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Impact of three window configurations on daylight conditions

Simulations with Radiance

BY OG BYG
Statens Byggeforskningsinstitut
Danish Building and Urban Research

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Preface

The present document reports the results of a pilot study on daylight conditions in simple rooms of residential buildings under the research project 434-21: “Enkel metode til beskrivelse af dagslyskvalitet i boliger”. The overall objective of the study was to develop a basis for a method for assessment of the daylight quality in a room with simple geometry and window configurations. As a tool for the analyses the Radiance Lighting Simulation System was used. In this study the simulations performed were for three rooms (window configurations) under overcast sky conditions and the rooms under sunny sky conditions at two different times of the day.

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By og Byg
Danish Building and Urban Research
Energy and Indoor Climate Division
September 2003

Søren Aggerholm
Acting Head of Department

Introduction

This report presents the results of simulations of daylight conditions in three rooms with three different window configurations:

– an ordinary, vertical window,
– a dormer window, and
– a roof window.

The simulations were performed with the Radiance Lighting Simulation System (Ward Larson & Shakespeare, 1998) included in the AutoCAD Desktop program. The aim of this project was to compare daylight conditions in three rooms under overcast sky conditions and under sunny sky conditions at two different times of the day (12:00 and 15:00). These simulation times are a minimum set to represent daylight conditions in the rooms. The three rooms studied had identical floor area and floor to ceiling height and orientation (south). They also had identical glazings (area and glass combination), glazing height and identical wall, floor, and ceiling reflectances.

Main findings

The main findings suggested that:

Daylight factor

- The roof window resulted in a significantly higher (average) daylight factor on a horizontal plane (0.7 m above the floor), i.e. more than twice as high compared with the vertical window, and more than triple as high compared with the dormer window.
- The roof window provided a wider range of daylight factor values compared with the vertical and dormer windows, which indicates a larger variation in lighting. This variation may be preferable since previous research found that people prefer an interior to possess a measure of “visual lightness” combined with a degree of “visual interest” (visual interest applies to the non-uniformity of the light pattern).

Luminance

- The roof window generally produced higher luminance values on lateral walls, ceiling and floor compared with the vertical and dormer windows.
- The dormer window resulted in the lowest luminances on lateral walls, ceiling and floor among the three windows studied.
- The dormer and roof window both had linings immediately surrounding the window with a high luminance. These surfaces allow a transition between the high window luminance and the luminance of the walls, ceiling and floor. The luminance ratios "window : linings : adjacent walls" were the most favourable with the roof window but the areas of the linings were small (compared with those of the dormer window). Increasing the linings’ area and further detailing of the transition borders between the bright areas and the adjacent surfaces could provide a better luminance transition with lower contrasts.
- At times with low sun position and high window-sun azimuth (sunlight partly from the side), e.g. 21 September at 15:00 hours, the luminances were significantly lower with the dormer window compared with the other windows, due to the fact that the direct sunlight patch hit the window linings.
- At different times of the year and day, all three window configurations generated a large direct sunlight patch, e.g. on 21 September, at 12:00 and 15:00 hours. This will result in a larger number of high luminance values, which could cause glare and necessitate the use of a shading device. Because of the geometry this might possibly happen more frequently for the roof window. How many hours each window configuration might cause glare problems have not been investigated in this study.

Shading

It was found that the high luminance values and resulting glare problems could be avoided by using a shading device, e.g. a simple white Venetian blind or a light coloured (not white) diffusing screen. However, it was not investigated how often different glare protective shadings would necessitate a complete block of the view out, or how this would differ in the three window configurations.

Description of the method

Simulations with Radiance

The simulations presented in this report were performed using the Radiance Lighting Simulation System (Ward Larson & Shakespeare, 1998) included in the Autocad Desktop program, which runs on the Windows operating system. Radiance is a suite of programs for the analysis and visualisation of lighting in design. It is used by architects and engineers to predict illumination, visual quality and appearance of innovative design spaces, and by researchers to evaluate new lighting and daylighting technologies. Input files specify the scene geometry, materials, luminaires, time, date, and sky conditions (for daylight calculations). The primary advantage of Radiance over simpler lighting calculation and rendering tools is that there are no limitations on the geometry or the materials that may be simulated. Calculated values include spectral radiance (i.e. luminance + colour), irradiance (illuminance + colour) and glare indices. Simulation results may be displayed as colour images numerical values, and contour plots. Radiance is one of the most advanced daylighting/lighting simulation tools available today and it has been fully validated (Mardaljevic, 1999; Aizlewood et al., 1998; Ubbelohde & Humann, 1998; Jarvis & Donn, 1997, etc.). Note that the rendering options used in the calculations presented in this report can be found in the Appendix (Table A.2).

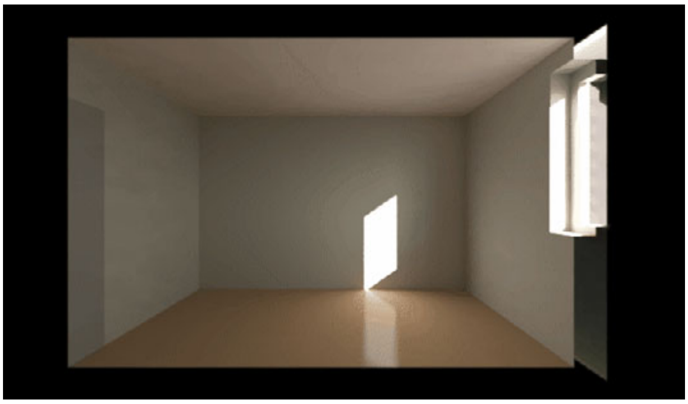
Geometry of the rooms and windows

For the benefit of comparisons of daylight conditions, the studies of the three window types were performed in rooms that were identical on all possible measures. The rooms studied measured 3.25 m by 3.85 m (width × depth) and had a floor to ceiling height of 2.5 m. The glazing area measured 0.765 m by 1.15 m (width × height), the window area measured 0.887 m by 1.339 m (total opening, width × height) and the frame was 0.072 m wide at the bottom, 0.061 m wide on the sides and 0.117 m wide at the top. The frame depth was 0.083 m. In all three cases, the window was located at exactly 1.0 m above the floor level and was centered with respect to lateral walls. The small-scale details of the frame and sash were not modelled in order to simplify the calculations[1]. Figure 1 shows a section-perspective rendering of the three rooms, which explain their geometry. As shown in Figure 1, the exterior surfaces were not modelled, except in the case of the dormer window where the roof slope under the window was added. The exterior surfaces had no impact on interior lighting conditions when they were parallel to the window plane (none of the light rays reflected off the surfaces meet the window). In the case of the dormer window, the roof slope under the window did have an impact on interior lighting conditions because it was not parallel to the window plane.

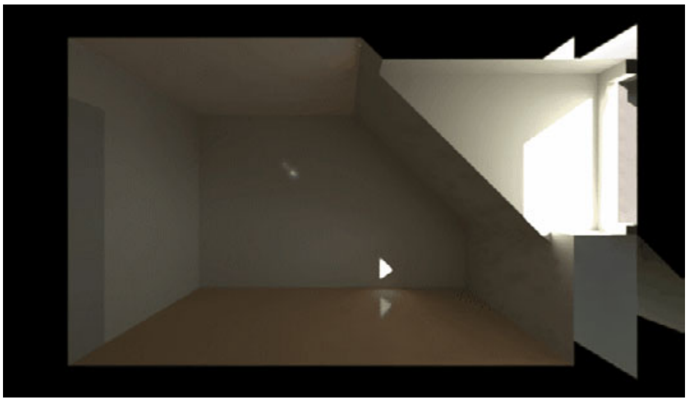
[1] The details of the sash and frame have a negligible impact on daylight conditions at the scale of the room and their impact will be the same in all three rooms provided that the details are exactly the same in all three rooms. Adding those details will cause the simulation program to sample a much larger number of rays around small unsignificant surfaces, which will substantially increase the length of calculations and may even cause the program to "overkill".

