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RAPPORT

Title:	**Daylighting conditions at the Borgen Community Centre**
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Description:	The rapport describes the results of daylighting studies carried in connection with the retrofitting of the Borgen Community Centre, Asker, Norway. The scientific method implies an analysis of a few alternatives of the middle part of the building and the home bases. The physical models representing the respective alternatives were built and daylighting factors were measured in the models under the artificial sky in the daylighting laboratory at the Faculty of Architecture and Fine Art, NTNU. The optimal sloping of the glazing in the best alternative for the main building was calculated, too.
Date:	18.03.2005

1. WHY DAYLIGHT?

1.1 Qualities of daylight

Daylight is characterized by very high illuminance values. When electric light give us between 100 and 1000 lx, the typical values of daylight lie between 10 000 and 100 000 lx. This makes that even a small percent (2 – 5%) of available daylight outside provide sufficient lighting inside buildings.

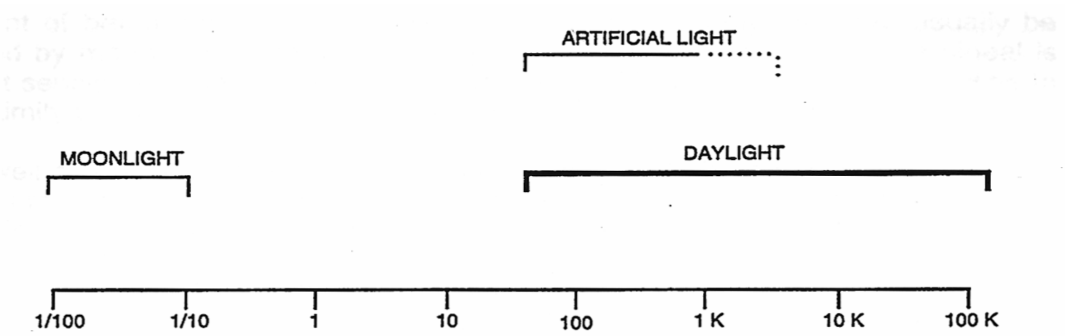
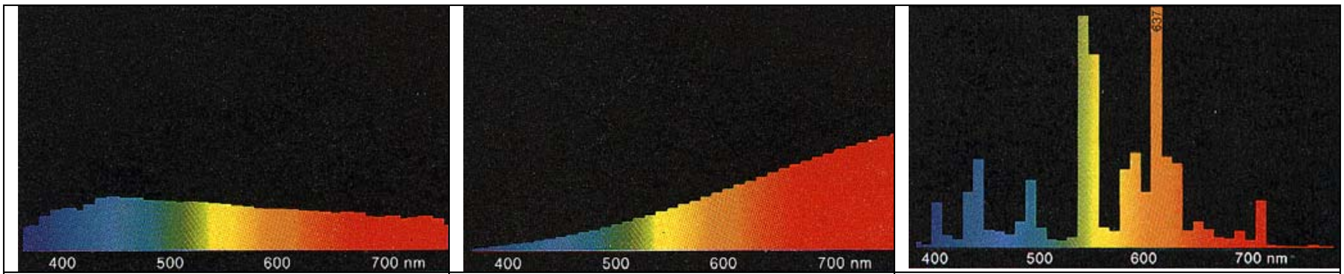


Figure 1. Electric light and daylight on the logarithmic scale. K = Klx

Another unique quality of daylight is connected to its spectral distribution that stretches from short waved UV radiation through visible light to long waved infrared radiation. We perceive the various wavelengths of light spectrum as different colours. Daylight has a very even spectral distribution compared to electric light sources. This results in a very high colour rendering and colour discrimination. Daylight is an ideal model that the producers of electric light sources are trying to imitate.



Daylight	Traditional light bulp	Typical fluoresent tube

Figure 2. Spectral distribution of typical light sources.

The third and perhaps most important quality is variability; variability in spectral content, direction and strength. We accept all changes of daylight that arise during the day and throughout the year because they have meaning, they give us information about the time and the weather. The human eye, developed during many thousand ’s years of evolution in the presence of daylight, is best stimulated by this dynamic light source. Artificial light with constant illuminance, colour and distribution appears as boring and more tiring.

More daylight will contribute to better vision conditions.

In addition to the positive influence for visual conditions, daylight contributes very positively to non-visual, but very important health-related functions of the body.

Studies of psycho-physical effects of daylight became a very important research field within the lighting research during the last few years. There are many research results that point out the relation between the exposure to daylight and psycho-physical activities in living organisms, including human beings.

1.2 Circadian rhythm

During the evolution process sunlight was crucial for forming life on earth. The human body has adapted to the characteristic diurnal variations of sunlight and functions in a typical day-night circadian rhythm. As shown in figure 3, body activity, body temperature, metabolism and the production of hormones goes on in a characteristic 24-hour circadian cyclus.

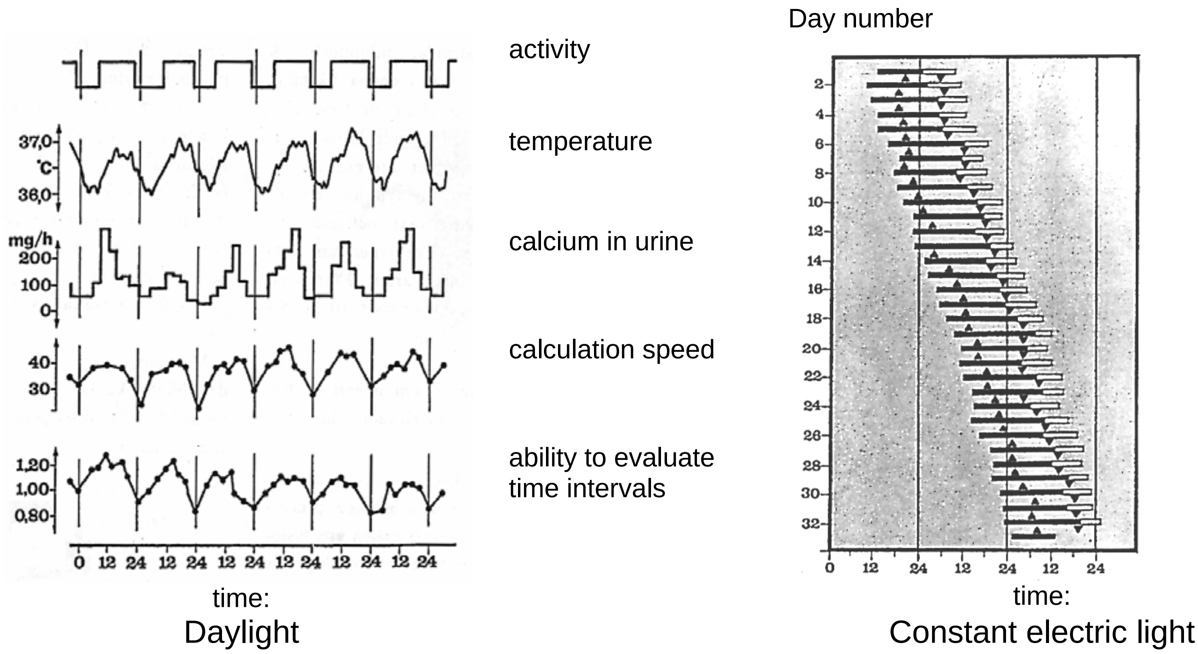


Figure 3. Circadian rhythm.

1.3 Hormones: melatonin and cortisol

The circadian rhythm is synchronized with sunrise and sunset. For human beings this rhythm is controlled by the melatonin hormone.

The light absorbed by retina causes nerve impulses that go to the pineal gland in brain, a pea sized organ at the base of the brain where the release of melatonin into the blood stream during the hours of darkness occurs.

Release of melatonin during the night makes us feel sleepy, reduces stress and slows down other body functions that might interfere with sleep. All of these effects are then reversed during daytime, when the melatonin secretion is turned out.

To say that these cycles are switched off and on by the presence or absence of daylight is an oversimplification. Experiments have shown that circadian cycles still occur, even without the stimulus of daylight, but they slow down by approximately 1.1 hour in every 24 h. After many days without daylight the cyclus will be enlarged with many hours, figure 3. The role of daylight is to speed up the body’s circadian rhythm so as to coincidence with the 24 h daily cycle. This is described as phase shifting and appositive shift of about 1.1 h is thus needed on a daily basis.

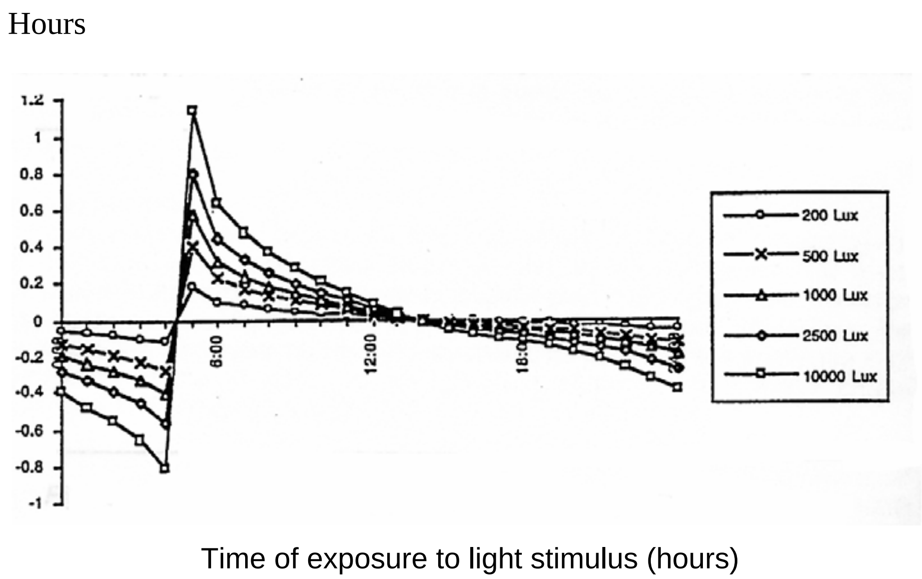


Figure 4. Human sensitivity to light exposure.

The pineal gland is much more sensitive early in the morning than during the day. At peak sensitivity (at about 4 am), even low intensity light can result in a positive phase shift, but as the day progress, the sensitivity gradually declines, so that higher light intensity or longer duration is required to obtain the same effect. According to currently accepted model of Kronauer, there is in fact a crossover point (at about 2 pm), after which exposure to daylight increasingly slows circadian rhythm down again.

The cortisol hormone, in contradiction to the melatonine, functions as a stress hormone. The production of cortisol is also controlled in pineal gland. The concentration of this hormone varies with the body's needs and follow the circadian rhythm with high amounts during the day and low during the night.

What are the consequences of the underexposure to daylight?

