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Paper

The Use of Task Lighting in an Industrial Work Area Provided with Daylight

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ABSTRACT

A dimmable task lighting system was installed at six working places in a luminaire factory in France. The factory hall had skylights that provided a lot of daylight. The purpose was to study which illuminances users select, how often they use additional task lighting, whether they liked the lighting system and if their selections were influenced by the amount of daylight or the type of work. The workers were free to use the task lighting in any way they wanted. The settings of the task lighting were recorded between the winter of 2004 and the spring of 2005. The opinions of the users were sought by means of questionnaires after the testing period. It was found that those workers who worked in the area on more than 20 days in the testing period used the task lighting (viz. switched it on) on average only during 6.5% of the total working time. The task lighting was used more frequently during the times when the amount of daylight was limited (darkness or dark weather) and less frequently when there was more daylight in the area. And the task itself also had an influence on the preferred illuminance, and hence on the frequency of use of the task lighting. The preferred horizontal task illuminances supplied by the task-lighting luminaires varied from person to person, with an average of around 600 lux. The users expressed the wish that they wanted to keep the system after the test period, and 41 per cent of the users felt that the task lighting helped them to perform better.

KEYWORDS: industrial lighting, skylights, preferred illuminances

1. Introduction

Many industrial environments do not have any windows. A typical industrial hall is large; and even if there are windows, the amount of daylight they provide is usually limited. Furthermore, the possible locations of the windows are mostly not very good for offering a view out (and mostly the view is not nice). Daylight in an industrial hall is typically provided by skylights. Many older industrial halls in particular have sawtooth-shaped roofs, with window openings located in the vertical surfaces. Another, quite-often employed solution in newer flat-roofed halls is to provide daylight by some form of plastic-bubble skylights. However, skylights are more expensive to build than simple flat roofs, and they can give rise to problems with heat and water leakage. For these reasons they are not used on a large scale in Europe.

The common way to light an industrial interior is to use uniform general lighting. Task lighting is sometimes used for special tasks, but such lighting is generally not dimmable. In those places where task lighting is present, it is usually controlled by an on/off switch. Table luminaires are sometimes used in very fine assembly work, giving the user the opportunity to influence the direction of the light as well.

During the last ten years more research has been done for office lighting than for industrial lighting, although many people are working in an industrial environment. In office-lighting studies, where lighting-control behaviour has been studied[1)-7)], daylight was usually available. Hunt (1980) found that the probability of employees switching on the artificial lighting in a daylighted space was most closely related to the minimum working plane illuminance. It has also been found that office workers are satisfied with controllable lighting systems, even though they use lighting levels below the minimum required by the standards[3)]. The lighting-control behaviour of workers has also been studied for industrial workers, but in an area without daylight[8)]. The workers always used the task lighting and preferred lighting levels between 300 lux and 3000 lux.

The factory in which the study described in this paper has been performed, and in which dimmable task lighting was installed, has a lot of daylight. The amount of daylight in the present study varied more and had

higher maximum values than in the typical office-environment studies, where daylight is provided by way of windows. In this study, the daylight enters the working area through skylights. So both the direction of the light and the view out are different from the those found in offices. Furthermore, the type of work found in offices is different from that carried out at industrial assembly tables.

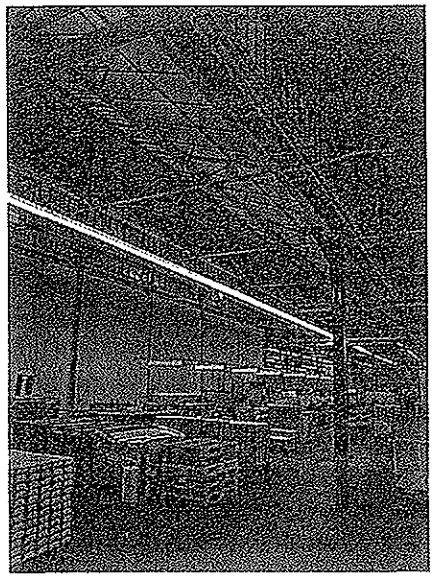
The purpose of the study was to find out the preferences of industrial assembly workers for task lighting in a condition where a lot of daylight was available. The questions to be asked were: 1. What kind of task lighting levels users select? 2. How often is the task lighting used? 3. Does the amount of daylight or the type of task have an influence on the selected illuminance or on the use of additional task lighting? 4. Is the additional task lighting liked by the users?

