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The use of shading systems in VDU task offices: A pilot study

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Abstract

We registered how eight subjects used their remotely controlled black Venetian blinds in eight individual offices, every 15 min, over a period of 30 weeks. This also included measuring parameters such as the illuminance on the window, the illuminance on the VDU screen, the ambient temperature inside the room, the presence of the worker and the state of the artificial lighting. During the same period, we registered the position of the blinds in seven other offices fitted with manually controlled fabric blinds, through webcam pictures taken every 15 min. There was no further monitoring inside these offices.

With the data collected, several hypotheses regarding the use of Venetian blinds in offices were tested. It appeared that office workers were consistent in the way they used their shading system, however it was difficult to draw general conclusions on blind usage. The type of control of the shading system also seemed to be important. Remotely controlled black Venetian blinds were used three times more often than manually controlled fabric blinds. In addition, most of the time users adjusted the tilt of the slats of the Venetian blinds downwards, towards the external ground. We also came to the conclusion that the higher the quality of the VDU screen (in terms of emitted luminance levels), the more likely a worker was to tolerate high levels of diffuse reflections on it, hence taking more advantage of the daylight available.

Keywords: Visual comfort; VDU; Venetian blinds; Pilot study; Shading systems

1. Introduction

In order to guarantee good visual comfort conditions to an office worker, it is necessary to take special care of the quantity of light arriving on and surrounding the VDU screen. The best way to control the amount of daylight hitting the VDU screen area remains shading system.

Establishing relations between user behaviour and physical parameters is a challenging task. When it comes to daylight in offices and user perception of their luminous environment, it is difficult to identify the right parameters that determine the way users experience their lighting conditions. One of the first objectives of our work was to check how various visual comfort and performance criteria could actually predict office workers' perception of their luminous environment. Another objective was to focus on the way office workers used their shading system, and what caused them to do so.

In this pilot field study, we tried to understand how VDU office workers used their blinds with regards to various physical parameters.

2. Experimental set-up and methodology

We conducted in parallel two different measurement campaigns aimed at providing a better understanding of the way office workers used their shading system.

2.1. First experiment

We accurately monitored how eight VDU office workers used their Venetian blinds over a 30-week period. We selected eight individual offices in a building at ENTPE, in the city of Vaulx-en-Velin, near Lyon in France. All offices faced south-east. Fig. 1 shows the arrangement of the offices on the facade. In each office, we replaced the manually controlled blinds by remotely controlled black Venetian blinds. Black blinds were selected because they offer a wider range of transmittance than light coloured ones.

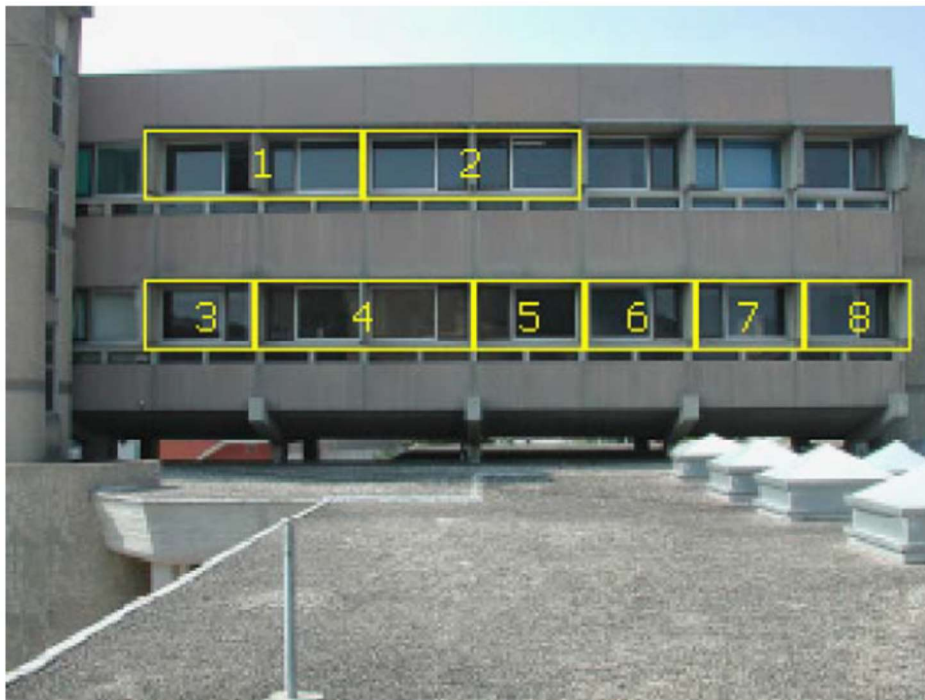


Fig. 1. The eight offices monitored.

The eight subjects working in each of these offices agreed to take part in this experiment. They were two men and six women aged between 27 and 54. They were performing mainly administrative work and spent around 70% of their daily work time in front of their computer. In each office, every 15 min, we measured and stored the following data:

- The vertical global outside illuminance, measured onto the window.
- The illuminance on the VDU screen, measured by a sensor placed vertically on the top of the VDU screen, as can be seen in Fig. 2 (black circle).
- The position of the Venetian blinds (tilt angle of the slats and height above sill).
- The state of the artificial lighting (on/off).
- The indoor ambient temperature.
- The presence of the office worker.



Fig. 2. Inside office 3.

The illuminances, the position of the Venetian blinds and the occupancy information were registered through a network connected to a computer, using several devices.

Venetian blinds were fitted with encoding motors allowing the information to be sent to the computer. Each motor contained an infra-red receptor receiving the signal sent by the remote controllers, the motor itself fitted inside the upper part of the Venetian blind and a 2DCE control box translating the infra-red signal into a command for the blind. All the motors were connected to the central computer, via a Lon-Works network. An interface (technically called WAGO) could receive signals from various natures: analogical (i.e. illuminance sensors) or numerical (i.e. occupancy sensors).

Illuminances were measured using Li-cor LI-210SA sensors. Occupancy was measured using security type volumetric infra-red detectors from the company Tecnalarm. The model used was the Infromin V.

The state of the artificial lighting as well as the ambient temperature inside each office, were stored on stand-alone data loggers HOB0 RH/TEMP/LI. Sensors were placed inside the ceiling luminaire to measure the state of the artificial lighting and under the desk for the ambient temperature.

To test some of the hypotheses detailed below, we used PHOTOLUX, the luminance mapping system developed at ENTPE [10]. It is made of a digital camera calibrated in luminance, and software. It covers luminances from 10 to 70 000 cd/m².

