Lighting in schools

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INTRODUCTION

Good quality of light plays a significant role in the psychological and biological processes of human beings. From literature we know that performances of students increase by a good visual environment[1,4]. Besides that, energy use by electric lighting is one of the important energy costs for schools in The Netherlands [2]. All reasons to research the design possibilities for an optimum use of daylight. However, a classroom is a difficult space to light with daylight, because of the depth of the classroom and the different tasks which must be performed in it. At the university of Delft research has been done in order to optimize the daylight access by the design of classrooms. In a first step the luminances and illuminances in a number of existent schools were measured. From this, nine possible design models of classrooms have been draw up. These designs are compared to each other by simulation of the light performances with the light simulation program desktopRadiance [5].
During the school periods, especially in primary schools, many hours can be worked with sufficient daylight, but still during a great part of the day the electric lighting is used. Some years ago 'TNO Built Environment and Geosciences' has done reaearch of electric lighting in schools by order of NOVEM. The primary objective was the improvement of the light conditions in classrooms in respect to energy use and comfort. In this paper we will show that a combination of a good daylight design together with a good electric lighting concept will give a comfortable education and working environment, in an energetically efficient way.

TASKS AND ZONES

In order to get a good lighting concept, knowledge of the different tasks in classrooms is important. Each task needs its own light conditions. During the day there are a number of different visual tasks in a classroom. So, high requirements for the light quality are important.
Students and teachers have benefit by a lighting which supports them optimally in doing their activities. Important for a good lighting design is that the needs of the human being are central, but in the same time the energy efficiency may not be neglected. The European norm EN 12464-1 gives requirements for the illuminances in schools, see table 1.

Table 1: Overview of tasks in a classroom together with the requirements for the illuminances.

Task	**the teacher**	**the student**	**Standard Illuminance**	
			In the class	In general
1	Writing on blackboard	Reading on blackboard	500 lux (vertical)	200 lux
2	Talking to the students	Paying attention to the teacher	300 lux	300 lux
3	Showing a presentation (slides, powerpoint, television program, etc.)	Looking onto the screen	300/10 lux	10 lux
4	Paying attention to working students	Writing, reading drawing, etc.	300 lux	300 lux
5	Coaching computer activities	Looking to the computerscreen and the paper	50 lux	300 lux above the computer
6	Preparing lessons	Not present	300 lux	50 lux

The following values for luminances and contrasts have been required: the luminances must be below 3000 cd/m² and the luminance contrasts in the (wide) visual field must be lower than 1:30.
According to the tasks of teacher and student and the light requirements for the different activities the classroom has been divided in zones: A blackboard zone and a classroom zone. The classroom zone has again been divided in two zones parallel to the facade in order to create the possibility to optimize the use of daylight: a window zone and a corridor zone

DAYLIGHT

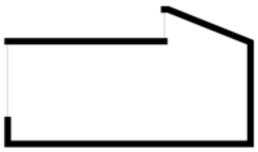
First, for a better understanding of daylight quality in schools, measurements have been done in a number of existing schools [16]. That has showed, it was difficult to compare the different schools to each other (figure 1 and 2). The divisions of the classrooms were different and the same holds for plants at the window-sill, drawings on the window-glass, opposite buildings and public green, etc. And of course the most important problem, measurements in different schools could not be done at the same time under the same weather conditions. For that reason, in order to get more insight into the daylight qualities in schools, nine different classroom designs were simulated with dRadiance. Figure 3 shows the different designs: a reference model, five basic models and three situation models. Basic model 'Corridorwindow' has a roof window above the corridor and situation model 'Corridor 02' has shed roofs above the corridor. The situation models are based on designs of real schools. All the nine models satisfy the Dutch Building Regulations.

Fig.1. Luminance measurements in a North and a South classroom at primary school ' De Tjalk'.

Fig. 2. Luminance measurements in a North and a South classroom at primary school 'De Walvis'.

