INFLUENCE OF AMBIENT LIGHT ON THE PERFORMANCE, MOOD, ENDOCRINE SYSTEMS AND OTHER FACTORS OF SCHOOL CHILDREN

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1 Abstract

The school is the workplace for both children and teachers. Lately there has been a discussion about the environment in the school. Signals that children under-perform, behave in a bad manner and are tired have reached responsible departments.

One part of the environment is the physical environment and several studies show that physical environmental factors may have an impact on the abovementioned factors [1]. Lighting conditions is considered as an important part in the physical environment [2].

This report covers the findings of our study from October 2008 until May 2009. The evaluation of the study is still ongoing and full results will be published in due course.

1.1. Background

Correlations may exist between the physical parameters of light and the diverse biological and psycho-physiological effects. Both the intensity, spectral composition, spatial and temporal distribution, may be of relevance.

A major step was taken when [3] in a study on rat, showed that neither rods nor cones were needed to modulate the circadian pacemaker, instead retinal ganglion cells with the photopigment called melanopsin innervating the SCN were intrinsically photosensitive.

During the last three years several convincing studies have shown that the human circadian rhythms are affected by these retinal ganglion cells also today mentioned as the 'third receptors' [4,5,6,7]

Due to the fact that more elaborated knowledge about the details of the circadian photoreceptors were established, the research on how specific wavelengths within the light spectrum affected the physiological responses rapidly grew. It has been shown that certain wavelengths have peak melatonin suppression on humans. [8,9].

1.1.1. Studies related to ambient light

The above mentioned studies are laboratory studies. Turning to application and field studies there are less clear results. Few studies take both visual, biological and emotional aspects into account. However, one early study by Küller and Lindsten [10] investigated the impact of daylight on both behavioural and physiological parameters amongst children in classrooms. They showed that children situated in classrooms without windows displayed a different annual variation of the chronobiological marker cortisol in comparison to those who were situated in a classroom with windows. Furthermore, the children's behaviour was also affected.

According to Hershong et al [11] there were significant effects of daylighting on the performance of school students: daylight boosting the performance in maths and reading tests.

Recent research by Govén et al, [12] has found that it seems that the ambient light is of upmost importance. In a full scale laboratory study three different ambient luminance levels (20, 100 and 300 cd/m^2) keeping 500 lx constant at the working plane were compared according to the level of cortisol in the afternoon. The cortisol levels showed a linear positive relation to the ambient luminance level.

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However concerning positive and negative feelings the curve was inverted U-shaped showing that 100 cd/m^2 gave the highest rating of positive feelings.

In relation to this it is worth mentioning a study where subjects were asked to adjust the proportions of light between indirect and direct light distribution from luminaires in an open plan area. The result showed that the preferred proportions were 55 % indirect and 45 % direct light. With this proportion the preferred average luminance in the ceiling was 128 cd/m^2 and 78 cd/m^2 on the wall having a constant horizontal illuminance level of 500 lx on the work plane [13].

1. 2 Aims of the study

One aim of the study was to explore in what way the ambient light may have an impact on the children's emotional status, achievement and well-being described both subjectively and physiologically considering both daylight and artificial light.

A second aim was to investigate in which way different lighting control systems affect the use of energy in classrooms. The results of that part of the study are reported separately.

The presentations of results are divided into different parts according to elements of the VBE-model which takes visual, biological and emotional aspects into consideration.

2. Design of the study

The study was carried out in a junior school located in the south of London. For ethical reasons the only children taking part in the study were those whose parents provided positive consent. About 50 % of the children in the school year took part in the study.

Four classrooms of the same size were investigated. Two experimental classrooms (E1 and E2) were equipped with a new lighting design based on an increased horizontal and ambient light in relation to two control classrooms. The two control classrooms (C1 and C2) were equipped with an existing lighting system based on general lighting.

Figure 3. The south elevation of the classrooms

In order to have the same light emission in all classrooms, the luminaries in the control classrooms were changed to new luminaires of similar type equipped with high frequency ballasts.