2.2. Second experiment

During the same period, seven different offices in an east facing building fitted with manually controlled yellow fabric blinds were monitored. The purpose was to evaluate how manually controlled shading systems were being used and to compare this to the use of remotely

controlled blinds. For these offices, which can be seen in Fig. 3, the measurements consisted of taking pictures of the facade every 15 min with a webcam.

The pictures were then analyzed manually to determine the number of actions on the blinds throughout the measurement period.



Fig. 3. The seven offices monitored by the webcam.

2.3. Data collected

From these two experiments, over a million pieces of data were collected between January and September 2002. They were then used to test several hypotheses regarding visual comfort and shading system usage.

The dataset from the first experiment was reduced by removing all the data collected when workers were not in their office. For this, we used the information from the occupancy sensors. The dataset from the second experiment was only used to test Hypothesis 4.

2.4. Questionnaire prior to the first experiment

Before the first experiment, we submitted a simple questionnaire to the eight subjects involved. The questionnaire, based upon Hygge's studies [22], was aimed at giving a preliminary idea of the subjects' attitudes towards daylight and the way they occupied their workspace. The results were never meant to be generalized considering the small amount of subjects, however they helped us to formulate the hypotheses presented below.

Five of the subjects said they were using their shading system every time they felt the need to, and that they did not consider this action to be a constraint. The three other subjects pointed out the difficulty in accessing the control point of the blinds. These three also mentioned that the blinds would not help to mitigate the presence of background reflections of the room on their VDU screen. All participants claimed that they were using their shading system once or twice a day. Only three of them thought that motorized blinds could change the way they used them.

After a month or two of monitoring, we observed some interesting individual trends in some of the subjects:

- In office 1, a 50-year-old female appeared to be quite photophile as her blinds were raised most of the time.
- In office 2, a 27-year-old male had his blinds totally lowered most of the time. This seemed to be due to the fact that the VDU screen was facing the window which was permanently reflecting on it.
- In office 3, a 54-year-old female tended to use her artificial lighting and keep her blinds down even when daylight would have been enough.
- In office 4, a 40-year-old female appeared to rarely use her blinds. She left them down, slats being horizontal, most of the time.
- In office 5, a 38-year-old female did not show any obvious consistent behaviour.
- In office 6, a 41-year-old male appeared to have a very systematic use of the blinds. He was the subject who was using them in response to the available daylight the most.
- In office 7, a 36-year-old female did not show any obvious consistent behaviour.
- In office 8, a 43-year-old female did not show any obvious consistent behaviour.

It was interesting to see that some of these users consistently used the same blind control strategy throughout the 30 weeks of the field study.

3. Hypotheses tested

Two groups of hypotheses related to the use of shading systems were considered. The first group regarded the visual comfort and performance conditions that users experienced when they adjusted their shading system. The second group was concerned with why and how users adjusted their shading system.

3.1. Hypotheses concerning visual comfort and performances

Visual comfort and performances are notions that are directly linked to glare. According to the International Vocabulary of Lighting [1], glare is characterized by visual conditions under which one experiences an unpleasant sensation or a reduction in the ability to distinguish details or objects, due to an unsuitable distribution of luminances or to excessive contrasts. Two categories of glare can be distinguished : discomfort and disability.

Discomfort glare is a non-instantaneous sensation, it does not necessarily reduce visibility and such conditions can remain unnoticed by individuals, causing headaches or eyestrains on the long term. It is a psychological phenomenon that is not easy to quantify. On the other hand, disability glare, or in other words the reduction of visual performance, is an instantaneous physiological phenomenon that is more likely to be quantifiable. Three visual comfort and performance criteria were tested with the data collected.

3.1.1. First hypothesis, Blackwell's criterion

When working on a VDU screen, ambient light that is reflected off the monitor can be a source of disability glare. The luminance resulting from this added light is called the veiling luminance. Blackwell showed that, to remain in good visual performance or contrast conditions, the veiling luminance of the task must not exceed a certain level. Blackwell's experimental results can be a reference for the measurement of visibility in real conditions. They consisted of finding the optimal contrast threshold of a normal observer under various experimental conditions; the method was based on the notion of visibility levels [2].

According to Denieul, Blackwell's results can be applied to any sort of office-related task [3]. The maximum veiling luminance of a computer screen that can be tolerated is a function of its

luminance in the dark. This level can be determined by using Blackwell's charts [4]. Fig. 4 is based on these charts and it shows the relationship between the maximum acceptable veiling luminance of a VDU screen as a function of its original luminance (as measured in the dark).

This method enabled us to determine the maximum acceptable veiling luminance of a computer screen for visual performances not to be altered, this for any type of screen. We used the data collected and this method to test our first hypothesis.

Hypothesis 1. The veiling luminance of a VDU screen doesnot exceed that deduced from the Blackwell charts.

The illuminance on the VDU screen was measured every 15 min in each of the eight offices. This measurement enabled us to estimate the veiling luminance of each VDU screen (using the Blackwell's chart in Fig. 4), treating the screen as a Lambertian surface. We are aware that veiling reflections on a VDU screen are a result of the diffuse and specular reflections on the screen.

The reason why we treated the VDU screen as a diffuse surface was of a practical nature. With our measurement set-up, we could not measure the luminance distribution of the hemisphere facing the screen, therefore the luminance of the sources that could cause potential specular reflections was unknown.

To simplify the analysis, the screens were grouped into three categories based on their luminances in the dark (see Table 1).

Table 1
Screen quality definition and offices concerned

Screen quality	Screen luminance (cd/m ²)	Number of offices concerned
Bad	<35	3
Standard	35–60	4
Good	>60	4

This classification is relative to the screens that were used in the eight offices. In absolute terms, the "standard screen" category would nowadays include screens with a luminance above

100 cd/m². Three out of the eight offices monitored had their screens changed 2 months before the end of the measurement campaign (this is why the total of offices adds up to 11 and not 8 as 3 of them could be included into two different categories). A frequency analysis of the veiling luminance values for each screen category is shown in Fig. 5. The three vertical lines correspond to the average maximum veiling luminance for the three screen categories defined in Table 1.