2. Experimental set-up

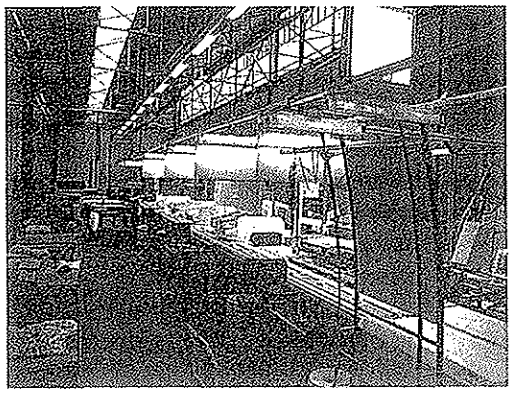
2.1 Lighting and data logging

A task-lighting system was installed at six workstations in a luminaire factory in France. Two luminaires (2*54 W T5, 4000K, low-luminance optics) were installed crosswise above each test workstation. The users had the opportunity to control the task lighting by infrared remote controllers when and how they wanted. The voltages employed to control the lighting were recorded and transformed to illuminances by using formulas based on measurements. At the beginning of every break, the task lighting was automatically switched off. In the factory hall there were three identical production lines, one of which was used and equipped for the test. The other lines were used as reference. There was no task lighting before this test. The general lighting (4000K) was controlled by a daylight sensor (three control levels: 0%, 50%, and 100% light output). The general lighting could provide approximately 320lux (100%) on the tables. 300lux was also guaranteed as a minimum level, since the 50% dimming only occurred when the daylight provided more than 300lux in the area. In addition to that, the task lighting provided between 800 and 1500lux on the different work tables.

Figures 1(a) and (b) show the test area. Figure 2 describes area with measures. To limit the influence of the task light on the adjacent workstations, grey plates were installed between the assembly stations to block the light. A lot of daylight came from large horizontal and vertical skylights in the area. The vertical skylights are north facing. During the summer months, users complained about the heat and the amount of sunlight, so a white curtain was installed below the horizontal skylights. Two luxmeters were installed in the test area, one on top of the task-lighting trunking and one below the vertical skylight. Both were measuring values up to



(a)



(b)

Figure 1 A and B Test area with skylights

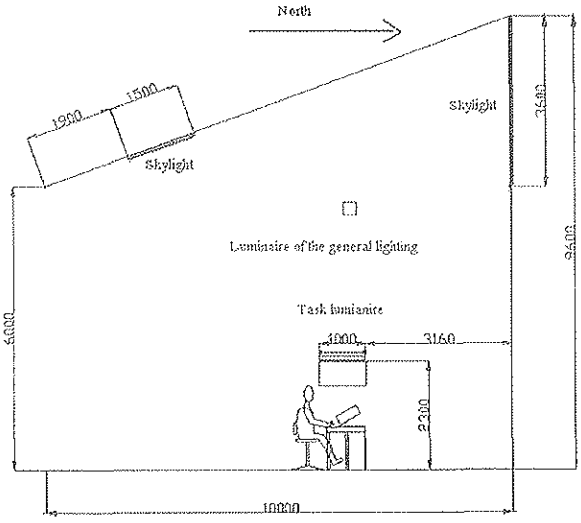


Figure 2 Illustration describing task area, skylights and artificial light

around 10000lux during the measuring period. As Figures 1 and 2 show, the task-lighting installations were blocking the general lighting and the daylight, but the daylight still provided thousands of lux on the tables on a sunny day. Daylight and the amount of task lighting employed were recorded between the winter of 2004 and the spring of 2005. During this period, a record was kept of who was in which workstation and when.

2.2 Work

The production area shown in Figure 2 is a manual assembly line. The tasks were mainly in the horizontal plane. The work was the normal industrial work and had not been adapted because of the test.