1. Reference

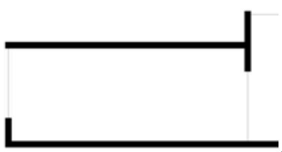
2. Basic/High window



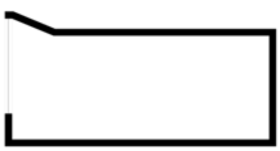
3. Basic/Roof window

4. Basic/Daylight-view

5.Basic/Floorwindow

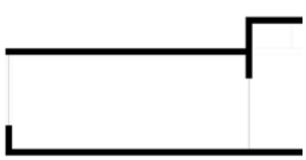


6.Basic/Corridorwindow



7.Situation/Highwindow

8. Situation/Daylight view



9. Situation/Corridor02

Fig. 3. Nine different designs of a classroom

Illuminances

The illuminances in the classroom zone have been simulated at desktop level at a 16-points grid, in order to make a differentiation for the different student places in the classroom. The vertical illuminances on the blackboard are simulated too, with a 15-points grid. The simulations have been done for a cloudy sky (CIE-overcast sky) at 21 December at 12 o'clock. The walls and the ceiling of the simulated classrooms have been chosen ‘off-white’ with reflection coefficient of 67% and the floor 'yellow' with reflection coefficient 37%.

Figures 4 and 5 show the the illuminances on a line at the middle of the classroom. All the models show illuminances below 500 lux on the blackboard; figure 6 shows the illuminances on the blackboard for the reference model and the three classroom models which receive daylight from two different sides. Table 2 shows the minimum daylight factors (df) in the classroom zone at the window side and at the corridor side and the ratio between the minimum and maximum illuminances in the classroom zone. Further in this table are mentioned the minimum daylight factors on the blackboard. From all these results we see that the classrooms with two-side daylighting have the best performances.

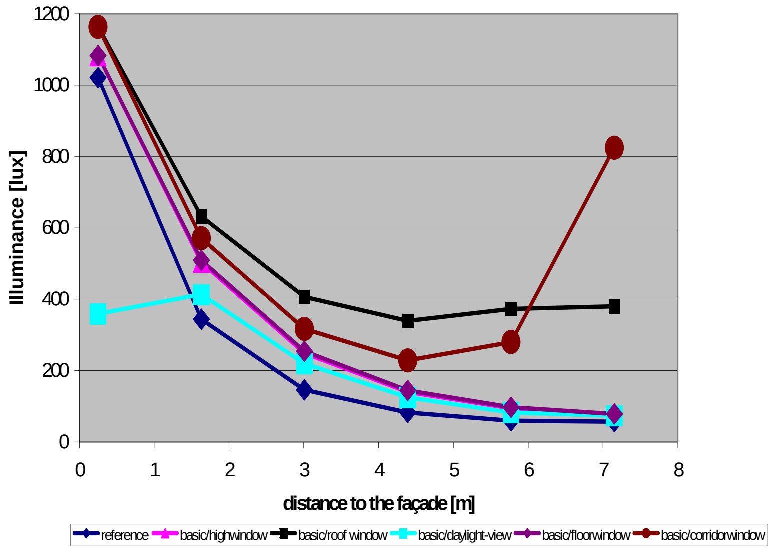


Fig. 4. Illuminance distribution for the reference model and the five basic models.

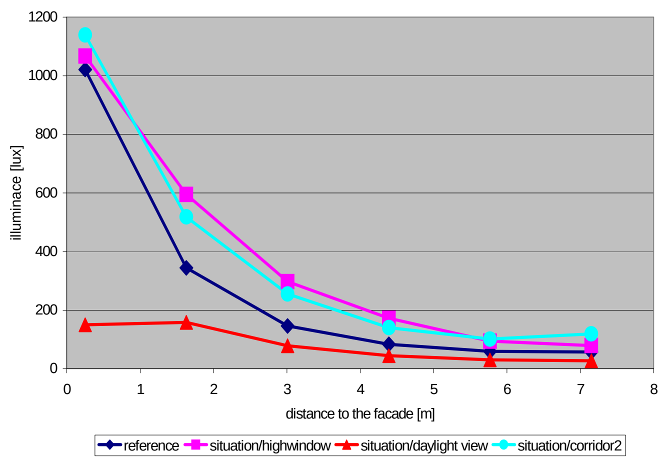


Fig. 5. Illuminance distribution for the reference model and the three situation models.