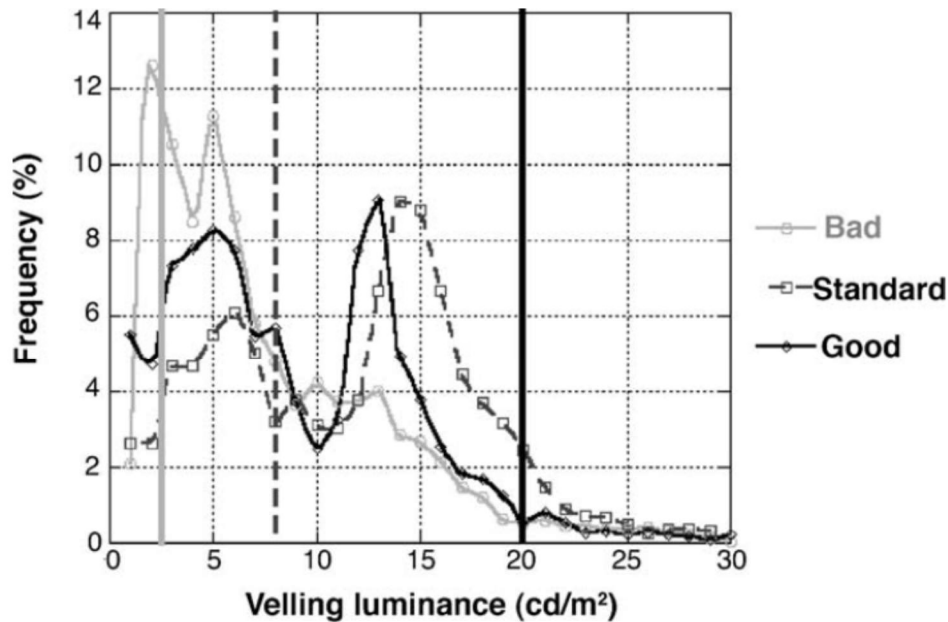


Fig. 5. Frequency distribution of the veiling luminances according to the screen quality.

Several comments can be made on the results presented in Fig. 5:

- Whatever the screen quality, in most cases users positioned their shading systems so that the veiling luminance of the screen remained below 20 cd/m².
- Blackwell's thresholds were too restrictive for bad quality screens.
- Users working on standard and good quality screens tolerated higher levels of diffuse veiling reflections on their VDU screen. Again, Blackwell's thresholds seemed to be too restrictive.

Overall we could conclude that users with a better quality screen tolerated higher veiling reflections, allowing them to take more advantage of the amount of daylight available. Further research could be done to investigate the connection with the current generation of high quality flat screens and how they might influence the use of shading systems.

3.1.2. Second hypothesis, luminance ratios in the visual field

The 1:3:10 luminance ratio rule of thumb is often used as a standard for good lighting in offices. It states that luminance ratios in the visual field of any worker doing regular office work, must remain within certain limits in order to maintain good visual comfort and performances. The literature [5–8] provides several versions of this recommendation.

These references all mention luminance ratios of 1:3:10 between the task (the screen or the paper), the surrounding zones and the non-surrounding zones. But the definition of these zones remains sometimes unclear. Dubois [9] defined these zones by saying that to remain in good visual conditions the luminance in the visual field (608) must not exceed three times the luminance of the visual task (here, the VDU screen), or be less than a third of. As well as this, the luminance in a cone of 1208 must not exceed 10 times the luminance of the visual task or be less than a 10th of. The resulting spatial zones are shown in Fig. 6 for an example of a VDU workspace.

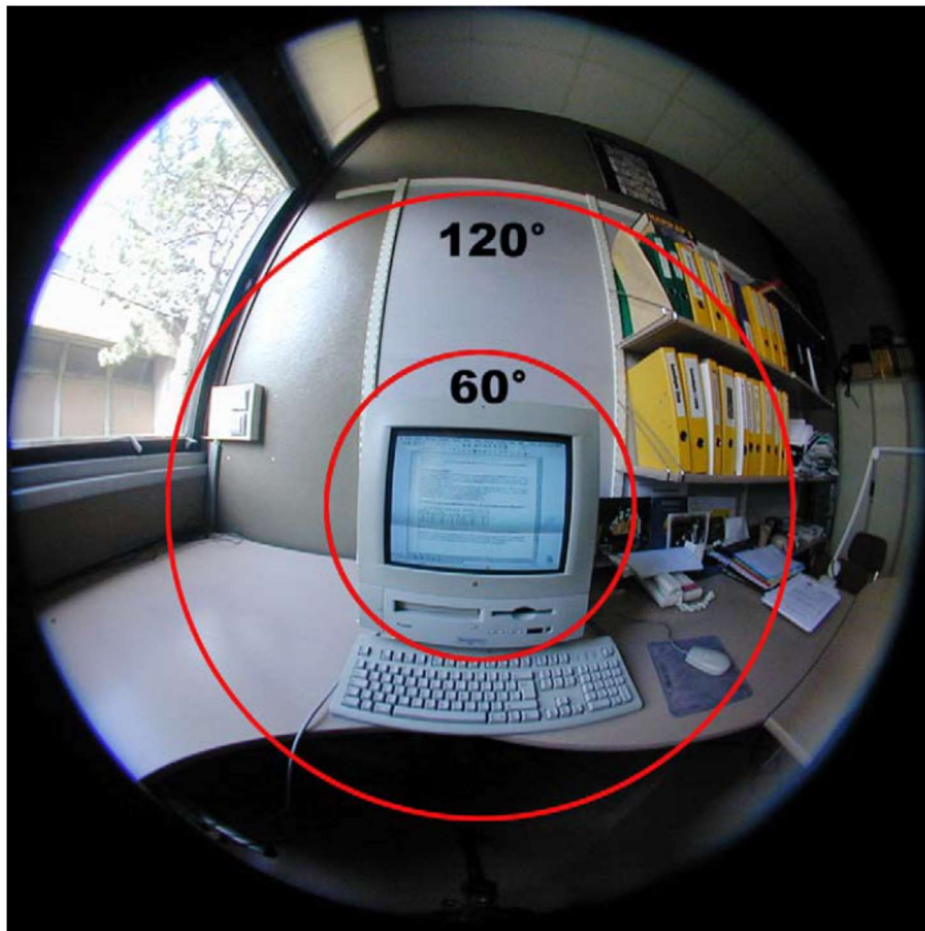


Fig. 6. Definition of the spatial zones.

Hypothesis 2. Luminances in the visual field of a VDU office worker are in a 1:3:10 ratio.

During the course of a week, we used the PHOTOLUX luminance mapping system [10] to measure all luminances in the field of view of the users. This was done several times a day in each office. We only measured luminances when the subjects were satisfied with their luminous environment. We used the luminance maps produced by PHOTOLUX to check the ratios between the minimum and maximum values of each field.

This analysis showed that luminances were in a 1:3:10 ratio as long as no source of daylight was visible in the user's visual field. If a window was part of the worker field of view, the analysis of the data showed that luminances were in a 1:6:20 ratio, rather than 1:3:10. In this case it was observed that a tolerance up to 1:50 could occur if the patch of bright luminance remained fairly small (about 5% of the whole field of view).