Properties of inner surfaces, glazing and shading screen

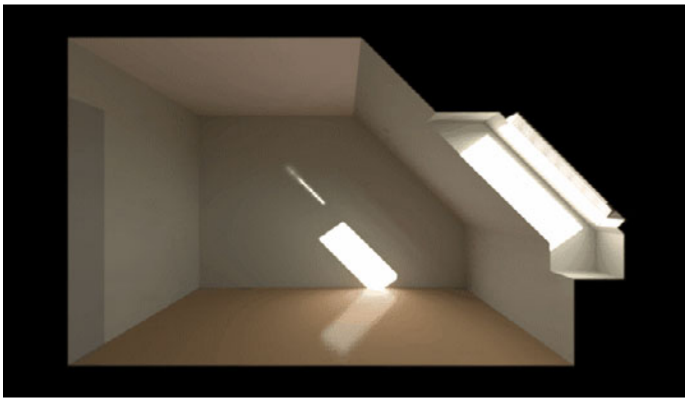
The red (r), green (g), blue (b) and integrated reflectance (R) and transmittance (T) for inner surfaces, glazing and shading screen are presented in Table 1. “Spec” is the value for specularity in the input to Radiance. The *specularity* is the amount of light reflected (or transmitted) by specular (mirror-like, not diffuse) mechanism (Ward Larson & Shakespeare, 1998). “Rough” is the value for roughness in the input to Radiance. The *roughness* is a measure of the average instantaneous slopes of a polished surface, which determines to what degree a semi-specular highlight will be dispersed (Ward Larson & Shakespeare, 1998). The specularity and roughness control the way light will be reflected off the material. If both are set to zero, the surface is perfectly diffuse and reflects light equally in all directions. On the other hand, if the material is purely specular (high specularity) and has a roughness of zero, it is a mirror (Larson in Ward, 1996). All exterior and interior surfaces except the floor were assumed to be totally diffuse (Spec = 0) and smooth (Rough = 0).



a) Vertical window.



b) Dormer window.



c) Roof window.

Figure 1. Rendering showing a longitudinal section-perspective of the three rooms modelled in Radiance.

Table 1. Red (r), green (g), blue (b) and integrated reflectance (Rtot) and transmittance (Ttot), specularity (Spec) and roughness (Rough) of inner surfaces, glazing and shading screen modelled in Radiance.

Surfaces/ element	Colour/ material	Digital sample*	R(r) (%)	R(g) (%)	R(b) (%)	Rtot (%)	T(r) (%)	T(g) (%)	T(b) (%)	Ttot (%)	Spec. -	Rough. -
Walls Slopes Linings	light grey paint (1k102)		58.3	57.3	50.7	57.0	n.a.	n.a.	n.a.	n.a.	0.00	0.00
Floor	chestnut wood		52.5	34.4	19.0	37.9	n.a.	n.a.	n.a.	n.a.	0.03	0.03
Ceiling	pure white (RAL 9010)		92.3	80.8	76.1	83.5	n.a.	n.a.	n.a.	n.a.	0.00	0.00
Door	light grey paint (1k108)		39.1	39.0	36.7	38.8	n.a.	n.a.	n.a.	n.a.	0.00	0.00
Glazing		-	n.a.	n.a.	n.a.	n.a.	78.0	85.0	80.0	78.0		
Roof (exterior)	grey		30.0	30.0	30.0	30.0	n.a.	n.a.	n.a.	n.a.	0.00	0.00
Shading screen	grey	-	3.4	3.4	3.5	3.4	19.6	19.9	19.9	19.8	0.00	0.00

n.a.: not applicable i.e. either the value is not present in the input or it is not relevant.

* The sample shown is affected by settings in the computer screen and printer.

Context and orientation

The rooms were modelled with a south orientation. A free horizon (no external obstructions) was assumed, as for example for rooms on first floor or higher, and the ground light reflectance was set to 15 % and assigned a green colour.

Simulation days and times

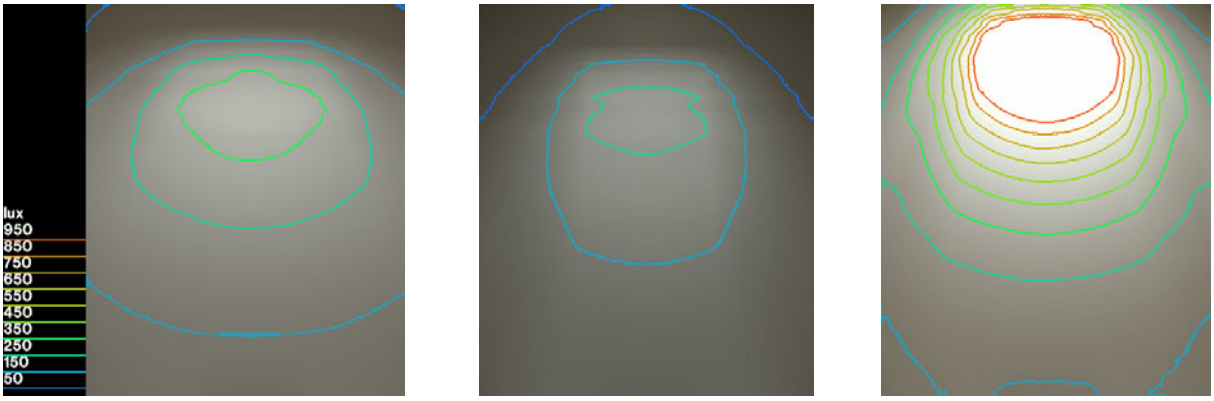
The simulations were performed for the location of Copenhagen (latitude 55,4ºN; longitude 12,35ºE) under the following sky conditions:

1. CIE overcast sky
2. CIE sunny sky, at the equinox (21 September), at 12.00 and 15.00 hours, true solar time. At 12.00 hours, a simulation with the shading screen described in Table 1 was also performed. This screen was pulled all the way down in front of the window.

Results

Daylight factor (on a horizontal plane at 0.7 m above floor level)

The results indicated that the vertical and dormer windows produced similar illuminance distribution patterns on a horizontal plane located at 0.7 m above floor level, as illustrated in Figure 2. The illuminance pattern was more concentrated in the case of the dormer window. The illuminance level was also generally lower in this case. The roof window produced a unique illuminance pattern with a large oval area of high illuminance in the area under the window.



a) Vertical window b) Dormer window c) Roof window

Figure 2. Isolux contours showing illuminance (lux) on a horizontal plane at 0.7 m above floor level for the a) vertical, b) dormer, c) roof windows, under overcast sky conditions. The exterior horizontal illuminance was 14,613 lux (divide by this number to obtain the daylight factor).

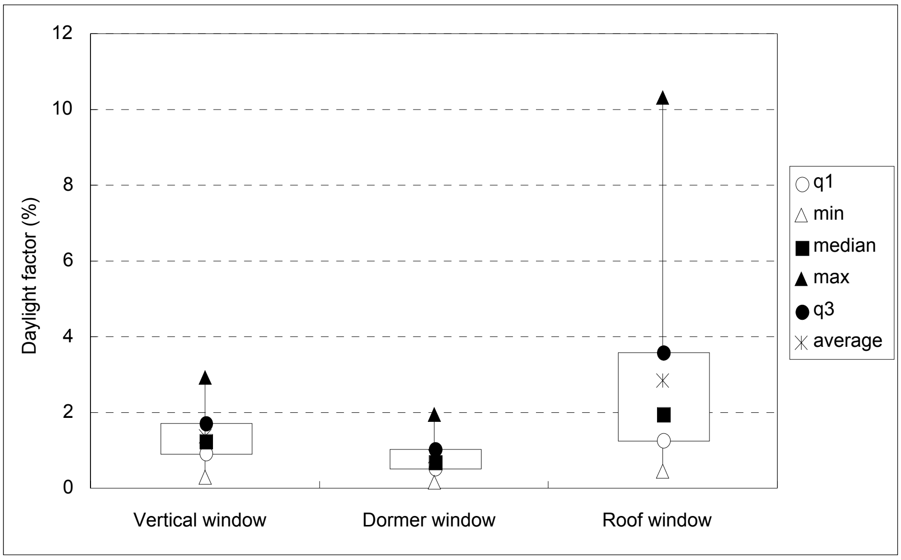


Figure 3. Minimum, maximum, median, average and interquartile range (q1, q3) for the daylight factor (%) on a horizontal plane, at 0.7 m above floor level, overcast sky conditions (numerical values are presented in Table A.1 in the Appendix).