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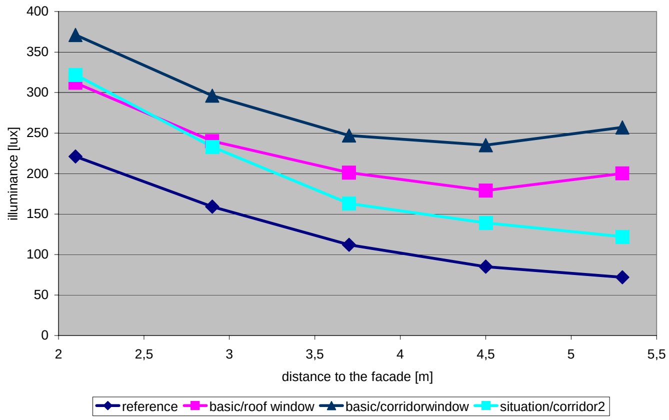


Fig. 6. Illuminance distribution on the blackboard for the reference model and the three models with two-side daylighting.

Table 2. Minimum daylight factors (df) at the window and at the corridor side and the distribution of the illuminance in the taskfield and the minimum daylight factor on the blackboard .

model	df window	df corridor	distribution	df blackboard
reference	2.71	1.09	1:6.5	1.36
Basic/Highwindow 01	4.51	1.74	1:6.0	2.08
Basic/Roofwindow	6.13	4.92	1:2.4	3.46
Basic/Daylight-view 01	4.01	1.54	1:5.7	1.76
Basic/Floorwindow	4.81	1.77	1:5.9	2.17
Basic/Corridorwindow 01	5.67	4.03	1:2.9	4.76
Situation/Highwindow	5.55	1.65	1:7.5	1.94
Situation/Daylight-view	1.53	0.53	1:6.4	0.69
Situation/Corridor window 02	4.84	1.69	1:6.3	1.94

Luminances

For the luminances and the visual comfort a winter and a summer situation has been simulated with a CIE-overcast sky as well as with a clear sky with solar radiation.

In December as well as in June a CIE-overcast sky show luminances below 3000 cd/m^2 for all the models. There is no real discrimination between the different designs, only the 'roofwindow' model shows higher luminance levels than the other designs (figure 7), which is plausible because the roof window opens a view on a higher part of the sky. In June, however, the luminance level is only just above 3000 cd/m^2. Which a CIE-overcast sky all the designs show low luminance contrasts. This is especially important for school designs with classrooms facing North. As we showed already with research in existing schools (see figure 2) the North classrooms have less luminance contrasts, as result the electric lighting was always switched on.

In case of simulations with a clear sky all classrooms facing South show luminances far above 3000 cd/m^2. In fact, all the designs show the same: In December the sun altitude is never more than 15^o, as a result the highest luminances are at the upper part of the window in the facade (figure 8); in June the sun altitude is high, then the highest values of luminances are at floor level or at the window-sill (figure 9).

Simulations with classrooms facing North in June show problems for the corridor models, because there are high luminances in the corridors coming from the South, far above 3000 cd/m^2 (figure 10).