In the four classrooms the luminaries were equipped with the same type of tri-phosphor fluorescent tubes with a colour temperature of 4000 K and a CRI (Ra) of 80.

E1 and C1 were situated on ground floor with daylight penetration from one side, south.
E2 and C2 were situated on the 1st floor with daylight penetration from two sides, north and south. Figure 1 shows a plan of the classrooms. Blinds are only installed only on south facing windows.

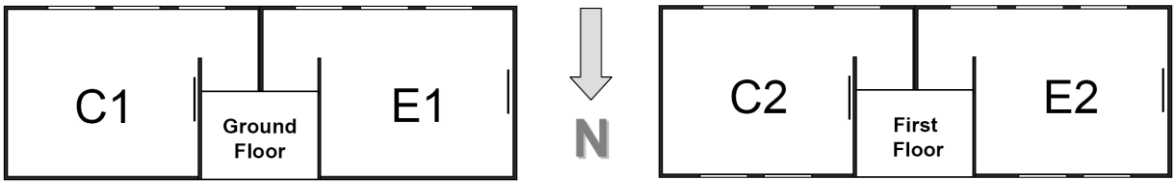

Figure 1. Plan of the different classrooms

The both experimental classrooms (E1-E2) had a general lighting system adjusted to an illuminance level at working plane of approximately 500 lx. Luminaires for general lighting were suspended from the ceiling and had a direct/indirect light distribution. Additional wall-washers were installed to achieve an increased ambient light level on the walls. Measured iIlluminance values achieved in the classrooms are given in table 1.

Furthermore both of the experimental rooms (E1 and E2) were equipped with an absence and daylight control system. In one of the experimental rooms (E2) an algorithmic scene-setting system was installed in order to achieve an increased illuminance during the first lesson in the morning and the first lesson after lunch each school day for the whole school year. See table 1.

The both control classrooms had a general lighting system with an illuminance level at working plane of approximately 300 lx without any additional wall-washers. All luminaires were ceiling mounted.

The control classrooms were both manually controlled.

Table 1. Measured illuminance levels in the different classrooms due to electric light only.

Illuminance levels	C1	E1	C2	E2 standard	E2 algorithmic
Average horizontal illuminance (working plane) (lx)	316	520	311	508	575
Average vertical illuminance - front wall (lx)	120	280	118	350	650
Average vertical illuminance - back wall (lx)	131	302	128	350	650
Average ceiling illuminance (lx)	98	321	84	297	347
Vertical illuminance, at eye level - centre of room (lx)	234	240	230	236	325

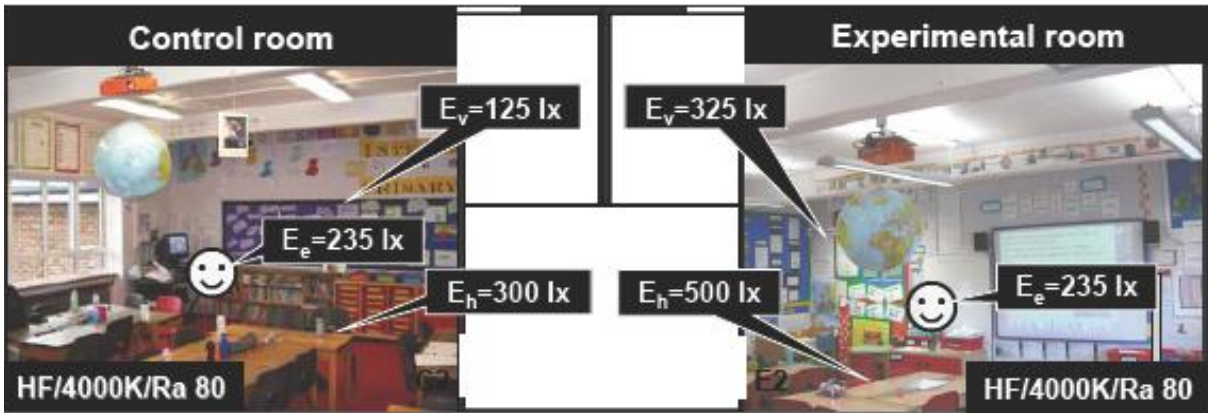

Figure 2. The figure shows the design of the control room vs. the experimental room and the horizontal and vertical illuminance as well as the type of fluorescent tubes.