If the intensity of light reaching the retina is too low, the pineal gland's cycle of melatonin secretion will gradually lengthen to its free-running value of 25.1 h. The melatonin will be released at the wrong times of the day, resulting in lethargy and drowsiness. For certain individuals this gives rise to a condition known as Seasonal Affective Disorder.

For most of the year the greatest opportunity for positive phase shifting occurs at home, when students get up in the morning and during they way to school. But such pre-exposure is not sufficient and without adequate daylighting at school the correct daily positive phase shift is difficult to achieve. At high latitudes as winter approach students will be exposed to less daylight before school time and in wintertime students reach school in the dark.

More daylight will contribute to more awaked students, that is an important condition for effective learning.

1.4 Seasonal variations in hormon production

The last studies indicate that people that live in areas long from the equator notice seasonal variations in hormon production. Two Swedish studies curried out by R. Küller have shown a clear decrease in concentration of cortisol in urine early in the morning in the dark part of the year. The decrease was clearest in the November-December. There is also a connection between cortisol level in the body and the immune response.

The shortage of daylight in the wintertime causes a lower level of cortisol, something that reduces of body's immune response toward infections and flues etc.

More daylight will reduce the students' absence at school.

1.5 Ultra violet radiation

Human evolution has occurred in the context of exposure to daylight including UV and the human physiology depends on a certain degree of exposure to UV.

The UV on the human skin has several benefits, as:

- production of D vitamin
- stimulation of the immune system and hormone production
- defence against microbes
- secretion of antiseptic oils
- increasing of oxygen carrying capacity
- reduction of cholesterol level in blood
- reduction of blood pressure

More daylight will increase the health of students and teachers.

1.6 Electric light saving/energy saving

A high daylight level and rather even daylight distribution makes a large potential for energy saving for lighting. If the electric light is switched out when daylight gives enough light level, the electric power can be reduced considerably. It can be done automatically using a control system for lighting that adjusts the power of electric light such as the sum of electric light and daylight is higher than the illuminance level recommended by the Norwegian lighting association, Lyskultur.

More daylight will create energy saving potential for lighting.

1.7 The visual impression

The buildings with high daylight level are usually perceived as open, friendly and spacious. Most people enjoy being in extensively daylighted buildings as long as there is possible to control the direct sun radiation in to the building.

More daylight will make the school building more friendly.

2. DAYLIGHT DEMANDS IN THE NOREWGIAN BUILDING STANDARD

2.1 What demands the building standard?

In the Norwegian Building Standard, called Byggeforskrift 1997, the following recommendation is formulated:

"A room for permanent stay should have a satisfactory daylight level, as long as the stay or the work situation justifies something else."

In the guidance to this standard the three following criteria for satisfying the standard are formulated:

Alternative 1

Daylight factor should be minimum 1 % in a point 1,0 m from a sidewall, on a height of 0,8 m over the floor and at the middle width from the window wall.

Alternative 2

The windows light area should the Swedish standard SIS 91 42 01. The standard define the minimum glass area to a factor $f*A_{floor}$. Without any outside shading the factor f is 0,075, also 7,5%. The diagram showing the relation between the factor f and the shading angle is included in the standard.

Alternative 3

The window glass area should be minimum 10 % of the floor area. If the shading angle measured from the middle height of the window is larger than 20 %, the glass area has to be increased.

2.2 Why the objectives for daylighting in the Borgen Community Centre are higher than the building standard demands?

The very positive effect of daylight on the human health, well-being and productivity are the reason for defining of all teaching areas as daylight dominated areas, areas were electric light is usually not used during daytime. The goal is to minimalise the usage of electric light and to create best possible light conditions for students, teachers and all employees.

The British "CIBSE Code for interior lighting (1984)" gives a clear recommendation for daylight level in a daylight-dominated area.

"If electric lighting is not normally to be used during daytime hours, the average daylight factor should not be less than 5%. It is important that the distribution of the light is even in the room or supplementary electric lighting may be required. …

If electric lighting is to be used during the daytime the average daylight factor should not be less than 2%, if it is then the general appearance of the room will be of an electrically lit interior."

The recommendation for 5% daylight factor indicates a high ambition level. In a typical room build according to the Byggeforskrift 1997 the mean daylight factor will vary between 1,5 and 3%, depending on the room geometry and the reflectances on the room surfaces. In the back part of a typical side lighted room the daylight factor will fall below the 0.5%.

The three alternative criteria cited above refer to a typical rectangular room with windows in one wall. The recommendation in the alternative 1 is most specific. In the side lighted room people prefer to stay in the window zone, in the area were daylight factor is higher than 1%. In school buildings, especially in the teaching areas, about a half part of students has working paces situated in the back zone of the classroom. Therefore it is reasonable to demand minimum 1% daylight factor in the whole teaching areas.

In addition to daylight factor that describes only the general daylight level, more detailed goals are formulated for the solar glare, the luminance distribution, modelling, light colour and the control of the electric light. These goals have to be achieved if one wishes to create a room with a good visual environment.

2.3 Objectives for daylight in the Borgen Community Centre

2.3.1 Daylight level

The table below shows the recommended daylight factors for the Borgen Community Centre.

	Mean daylight factor	Minimum daylight factor
Teaching areas	5 %	1 %
Working places for teachers	2 %	1 %
Offices	3 %	1 %
Secondary rooms	(2 %)	-

2.3.2 Solar glare

Daylight openings and any reflecting surfaces should not cause a glare. The glare from both, the direct and the reflected sunlight are especially important to avoid at the teaching areas and at the fast working places.

2.3.3 Luminance distribution / contrast

A working object should have higher luminance than the luminance in the visual field because the attention easiest directs to the highest luminances. On the other hand, too high differences in the luminance makes that the eye is exposed to continually, fast adaptations, something that reduces the visual comfort considerably.

The maximum differences in luminances are formulated in IESNA RP-1 VDT Lighting Standard.

Visual field/working field	3 : 1
Visual object/computer screen	3 : 1
Visual object/surroundings	10 : 1
Maximum contrast in a room	40 : 1

2.3.4 Modelling

The light should have such direction distribution that the shape and texture of three-dimensional objects is revealed. The modelling is especially important in the places for presentation.

2.3.5 The colour of light

The spectral distribution of light should give sufficient colour rendering. It is important that daylight level is high and that electric light has high colour rendering index in art and craft rooms and rooms for cooking.

2.3.6 Light level/Control of electric light

The electric light should be controlled with the help of daylight sensors such as the sum of electric light and daylight is minimum 300 lx in all teaching areas.

The Lyskultur recommends 300 lx in teaching areas and 500 lx at the blackboard.

3. DAYLIGHT IN THE BORGEN COMMUNITY CENTRE

3.1 Daylighting before retrofitting

The main building has a width of 27 m. Daylight penetrates into the building through the side windows. On the outside of the building, in front of the facades there is an opaque roof that obstructs daylight very effectively. The approximate calculations done with the LesoDial program show that even if the roof will be removed, the existing windows will give adequate daylighting only in a 4.5 m wide stripe along facades. In classrooms having a depth of 8-9 m the daylight level will be too low. Therefore the electric light is used as the only form of light in the school independently on the season or the time of the day. Some of rooms e.g. the library do not have windows at all.

The main building seen from the outside

Outside circulation area

Teacher room

Classroom

Library

Main corridor

Figure 5. Photos of the Borgen school taken 06 June 2001.

3.2 Methods for improving of daylight conditions

To increase the daylight conditions in the building the following changes are recommended:

1. removing of the roof outside the building
2. increasing the size of windows
3. placing the windows as high as possible in the facade walls
4. introducing new large daylight openings in the buildings roof to increase daylight level in the middle zone of the building.
5. introducing glass walls between the middle part and the side parts of the building to increase the penetration of the daylight from the middle zone to the side areas

In addition use the automatic control of electric light.

3.3 Method

The scientific method implies an analysis of a few alternatives of the middle parts of the building. For each alternative the minimum glass area in the middle part necessary to meet the specified objectives is to be found. The A*U (glass area multiplied by the U-value) is to be calculated as an indicator for energy loss through the glazing. In this way the comparison of alternative solutions can be made with the energy consumption perspective. The next step is to analyse the sunlight penetration and the methods for control of sunlight penetration in building is to be proposed.

The solution for ventilation system in this building is different in the home bases and the rest of the building, called the main building in this rapport. The method described above is to be used both, for the home bases and for the common areas independently. The home bases should be studied both, with and without an outside glazed façade, which is a possible alternative for the ventilation solution with a culvert.

4. ALTERNATIVE SOLUTIONS

4.1 Proposal for the main building

4.1.1 Alternative A

A large glass surface to the north placed highly over the floor will give a high and even daylight level in the middle zone of the building, figure 6. The daylight will also penetrate to the side zones through the glazing in the partition walls and will considerably increase daylight level in these areas.

On the basis of the orientation of the building and the operation time of the school (8:30-16) the optimal sloping of the north oriented glass façade can be calculated to avoid sun shading devices and at the same time to ensure en extensive penetration of diffuse skylight. The sloping of about 56º from the horizontal plan satisfies those objectives, see chapter 6.

Approximate calculations done with the LesoDial program have shown that the long glass facade oriented to the north should have a width of about 3.0 m to meet the objectives for daylight factor for this building.

Another conclusion taken from the LesoDial calculations was that it is preferable to supplement the north oriented glass façade with a daylight opening from the opposite direction. A narrow, horizontal split was proposed between the roof of the south ventilation duck and the roof over the central part of the building. The split will enable sunlight penetration to the building from the south. The roof over the ventilation duck will function as a light shelf.