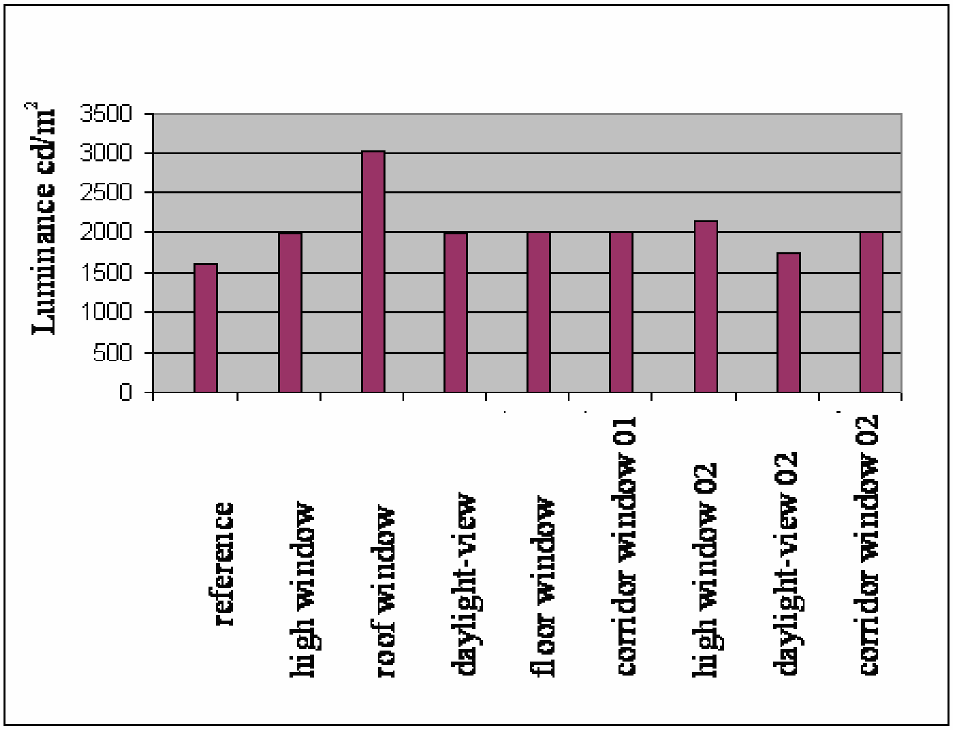


Figure 7. The highest luminances simulated for a cloudy sky in the summer, 21 June at 12:00 o'clock.

Conclusion

Observing the simulations of the illuminances and the luminances we see that the 'roofwindow' model has a good performance. A short comment, however, has to be made. The luminance simulations in dRadiance have only shown the situation from one camera position. In case of a classroom design with a roof window it is reasonable to make more simulations with different camera positions, looking from the different student seats, in order to provide, with a further specification of the design, for a visual comfortable situation for all students.

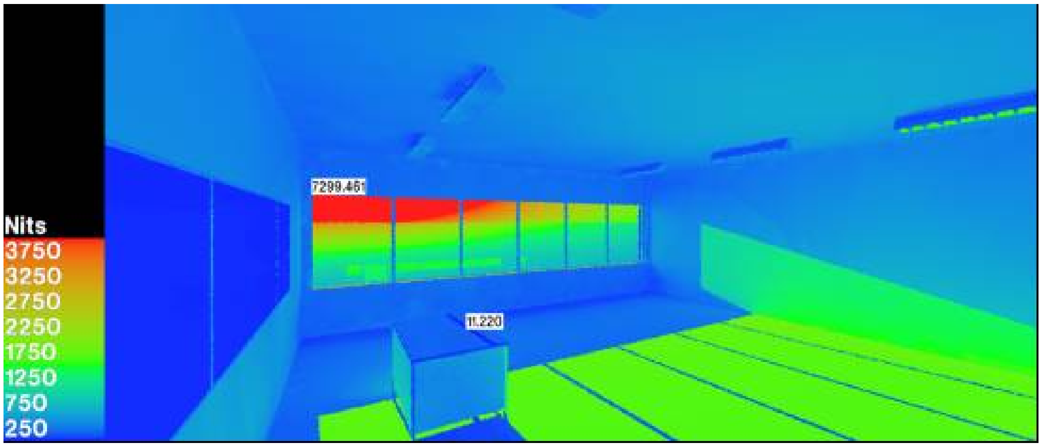
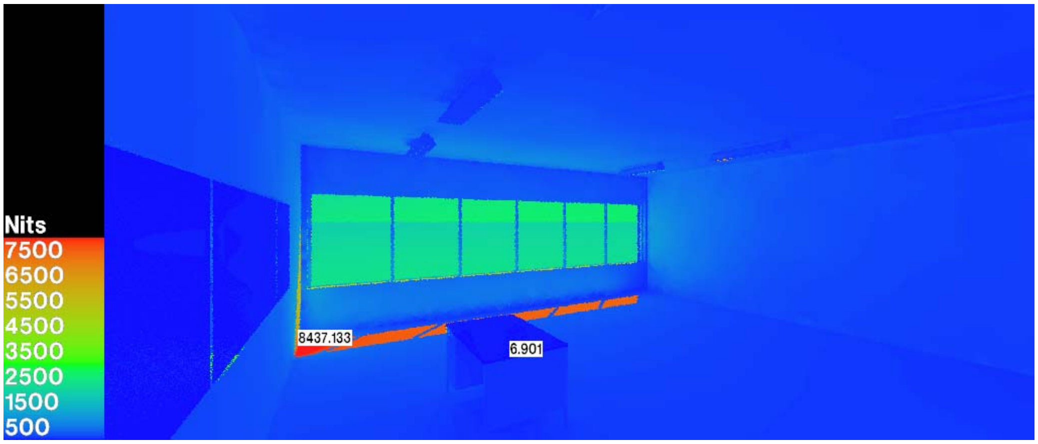