The vertical window resulted in slightly higher daylight factors, in average, than the dormer window, but the difference between the two cases was small. The roof window produced much higher average, median, minimum, maximum and interquartile range[2] values for the daylight factor compared with the other cases, as shown in Figure 3.

The roof window produced a wider range of daylight factor-values. This is evident from Figure 3, but may also be visualised clearly in a diagram showing the frequency distribution of daylight factors for the three cases (Figure 4). A plot of the daylight factors along an axis perpendicular and centered about the window also shows that the roof window produced a much higher amplitude of daylight factors (Figure 5). While extreme variations of the daylight factor should be avoided, it is not either desirable to create totally even light distributions. Dull uniformity in lighting, though not harmful, is not pleasant, and can lead to tiredness and lack of attention (Hopkinson, Petherbridge & Longmore,1966). According to Loe (1997), people prefer an interior to have a measure of “visual lightness” combined with a degree of “visual interest” (visual interest applies to the non-uniformity of the light pattern). According to IES (1993), it is important to provide enough variation in the light pattern to contribute to a stimulating, attractive environment. Small visual areas that exceed the luminance-ratio recommendations are desirable for visual interest and distant eye focus (for periodic eye muscle relaxation throughout the day). Veitch (2000) recommends using meaningful luminance patterns to create interest and integrating luminance variability with architecture to satisfy attention and appraisal processes.

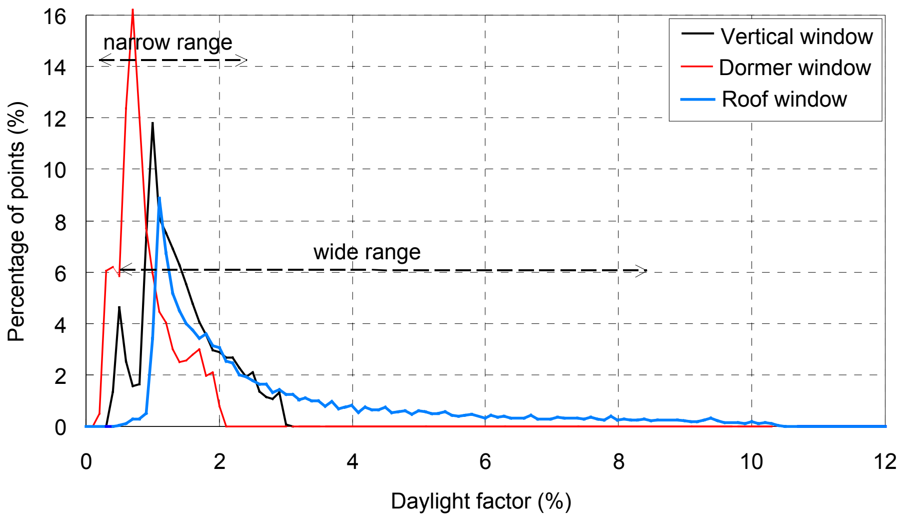


Figure 4. Frequency distribution for the daylight factor (%) on a horizontal plane, 0.7 m above floor level, overcast sky conditions.

[2] The interquartile range comprises the values of 50 % (n=9950) of all calculated points (n=19900). Thus, 25 % (n=4975) of the points have a daylight factor below the interquartile range box and 25 % have a daylight factor above the interquartile range box.

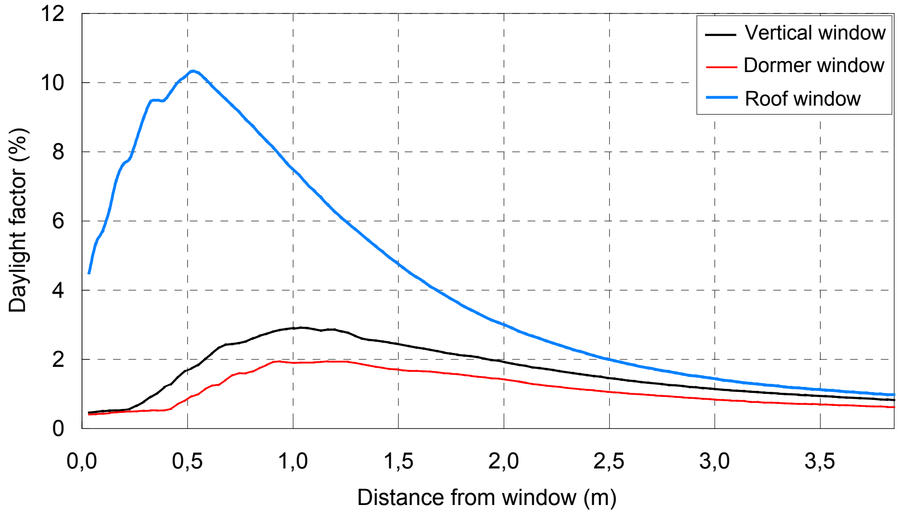


Figure 5. Daylight factor (%) at 0.7 m above floor level along an axis perpendicular and centered about the window, overcast sky conditions.

In the case of the roof window, nearly 100 % of all daylight-factor values were over 1 %, 50 % were above 2 % and about 15 % were above 5 %, as shown by a cumulative frequency distribution diagram (Figure 6). In comparison, the dormer window had no values above 2 % and only 30 % of daylight-factor values above 1 %. The vertical window performed slightly better with 20 % of values above 2 % and 80 % above 1 %.

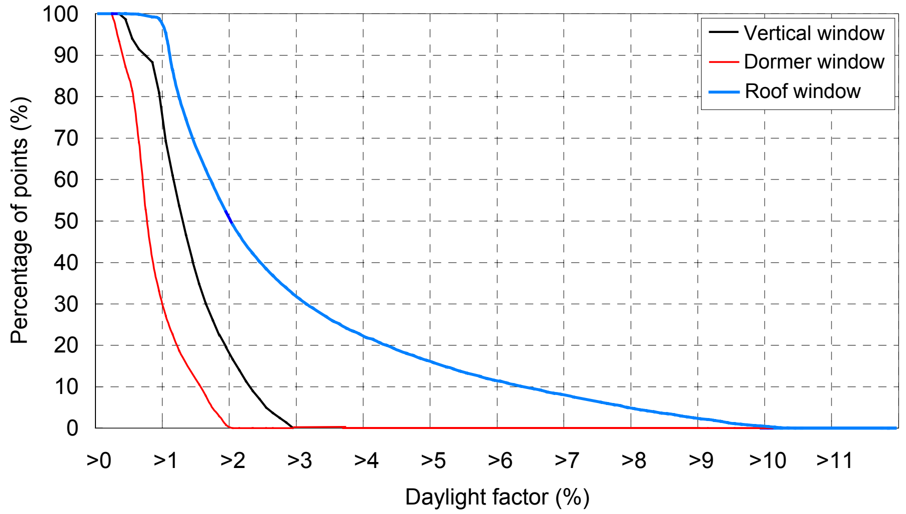


Figure 6. Cumulative frequency distribution for the daylight factor (%) on a horizontal plane, at 0.7 m above floor level, overcast sky conditions.

A daylight factor of 5 % means that there will be 500 lux on the "workplane" under an overcast sky of 10 klux (which is commonly used as reference in northern Europe). In Denmark, the diffuse illumination from the sky lies over 10 klux 60 % of the working time (8-17 hours) (Christoffersen & Petersen, 1997).