Table 2. Cylindrical illuminance in the centre of the room [lx]

Room	Total [lx]	Direct lighting only [lx]	Indirect lighting only [lx]	Direct / Indirect %
C1	205	110	95	54/46 %
E1	216	52	164	24/76%
C2	213	122	91	57/43 %
E2	220	53	167	24/76 %

Table 2 shows the contrast between the rooms in terms of the ratio of direct to indirect light contributing to the cylindrical illuminance. In the case of the control rooms (C1 and C2) the ratio of direct to indirect is about 1.2 and it is 0.33 for the experimental rooms (E1 and E2). This increase in indirect light is closely related to the greater lightness perceived in the experimental room.

2.1 Daylight availability

There is significantly more daylight available in the top floor classroom (C2 & E2) as they have windows on both sides of the room and they are less shaded by the trees outside. Moreover, the north facing windows in the top floor rooms do not have blinds fitted and so when the daylight factor in the rooms does not drop very low.

Table 3. Daylight penetration in the different classrooms.

Daylight factor (DF) - without curtains	C1	E1	C2	E2
Average horizontal daylight penetration	2.43%	1.57%	5.53%	4.67%

Table 4. Daylight penetration in the different classrooms.

Daylight factor (DF) - with curtains	C1	E1	C2	E2
Average horizontal daylight penetration	0.06%	0.04%	1.73%	1.71%

2.1.1 Other physical measurements

The rooms used were all well ventilated and regular checks of CO_2 levels revealed levels in the region of 1,000 to 1,200 PPM. Temperature in all classrooms varied during the winter period between 22 - 24°C.

2.2 Dependent measures

The dependent measurements were planned to be taken at 6 consecutive occasions during the school year. The measurements started in the beginning of October 2008 (autumn equinox) and continued in the middle of December, (the darkest period) in middle of February, in the end of March (spring - equinox). Additional measurements will be taken in the end of end of May and finally in June 2009 (the brightest period). In addition to this supplementary measurements were taken between these dates. The dependent measures covered the biological and emotional aspects. The use of energy and controls were continuously measured over the year.

2.2.1 The children

The dependent variables were examined in different ways.

Mood; The children's mood were measured by 9 items describing how the child felt at the moment [14] The items were originally in French, but were translated into English.

In order to evaluate participants' perceived sleepiness, a pictorial scale [15] was employed

Quality of sleep; In order to evaluate children's perceived sleep adequacy and their perceived difficulties in initiating and maintaining sleep six relevant items of the Sleep Self Report [16] were employed. The items were rated on the three-point scale as the Sleep Self Report.

Academic performance; Results of tests taken as part of the normal school program were used to access academic progress.

Sick-leave; The rate of absence of the experimental subjects and it was found to be very similar in each of the classes with each subject on average having just over half a day per month off sick.

Chronobiological markers;

Saliva samples were taken at three times during the day at 9.50, 11.45 and 14.45. All samples were analysed for cortisol but only the 9.50 samples were analysed for melatonin.

2.2.2 Statistics

The initial treatments of the data were carried out by one-way analysis of variance with post-hoc analysis. Findings of this work are presented in section 4.1.1. Also t-tests were applied for some analyses. The further treatment of data was carried out mainly by means of analysis of variance with a repeated measures design. This is a factorial design involving the following four independent factors;

1. General lighting vs. increased general lighting and increased ambient lighting
2. Daylight penetration in one direction vs. daylight penetration I two directions
3. Increased ambient lighting vs. increased ambient lighting at a higher amount at certain times of the day (algorithmic scene-setting)
4. The periods of the school year

The independent factors, 1 to 3, were tested between subjects as well as their interaction, while factor 4 was tested within subjects.

In most analyses, data were grouped in six blocks corresponding to the six measurement occasions during the school year. SPSS 15.0 statistical package was used for the analyses.