Figure 8.Luminance distribution of the reference model at 21 December at 12 o'clock, simulation with a clear sky (Nits = cd /m^2).



Figuur 9. Luminance distribution of the reference model at 21 June at 12 o'clock, simulation with a clear sky (Nits = cd /m^2).

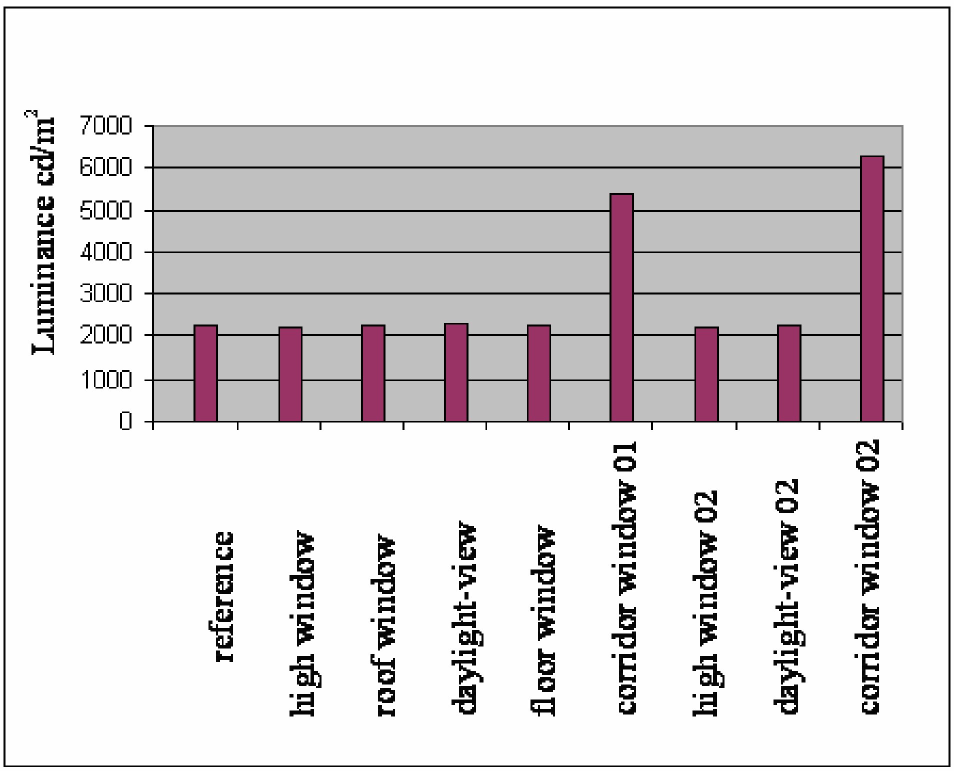


Figure 10. The highest luminances in classrooms faced to the North, simulated with a clear sky, 21 June 12 o'clock.

ELECTRIC LIGHTING

When there is insufficient daylight to light the classroom a combination will be made with electric lighting. A small survey at 20 primary schools showed that 60% of the schools have a conventional equipment in classrooms with an installed power of more than 500 Watt. In many cases these lighting equipments are based on obsolete requirements dating from around 1980. Since that time the education systems have changed. Computers have been introduced at schools and visually impaired students go to an ordinary primary school as much as possible. So, higher requirements are necessary for school lighting and there is a need to develop a new lighting concept to replace the obsolete one [6]. This concept is published in different (mostly Dutch) journals [7, 8, 9, 10, 11, 13, 14, 15, 17]. We summarize it here.