There were six workstations in the line. The first four were assembly stations, the fifth was a testing station, and the last (sixth) was a packaging station. In the assembly stations, different components, such as wires and lamp caps, were mounted in the luminaire frames. The frame was then moved to the next assembly station, where more components were installed. The speed of the line was defined by machinery before the line. At the fifth station, the luminaire was tested. Here the worker had to connect the supply voltage to the luminaire and check if a test lamp on a vertical plane above his/her head lit up. At the packaging station, a worker put the luminaire into a cardboard box.

The first assembly workstation was always occupied by two persons, one at each side of the table. Here the illuminances employed was chosen by the worker who was on the side of the table where the infrared controller was located. The other stations were individual stations, with one person working at each. In the European standard EN 12464-1 (2.6 Electrical Industry, 2.6.2 Assembly Work, Medium), the minimum illuminance required for this kind of work is 500lux (maintained).

Depending on the work load, there were one or two shifts per day. There was a break approximately every one-and-a-half hours, and after the break the workers changed to another workstation. In total, 72 persons worked in the test area during the measuring period. However, many of them were present only on particular days.

2.3 Questionnaire

After the test period (April 2005), questionnaires were distributed amongst the workers involved. The first two parts of the questionnaire were devoted to the working environment in general, while the last part contained specific lighting-related questions.

3. Results

3.1 Questionnaire

Thirty-four workers completed the questionnaire. The means and standard deviations of the first part are given in Figure 3, where we can see that the décor was not considered to be important in a factory environment. Low sound level, good ventilation, windows, much light, much space, and comfortable temperature were seen as important aspects in a work environment.

Figure 4 shows how workers have evaluated their own environment. Most of the aspects are stated to be slightly positive —"Bright" being the most positive characteristic of the environment. Compared to Figure 3, where "low sound level" was considered to be the most important issue in the working environment, it is interesting that "quiet" is now stated to be clearly negative. Also "warm", "cosy" and "spacious" are stated to be on the negative side.

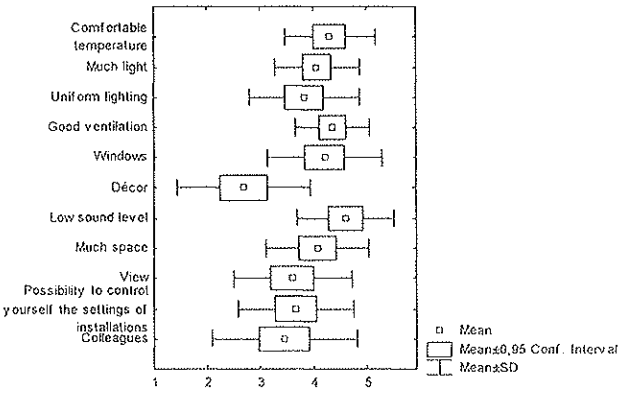


Figure 3 Answers to the question: "Please indicate how important the following characteristics are for you in a factory environment". The order of the characteristics is same as in the questionnaire (1 not important, 5 very important) (The "box" shows the 95% confidence interval)

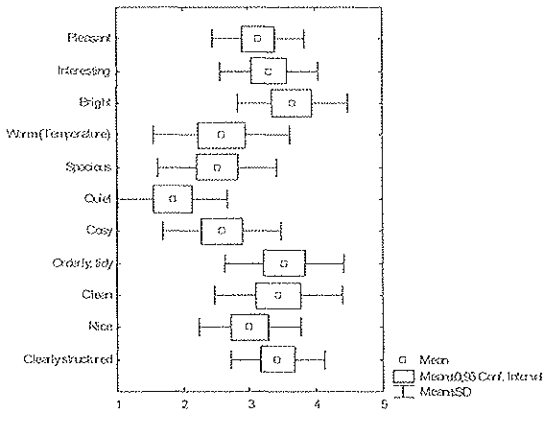


Figure 4 Answers to the question: "What is your general impression of your working environment?" The order of the characteristics is same as in the questionnaire (1 very negative, 2 negative, 3 neutral, 4 positive, 5 very positive) (The "box" shows 95% confidence interval)

Figure 5 shows the answers to the different questions concerning the lighting. It is clear that most of the subjects know how to use the task lighting and that they would prefer to keep the system. The answers also indicate that they would like to have more daylight. Distinguishing colours is not considered a problem for the workers.