According to a British Lighting Guide (CIBSE, 1997), an average daylight factor of 5 % or more will ensure that an interior looks substantially daylit, except early in the morning, late in the afternoon or on exceptionally dull days. An average daylight factor below 2 % generally makes a room look dull; electric lighting is likely to be in frequent use. In domestic interiors, however, 2 % will still give a feeling of daylight, though some tasks may require electric lighting. The BS 8206 code of practice recommends average daylight factors of at least 1 % in bedrooms, 1.5 % in living rooms and 2 % in kitchens, even if a predominantly daylit appearance is not required. Figure 3 shows that the average daylight factor was 1.37 % for the vertical window, 0.83 % for the dormer window and 2.85 % for the roof window. The daylight factor was thus more than twice as high with the roof window compared with the vertical window.

Luminance

Renderings of the room were produced at each time studied. These renderings are presented in the Appendix. Half of the renderings show half of the room towards the window wall, and half of the renderings show the other half of the room (towards the back or north wall). Both renderings are complementary and contain 100 % of the luminance points in the room. The first series of images shows a view mimicking human vision (using the pcond program[3] included in Radiance) while the second series presents a false colour rendering where the luminance of each pixel is replaced by a colour corresponding to a luminance value (in Nits, 1 nit = 1 cd/m^2).

Overcast sky conditions

Under overcast sky conditions, the luminance of the floor, walls and ceiling was higher with the roof window than with the other two windows (Figure A.2). In contrast, the main inner surfaces of the rooms were significantly darker with the dormer window, even compared with the vertical window (Figure A.2, 7a). This is also indicated by Figure 7a, which gathers minimum, maximum, average, median and interquartile range values in the view towards the window wall.

However, the linings surrounding the dormer window were rather bright, which might contribute to make the high window luminance more acceptable than in the case of the vertical window. Table 2 presents the average luminance of different parts composing the view. It shows that in the case of the vertical window, the luminance ratio between the window (sky) and south (immediately surrounding) wall was 100 : 0.8 (i.e. if the average luminance of the sky was 100 cd/m^2, the average luminance of the south wall would be 0.8 cd/m^2)[4]. In the case of the dormer window, the ratio was 100 : 3.6 : 0.4 (window(sky): linings: south wall or slopes) while it was 100 : 10.4 : 1.8 or 1.2 (window: linings: south wall or slopes) for the roof window. While the luminance ratios between these surfaces were more favourable in the case of the roof window than in the case of the dormer window, it should be noted that the area of the linings was not as large in the case of the roof window and may not have been sufficient to allow a good luminance transition from the high sky luminance to the luminance of the main inner surfaces.

As shown in Table 2, the luminance ratio between the window (sky), window linings and adjacent walls was to be preferred for the roof window compared with the dormer window. Figure 9 shows the average luminance of surfaces located within a band of 40º about the eye height (for a sitting person). Loe, Mansfield & Rowlands (1994) showed that the field of luminance within a 40º band about the eye height is the most important to consider for visual comfort. Figure 9a clearly shows that the roof window provided higher wall luminance and softer luminance transitions from the window to the wall area compared with the other cases.

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[3] The pcond program provides powerful tools for easily manipulating Radiance's map of spectral radiance into a displayed image that causes a response in the viewer that closely matches the response a viewer of the real-world equivalent environment might experience. Pcond uses a variety of mathematical techniques to determine an appropriate exposure and simulate loss of acuity and veiling glare, loss of focus, and loss of colour sensitivity.

[4] In this case, it was impossible to obtain the luminance of the linings because they were too small.

In general, the dormer and roof windows had a wider range of luminance values compared with the vertical window, where the interquartile range box (comprising 50% of all values) was rather small. (Figure 7a). This indicated that the luminance field was more balanced in the case of the dormer and roof window than in the case of the vertical window.

Table 2. Normalised average luminance (cd/m²) in different parts of the view, under a) overcast conditions, b) on 21 September at 12.00 hours, c) on 21 September at 12.00 hours (including a shading screen), d) on 21 September at 15.00 hours.

	Window (sky) original data (cd/m²)	Window (sky)	Window (whole)	Window (ground)	Linings	Floor (front)	Floor (back)	Ceiling (front)	Ceiling (back)	West wall (front)	West wall (back)	East wall (front)	East wall (back)	North (back) wall	South wall	Slope south
Overcast																
Vertical	1944	100.0	92.3	7.3	-	1.9	1.3	1.7	1.3	1.6	1.4	1.6	1.4	1.3	0.8	-
Dormer	1891	100.0	90.9	7.5	3.6	1.2	0.9	0.7	0.8	0.6	0.6	0.6	0.6	0.9	0.4	0.4
Roof	1828	100.0	94.0	10.2	10.4	3.8	1.9	2.0	1.8	1.9	1.6	1.9	1.6	1.5	1.8	1.2
21 September at 12:00																
Vertical	7743	100.0	92.3	7.6	-	9.2	11.7	3.5	3.3	2.2	2.4	2.2	2.3	2.4	1.5	-
Dormer	7635	100.0	91.0	7.7	4.4	9.0	10.7	3.0	2.9	1.7	1.8	1.6	1.8	1.9	1.1	1.8
Roof	7379	100.0	94.2	7.8	3.2	14.6	13.3	4.2	4.2	2.5	2.7	2.4	2.7	2.8	1.6	2.8
21 September at 12:00 with shading screen																
Vertical	3401	100.0	100.0	100.4	-	1.8	1.3	2.3	1.3	1.8	1.8	1.7	1.4	1.3	0.9	-
Dormer	3481	100.0	100.1	101.4	4.3	1.2	0.9	0.9	0.8	0.7	0.8	0.7	0.6	0.9	0.5	0.5
Roof	4012	100.0	86.9	98.5	2.7	2.1	1.9	1.0	1.8	1.0	1.1	1.0	1.6	1.5	0.7	0.7
21 September at 15:00 hours																
Vertical	3404	100.0	92.5	9.7	-	3.7	2.1	4.6	3.3	3.6	2.9	19.3	2.8	2.3	2.9	-
Dormer	3428	100.0	91.2	9.6	13.9	1.4	1.0	1.4	1.5	1.7	1.5	1.8	1.1	1.3	1.0	0.7
Roof	3428	100.0	92.3	10.3	17.0	4.9	2.7	3.8	3.5	4.1	3.4	36.9	7.0	2.5	3.2	2.5

Sunny sky, 21 September at 12.00 hours

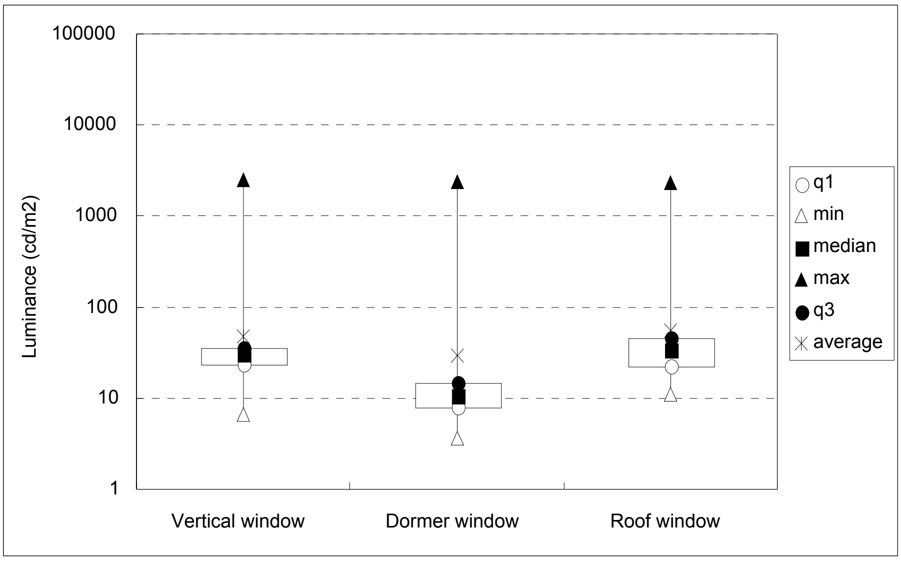
The renderings for 21 September at 12.00 hours showed that the dormer window resulted in a generally darker interior, which is confirmed in Figure 7b. The difference between the three cases was not as large at this particular time. This was easily explained by looking at the direct sunlight patch: it was approximately the same size and therefore it contributed to indoor light in approximately the same way. One important difference between the three cases, however, was that the sunlight patch penetrated deeper into the room with the roof window and there was therefore more light in the back of the room in that case. Figure 8b also shows that the luminance values were generally higher for this time and about 4-5 % of all values were above 2000 cd/m^2 and 1 % were above 5000 cd/m^2 in all three cases. These high luminance values are likely to cause glare and it was essential, in this particular case to provide a shading device. Note that the high luminance values are also present in the back of the room (Table 3b).