The electric lighting concept

For the electric lighting concept the classroom zone is prefarably divided in two rows of three luminaires parallel to the window (fig.11). They all have a daylight responsive control system which provides for the general lighting. The blackboard zone has its own blackboard luminaire. The blackboard luminaire must be switchable independent of the general lighting. For user's ease the blackboard switch should be placed in the neighbourhood of the blackboard.

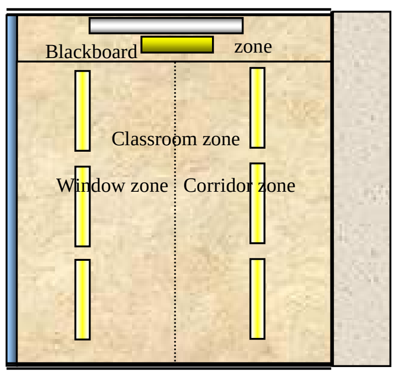


Figure 11. The specific zones.

In schools students work with computers, too. For user's comfort it is important that computer screens are protected against glare. A bare tube-light fixture or a broad-beam luminaire, mounted perpendicular on the window facade, are not advised because it is uncomfortable for the user. Today, this traditional manner of lighting is still present in many schools.

A high-efficiency, optimized reflective light fitting with high-frequency ballast is more comfortable and besides, more energy efficient. In this way two rows of three luminaires can provide for the general lighting. With a daylight responsive control system much energy can be saved. Together with the energy efficient general lighting system it is necessary to install an extra (asymmetric) blackboard lighting.

The choice of the shielding element.

One can choose a screen-friendly or a normal louver for the shielding of the high-efficiency luminaire. The screen-friendly louver directs the light more downward and gives high illuminances on some places, a normal louver gives a more equal illuminance distribution. With a screen-friendly louver the ambience of the space is less, because walls and corners are not lit well. The screen-friendly louver gives least reflections and so it is most comfortable for the eye in computer work. For classrooms with much computer lessons such louvers are recommended, otherwise a normal louver is satisfactory.

THE ENERGY USE.

If a classroom is divided in a window zone, a corridor zone and a blackboard zone, and the electric lighting can be switched on and off separately in the different zones, then for an overcast sky the energy use can be calculated for the nine different design models. So, for that sky, the most energy-efficient model can be indicated:

For the window zone, the corridor zone and the blackboard zone the minimum illuminance in each zone has been taken from the simulation results. With these values and the help of figure 12 it is possible to determine for each zone the part of the year that there is enough daylight. Table 3 shows, for each model, the percentages of the year that electric lighting is necessary in the different zones.

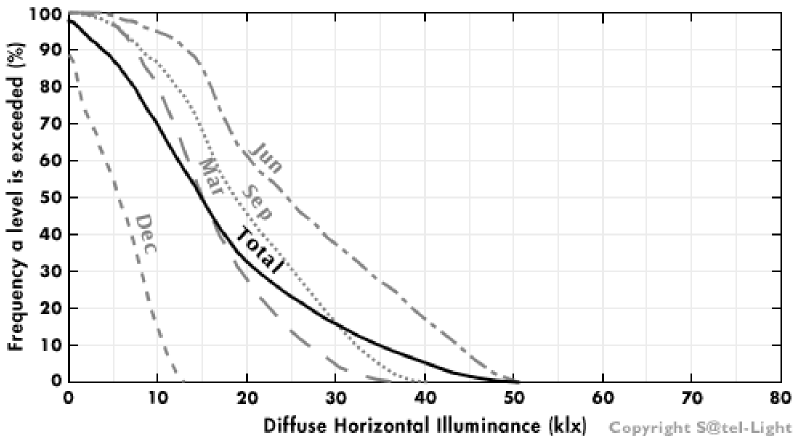


Figure 12. The illuminances in a horizontal plane, throughout the year, with an overcast sky.