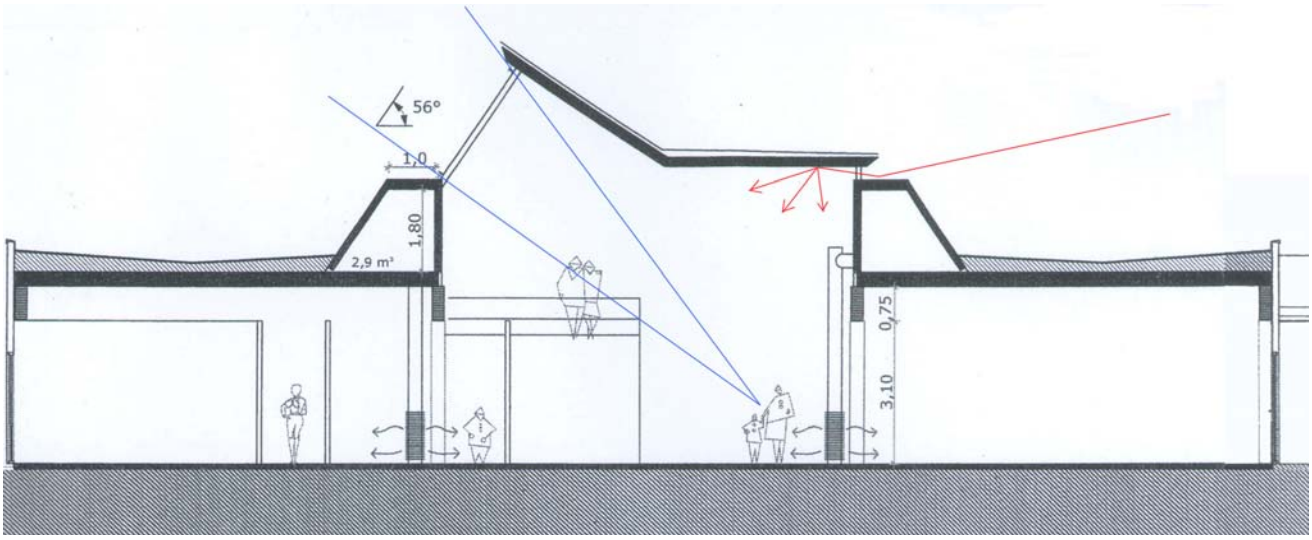


Figure 6. Cross section through the main building, alt. A

Daylight solution developed in the preliminary project is based on the alternative A.

4.1.2 Alternative B

The ventilation duck on the north side is made of two glass walls: a vertical one and a sloping one, figure 7. The ventilation duck functions as a daylight source for the main building. Two glass layers in the sloping glass wall and one or two glass layers between the duct and the main room will enable the penetration of diffuse skylight to the high main room that is created after the roof over the main part of the building is lifted up. Some daylight may also penetrate from the ventilation duck directly to the side areas through a point formed daylighting opening in the roof.

The glazing in the south wall should have a daylight system that redirect sunlight to the main roof.

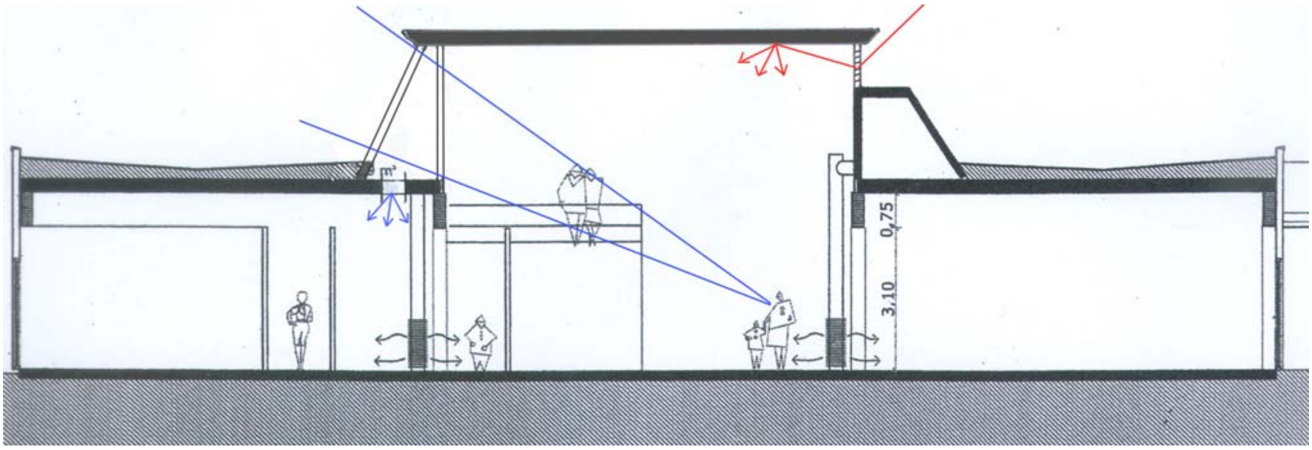


Figure 7. Cross section through the main building, alt. B.

4.1.3 Alternative C

Two linear skylights with a clear glass, figure 8. The skylights will contribute to very high daylight level mainly along the axes. The idea of using a clear glass is to enable as large penetration of sunlight as possible down to the space and to diffuse it afterwards. The sunlight will fall on the sidewall of the north ventilation duck. Under the south skylight there is necessary to design some vertical specular blinds to change the direction of the sunlight.

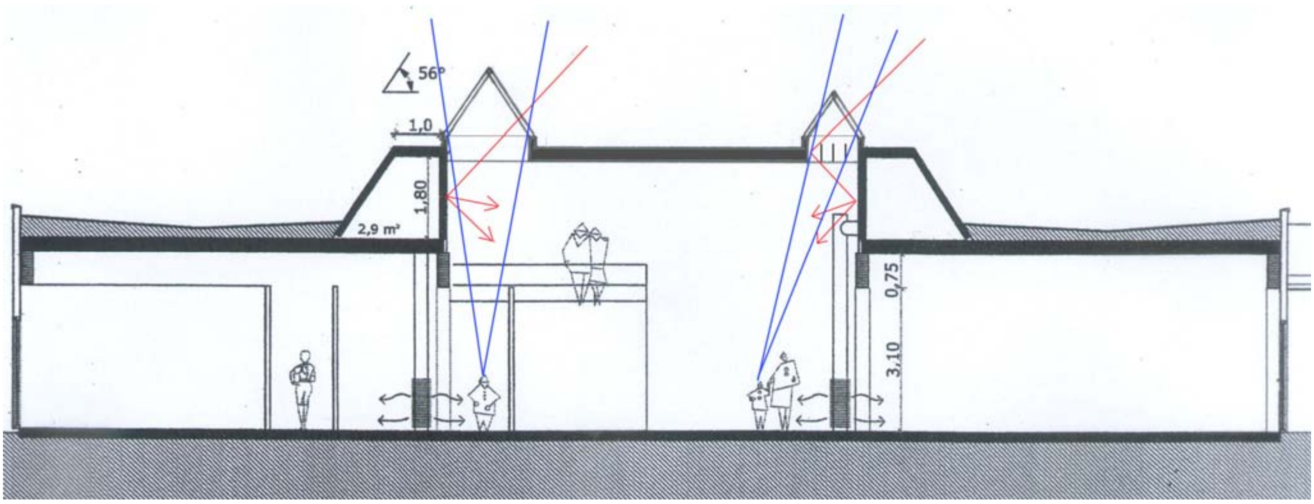


Figure 8. Cross section through the main building, alt. C.

4.2 Proposal for the home bases

4.2.1 Alternative A

Alternative A, figure 9, is similar to alt. A in the main building. The bend roof in home bases will enable the penetration of daylight from east and west in addition to the north and south.

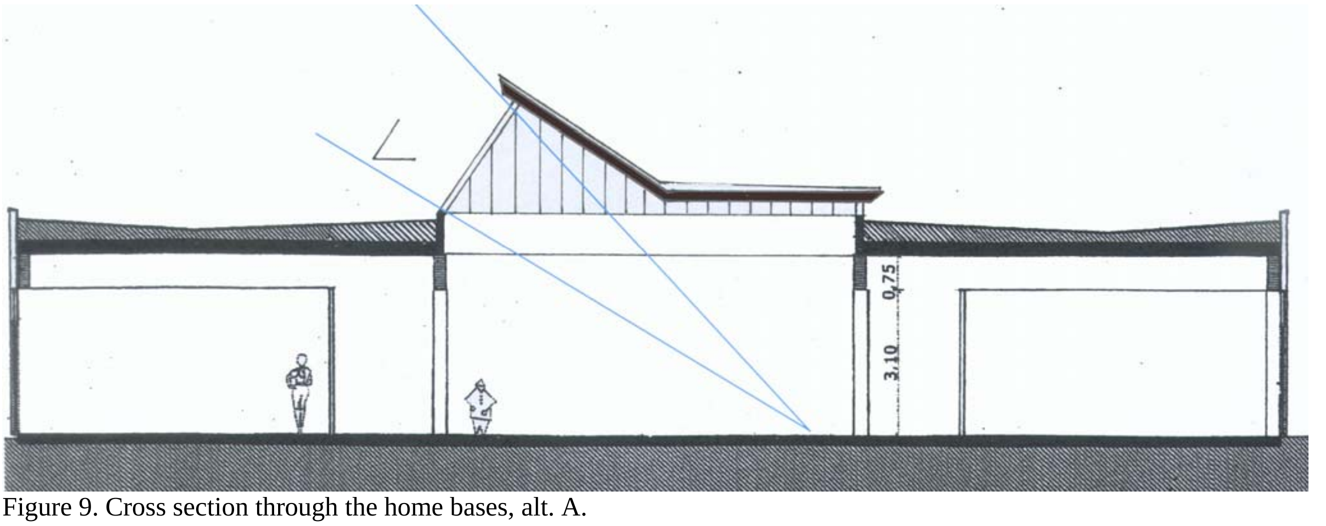


Figure 9. Cross section through the home bases, alt. A.

4.2.2. Alternative B

This alternative is similar to the alternative B for the main building. A flat, horizontal square part of the roof is lifted up. The split between the roof and the rest of the building is filled by vertical glazing creating a lantern. On the south oriented glazing a sun directing blinds have to be used. On the east and west oriented glazing an outside vertical shading system has to be used.

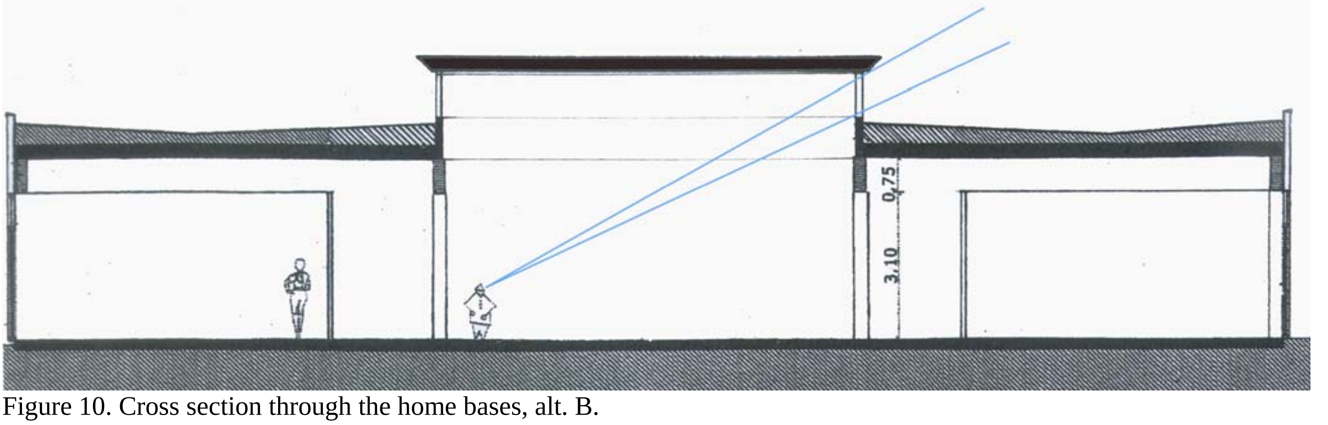


Figure 10. Cross section through the home bases, alt. B.