Sunny sky, 21 September at 12.00 hours, with a shading screen

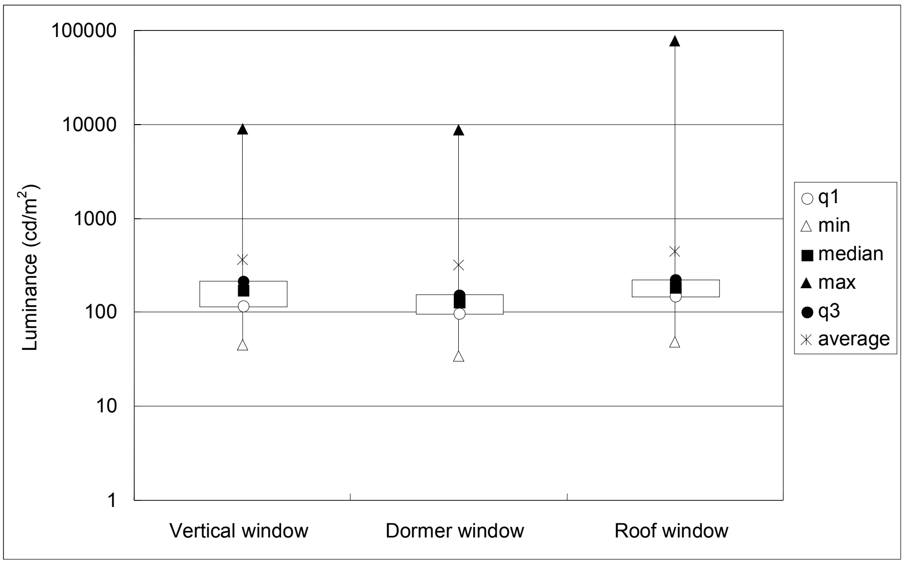
On 21 September at 12.00 hours, a shading screen was modelled in the front of the window. This shading screen was assumed to have a totally isotropic, diffuse transmittance. In the program, the light rays traversing through the screen are assumed to be spread equally in all directions of the half sphere. This explained why the false colour renderings of the vertical window (Figure A.6) showed that the ceiling had a relatively higher luminance with the vertical window at that time (compared with the other two cases and with the overcast sky conditions). This is also shown in Table 2 where the luminance ratio between the window (sky) and ceiling is 100 : 2.3 for the vertical window and around 100 : 1 for the other two cases. The high ceiling luminance boosted the average and median luminance values of the whole scene, as shown in Figure 7b. In reality, shading screens do not usually have a totally isotropic, diffuse transmittance so this case should be tested in a laboratory or a more detailed description of the transmittance distribution of the shading screen should be provided for a more accurate rendering and analysis.

Sunny sky, 21 September at 15.00 hours

On 21 September at 15.00 hours, the false colour renderings showed that the room was brightest with the roof and vertical window and significantly darker with the dormer window. This is also apparent in Figure 7d.
The dormer window created a region of high luminance surrounding the window and the ratio between this region and the south wall and slope might be the source of discomfort glare (13.9 : 1.0 or 0.7 so there was 13.9 and 19.9 times more light in average on the linings than on the south wall and slope respectively). In comparison, the luminance gap between the window linings and the south wall and slope was 17 : 3.3 and 17 : 2.5 in the case of the roof window (thus 5.1 and 6.8 times more light on the south wall and slope than on the lining, which was an acceptable luminance gap).
However, because of its geometry, the roof window produced a large direct sunlight patch, which penetrated deeply into the room (also visible on the renderings of the back wall view, Figure A.7). Table 3 shows the percentage of values in each view exceeding a given luminance and Figure 8 presents cumulative frequency distribution diagrams. These figures and table show that when there was no shading screen in the window, the luminance values were higher in the case of the roof window. The dormer window produced lower luminances, especially on 21 September at 15.00 hours. There was a marked difference at that time between the dormer window and the other two windows. This was due to the geometry of the dormer window that reduced the size of the direct sunlight patch, which contributes significantly to indirect lighting. Table 3 also shows that on 21 September at 15.00 hours, 6 % of the points had a luminance above 500 cd/m^2 and around 5 % had a luminance above 1000 cd/m^2 in the case of the roof window (view towards the window wall). The dynamic range of the visual system is large but finite. In daylight, luminances below about 1 cd/m^2 are seen as black, while those above 500 cd/m^2 are said to be glaring (Canter, 1975, in Baker, Fanchiotti, Steemers, 1993).

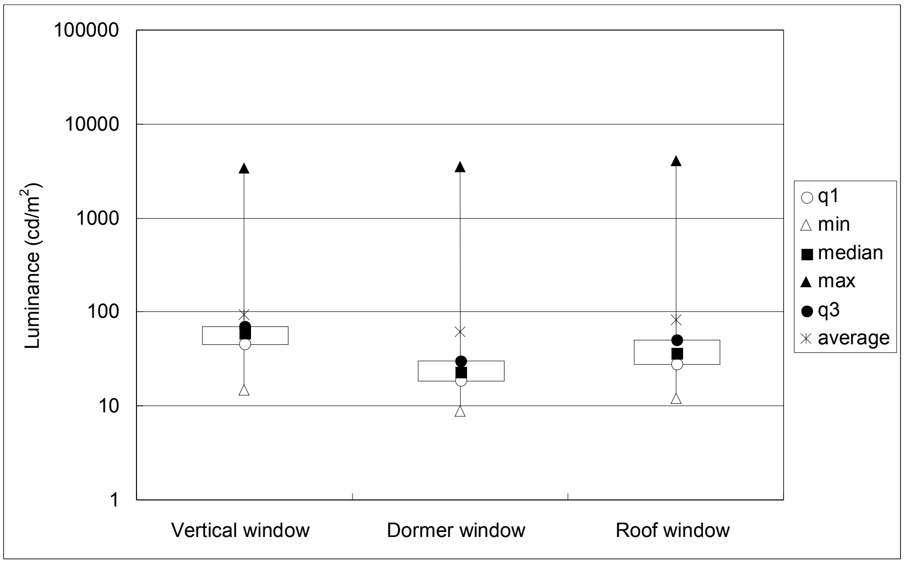


a)

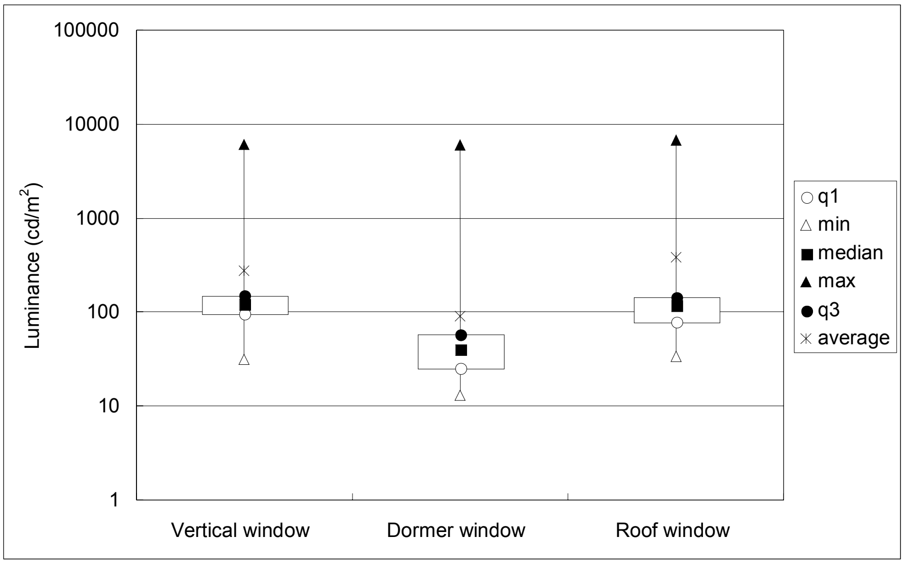


b)

Figure 7.1. Minimum, maximum, median, average and interquartile range (q1, q3) for luminance (cd/m^2), in the view towards the window wall, under a) overcast conditions, b) on 21 September at 12:00 hours, and next page: c) on 21 September at 12:00 hours (including a shading screen), d) on 21 September at 15:00 hours.