Figure 6 shows the answers to the questions about the (use of) controllable task lighting. Looking at the "black" bars, it can be seen that 14 users felt that task lighting helped them perform better and six disagreed (and 14 had no opinion). The "white" and "dotted" bars indicate how many workers have used the task lighting never or often, respectively.

3.2 Use of the task lighting

Figure 7 shows the use of the task lighting system for the different workstations. The task lighting system has been used most in the "testing" workstation. One-way ANOVA (Analysis of Variance; dependent variable: use of lighting, factor: workstation) and Tukey's HSD (Honestly Significant Differences) yielded that the difference is significant ($p<0.05$). The task lighting was never on at all the workstations at the same time for the whole working period between two breaks. During 54.5% of the time that task lighting was used, only one person at a time was using it (23% two persons, 15% three persons, 6% four persons and 1.5% five persons). This indicates that using the task lighting was a clear individual choice, not an action influenced by other users switching the lighting on.

The location of the luminaires with respect to the working area was different for every workstation, which resulted in different maximum task-lighting illuminances for each workstation. In Figure 8 these maximum task-lighting illuminances (maximum light output) are plotted as bars. In the same figure, the average illuminances employed have been plotted by dots. One-way Anova (dependent variable: illuminance, factor: workstations) and Tukey's HSD were performed to test the differences between the selected illuminance values at the different workstations.

The selected illuminances at "Assembly 1" are significantly different ($p<0.05$) from the selected illuminances at assembly 2, 3 and 4. The selected illuminances at "Assembly 2" are significantly higher ($p<0.05$) than at the other workstations. The selected values at "Assembly 3 and 4" are significantly lower than for the other stations ($p<0.05$). The selected values at "Testing" and "Packaging" are different from the other stations ex-

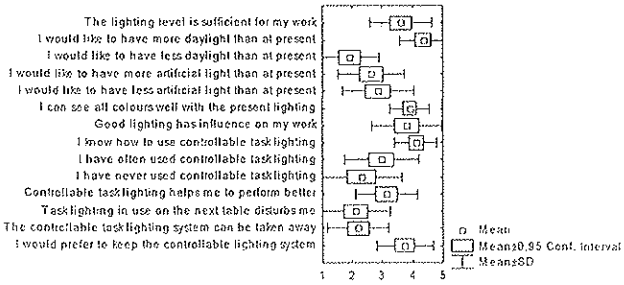


Figure 5 Answers to the lighting related statements. The order of the characteristics is same as in the questionnaire (1 totally disagree, 2 disagree, 3 no opinion, 4 agree, 5 totally agree) (The "box" 95% confidence interval)