3.1.3. Third hypothesis, visual comfort index

Several experiments have been conducted to assess discomfort glare, which led to various formulae providing a glare index value [11,24]. Discomfort glare is due to an unsuitable distribution in the visual field or to high luminances.

We decided to test the glare index (GI), Eq. (1), rather than the daylight glare index (DGI), Eq. (2). The reason for this is that the glare index takes into account not only the window, but also any secondary potentially glaring source within the visual field, whereas the daylight glare index only

considers the luminance of the sky through the window and that of the whole window as being potentially glaring:

$$GI = 10 \log \left[0.478 \left\{ \frac{L_s^{1.6} \Omega^{0.8}}{L_{b1} + (0.07 \omega^{0.5} L_s)} \right\} \right] \quad (1)$$

$$DGI = 10 \log \left[0.478 \left\{ \frac{L_{sky}^{1.6} \Omega^{0.8}}{L_{b2} + (0.07 \omega^{0.5} L_{wp})} \right\} \right] \quad (2)$$

where L_s is the luminance of the source (cd/m²); L_{b1} the average luminance of the background without the glaring source (cd/m²); L_{sky} the luminance of the sky seen through the window (cd/m²); L_{b2} the luminance of the background, average of the luminances inside the room (cd/m²); L_{wp} the luminance of the window plane (cd/m²) and Ω the solid angle subtended by the source, modified according its position in the visual field with the Guth position index, ω is the solid angle subtended by the source (sr).

The glare index threshold value between visual comfort and discomfort is 22, the third hypothesis tested.

Hypothesis 3. The glare index remains smaller than 22.

To test this hypothesis, we used all the luminance maps generated for Hypothesis 2. We computed the glare index with the PHOTOLUX software. Each pixel of the luminance map was classified as “source” or “non source” according to its luminance value. We chose a threshold value of 500 cd/m² based on a French recommendation [12]. This is a reasonable value for luminous environments typical of office work. The background luminance was computed from all the “non source” pixels by calculating the resulting illuminance and assuming the background Lambertian. The contribution of each “source” pixel was then taken into account according to Eq. (1). The position index was computed using a formula given by Fry [23].

We computed the glare index of 40 scenes. Values varied from 13 to 57 with an average of 42. Fig. 7 shows examples of scenes and their corresponding glare index value. The conclusions went in the same direction as for Hypothesis 2: results were very different if a source of daylight was or was not present in the field of view. The glare index very often over-estimated glare when a window could be seen in the field of view. As often stated, tolerance to glare due to daylight is higher than that due to artificial light. This raises the importance of the view through the window.



Fig. 7. Examples of scenes with their values of glare index.

3.2. Hypotheses concerning the use of shading systems

The second set of hypotheses dealt with how the shading systems were operated by the monitored subjects. The data collected was used to assess how VDU office workers used their shading system in order to determine tendencies and thresholds.

The hypotheses were elaborated using previous research [9,11,17], a questionnaire submitted to the subjects and observations made as the monitoring was going on [13].

3.2.1. Fourth hypothesis, influence of the control system of the blinds

It seems logical that the type of control system of a shading device (manual, remotely controlled or automated) has an influence on the way they are used. Inoue et al. [14] observed that an average of 60% of the shading systems in offices remained unmoved by users. Faber [15] reported that once shading systems were lowered, it required a drastic change of external luminous conditions for users to raise them. Foster and Oreszczyń [16] also observed that users often positioned their blinds in a certain way and did not really change this position on a weekly basis. Regarding automated shading devices, Reinhart and Voss [17] observed that users rejected 45% of the actions decided by the system.

The eight subjects monitored in the first experiment estimated that they were using their manually controlled shading system about 1.5 times a day before we installed remotely controlled Venetian blinds in their offices. Our original thought was that having remotely controlled blinds would lead them to use them even more often than manually controlled ones, hence our fourth hypothesis.

Hypothesis 4. When office workers have motorized shading systems, they use them more than twice a day.

To test this hypothesis, we used the data from the second experiment where blinds were manually controlled. We were only interested in the number of actions the workers took on their shading system. We made sure to use situations where workers in both experiments would be in their office. In the seven offices where the shading system was controlled manually, a total of

228 actions on the blinds were monitored over 58 days. This gives an average of 0.7 action per day when there was at least one movement of the shading system, per office.

The same analysis was conducted for the eight offices fitted with remotely controlled black Venetian blinds. We monitored a total of 832 actions over an average of 50 days over the 30 weeks of measurements. On average, the subjects used their remotely controlled Venetian blinds 2.1 times a day. Since different types of shading system were used in the two experiments, Venetian blinds and fabric blinds, we cannot draw a conclusion on the impact of motorized systems alone. However, we can conclude that remotely controlled black Venetian blinds were used three times more often than manually controlled fabric blinds.

3.2.2. Fifth hypothesis, preferred Venetian blinds positions

As the monitoring was going on, some behavioural patterns started to show up. It was observed that some users left their blinds completely lowered and only tilted the angle of the slats, rather than raise them. This is the fifth hypothesis we tested.

Hypothesis 5. Venetian blinds are either totally raised or totally lowered and users only adjust the tilt angle of the slats.

All the blinds positions registered were analysed in order to check which positions were preferred by the subjects involved in the first experiment. Table 2 shows the percentage of time of Venetian blinds positions selected by each subject and Fig. 8, the averaged percentages for all the subjects.

Table 2
Percentage of blinds positions in each office

Blinds position	Office 1	Office 2	Office 3	Office 4	Office 5	Office 6	Office 7	Office 8	Average
Up	61.9	1.2	0	4.9	4.3	0	26.8	42.4	17.7
Intermediate	0	0	0.7	0	13.6	0	7.7	30.3	6.5
Down = 90°	0.4	2.3	7.3	86.5	16.5	39.3	2.6	5.8	20.1
Down > 90°	0	1.8	15.8	0.2	13.5	6.7	0.4	0.2	4.8
Down < 90°	37.7	94.7	76.2	8.4	52.1	53.9	62.5	21.4	50.9