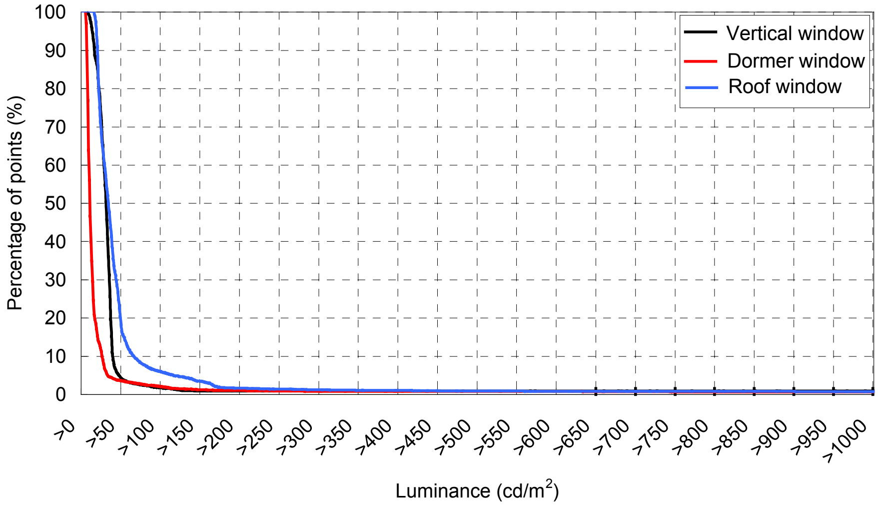


c)

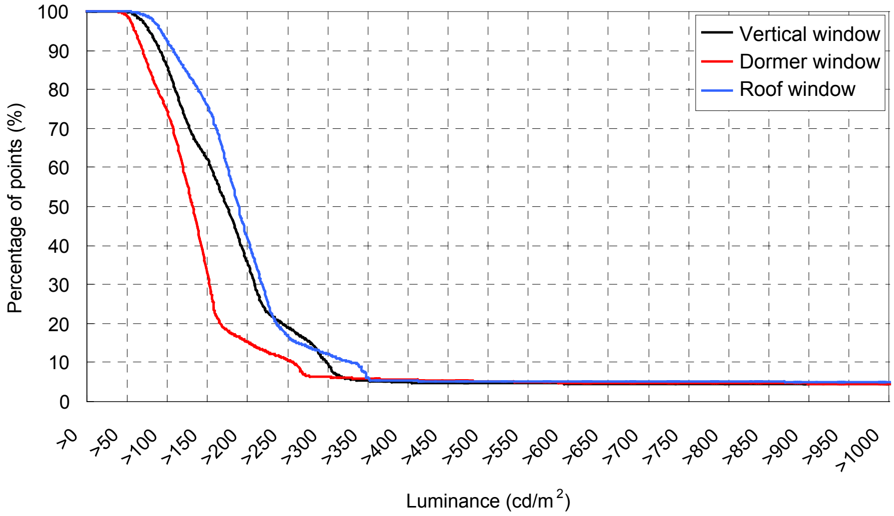


d)

Figure 7.2. Minimum, maximum, median, average and interquartile range (q1, q3) for luminance (cd/m^2), in the view towards the window wall, under previous page: a) overcast conditions, b) on 21 September at 12:00 hours, and c) on 21 September at 12:00 hours (including a shading screen), d) on 21 September at 15:00 hours.

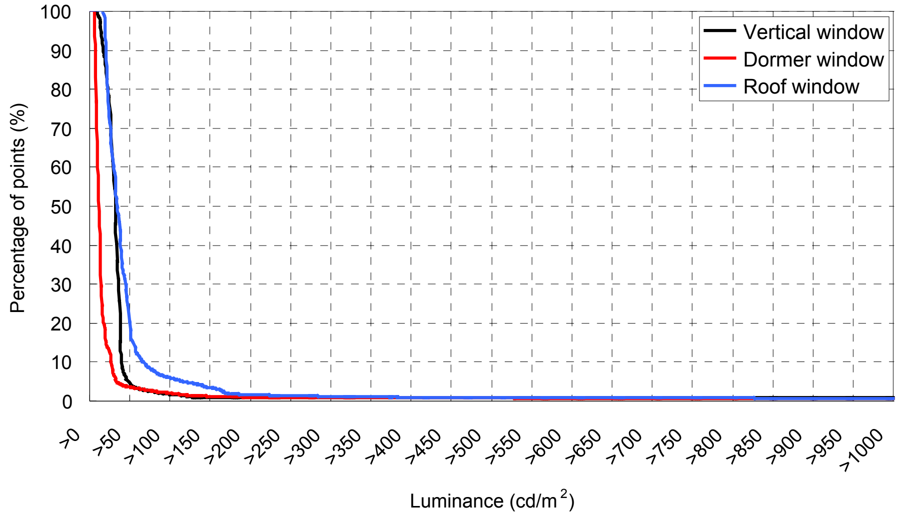


a)

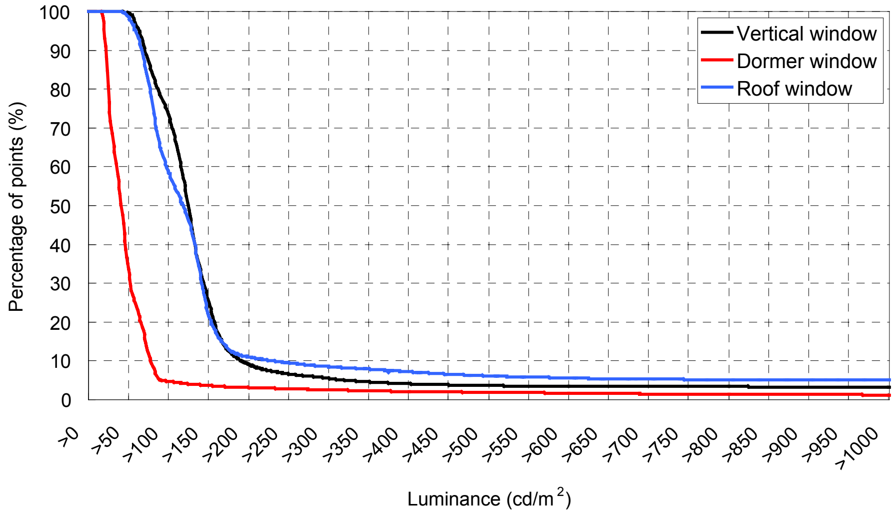


b)

Figure 8.1. Cumulative frequency distribution of the luminance (cd/m²) in the view towards the window wall, under a) overcast conditions, b) on 21 September at 12:00 hours, and next page: c) on 21 September at 12:00 hours (including a shading screen), d) on 21 September at 15:00 hours.