5. MEASUREMENTS UNDER THE ARTIFICIAL SKY

5.1 Method

The evaluation of the proposed solutions was done by measurements of daylight factor in two physical models. The first one represented a part of the main building, the second one represented one of the home bases, figure 11. Both models were done in the 1:50 scale. Each model had a permanent part and a changeable part. The permanent part consists of the floor, all outside walls, pillars and beams. A few differently shaped roofs that represent the proposed alternatives can be put on the permanent part. To get as high precision in measurements as possible, all daylighting openings were made with a very high precision. A 2 mm thick acryl sheet was used in models to simulate glass in windows, 4 mm thick acryl sheet to simulate glass in skylights. Also the reflectances on the room surfaces were chosen to represent the surfaces in the building with great accuracy.

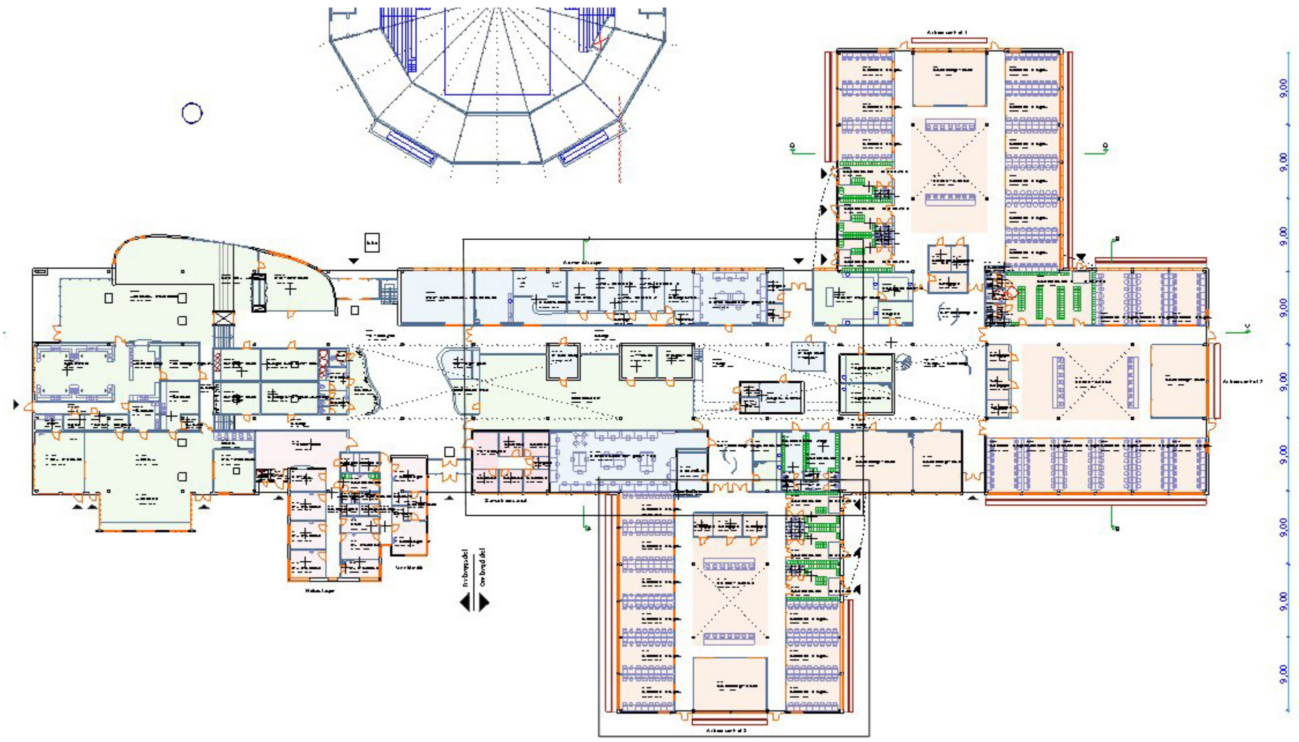
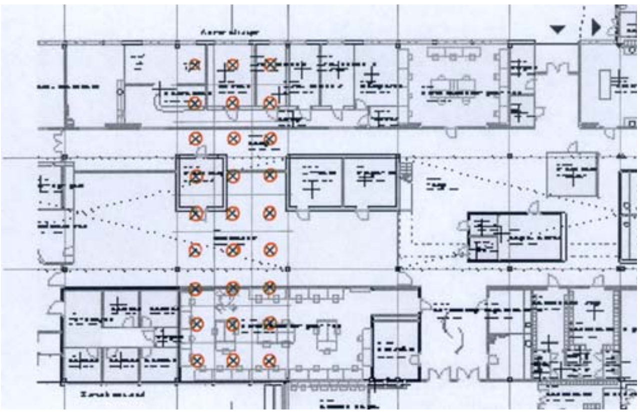


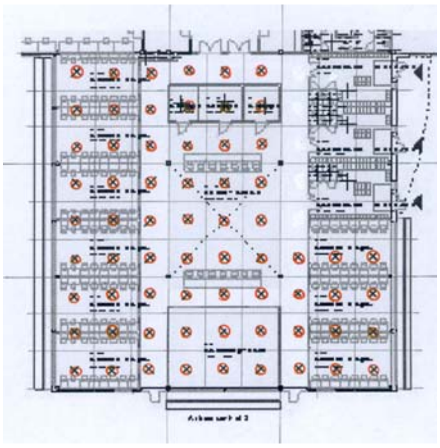
Figure 11. Proposal for a new ground floor plan for the Borgen Community Centre, drawn by HUS architects. The scale models are made for the parts of the building shown with the black rectangles.

The measurements were done under the artificial sky in the daylighting laboratory, developed in the last years at the Faculty for Architecture and fine art, NTNU. The artificial sky is constructed after the mirror box principle, a DIAS computer based measurement system was used during the measurements of illuminance.

The floor in the model was divided into a grid, about 3 x 3 m in full scale, figure 12. One photo-sensor was placed in the centre of each grid element, a cross in a red ring in figure 12. One sensor was placed on the roof of the model to measure illuminance on the unshaded horizontal surface outside the building.



Main building



Home bases

Figure 12. Placing of photocells in the models.

5.1 The results for the main building

The measurement results for alternatives A, B and C in the main building are presented in figures 13-16. The measurement points are ordered from the north to the south. The diagrams show the results for each alternative. To find out how much of daylight penetrates into the building through the skylights, the measurements were taken with the facades cowered with a black opaque textile, see the line called opaque facades. To find out how much daylight penetrates into the building from the sides, the measurements were done with the covered skylights. The measurements were also taken with only one skylight cowered, both on the north and on the south side to find out the importance of each of them. The line called ”original” refers to the base case, a model without any cover.

Because the acrylic sheets, which were used in the model instead of glass, have the transmittance of about 0.95, it was necessary to use some factors that take into account the total transmittance of the glazed wall. The transmission factors are shown in the table 1.

	Transmission factor: **glass**	Transmission factor: **profiles**	Transmission factor: **total**	Transmission factor**,** adjusted with the trans-mission factor of acryl
Sidewalls in the home bases: two glass layers	0,75	-	-	0,8
Glass wall situated in the front of the window wall in home bases: two layers of glass i thin profiles	0,75	0,85	0,75 x 0,85 = 0,64	0,67
Ventilation duct in alt. B: three glass layers, thin profiles in the outside glass wall and very thin profiles in the inside glass wall	0,62	0,85 x 0,9 = 0,77	0,62 x 0,77 = 0,48	0,5
Skylight in all alternatives: to glass layers, very thin profiles	0,75	0,9	0,75 x 0,9 = 0,67	0,7

Table 1. Light transmission factors for daylight openings in the building.

The results for alt. A show that the effect of the large north oriented glazing is very strong; compare the daylight factors in the middle zone with the daylight factors in points 1 and 9 lying by the windows. Without the skylight, see the yellow line, the daylight level in the middle zone would be extremely low. In points 3 and 7, lying in the distance of about 7.5 m from the facades, the daylight factor decreases to less than 1%. The contribution of the skylight can be studied in figure 13; the red line represents results for opaque facades. In points 3 and 8 about 50% of light comes from the skylight, in point 7 almost 80%. It indicates that the skylights function as expected, especially the northern one; daylight penetrates considerably to the sides. The south oriented split, having 20 cm height in full-scale, contributes very little, compare the blue and the purple lines. The north oriented glass wall is too large; it contributes to higher daylight factors than the values formulated in the objectives for this project.

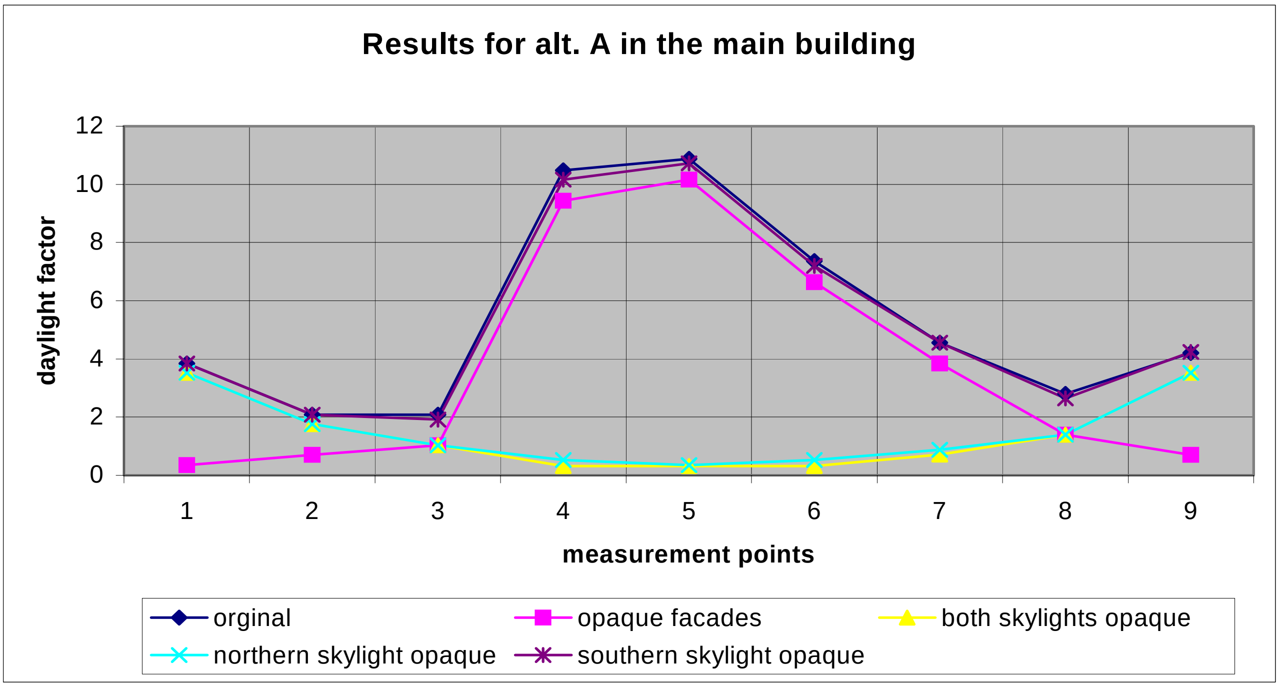


Figure 13. The main building, results for alt. A. North to the left.