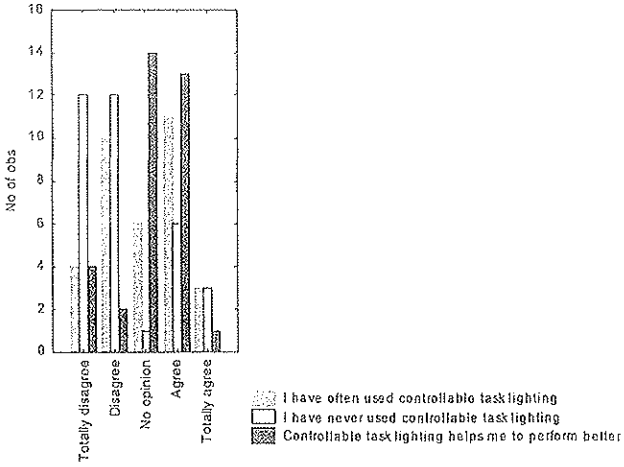


Figure 6 Distribution of the answers to a selection of the questions

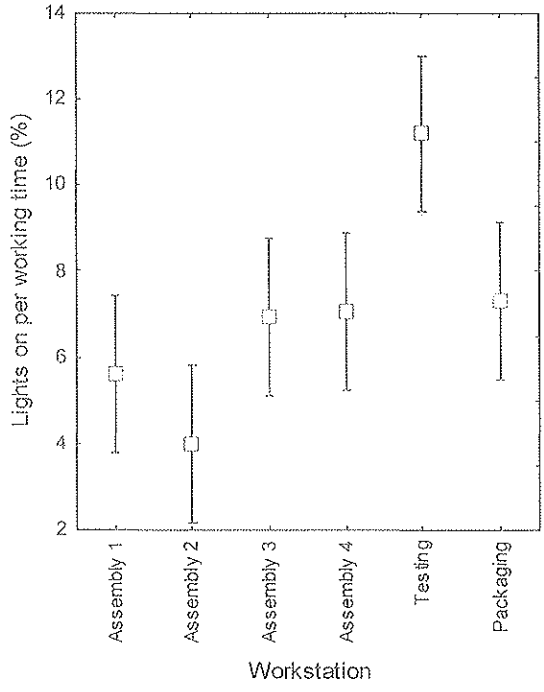


Figure 7 Percentages of total working time the lights were on per workstation (Vertical bars denote 0.95 confidence intervals)

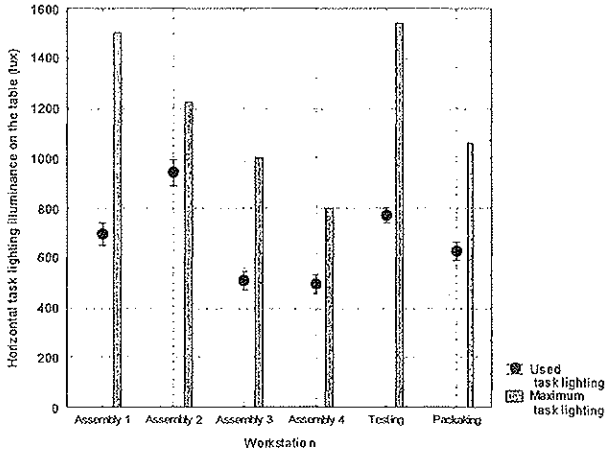


Figure 8 Average task lighting levels employed and maximum task lighting levels per workstation (Vertical bars denote 0.95 confidence intervals)

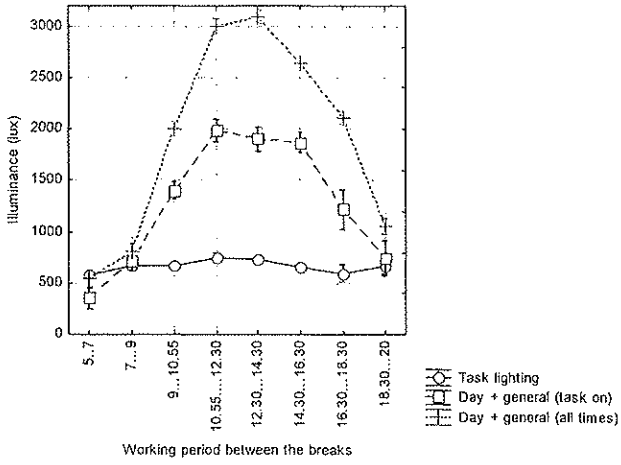


Figure 9 Average illuminances per working period for all work stations. Upper curve (plus marks) shows the average daylight + general lighting illuminance on the top of the task-lighting luminaires for all times that people were working in the area. The middle curve (rectangles) shows the average daylight + general lighting illuminance measured on the top of the task-lighting luminaires for the time that the task lighting was switched on. The lower curve (circles) shows the average illuminances on the table

cluding "Assembly 1".

At "Assembly 2" the users selected illuminance values that were quite close to the maximum for that workstation. At "Assembly 1" and the testing station the maximum illuminance was high but the workers used only half of the possible light.