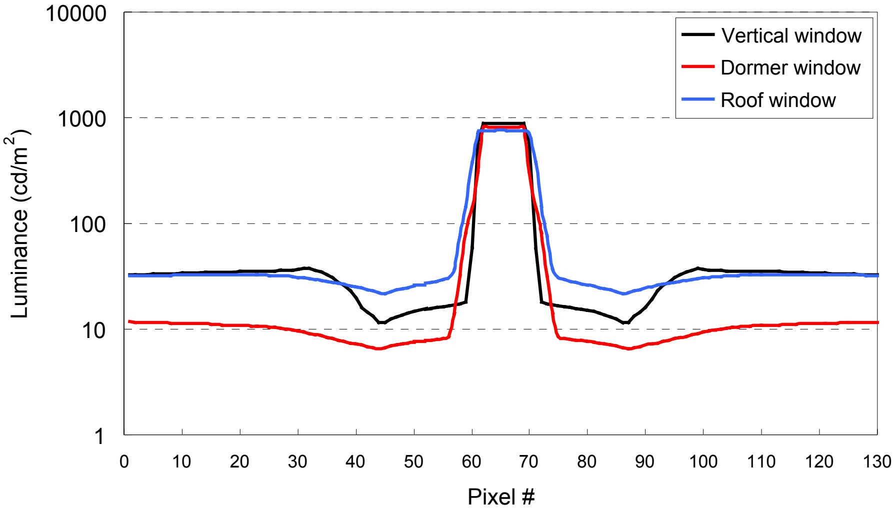


c)

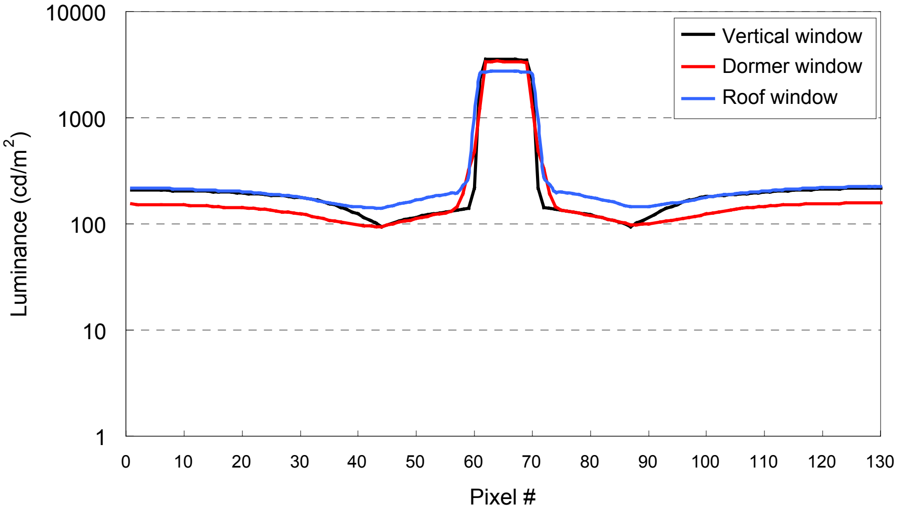


d)

Figure 8.2. Cumulative frequency distribution of the luminance (cd/m^2) in the view towards the window wall, under previous page: a) overcast conditions, b) on 21 September at 12:00 hours, and) on 21 September at 12:00 hours (including a shading screen), d) on 21 September at 15:00 hours.

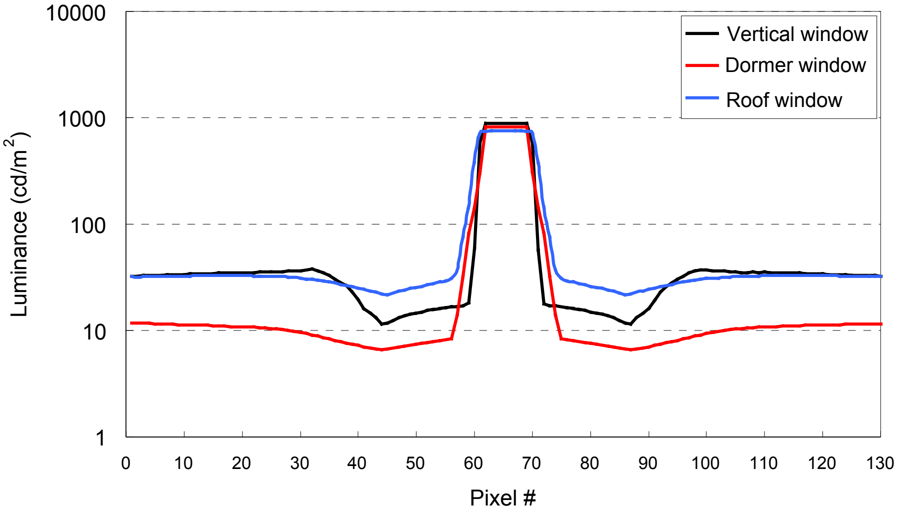


a)

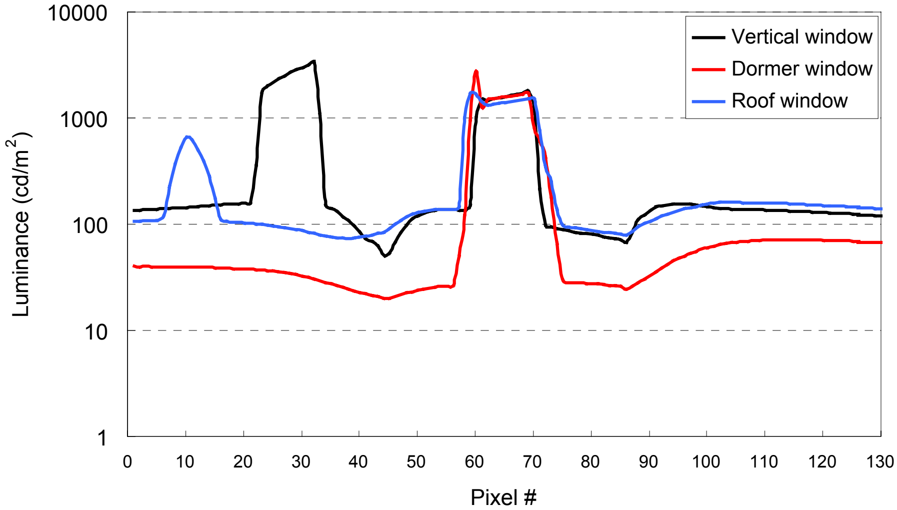


b)

Figure 9.1. Average luminance within a 40º band centered around the observer's eye looking straight ahead towards the window, under a) overcast conditions, b) on 21 September at 12:00 hours, and <u>next page</u>: c) on 21 September at 12:00 hours (including a shading screen), d) on 21 September at 15:00 hours.



c)



d)

Figure 9.2. Average luminance within a 40º band centered around the observer's eye looking straight ahead towards the window, under previous page: a) overcast conditions, b) on 21 September at 12:00 hours, c) on 21 September at 12:00 hours (including a shading screen), d) on 21 September at 15:00 hours.

Table 3. Percentage of the view with values over a given luminance (cd/m^2), a) for the view towards the window wall, b) for the view towards the back wall.

a) Window wall

	Overcast			21 Sept, 12:00			21 Sept, 12:00 (shading)			Sept 21, 15:00		
Luminance (cd/m^2)	Vertical	Dormer	Roof	Vertical	Dormer	Roof	Vertical	Dormer	Roof	Vertical	Dormer	Roof
>500	1	1	1	5	5	5	1	1	1	4	2	6
>1000	1	1	1	4	5	5	1	1	1	3	1	5
>2000	0	0	0	4	4	5	1	1	1	3	1	5
>5000	0	0	0	1	1	1	0	0	0	2	0	4
>10000	0	0	0	0	0	0	0	0	0	0	0	0

b) Back wall

	Overcast			21 Sept, 12:00			21 Sept, 12:00 (shading)			21 Sept, 15:00		
Luminance (cd/m^2)	Vertical	Dormer	Roof	Vertical	Dormer	Roof	Vertical	Dormer	Roof	Vertical	Dormer	Roof
>500	0	0	0	5	4	5	0	0	0	0	0	1
>1000	0	0	0	5	4	5	0	0	0	0	0	1
>2000	0	0	0	5	4	5	0	0	0	0	0	1
>5000	0	0	0	0	0	0	0	0	0	0	0	0
>10000	0	0	0	0	0	0	0	0	0	0	0	0

Discussion and conclusions

Daylight factor

- The roof window resulted in a significantly higher (average) daylight factor on a horizontal plane (0.7 m above floor level), i.e. more than twice as high compared with the vertical window, and more than triple as high compared with the dormer window.
- The roof window provided a wider range of daylight factor values compared with the vertical and dormer windows, which indicates a larger variation in lighting. This variation may be preferable since previous research indicates that people prefer an interior to have a measure of “visual lightness” combined with a degree of “visual interest” (visual interest applies to the non-uniformity of the light pattern).