The daylight distribution across the building in the alt. B is very even, figure 14. The daylight factor varies between 2 and 5%. The daylight penetrating through the ventilation duct on the north side and through the glazing on the south side is distributed evenly to the both sides. About 50% of light in point 3 and 70% of light in point 7 comes from above. There is better balance between the contributions from the north and south direction than in alt. A.

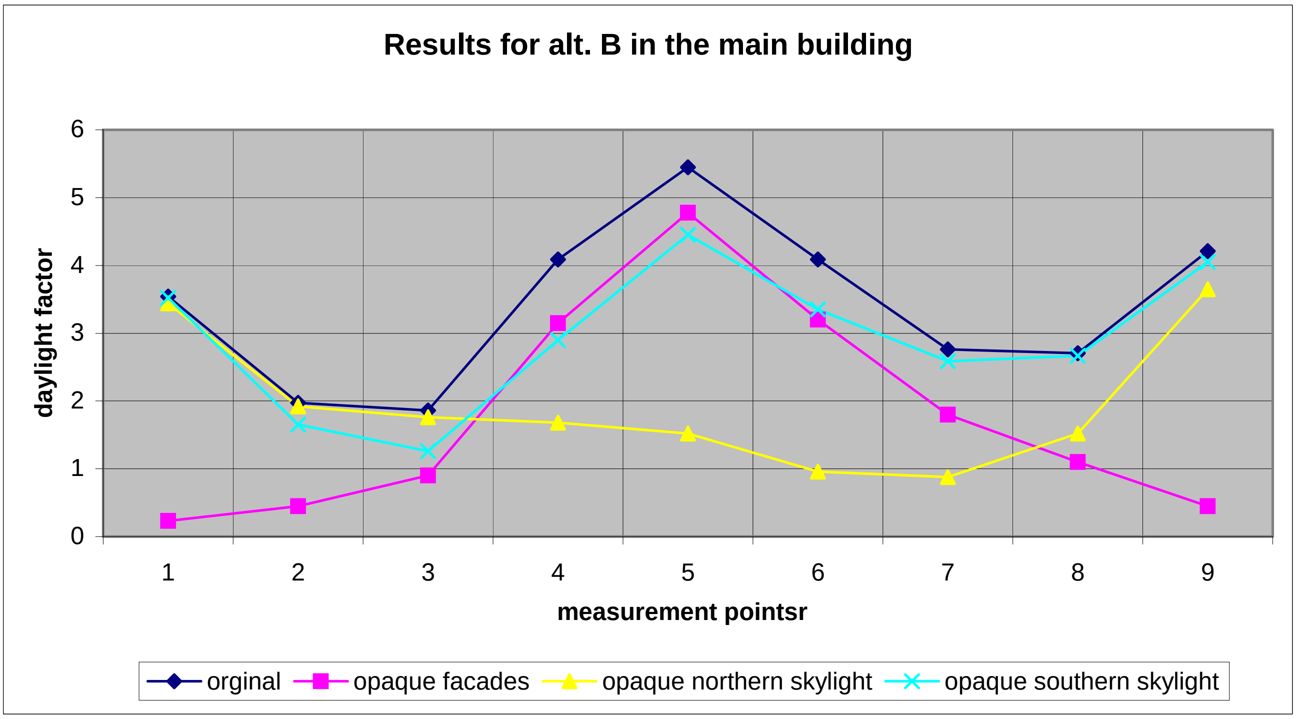


Figure 14. The main building, results for alt. B. North to the left.

In alternative C there is a huge contrast between zones lying directly beneath skylights and the side areas. The contribution from the skylights in the points 3 and 7 is considerably lower than in alternatives A and B, this indicates low spreading of light from the middle zone to the side areas. The skylight on the north side that is 1.6 m wide gives more than twice as much light as the skylight on the south side that is only 0.8 m wide. Both skylights are a little too large.

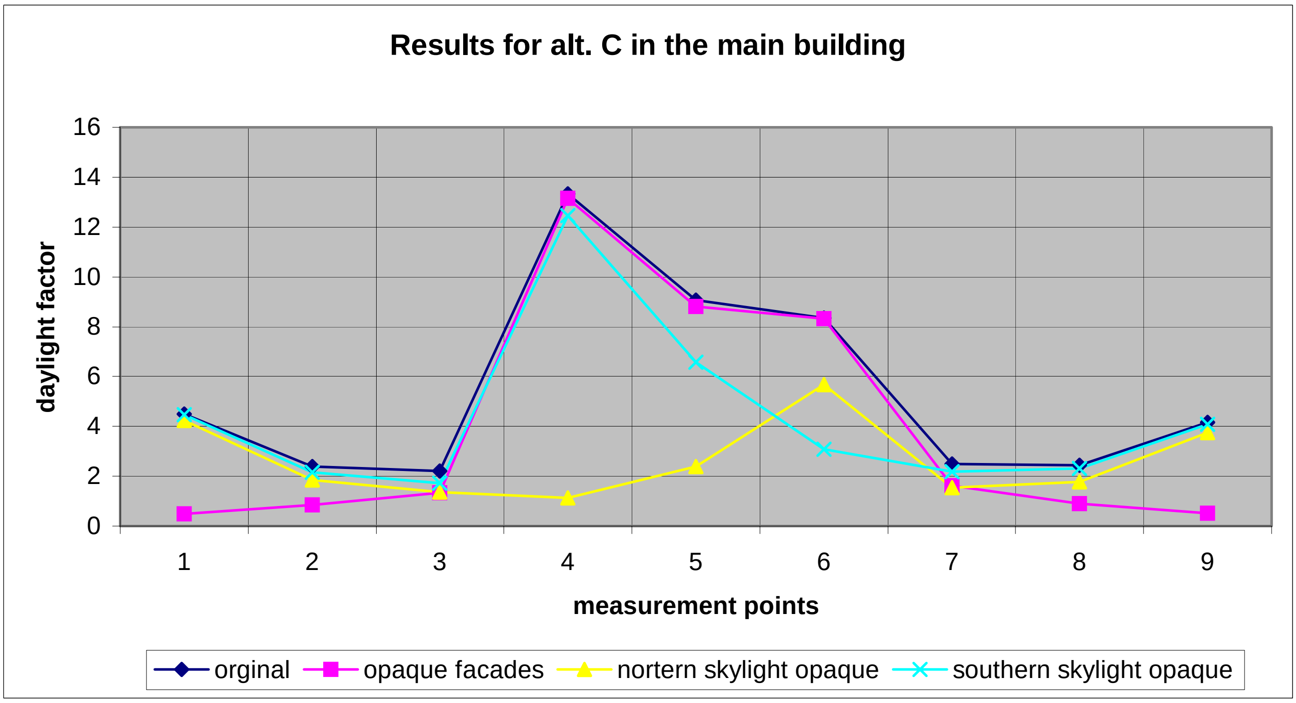


Figure 15. The main building, results for alt. C.

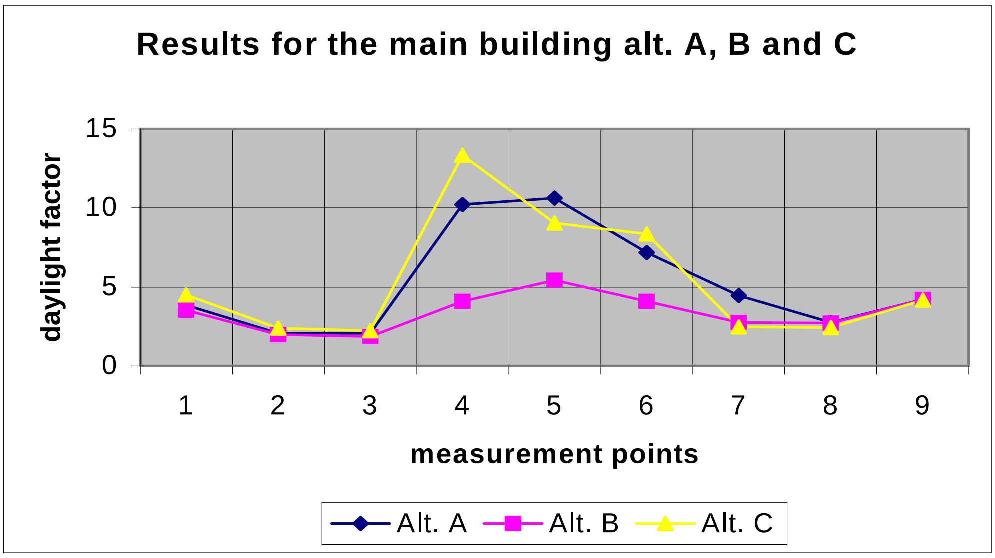


Figure 16. The main building, results for alt. A, B and C.

5.2 Conclusions for the main building

The alternative A gives most light in areas lying south for the middle zone. To increase the light penetration into areas lying north for the main axis, the split on the south side has to be increased, such that the height of the glass is minimum 40 cm. Because the mean daylight factor for the middle part is higher than the objective in this project (about 9%), the width of the north oriented glazed wall can be reduced from 3.0 m to almost 2.0 m. The daylight factor in the middle part will still be higher than 5%.

The alternative B gives most even daylight distribution. If this alternative will be chosen, the glass area on the north and on the south side should not be reduced. The height of the ventilation duct should be even increased from 3.15 m to 3.25 m to obtain the objective of 5% mean daylight factor. On the south side the glass height should be increased from 1.1 m to 1.2 m.

The alternative C gives very high daylight levels beneath the skylights but the penetration of daylight to the side areas is purest. If the recommendations formulated above are respected, the total glass area in alt. A can be only 55% of the total glass area in alt. B. The alt. A is recommended for the further project.

The daylight penetrating to the building through the side windows do not give high enough daylight levels in the rear parts of the side areas, the windows may be placed higher in the walls or increased.

