nonetheless taking account of the mechanisms can help to evaluate the importance of various aspects and to channel the applied effort in the correct direction. Changes in illumination can be implemented by various means and an increase in productivity achieved using the above-mentioned ten mechanisms. Lighting changes should be an integral part of a management process. It can have direct and indirect effects on productivity. Indirect effects such as wellbeing, alertness and reduced absenteeism are important goals. However, it is the direct goals such as reduced process times, higher output or increased production quantities which are the priority, since they are on the one hand more easily measured and on the other provide quick commercial gains. The following recommendations are intended for practitioners involved in lighting change.

1. **Study the present conditions.** Inform people that the planning of the lighting change is going on. Give them a possibility to influence, use unofficial interviews, questionnaire with also open questions or presentation in workers meeting. Using only questionnaires with multiple choices is not reliable way to estimate if people will benefit of the lighting change. Important questions to be answered are: What kind of lighting there is now? Is there something complained by people? Is something blocking the productivity (speed of the machine, salary system etc.)? What and where are the tasks?
2. **Create a plan.** In case something is blocking the productivity increase, try to find way to overcome the reason or take into account that direct productivity results cannot be achieved. Use mechanism model to evaluate the effects (direct and indirect) of the lighting chance and to plan a new lighting. Take into account possible needs for presenting working areas to customers as well as the needs for flexibility together with good energy management. Figure 2 shows a form that could be used as discussion tool with customer or as a check list. Consider using localized lighting and giving control to workers. Use norms and codes, but do not afraid to make better lighting installation than minimums according norms.
3. **Make a change.** In case lighting change seems to be a reasonable investment, do it by involving people and follow the process to be able to correct possible misunderstandings or installation errors.
4. **Evaluate the results.** Evaluating the results is important since maybe something was forgotten during the process and can be corrected also later. On the other hand designers or other parties involved the change, need feedback to be able to learn from the process.
5. **Make corrective actions and/or close the project**

Check list for the base of the lighting design **(workplace lighting)**

Mark the importance of the following items to the list

0 Not important at all
3 Very important

Visual performance (How well we are able to see)	0	*(Use lower maintained lighting level than defined in norm)*
	1	
	2	
	3	*(Use higher maintained lighting level than defined in norm.)*
Visual comfort (How comfortable it is to look)	0	*(Use solution, which is just according minimums in norm.)*
	1	
	2	
	3	*(Concentrate on optics and glare limitation & indirect lighting)*
Visual ambience (How the environment looks like)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(Add some ambience and accent lighting)*
Interpersonal relationships (How people work together)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(Concentrate on vertical illuminance and colour rendering)*
Biological clock (when we are awake)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(High lighting levels and/or special spectra as on option.)*
Stimulation (How alarm we are)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(High lighting levels and/or special spectra as on option.)*
Job satisfaction (How happy we are for our work)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(Clear lighting improvements and consider using personal control)*
Solving problems (Is there something so wrong)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(Correct the problem and make note of it)*
Change process (How to do the change)	0	
	1	
	2	
	3	*(Always important to inform and involve people)*
Flexibility (is the purpose of the space always same)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(Take flexibility under the consideration)*
Customers (Does it matter how visitors see the space)	0	*(Do nothing special for this purpose)*
	1	
	2	
	3	*(Use higher lighting levels and consider shop type solutions)*

Total

0 Standard 11 22 Demanding 33

Figure 2. Lighting change estimation form. (Customer and designer can together estimate if presented issues are important in the premises where people are working. It gives also some very simple recommendations if the importance of the issue is clear. Total points give an indication of complexity of lighting design.)

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