3. Subjects

A total of 56 children aged 8-9 years of age divided in four classes took part in the study. All the children attended the same educational program in the junior school.
The achievements between the four classes were reported to even regarding the grades from the previous year. They were allocated to their classrooms at the beginning of the semester by the school authority.

The distribution of children between the classrooms and gender are shown in table 5.

Table 5. Distribution of the children in the four classrooms

Gender	C1	E1	C2	E2	Total
Boys	7	7	7	9	30
Girls	7	4	8	7	26
Total	14	11	15	16	56

3.1. The routines

Two sorts of measurements were carried out, a main collection and a supplementary collection. The main measurement routine was co-ordinated with the daily school routine (see table 6).

Table 6. The daily routine of the main data collections

Time	Operation
8:30 a.m.-8:50 a.m.	Preparations
8:50 a.m.	Start of the school day Self-ratings of sleep
9:50 a.m.	Self-ratings of mood and sleepiness + Morning saliva samples (cortisol+melatonin)
10:15 a.m.-10:30 a.m.	Mid-morning break
11:45 a.m.	Self-ratings of mood and sleepiness + Late-morning saliva samples (cortisol)
12:00 p.m.-1:10 p.m.	Lunch
2:45 p.m.	Self-ratings of mood and sleepiness + Afternoon saliva samples (cortisol)
3:20 p.m.	End of school day

Table 7. The daily routine of the supplementary data collections

Time	Operation
8:30 a.m.-8:50 a.m.	Preparations
8:50 a.m.	Start of the school day Self-ratings of sleep
9:50 a.m.	Self-ratings of mood and sleepiness + Morning saliva samples (melatonin)

4. Results

The presentations of results are divided into different parts according to elements of the VBE-model which takes visual, biological and emotional aspects into consideration. However, initially the results of academic performance that could be seen as the outcome of the different parts of the VBE-model is presented first.

Academic performance

All of the academic performance test scores like reading, writing and math, showed a steady progress between the tests. However, there appears to have been a slightly higher rate of improvement in the experimental classroom on ground floor during the dark period of the year. The progress in academic performance in reading -, and math grades between the control room C1 and experimental room E1 are shown in graphs below.

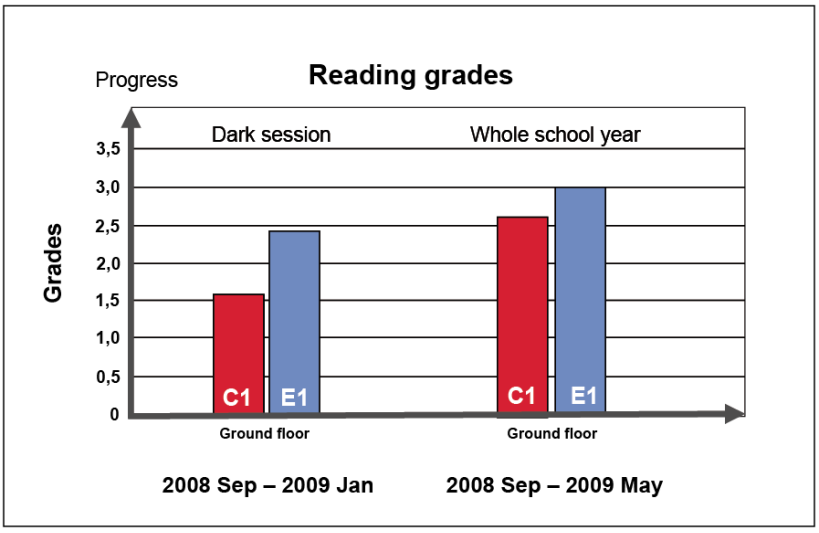

Figure 3. The progress in academic performance in reading grades between the control room and experimental room on Ground floor and First floor E1.
Reading differences: Sep to Jan F(1,24)=11,87, p=.002.