The daylight access in the office areas were the daylight does not penetrate through the windows or from the middle zone should be increased.

5.3 The results for home bases

The results for alternatives A and B i home bases are presented in figures 14-19 with the measurement points ordered from the south to the north.

The alternative A gives especially uneven daylight distribution in home bases. The daylight factor beneath the north part of the middle zone is higher than 10%. Even though the daylight level in point 6 is too high, the level in the point 7 is very low. It is due to the fact that there is not possible to see the sky from the point 7, the split between the roofs is too little. The skylight in this alternative is too large. Because the split between the roofs cannot be reduced, it is already very little (20 cm), it is not possible to reduce the glass area without changing the sloping of the roof.

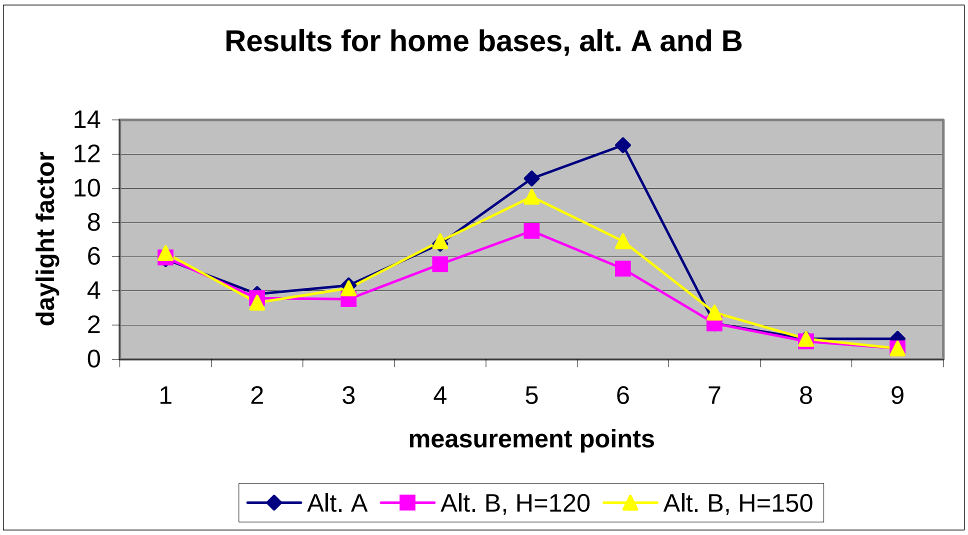


Figure 17. Home bases, the results for alt. A and B. South to the left.

The alternative B gives more balanced light distribution. A point where the daylight factor is highest is exactly at the middle. The figure 18 shows results for four heights of the glazing in the lantern. To obtain the objective of minimum 5% mean daylight factor, the height of the glass should be minimum 120 cm.

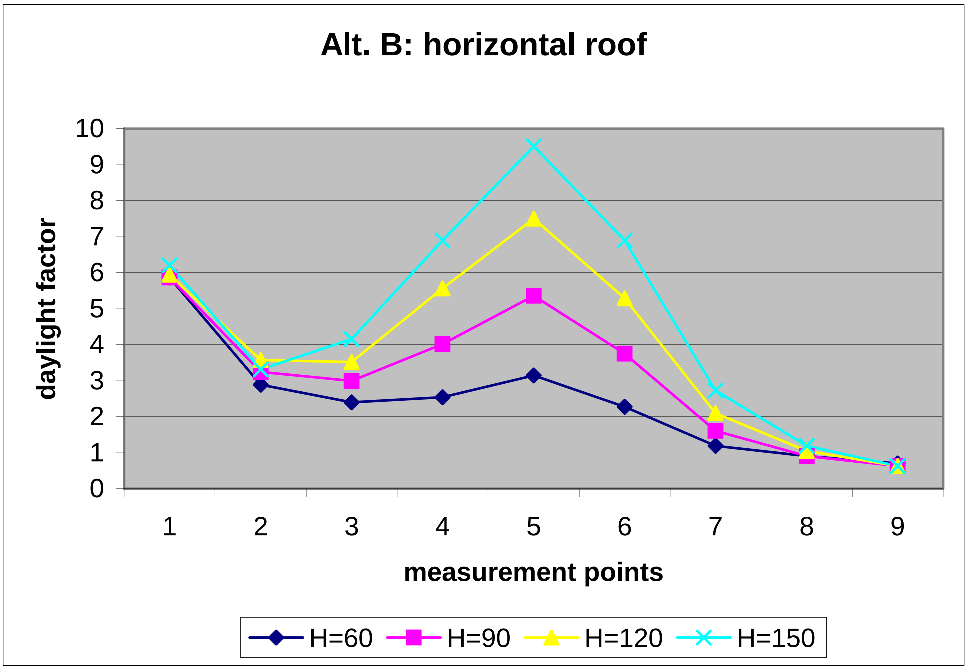


Figure 18. Home bases, the results for alt. B, the height of the glass varies from 60 to 150 cm. South to the left.

On of the valls in the lantern has to be opaque due to the ventilation tower that has to be placed on the roof. If the south oriented glass wall will be opaque, the daylight will be reduced mostly on the opposite side, e.g. on the north side, with about 20-25%, figure 19.

In the table 2 the mean daylight factors in the middle zone are presented. Because the middle zone is defined as a working area, the height of the glass in the lantern should be minimum 130 cm.

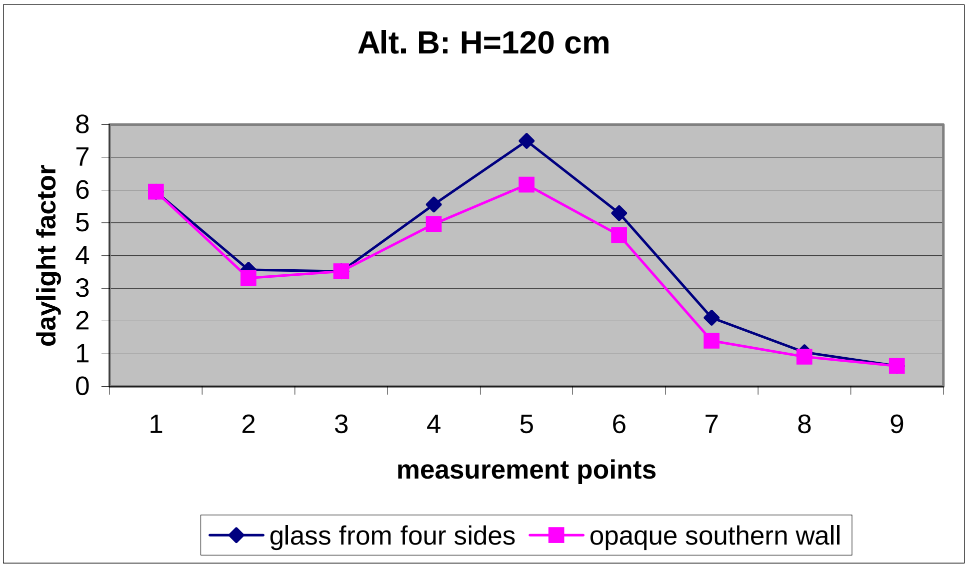


Figure 19. Home bases, the reduction of daylight level in the case the glazed wall will be opaque. South to the left.

The lowest daylight factors can be found in the working areas neighbouring the main building. The objective of minimum 5% mean daylight factor will be difficult to obtain with the glazed wall standing outside the window wall.

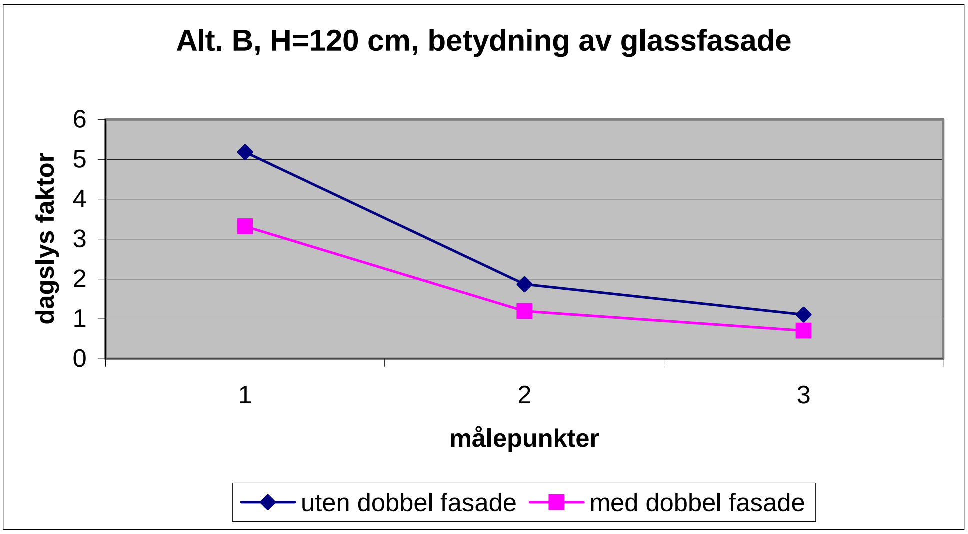


Figure20. Home bases, daylight factor in the ”student office” neighbouring main building.

Alternatives		Mean daylight factor in the middle zone:
Alt. A: bend roof		DF=7,1%
Alt. B: lantern:	H=60 cm	DF=2,1%
	H=90 cm	DF=3,0%
	H=120 cm	DF=4,3%
	H=120 cm, opaque from south	DF=3,7%
	H=150 cm	DF=5,6%
	H=150 cm, opaque from south	DF=4,7%

Table. 2. Home bases. Mean daylight factor in the middle zone.

5.4 Conclusions for home bases

Daylight penetrates deeply through the high side windows into home bases and gives adequate daylight levels in the teaching areas. Only in one “students office” neighbouring with the main building the daylight level is too low. This office gets less daylight from the lantern.

A glazed wall situated in the front of the facades reduces daylight level in the home bases with minimum 35%. The reduction is highest in the window zone.

In the corners of home bases in areas that gets daylight from two directions e.g. from south and east oriented windows or from west and south oriented windows, the daylight level is too high.

In alternative A there is too much daylight in the middle zone. The daylight distribution in the middle zone is very uneven, too. The glazing area in the north oriented skylight can be reduced with about 30%. Such a change is difficult to do without changing of the sloping angle of the roof.

The daylight distribution in alternative B is more balanced and even and therefore better than in alternative A. The daylight level in the middle zone can be chosen by adjustment of the height of the lantern. To obtain a minimum 5% daylight factor in the middle zone, the minimum height of the glazing in the lantern should be 120 cm.

An opaque wall in the lantern reduces daylight penetration especially to areas on the opposite side of the middle zone. If one wall in the lantern is to be opaque, the height of the glazing in the remaining transparent walls should be increased to minimum 130 cm.