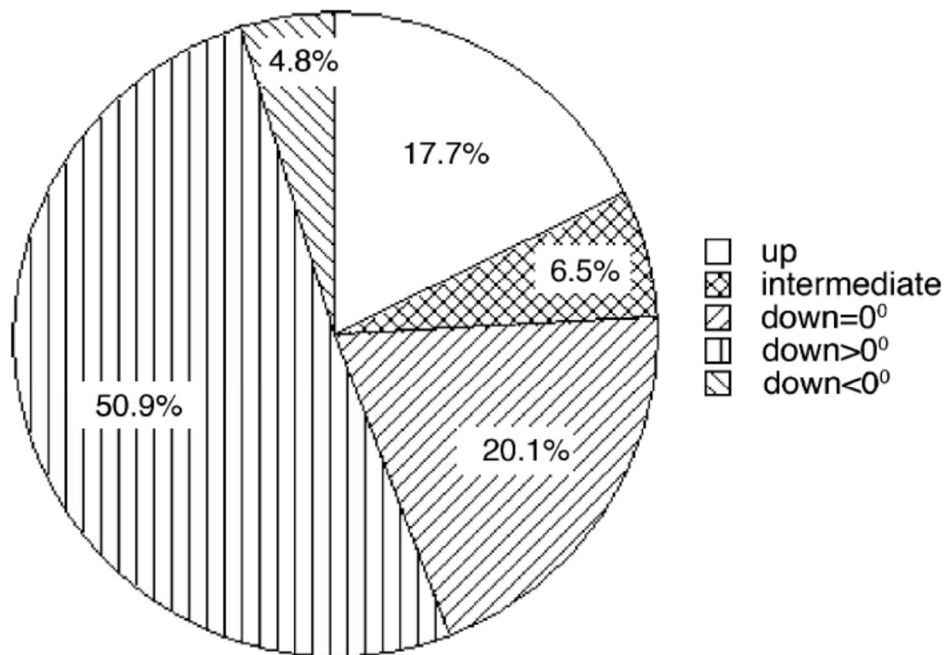


Fig. 8. Mean frequency distribution of the different blinds positions selected by the subjects.

We can see that, on average, the hypothesis is confirmed. Intermediate positions were selected only during 6.5% of the time on average and five out of eight subjects nearly never used intermediate blinds positions. We can also see that 50% of the time blinds were down and the slats had a positive tilt, i.e. towards the external ground. Blinds were lowered with a negative tilt, i.e. towards the sky, during less than 5% of the time. There seem to be two explanations for this. When the slats are tilted towards the sky, firstly direct sunlight is not blocked and secondly the view towards the outside is obstructed.

It is also interesting to see the differences in the way that each subject used their Venetian blinds. Subjects of offices 1 and 2, for example, made a totally different use of the blinds, as can be seen in Table 2. This could be explained by the position of the VDU with regard to the windows as the subject in office 2 had his screen facing the window which was reflecting on it permanently.

3.2.3. Sixth hypothesis, illuminance thresholds

Each user has specific lighting needs and preferences so it is difficult to find one threshold above which every user would adjust their shading device. Using the theoretical visual comfort and performance criteria mentioned in Hypotheses 1–3, it was found out that a window needed to be occulted when the external vertical global illuminance onto the window exceeded 8 klx [18]. We tested this as the sixth hypothesis.

Hypothesis 6. More than half of the blinds are lowered when the external vertical global illuminance exceeds 8 klx.

We looked at the average percentage of blinds raised as a function of the external vertical global illuminance, as shown in Fig. 9. We used only the data describing situations when users were in their offices and when blinds were either totally raised or totally lowered.

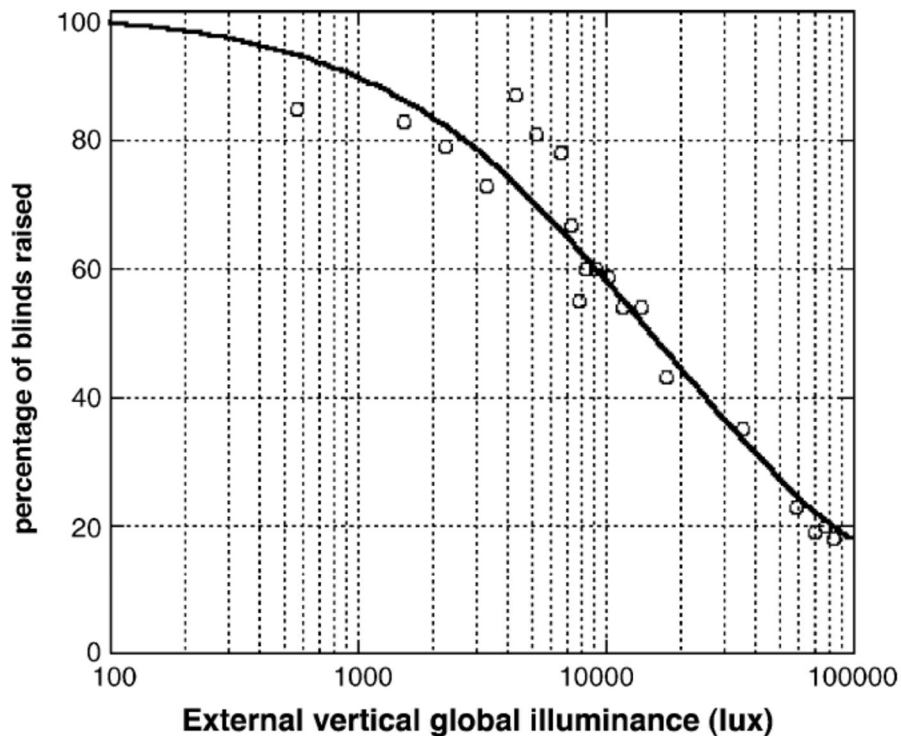


Fig. 9. Variation of the proportion of blinds raised as a function of the external vertical global illuminance.

We used the Logit method [19] to determine the tendency curve. This diagram shows that 50% of the Venetian blinds were lowered when the external vertical global illuminance was 15 klx. As for the hypothesis, we observed that when the external vertical global illuminance was 8 klx, 62% of the blinds were raised.

3.2.4. Seventh hypothesis, window luminance

Another approach was to consider the outdoor light as it is perceived by the user inside the office (via the luminance of the window) instead of that available on the window (the external global vertical illuminance on the window). Using the optical properties of Venetian blinds [13], we calculated the luminance of the window for situations when the direct radiation was blocked by the blinds.

Velds [11] asked office workers how long it would take them to close their blinds, if the window luminance was higher than 1800 cd/m², the answer was “within 30–60 min”. We used this threshold as a reference value for the seventh hypothesis.

Hypothesis 7. More than half of the time office workers adjust their shading system so that the window luminance does not exceed 1800 cd/m².

To compute the luminance of the window, we made the hypothesis that direct sunlight was blocked by the Venetian blinds, and then considered them as a diffusing surface. Using scale models, we measured the hemispherical–hemispherical transmittance function of the Venetian blinds, as a function of the tilt angle of the slats [13]. We are aware that this only gives us an estimation of the value of luminance of the window, but we could not to set-up a device to measure the luminance of the whole window continuously.