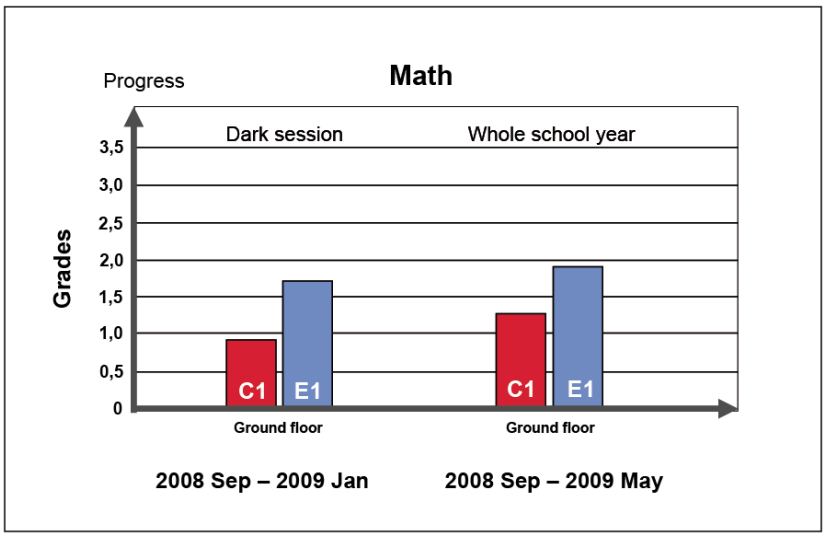

Figure 4. The progress in academic performance in math grades between the control room and experimental on Ground floor and First floor. Mathematics difference: Sep to Jan F(1,24)=3,749, p=.06

Visual aspects

Concerning the visual conditions in the four classrooms, all of them were equipped with new lighting systems concerning luminaires and fluorescent tubes. All of the classrooms went from conventional ballasts to high-frequency ballasts, i. e non-flickering light. All fluorescent tubes were changed to full-spectrum 4000 K in the classrooms. The interior and design of the classrooms were unchanged. All teachers experienced positive changes concerning the lighting conditions in the classrooms. All classrooms fulfilled the lighting requirements concerning horizontal illuminance, glare and colour rendering. No further analyses concerning differences between the classrooms were conducted.

Biological aspects

Cortisol

The analysis of the monthly trend of the cortisol levels at 09:50 revealed a significant interaction between different months and the two floors (interaction month x floor F(1,53)=4,123, p=.047), On the ground floor the analysis revealed a result that the pupils in the experimental room (E1) showed higher levels of cortisol over the whole school year than in the control room (Figure 5).

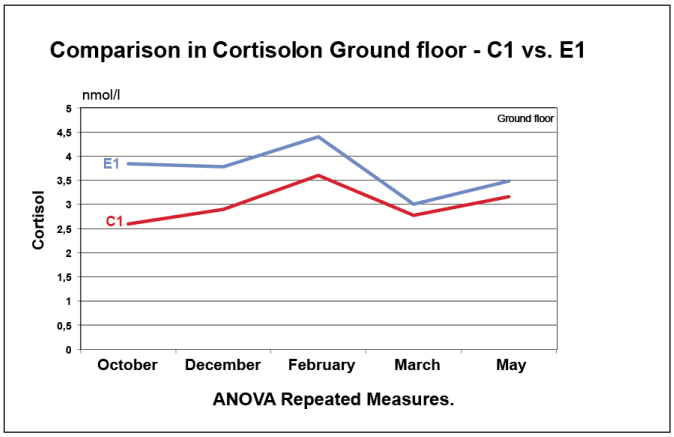

Figure 5. The analysis of the monthly trend of the cortisol levels at 09.50 revealed a significant difference between months contrast (F(1,22)=8,087, p=.009) and a significant difference between the rooms (F(1,22)=4,969, p=.036)

Melatonin

The analysis of the monthly trend of the melatonin levels at 09.50 hour revealed a significant difference between different months ((F(9,52)=5,87, p=.000). Furthermore, the results show that during the dark season (October-December) the melatonin reach the highest level in the classroom with lowest ambient light in comparison to the experimental room on the ground floor. However, this effect was not seen when looking at the whole school year.