6. OPTIMAL SLOPING OF THE GLAZING IN THE MAIN BUILDING

The light transmission of the glass differs with the incidence angle of the light rays. The incidence angle is defined as an angle between a sunray falling on the glass and the normal to the glass surface, the angle β in figure 21. The light transmission is highest for light falling orthogonally on the glass. In the case of very large angles, e.g. larger than 75°, the most part of the light falling on the glass will be reflected out. The light transmission for two layers of glass with a low energy transmission coat is lower then 30% for incidence angles higher than 75°.

During the design process of the daylighting openings it is necessary to take account for minimum two sky luminance distribution models: the overcast sky and the clear sky with sun.

The overcast sky has a rotation symmetric luminance distribution with the luminance in zenith equal three times the luminance at the horizon. It creates very diffuse skylight with rather low llluminance. It is desired to utilize this light source excessively because about half part of the day hours during the year are overcast. A horizontal glass transmits the light from the overcast sky most effectively because the strongest light from the zenith will fall on the glass orthogonally. If the glass is sloped, the total transmission reduces. A vertical glass transmits only 39,6% of the value typical for the horizontal glass. On the vertical glass the daylight is falling only from the half part of the sky, also the transmission of the strongest zenith light is very low because it falls on the glass with the very large incidence angles.

For clear sky with sun the transmission of the light from the blue sky should be high and the sunlight penetration should be very much controlled. The sunlight may cause a solar glare or the overheating, especially if the glass area is large comparing to the floor area.

In the main building a very large glass surface oriented north-east (20° to the east) is one of the options, figure 21 and 22. An optimal sloping angle of the glass surface should satisfy two demands:

1. it should be as little as possible to transmit as much as possible of skylight from the zenith area
2. the incidence angle of the sunrays on the glass surface during all school days in the year should be larger than 75°.

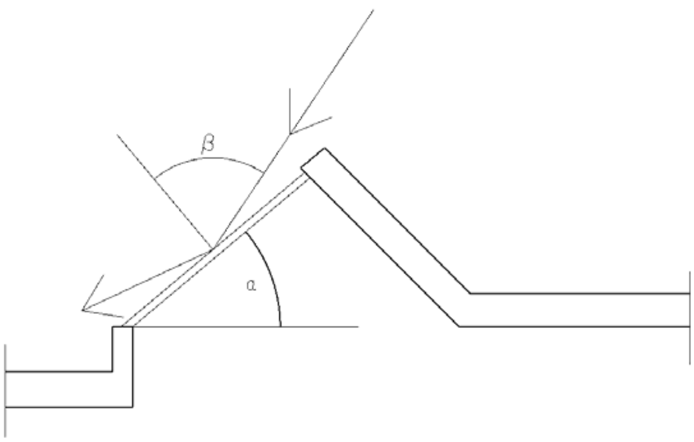


Figure 21. A simplified section through the middle zone in the main building.

The penetration of the sunlight is largest in the summer months when the elevation angle of the sun is highest. To calculate the optimal sloping angle of the glass, angle β in figure 21, two angles have to be known: the azimuth angle that defines sun’s position in relation to the north direction and the elevation angle that defines the position of the sun over the horizon. Both angles can be read from the solar diagram, figure 22. The values for June 21 (equinox) can be found in the table 3, too.

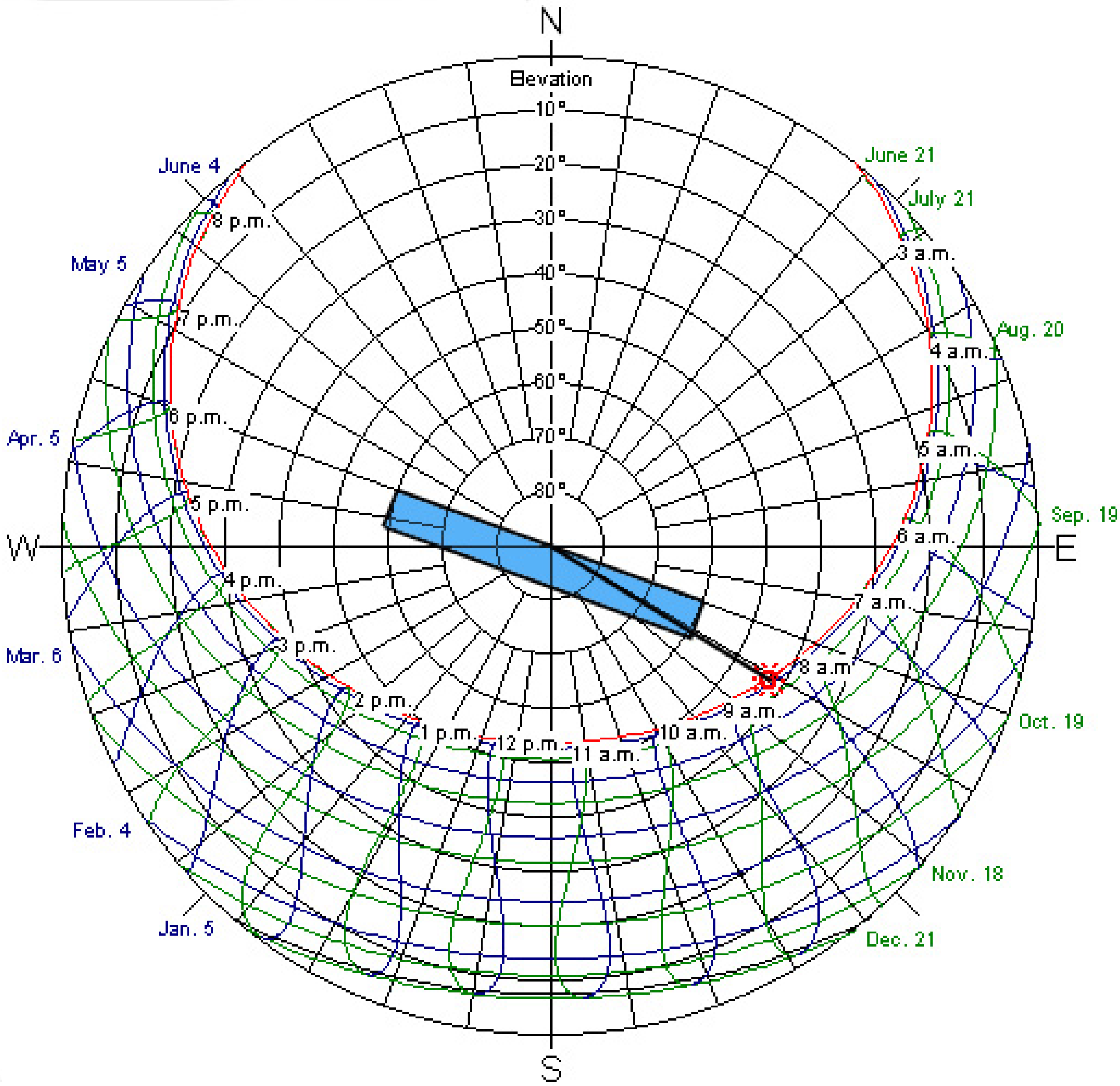


Figure 22. The solar diagram for Asker. latitude: 59°50’, longitude: 10°25’.

Timet:	Azimuth angle	Elevation angle
6:00	85,79	24,99
7:00	98,91	32,58
8:00	113,4	39,88
8:30	**121,42**	**43,25**
9:00	130,09	46,35
10:00	149,68	51,25
11:00	172,01	53,76
12:00	195,23	53,25
13:00	216,81	49,93
14:00	235,45	44,44
15:00	251,36	37,65
16:00	265,33	30,2
17:00	278,16	22,61
18:00	290,46	15,25

Table 3. Azimuth angles and elevation angles for June 21 in Asker.

6.1 Developing of algorithm for calculation of sunray's incidence angle on a sloping glass surface

Let's AO be a sunray that falls on the glass surface PRST in a point O, figure23. The angle λ is an elevation angle, the angle θ defines the orientation of the sun in relation to the orientation of the glass surface. It is equal to the difference between azimuth angle and the orientation angle of the glass surface (110°in this case).

Let's AE be a normal to the surface PRST, constructed from the point A.

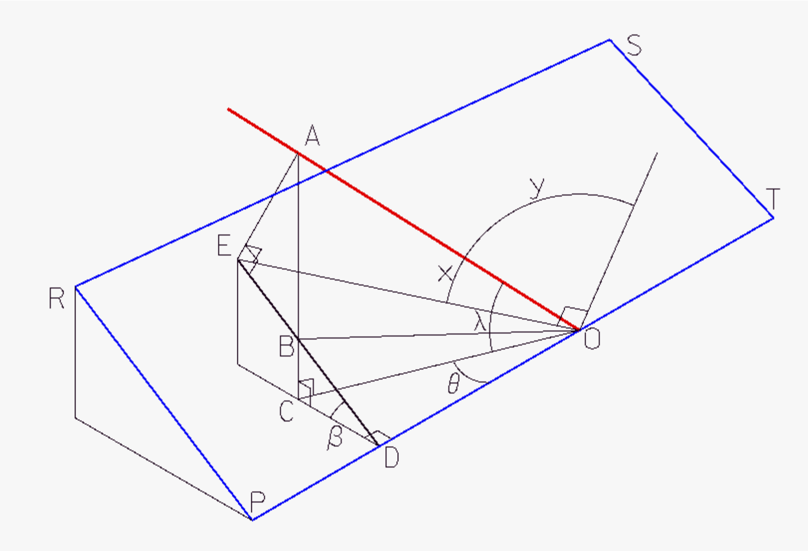


Figure 23. Illustration to the calculation of the incidence angle that is shown in table 4.

Calculation of the incidence angle of a sunray		Comments
$AC = AO \cdot \sin\lambda$	1	From triangle AOC
$CO = AO \cdot \cos\lambda$	2	
$CD = AO \cdot \sin\theta \cdot \cos\lambda$	3	From triangle CDO
$BC = CD \cdot tg\beta$	4	From triangle BCD
$BC = AO \cdot \sin\theta \cdot \cos\lambda \cdot tg\beta$	5	
$AB = AC - BC$	6	
$AB = AO(\sin\lambda - \sin\theta \cdot \cos\lambda \cdot tg\beta)$	7	From 6, 1 og 5. Because the angles CBD and EBA are equal and the angles BCD and AEB are both equal to 90°, the angles EAB and CDB are equal too.
$EA = AB \cdot \cos\beta$	8	From triangle AEB
$EA = AO \cdot \cos\beta \cdot (\sin\lambda - \sin\theta \cdot \cos\lambda \cdot tg\beta)$	9	From triangle EAO
$\sin x = \frac{EA}{AO}$	10	
$\sin x = \cos\beta \cdot (\sin\lambda - \sin\theta \cdot \cos\lambda \cdot tg\beta)$	11	
$y = 90 - a\sin[\cos\beta(\sin\lambda - \sin\theta \cdot \cos\lambda \cdot tg\beta)]$	12	Incidence angle y

Table 4. Calculation of sunray's incidence angle on the glass surface.