As can be seen from the dotted curve in Figure 9, the chosen illuminances were slightly higher during midday than during the evening and morning. The differences are, however, relatively small. The upper curve (marked +) shows the general lighting plus the daylighting for all working times. The middle curve (marked by rectangles) shows the general lighting plus the daylighting for those periods when someone was using the task lighting.

Factorial ANOVA with dependent variable illuminance daylight + general light and factors task lighting (on or off) and working periods showed:
a significant main effect for the factor task lighting:

$F(1, 22942)=256, p<0.0001$

a significant main effect for the factor working periods:

$F(7, 22942)=287, p<0.0001$

a significant interaction between task lighting and working period:

$F(7, 22942)=17, p<0.0001$

Tukey HSD pairwise comparison was used to compare the differences in daylight + general lighting between the times when the task lighting was switched on and the times that the task lighting was not switched on. Except for the periods between 5:00 and 7:00, 7:00 and 9:00 and 19:30 and 20:00 the daylight + general lighting levels were significantly lower in the cases when the task lighting was switched on than when it was not switched on. Looking at the simple main effects, there was a significant effect for task lighting. The average value of daylight + general lighting was 1270 lux (task lighting excluded, measured on the top of the luminaire) for the times that the task lighting was switched on and 1900 lux when it was not switched on. So task lighting was used less frequently when the daylight level was high.

In Figure 10 the results are shown of One-way ANOVA (dependent variable: use of lighting, factor: time of the day). Tukey's HSD showed ($p<0.05$) that the task lighting was used significantly more frequently in the early morning and evening (5:00 to 7:00 and 18.30 to 20:00) than during the midday hours (10:55 to 14:30). In Figure 9 we were able to see that the amount of daylight was significantly less during the early morning and evening than at midday. Figure 10 confirms that the amount of daylight influenced the frequency of use of the task lighting. The task lighting was used more frequently when there was less daylight in the area.

Figure 11 shows that the chosen lighting levels were quite uniformly spread. Of the 23 persons (average age

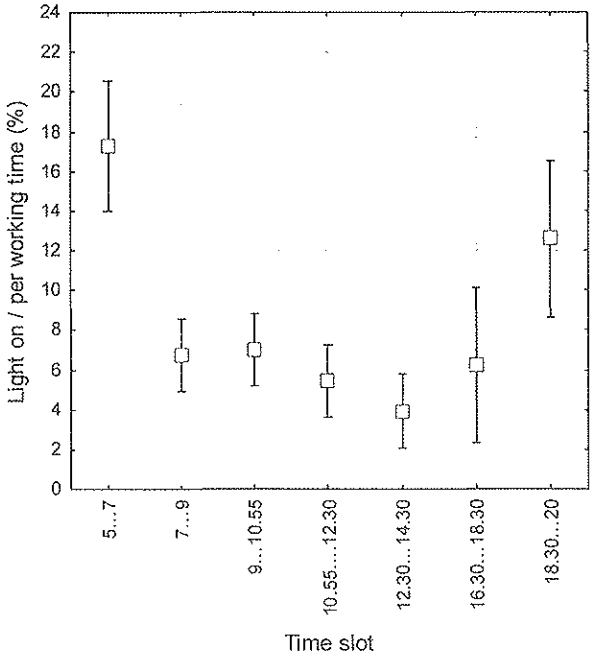


Figure 10 Percentage of total (working) time that the task lights were on, per working period for all work stations (Vertical bars denote 0.95 confidence intervals)

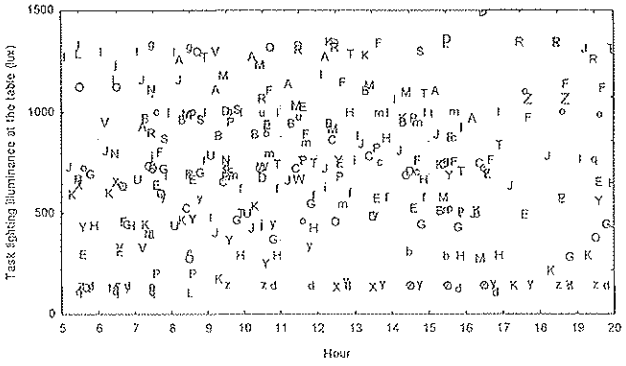


Figure 11 Average task lighting level per hour for the users who were in the area for more than 20 days, for all work stations (different letters denote different persons)

35: 3 men, 20 women) who were working in the area longer than 20 days, only one did not use the task lighting at all. The average task lighting level for those 22 persons who did use the task lighting and were present in the area for more than 20 working days was 610 lux, and the percentage of use was between 1% and 27% (average 6.5%) of the time.