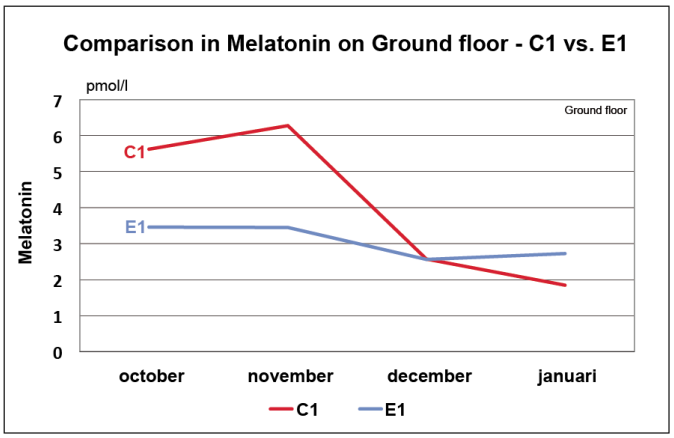

Figure 6. The analysis of the monthly trend of the Melatonin levels at 09.50 revealed a significant difference between months (F(3,23)=3,779, p=.014) and a significant difference between the rooms (F(1,23)=4,44, p=.05).

Emotional aspects

The analysis of the monthly trend of the overall mood at 09:50 revealed a significant difference between the classes on the ground floor and those on the 1st floor (Figure 7). On the ground floor the analysis of the monthly trend of the overall mood at 09:50 revealed a non-significant interaction between month and classroom on the ground floor (Figure 8).

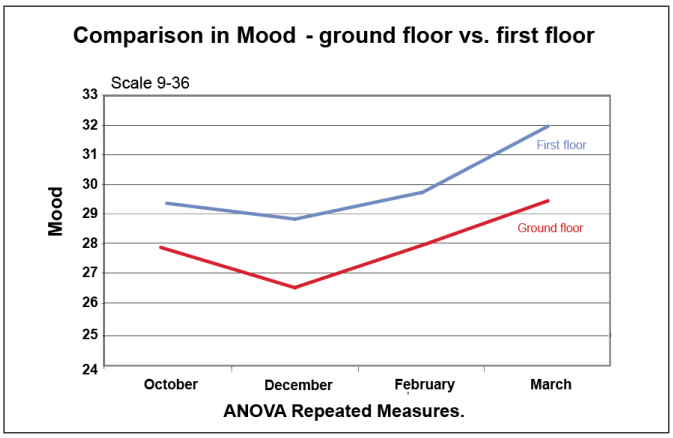

Figure 7. Mood assessments at 9:50. ANOVA Repeated Measures Ground floor vs. First floor.. General effect: F(3,33)=3,068, p=.031

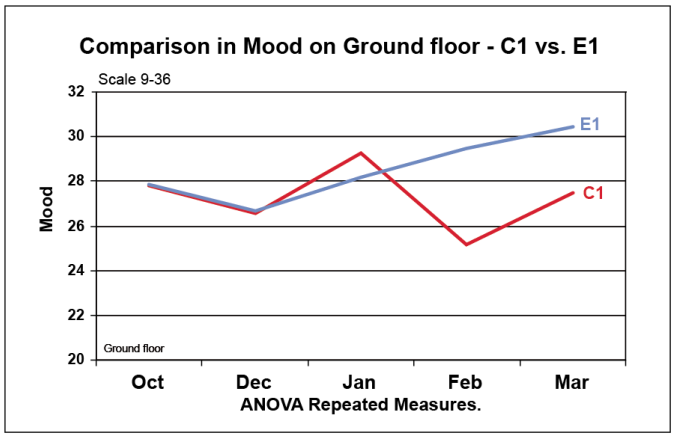

Figure 8. The analysis of the monthly trend of the overall mood at 09:50 revealed a tendency to an interaction month x classroom on the ground floor F(1,14)=2,665, p=.125.