6.2 Optimal sloping of the glass surface in the skylight in main building, alt. A

The most special time point in the Norwegian school is 8:30, when the bell call students and teachers to the first lesson. From this point the need for a comfortable working conditions in the school building is really important. The solar diagram shows the position of the sun 21. June at 8:30.

The developing of the formula with comments is presented in table 4. The formula was used in calculations of the incidence angle of sunrays during the 21. June on a glass surface having 45º sloping to the north, figure 24. The angle is lowest early at the morning, after the 10:00 it is higher than 75°.

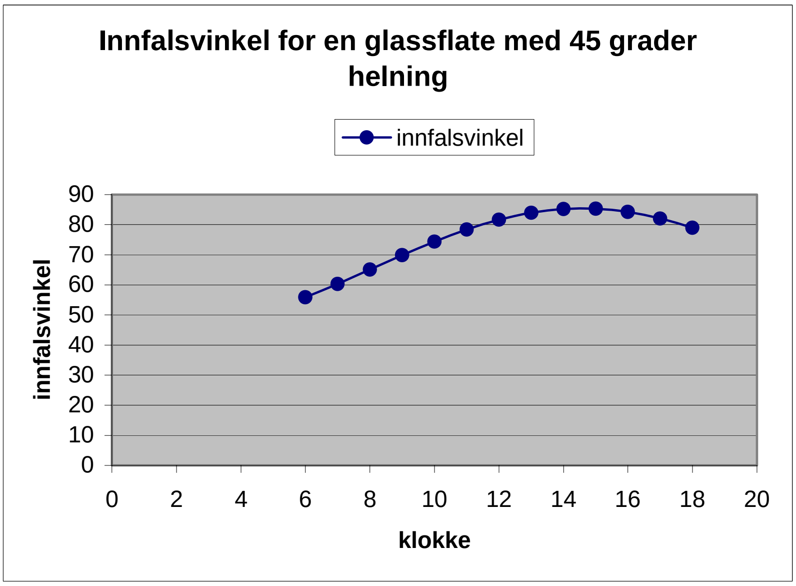


Figure 24. The incidence angle of sunrays during the 21. June on a glass surface having 45º sloping to the north-east

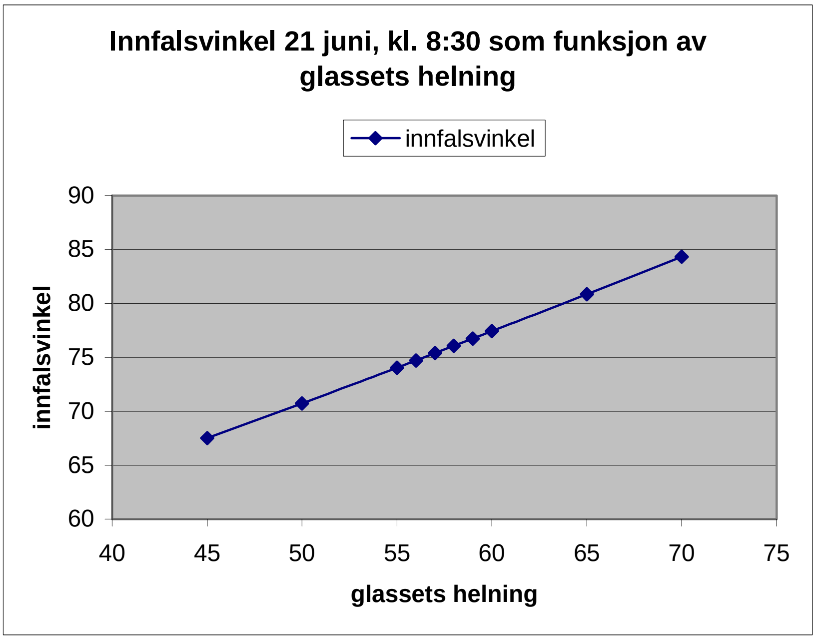


Figure 25. The sunray's incidence angle 21 June at 8:30 as a function of the sloping of the glass.

Figure 25 shows the incidence angle of sunrays June 21 at 8:30 for varied sloping of the glass surface. To satisfy the objectives specified above, the smallest sloping angle of the glass that gives the incidence angle larger 75° should be chosen. The optimal sloping angle is 56°.

7. SUN SHADING

There are two main reasons for applying of a sun shading system in buildings:

1. Protection against the infra-red part of the sunlight spectrum, the **solar heat**, which otherwise would be absorbed in the room and bring about overheating in periods with much sun radiation, high outside temperatures and/or much internal heat.
2. Protection against the visible part of sunlight spectrum, the **sunlight**, which can cause a solar glare or can fall at the unwanted places in the room. The sunlight falling on the people inside buildings is usually considered as unpleasant.

The following two cases can occur simultaneously or separately:

7.1 Solar heat

The placement of the sun-shading device in relation to the façade wall is the most deciding factor if the protection against the solar heat is the only objective.
External systems function best. The solar heat does not penetrate into the room, it is reflected from the shading device surfaces.

Internal systems, however, protect poorly against the solar heat because the sunrays penetrate through the window glass and fall on the material of the sun shading system that is located inside the room. The most part of the solar heat is absorbed in the material and than submitted to the room in the form of heat. Only a little part of this heat penetrates through the glass outside the building.

External systems are exposed to the climate changes, they have to be much more robust and solid, usually also more expensive.

7.2 Sunlight

Sunlight has many qualities (even spectral distribution, low colour temperature in relation to the light from the sky, UV radiation, very high luminous intensity), which makes it have positive effect on health, well-being and productivity. Sunlight can create a beautiful play of light and shadow and in this way it can enrich the visual expression of rooms. This is impossible to imitate with electrical light. It is also this very high luminous intensity of sunlight that causes problems. There are several methods for handling sunlight. The most important are:

1. Reflection out
2. Diffuse transmission
3. Specular transmission (the material must have low transmission factor)
4. Conducting into the room in desirable directions

Reflecting sunlight out, one eliminates the possibilities for utilization of sunlight's positive qualities. It is therefore a bad method, especially if shading against the solar heat is not necessary.

Diffuse transmission is a well-known method. Instead of having a light spot with a very high luminance, the sunlight may be diffusely distributed in all directions in the room. Various forms of curtains were used in hundreds of years for this purpose. We find a modern diffuse rolling curtains, sand blown glass, etched glass, diffusing foils and films in this category.

Specular transmission is an old method for protection against sunlight. The material that the sunlight pass through functions as a filter that reduces the luminous intensity, changes the colour, but does not change the direction of light. The stained glass and glass blocks were used for this purpose. Stained glass has typically very low transmittance. The luminous intensity of light passing through it is reduced to 1/3 – 1/10. There are many products in the modern glass technology that function in the similar manner. The coloured glass and the glass with a metal cover can be fined in this category.

It is possible to conduct the sunlight in desirable directions in the room with the help of both, external and internal blinds, lamellas or light shelves. The systems in this category function most effectively if the reflective elements have specular surfaces. In the scientific laboratories around the world a modern, translucent light redirecting materials are under developing. The reflection of sunlight happens often in the materials or systems.

The sunlight with all its positive and negative qualities is not continually present. In periods without sun the diffuse light from the sky, which gives about ten times lower illuminance than the sunlight, the only daylight source.

There is a tremendous difference between operable and permanent sun shading systems. The operable elements, which can be pushed aside, up or down, as curtains and venetian blinds, can be used only in the sun periods. The permanent devices, e.g. sun reflecting glass, fixed lamellas, etc. will shade sunlight during sun hours, but they will also shade the room against the weak light from the sky in periods without sunlight. The permanent shading systems are recommended only in rooms having very high daylight level and only if one wishes to reduce it.

7.3 Sun shading system in the Borgen Community Centre

In the building there are two types of windows that needs sun shading:

1. large, high windows in the outer walls oriented east, south or west
2. windows in the lantern in the home bases oriented east, south or west

In the base areas there is a need for protection against both, the solar heat and the sunlight. External blinds, proposed by Hus architects, will defence rooms against solar heat effectively. But after the blinds are closed for sunlight the rooms will be evaluated as dark and the electrical light will be used. To avoid this situation, a shading device with a separate control of the upper and lower part should be chosen. The lower part can shade against sun heat and sunshine, the upper part can reflect the sunshine and the solar heat to the roof. If the upper part makes up only a little part of the window area, the overheating problems will also be small. Vental Solex AS has such products in the DUOLUX series. An alternative to the external blind systems are external operable awnings at the front of the lower part of window and a sun conducting materials in the upper part.

The glazing in the lantern in the home bases are placed so high over the floor, that the solar heat will most probably not cause any reduction of thermal comfort at the working places beneath. A layer of warm air will appear at a large height during the sun hours, because of the large distance to the working places it will not cause any inconvenience. Because the protection against solar heat is not actual two following strategies may be chosen:

1. Diffusion
2. Reflection inside

To diffuse the sunlight a thin curtains or rolling curtains having the 10 - 25% transmittance can be used. The curtains can be used as a operable system inside the building. The objection is to admit the light from the sky and the sunlight from very low elevation angles, especially during the dark part of the year. The curtains should be used only during sun hours when the elevation angle of the sun is high. The sunlight will be diffusely distributed in the room as a comfortable, warm, diffuse light.

To reflect sunlight to the roof, a blind system is necessary, preferably with a adjustable sloping of lamellas. Horizontal blinds function most effectively on the south oriented facades, vertical blinds on the east and west oriented facades. Because the overheating is most probably not a problem here, the shading system can be situated on the inside of the glazing. The sunlight reflected to the roof will function as a secondary light source in relation to the room beneath. The roof will appear as very light; the room as very high, spacious and friendly with a nice and sometimes exiting visual expression.

An alternative to a blind system is a light deflecting foil or panel fixed to the glazing. Actually there are two products that can be used in buildings: laser cut panels, called Edmond's panels and Serra Glaze foil. Both products can be pasted directly to the glazing.

8. REFERENCES

8.1 Literature

Byggeforskrift 1997.

CIE 139-2001. The influence of daylight and artificial light on diurnal and seasonal variations in humans. A bibliography. ISBN 3 901 906 04 5.

Lyskultur 20/98. Skolebelysning.

Lyskultur 21/98. Dagslys i bygninger. Prosjekteringsveiledning.

8.2 Calculation programs

LesoDial 3.1 program for approximate calculations of daylight factor.

SunOrb 1.0 program for calculation of solar diargam.