The low frequency of use of the task lighting together with the huge differences between persons limit the possibilities to analyse the illuminance differences per seasons, weeks or days. For those 22 subjects just mentioned, there was no significant correlation between age and average illuminance used ($r=0.05$, $p=0.79$) or between age and percentage of use ($r=0.34$, $p=0.11$).

4. Discussion

The study clearly showed that offering task lighting to industrial workers does not automatically mean that they will use it. Most of the time, the majority of the workers did not use the additional task lighting at all. They were happy with the combination of the general lighting and daylight. The amount of daylight was extraordinarily high. It is not common to work in conditions where thousands of lux are provided by daylight. It is clear that good skylights can offer a great possibility for making savings on lighting energy. The results of the questionnaire indicated that the workers would prefer even more daylight. Providing indoor workers with more daylight is hardly possible without full glass ceilings, with their enormous problems with glare. The workers also considered windows to be important for the working environment. There were no windows (only skylights) in the factory hall. However, it is possible that they were missing the view out more than the daylight.

Even though the workers did not make much use of the task lighting, they clearly wanted to keep it. The task lighting was used more frequently when the amount of alternative lighting was limited. This does not tell us whether the reason for using the task lighting was one of visual perception or biological. The differences between the workstations in average illuminances and the percentage of use gives us reason to believe that selection was based on visual perception. Since the tasks were different, the visual demands varied also. Possible psychological and biological needs should not differ on different workstations. It is also interesting that almost half of the workers felt that task lighting helped them to perform better. All this indicates that additional task lighting might provide benefits even in those situations where a lot of other lighting is available.

The differences between workers were remarkable. How often they used task lighting and the illuminance selected varied greatly (this confirms the results of the study by Juslén et al. (2005), where a controllable task lighting system was installed at assembly workstations in an area where no daylight was available). The lighting level without the task lighting varied with time from averages per working period of 500 lux to more than 3000 lux. These workers really had very dynamic lighting conditions. And these big changes did not seem to bother them after the direct sunlight from horizontal skylights was blocked by using white curtains.

Since the workers were able to see other workstations, it is possible that this has influenced their decisions to

use the task lighting. However, during more than half of the time when the lights were used, only one pair of luminaires was on. And more than 90% of the time they were in use, a maximum of three pairs were on. This indicates that workers made quite individual choices.

The working environment part of the questionnaire showed the questionnaire's limitations. A low sound level was considered to be the most important aspect of the working environment. This was confirmed in the next part of the questionnaire, where workers were asked to evaluate their own work environment, by the negative ratings given to the impression of "quiet". This could indicate that the most important things might be the ones people consider a problem in their environment.

5. Conclusions

The most outstanding result of this study is that the additional task lighting provided was not used very frequently in the conditions prevailing, namely where an abundance of daylight was available during the main part of the working period. The workers who were in the area during more than 20 days used the task lighting on average only 6.5% of their working time.

Furthermore, it can be concluded that:

- Workers preferred to keep the controllable task-lighting system.
- Almost all workers used the task lighting sometimes.
- Many workers, but not all, felt that the controllable task lighting helped them to perform better.
- The task lighting was used most frequently when the amount of daylight was limited.
- Different tasks influenced the time and choice of illuminance.
- The illuminances chosen varied enormously.

The results of this study encourage the use of skylights, where possible, as a source of daylight. They can provide a lot of light without disturbing workers, and save (lighting) energy. An additional task-lighting system can provide a worker with extra benefits, such as a feeling of better performance and well-being, without a large increase in energy used.

Acknowledgments

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