Hence, every 15 min, knowing the position of the Venetian blinds and the value of the external vertical illuminance, we estimated the luminance of the windows in each office. Fig. 10 shows the frequency distribution of this luminance, for each office and as an average. This analysis shows that the luminance threshold suggested in our hypothesis (1800 cd/m²) was exceeded between 15 and 40% individually and 25% on average.

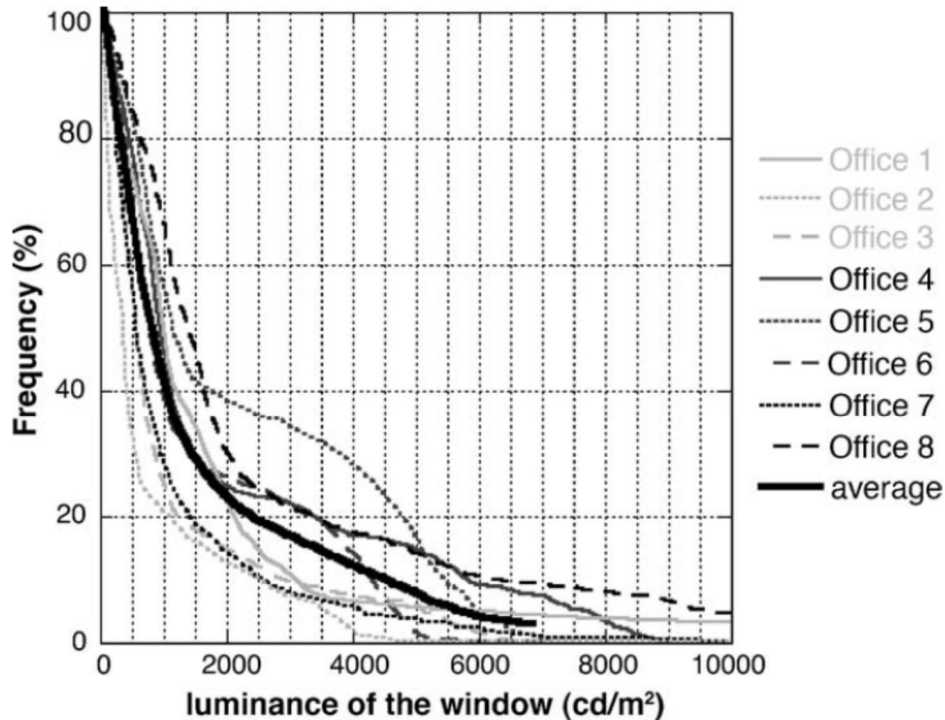


Fig. 10. Frequency distribution of luminances of the window as seen from inside the office.

As a conclusion, on average, our subjects decided to keep the luminance of their windows below 1800 cd/m² 75% of the time. In our experiment, the subjects sat less than 2 m away from the window. This restricts the hypothesis result to offices with similar configurations.

3.2.5. Eight hypothesis, hysteresis phenomenon

It seems that things are not as binary as the sixth hypothesis suggests. Several studies made clear that the thresholds at which blinds are lowered or raised are different. Inoue [14] suggested the phenomenon of hysteresis. He found that office workers lowered their shading systems at a higher level of external radiation (the whole solar spectrum was considered here, not only the visible spectrum) than the one at which they raised them. Reinhart and Voss [17] also observed, using visual measurements, that the illuminance on the window at which users closed their blinds tended to be higher than the one at which they opened them

Hypothesis 8.1. The illuminance level at which users lower their blinds is higher than that at which they raise them.

We split the data into two categories, in the first one we only kept the downwards actions on the blinds, and in the second one all the upwards actions. Actions on the tilt angle of the slats only were not included in this analysis. A frequency analysis of these actions against the value of the external vertical global illuminance is shown in Fig. 11.

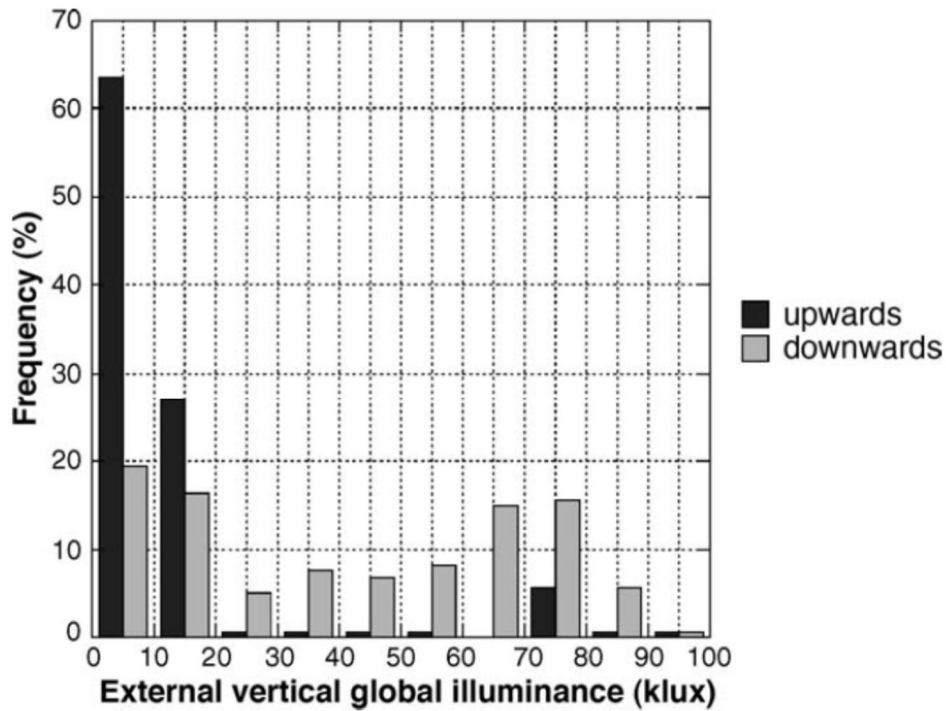


Fig. 11. Frequency of occurrence of the upwards and downwards actions on the blinds.

We can observe that, on average, the external vertical global illuminance at which blinds were lowered was higher than that at which they were raised. The average value for the first category was 41 and 13 klx for the latter. Reinhart and Voss [17] observed the same tendency with higher values: 50 klx for closing and 25 klx for opening.

Hypothesis 8.2. The window luminance value at which users close their blinds is higher than that at which they open them.

We conducted the same type of analysis as for Hypothesis 8.1, but this time for the luminance values of the window. As opposed to Hypothesis 7, where all the window luminances were taken into account, only the data relevant to the adjustment of the blinds was analysed.