Table 3. The percentage of the year electric lighting is needed.

	window zone	corridor zone	blackboard zone
Reference	25%	53%	92%
High window 01	14%	36%	78%
Roof window	10%	13%	50%
Daylight-view 01	15%	40%	83%
Floor window	14%	36%	76%
Corridorwindow 01	11%	15%	32%
High window 02	11%	38%	79%
Daylight-view 02	40%	77%	100%
Corridor window 02	13%	37%	79%

The above calculations are for the situations of an overcast sky and show very well the differences between the models. A further discrimination between the models in case of energy efficiency can possibly be made, too, with simulations of the clear sky. However, this needs much more simulations and further research.

CONCLUSIONS

The new concept for electric lighting for classrooms gives a comfortable, energy-efficient school lighting. This concept has been developed by taking into view the different tasks of teacher and students. In addition the classroom has been divided in different zones.

All nine simulated models satisfy the Dutch Building Regulations, but they differ completely to each other. From the daylight simulations of the illuminances and the luminances we know that the 'roofwindow' model has a good performance and is a good starting point for a further classroom design. However, more luminance simulations are necessary in order to make a good detailed design with a comfortable situation for every student.

By combining a good daylight design with a good electric lighting concept the energy for electric lighting can be reduced substantially. The performances of the 'roofwindow' and the 'corridorwindow 01' models are best. However, the climate in the corridor of the 'corridorwindow' model will not score well in summer, extra provisions and costs are needed to prevent overheating.

From measurements and simulations we know that the luminance contrasts in classrooms facing North are mostly low, the electric lighting is switched on the whole day. More colour contrasts in these classrooms can help to counter this.

Literature

1. W.E. Hathaway (1992); A study into the effects of types of light on children- A case of daylight robbery, Edmonton, www,lighttherapycanada.biz/schools.htm
2. SenterNovem (1995), Dat licht zo- energie-efficiente verlichting

3. NEN 3087 (1997)
4. Heschong Mahone Group (1999), Daylighting in schools, Fair oaks.
5. Berkeley University (2000): http://radsite.lbl.gov/deskrad/
6. TNO 2000 “Verlichting in Scholen”, TNO Bouw, TNO-rapport 2000-CBO-R002, Eindhoven Juni 2000.
7. Groot, E.H. de, J.S.C. van Putten, “Nieuw concept voor Schoolverlichting” (New concept for School Lighting) *Proceedings Nationale Lichtcongres*, 11 November 2000, Arnhem, pp. 102-107.
8. Groot, E.H. de, and J.S.C. van Putten, “Nieuw concept voor Schoolverlichting” (New concept for School Lighting) *Licht*, November 2000, pp. 16-17.
9. Groot, E. de (2001) “Daglichtafhankelijke regelingen kan een energiebesparing van 50% opleveren”, Schoolfacilities, nr.2, pp. 8-9.
10. Groot, E. de “Verlichtingsproject obs De Trumakkers; licht voor welbevinden, stemming en prestatie”, Schooldomein, januari/februari (2002) , pp.26-27.
11. Groot, E. de “Licht in Unterrichtsgebäuden”, Proceedings Licht 2002, 22-25 September 2002, Maastricht, pp. 73- 76.
12. NEN-EN 12464-1 (2003) “Licht en verlichting- Werkplekverlichting-Deel 1: Werkplekken binnen”, Nederlands-Europese norm, NEN, Delft.
13. Putten, J.S.C., E.H. de Groot, “Licht in Unterrichtsgebäuden”, Proceedings 25th Session of the CIE, San Diego, 25 June - 2 July (2003), pp. D3 94-97.
14. NSVV 2004 “Verlichting in onderwijsinstellingen”, NSVV publicatie, Arnhem November 2004.
15. Buitenhuis, E., S. van Eggelen, B. Gerritsen, E. de Groot, “Goede schoolverlichting, omdat kennis verhelderend werkt”, In Syllabus Het Nationale Lichtcongres 2004, 11 november 2004, Ede, pp. 108-111, NSVV.
16. E. Veldhuizen, afstudeerverslag (2004), faculteit Bouwkunde, TUDelft
17. Sliepenbeek, W., E.H. de Groot (2005), “Goede schoolverlichting - Omdat kennis verhelderend werkt” TVVL Magazine, volume 34, nr. 5, pp.48-49.