5. Discussion

The study shows that there seem to be seasonal differences concerning both the biological and emotional components of the VBE. The results also reveal that daylight seem to influence the mood level. Nevertheless, there are also systematic differences between the experimental room and the control room, especially on the ground floor where the daylight impact is less than on the first floor. Finally those results are most clear during the dark period of the year.

The mood of the children differed on the ground floor, where the children in the experimental room showed a positive improvement from December and onwards, while the children in the control room displayed a decline between January and February.

The cortisol levels were higher in the room with improved ambient lighting, on the ground floor over the whole school year. However, the difference in cortisol levels between the experimental and control room was largest in October-November, indicating that the artificial lighting has a larger impact during the dark season.

Melatonin showed expected differences over the year. Furthermore, during the dark period of the year there was a clear difference on the ground floor between the experimental room and the control room showing that in the experimental room the children showed lower melatonin levels.

Also the academic performance show differences on the ground floor with results pointing in the same direction. The children in the experimental room perform better during the dark season.

To summarize the study show that there are possibilities to enhance the lighting situation of classrooms in order to improve the conditions of the pupils. The effects seems to be most pronounced when the classrooms has less daylight and during the dark season of the year.

The results imply that it is necessary to take the non-visual effects of light in consideration when designing study-environments for children. The results also indicate that the VBE-model may be a useful tool when assessing lighting applications.

References

1. Bechtel, R. & Churchman, A. (2002). Handbook of environmental psychology. New York: Wiley.

2. Boyce, P. (2008). Human factors of lighting 2nd edition, Troy: CRC Press.

3. Berson, D.M. (2003). Strange vision: ganglion cells as circadian photoreceptors. *Trends in Neurosci.* 26: 314-320.

4. Hannibal J, Hindersson P, Ostergaard J, Georg B, Heegaard, S, Larsen PJ. & Fahrenkrug J. (2004). Melanopsin is expressed in PACAP-containing retinal ganglion cells of the human retinohypothalamic tract. *Investigative Ophthalmological Visual Science*, 45, 4202-4209.

5. Melyan Z, Tarttelin EE, Bellingham J, Lucas RJ, and Hankins, MW. (2005). Addition of human melanopsin renders mammalian cells photoresponsive. *Nature*, 433, 741-745.

6. Qiu X, Kumbalasiri T, Carlson SM, Wong KY, Krishna V,Provencio I, and Berson D. (2005). Induction of photosensitivity by heterologous expression of melatonin. *Nature*, 433, 745-749.

7. Panda S, Nayak SK, Campo B., Walker JR, Hogenesch JB, & Jegla T. (2005). Illumination of melatonin signalling pathway. *Science*, 307, 600-604.

8. Brainard, G.C. and J.P. Hanifin. (2005). Photons, clocks and consciousness. *Journal of Biological Rhythms*, 20(4):314-325.

9. Thapan K, Arendt J, and Skene DJ. (2001). Inaction spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. *Journal of Physiology*, 535, 261-267.

10. Küller, R.; Lindsten, C. (1992). Health and behaviour of children in classrooms with and without windows. *J. Environ. Psychol.* 12, 305-317

11. Hershong, L., Wright, RL. and Okura, S. (2002). Daylighting impacts on human performance in school. *Journal of the Illuminating Engineering Society*

12. Govén, T., Laike, T., Pendse and B. Sjöberg, K. (2007). The background luminance and colour temperatures influence on alertness and mental health. CIE 26 Beijing

13. Govén, T et al. (2002). Preferred luminance distribution within working areas. Right Light 5, Nice.

14. Derbaix, C. and Pecheux, C. (1999). Mood and children: proposition of a measurement scale, *Journal of Economic Psychology*, 20 (5), 571-591.

15. Maldonado, C.C., Bentley, A.J., Mitchell, D. (2003). A pictorial sleepiness scale based on cartoon faces, *Sleep*, 27 (3), 541-548.

16. Owens, J.A., Spirito, A., McGuinn, M., Nobile, C. (2000). Sleep habits and sleep disturbance in elementary school-aged children. *Journal of Developmental and Behavioural Padiatrics*, 21 (1), 27-36