Fig. 12 shows a frequency analysis of the luminance values of the window for the adjustment of the blinds allowing more light inside an office, and Fig. 13 those allowing less light. These diagrams show the frequency of occurrence of window luminances before and after the adjustment of the blinds for each category.

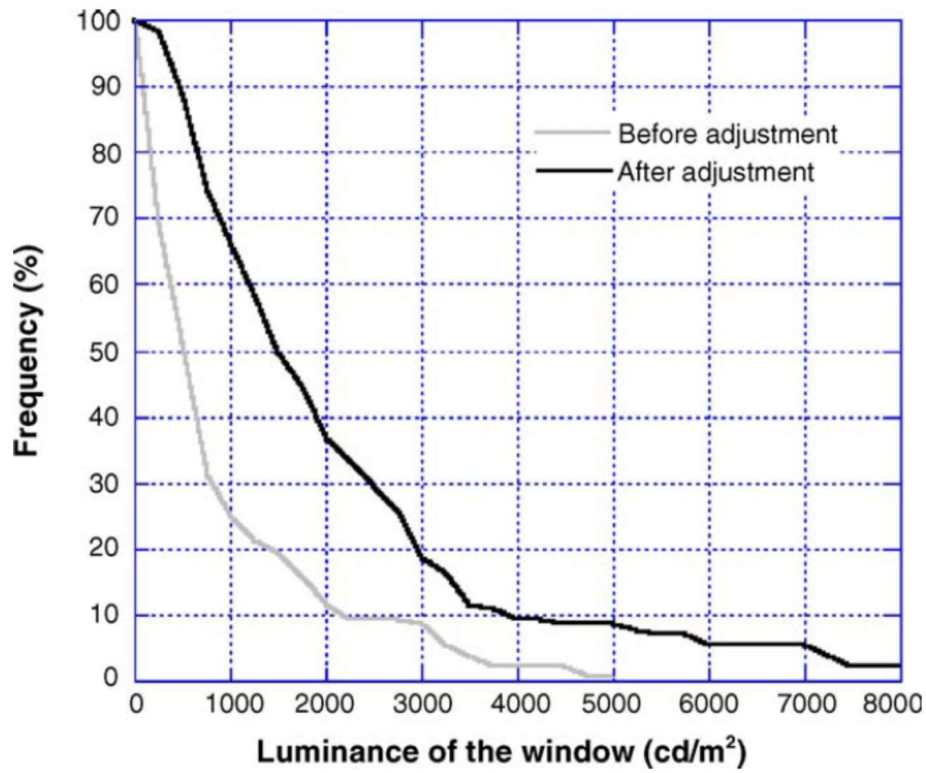


Fig. 12. Frequency analysis of the window luminances when users adjust the blind for more daylight.

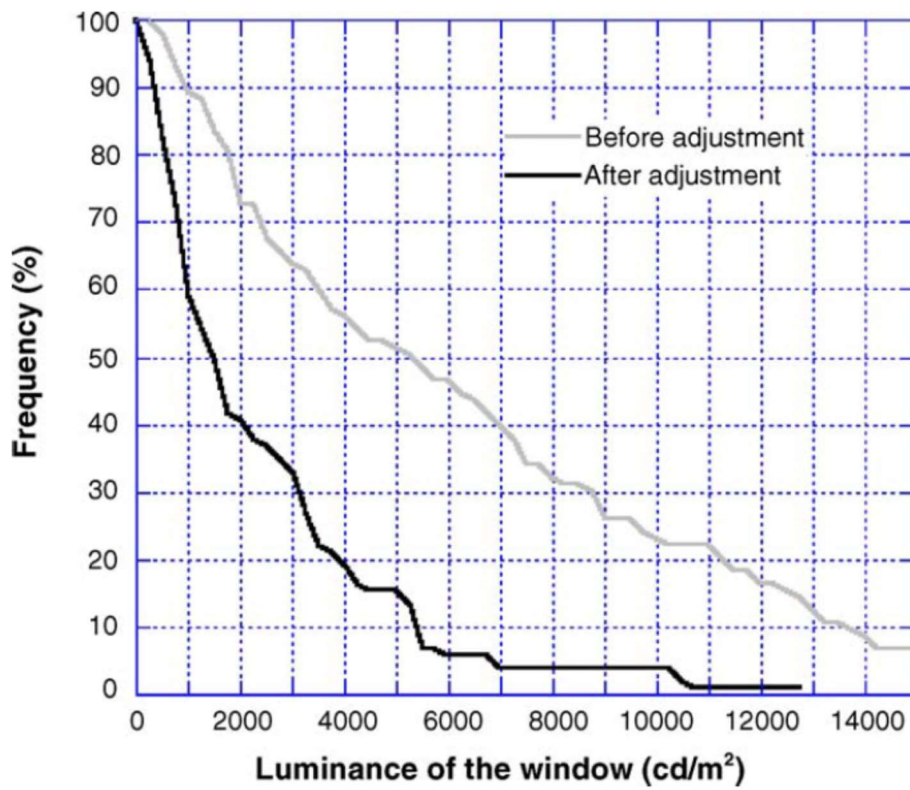


Fig. 13. Frequency analysis of the window luminances when users adjust the blind for less daylight.

Like for the illuminance values on the window, the luminance of the window at which blinds were open was lower than that at which they were closed. The average window luminance after adjustment of the blinds was 2100 cd/m² for the first category and 2400 cd/m² for the latter.

When users wanted more daylight, we can see in Fig. 12 that 75% of the time the window luminance before adjustment of the blinds was below 1000 cd/m², and that after adjustment was below 2800 cd/m². It seems that users who did not have enough daylight tried to adjust the blinds so that the window luminance was multiplied by 3 when it was below 1000 cd/m² (before adjustment), and by 2 when it was above 1000 cd/m².

When users wanted less daylight, we can see in Fig. 13 that 75% of the time the window luminance before adjustment of the blinds was below 9000 cd/m², and that after adjustment was below 3200 cd/m². It seems that users who had too much daylight tried to adjust the blinds so that the window luminance was divided by 3 when uncomfortable visual conditions occurred.

3.2.6. Ninth hypothesis, influence of the indoor temperature

The influence of the indoor ambient temperature on the perception of light is a phenomenon that has often been considered when trying to assess general comfort in offices. Laurentin [20] showed that while indoor temperature does not seem to have an obvious effect on light perception, the season does. For example, it was observed that users preferred higher indoor illuminance levels in the winter than in the summer. As mentioned by norm NF EN ISO 7730 [21], in summer conditions the operating ambient temperature in an office should remain under 26°C in order to provide office workers with good comfort conditions. It is the ninth hypothesis we tested.

Hypothesis 9. If the ambient temperature inside an office exceeds 26°C, the illuminance threshold at which shading systems are closed is reduced.

We split the data into two categories, one for all the actions taken on the Venetian blinds when the ambient temperature inside the office was less than 26°C, and one for all the actions when the temperature was greater than 26°C. Like for Hypothesis 6, using the Logit method [19], we plotted the proportion of blinds raised against the external global vertical illuminance for both categories, as shown in Fig. 14.

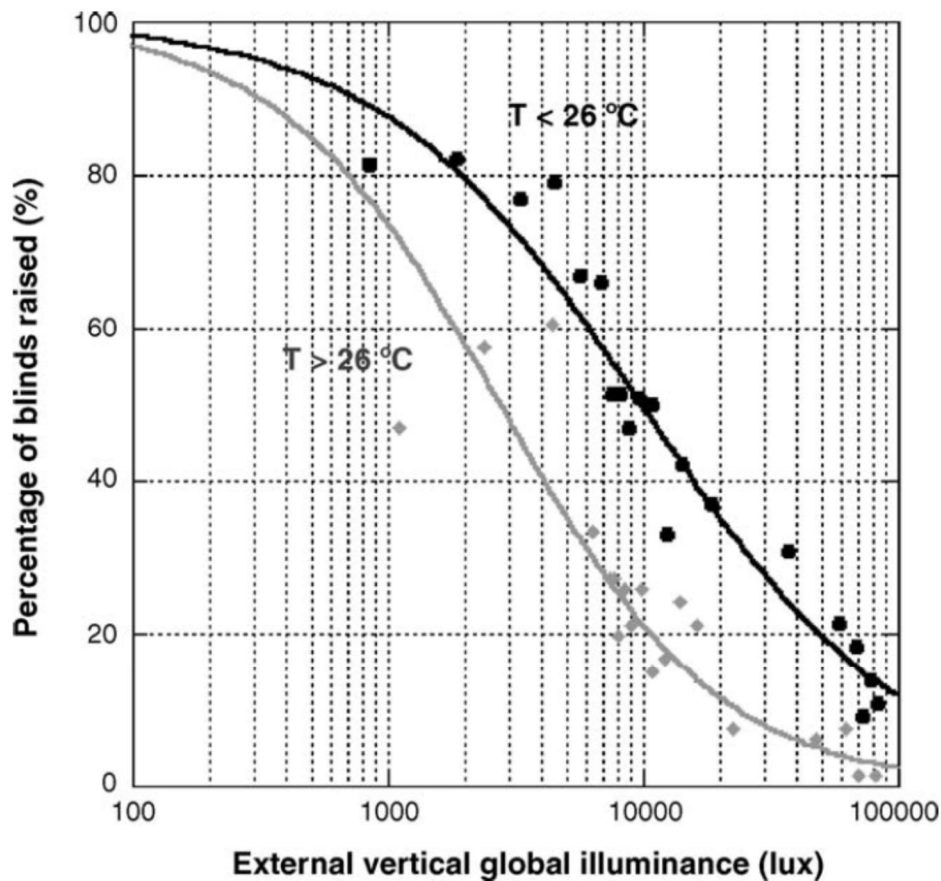


Fig. 14. Percentage of blinds raised when the temperature inside each office is smaller or greater than 26 °C.

We can observe in Fig. 14 that between 15 and 30% more blinds are raised when the temperature was below 26°C inside the office. The same kind of analysis was conducted on the tilt angle of the slats and it showed that they were tilted 10° (downwards, towards the ground, for more occlusion) more when the temperature inside the office was above 26°C.

This finding suggests that the ambient indoor temperature did have an effect on how users controlled their shading systems. However, as mentioned by Laurentin [20], it seems that the season has a greater effect on luminous preferences than the temperature. Since temperatures higher than 26°C mainly occurred in summer, we could probably conclude that our results show the effect of both the season and the temperature.

4. Conclusions

Over a 30-week period, we collected information regarding the use of shading systems in offices where users were working on VDUs. The analysis of this data lead to several conclusions.

Even if it seems difficult to establish general tendencies regarding shading systems usage in offices, we observed that some users were relatively consistent with their behaviour when it came to the visual environment in their office. The results of our study are summed up in Table 3.

The conclusions from this field study have also been used to develop a control algorithm for Venetian blinds. This algorithm has not been published as of yet.

Table 3
Hypothesis results and comments

Hypothesis	Verified	Comment
1. The veiling luminance of a VDU screen does not exceed that deduced from the Blackwell charts [2,4]	No	Blackwell's criteria seemed to be too restrictive in most cases. VDU screens with a high luminance allowed users to let more daylight inside their office
2. Luminances in the visual field of a VDU office worker are in a 1:3:10 ratio [5–9]	Partially	1:3:10 luminance ratios occurred when users could not see the window. Otherwise, luminance ratios went up to 1:6:20
3. The glare index remains smaller than 22 [24]	No	The glare index over-predicted glare when users could see the window
4. When office workers have motorized solar protections, they use them more than twice a day [13]	Partially	Office workers used motorized Venetian blinds three times more often than manually controlled fabric blinds
5. Venetian blinds are either totally raised or totally lowered and users only adjust the tilt angle of the slats [13]	Yes	Most of the time Venetian blinds are lowered and users adjust the slats towards the external ground. They were either totally lowered or raised but rarely in an intermediate position
6. More than half of the blinds are lowered when the external vertical global illuminance exceeds 8 klx [13,18]	No	It was observed that when the external vertical global illuminance was 8 klx, 62% of the blinds were raised
7. More than half of the time, office workers set their solar protection so that the window luminance does not exceed 1800 cd/m ² [11,13]	Partially	75% of the time, users set their solar protection so that the luminance of the window remained smaller than 1800 cd/m ² . These results may not be extended to office configurations different from the ones of our experiment
8.1. The illuminance level at which users lower their blinds is higher than that at which they raise them [14,17]	Yes	A hysteresis phenomenon was observed between the lowering and raising actions on the blinds. It seemed that users waited until the level of daylight in their offices was very low before raising their solar protection
8.2. The window luminance value at which users close their blinds is higher than that at which they open them [13]	Yes	Similar comment as 8.1. Also, it was observed that when users wanted more daylight they adjusted the blinds so that the window luminance was multiplied by 3, when the luminance was below 1000 cd/m ² , and 2, when the luminance was above 1000 cd/m ² . When users wanted less daylight, they adjusted the blinds so that the window luminance was divided by 3
9. If the ambient temperature inside an office exceeds 26 °C, the illuminance threshold at which solar protections are lowered is reduced [20,13]	Partially	Our measurements confirmed this hypothesis. However this result could be a coupled effect of both the season and the room temperature

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