Luminance

- The roof window resulted in higher luminance values on lateral walls, ceiling and floor compared with the other two cases.
- The dormer window resulted in lower luminance values on walls, ceiling and floor.
- The dormer and roof windows both had window linings with a high luminance allowing a transition between the high window luminance and the luminance of the walls, ceiling and floor. The luminance ratios “window : linings : adjacent walls” was most favourable with the roof window but the area of the linings was small (compared with the dormer window) and may not be sufficient to allow a favourable luminance transition. Increasing the linings’ area and further detailing of the transition borders between the bright areas and the adjacent surfaces may provide a better luminance transition with lower contrasts.
- At times with low sun position and high window-sun azimuth (sunlight partly from the side), e.g. 21 September at 15:00 hours, the luminances were significantly lower with the dormer window compared with the other windows, due to the fact that the direct sunlight patch hit the window linings.
- At different times of the year and day all three window configurations generated a large direct sunlight patch, e.g. on 21 September at 12:00 and 15:00 hours. This will result in a larger number of high luminance values, which may cause glare and necessitate the use of a shading device. Because of the geometry this will possibly happen more frequently for the roof window. How many hours each window configuration may cause glare problems have not been investigated in this study.

Shading

- It has been shown that the high luminance values and resulting glare problems can be avoided by using a shading device, e.g. a simple white Venetian blind or a light coloured (not white) diffusing screen. However, it has not been investigated how often different glare protective shadings will necessitate a complete block of the view out, or how this will differ in the three window configurations.

This study mainly shows that the window configuration affects daylight conditions (distribution and intensity) significantly. However, the conclusions for the sunlit case only cover one day at two different times (one with a shading screen). It is desirable to include more simulation days and times to obtain a more complete picture of daylight conditions in the rooms under direct sunlight conditions. A minimum study of sunlit situations should include the winter and summer solstice days (21 December and 21 June), at noon time and once in the afternoon or morning (afternoon and morning are symmetrical for a south orientation).

The shading screen was modelled with a diffuse, isotropic transmittance. This means that light rays traversing through the screen are transmitted equally in all directions. In reality, most screens do not have this behaviour: the diffuse transmittance is rarely isotropic and there is often a specular (direct) component. It is necessary to obtain the detailed BTRD (bi-directional transmittance and reflectance distribution) function to model the real screen behaviour correctly. The renderings and results produced for the screen in this report should be evaluated bearing this major limitation in mind.

Although we have presented a detailed picture of daylight conditions in the three rooms, the human acceptance factor is missing. The study must be supplemented by subjective assessments in a laboratory or in scale models.

Finally, we must underline that all results discussed in this report are solely based on computer simulations and that any computer program has limitations and a limited accuracy compared with reality. It is necessary to supplement this piece of work with measurements in a laboratory.

Summary (in Danish)

By og Byg Dokumentation 047: Vinduesplaceringens betydning for dagslysforholdene i et rum

Rapporten præsenterer resultaterne af edb-simuleringer af dagslysforholdene i tre rum med tre forskellige vinduestyper: Et almindeligt lodret facadevindue, et kvistvindue og et (skråt) tagvindue. Simuleringerne er gennemført med programpakken *Radiance Lighting Simulation System* (Ward Larson & Shakespeare, 1998). Det overordnede formål med projektet var at udvikle et grundlag for en metode, der gennem få parametre kan give en forenklet beskrivelse af *dagslyskvaliteten* i enkle rum i boliger. Som første fase til at nå dette mål, er der gennemført sammenlignelige simuleringer for de tre vindues- og rumtyper, dels under overskyet himmel og dels under en klar skyfri himmel (den 21. september) på to forskellige tidspunkter af dagen (kl. 12 og kl. 15). Antallet af gennemførte simuleringer må betragtes som et absolut minimum for at opnå et vist billede af dagslysforholdene i et simpelt rum.

Rum- og vindueskonfigurationer

Rummene, der er simuleret, har alle et gulvareal på 3,25 m × 3,85 m (B × D) og en rumhøjde på 2,5 m. Vinduesarealet (lysningsmål) er i alle tilfælde 0,887 m × 1,339 m med et glasareal på 0,765 m × 1,15 m, og vinduet er placeret 1,0 m over gulv, midt mellem sidevæggene, jf. figur 1 side 9. Overfladernes egenskaber er beskrevet i tabel 2 på side 10. Rummene er alle orienteret mod syd, og der regnes med en fri horisont samt en udvendig lysreflektans på 15 % fra en grønlig overflade.

Resultater

Dagslys faktorer

– Tagvinduet resulterer i markant højere (middel-)dagslysfaktor på et vandret plan 0,7 m over gulv, nemlig mere end dobbelt så høj som ved det lodrette vindue og tre gange så høj som ved kvistvinduet.
– Tagvinduet medfører et væsentligt bredere interval af dagslysfaktorer, hvilket indikerer en større variation i lyset. Denne variation kan antages at blive foretrukket af brugere, idet tidligere undersøgelser har vist, at personer ønsker et visuelt miljø, der rummer en vis grad af "lyshed" (visual lightness) kombineret med en vis grad af lysvariation (visual interest).

Luminanser

– Tagvinduet giver generelt højere luminansværdier på sidevægge, loft og gulv sammenlignet med det lodrette vindue og kvistvinduet.
– Af de tre vinduer giver kvistvinduet de laveste luminanser på sidevægge, loft og gulv.
– Der optræder høje luminanser på lysningspanelerne omkring både kvistvinduet og tagvinduet. Disse overflader medfører en blødere overgang mellem vinduets meget høje luminans og luminansen af rummets overflader (vægge, loft og gulv). Luminansspringene mellem vindue, lysningspanel og væg er mindst og derfor mest fordelagtige ved tagvinduet, men arealet af lysningerne er små sammenlignet med kvistvinduet. En forøgelse af lysningspanelernes areal og en mere omhyggelig detaljering af overgangene mellem de lyse flader og de tilstødende vægflader kunne

muligvis give en mere fordelagtig luminansovergang med lavere kontraster mellem lyse og mørke flader.

- På tidspunkter med lav sol og høj vindues-sol azimut (solen kommer skråt fra siden), fx den 21. september kl. 15, er luminanserne markant lavere i rummet med kvistvindue sammenlignet med de to andre vinduer. Dette skyldes, at solen rammer de lodrette lysningspaneler.
- På mange tidspunkter af året og dagen genereres der ved alle tre vinduestyper et stort felt med direkte sollys, fx den 21. september kl. 12 og kl. 15. Dette medfører store områder med høje luminanser, hvilket kan være årsag til blænding og nødvendiggøre brug af solafskærmning. På grund af geometri og vindueshældning må dette forventes at optræde hyppigere ved tagvinduet. Antallet af timer, hvor solafskærmning måtte være nødvendig, er imidlertid ikke undersøgt i dette projekt.

Afskærmning

- Simuleringerne viser, at de høje luminansværdier med resulterende blændingsproblemer kan undgås ved anvendelse af en enkel solafskærmning, fx en simpel persienne eller et lyst farvet (ikke hvidt) rullegardin. Det er ikke undersøgt, hvor hyppigt det vil være nødvendigt at benytte solafskærmninger for de tre vinduestyper eller, hvor ofte forskellige solafskærmninger vil medføre generende blokering for udsigten gennem vinduerne.

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Appendix

Table A.1. Minimum, maximum, median, average and interquartile range for the daylight factor (%), overcast sky conditions

	Vertical window	Dormer window	Roof window
minimum	0,29	0.16	0.44
q1	0.94	0.55	1.29
median	1.25	0.71	1.97
q3	1.73	1.05	3.60
maximum	2.92	1.94	10.33
average	1.37	0.83	2.85

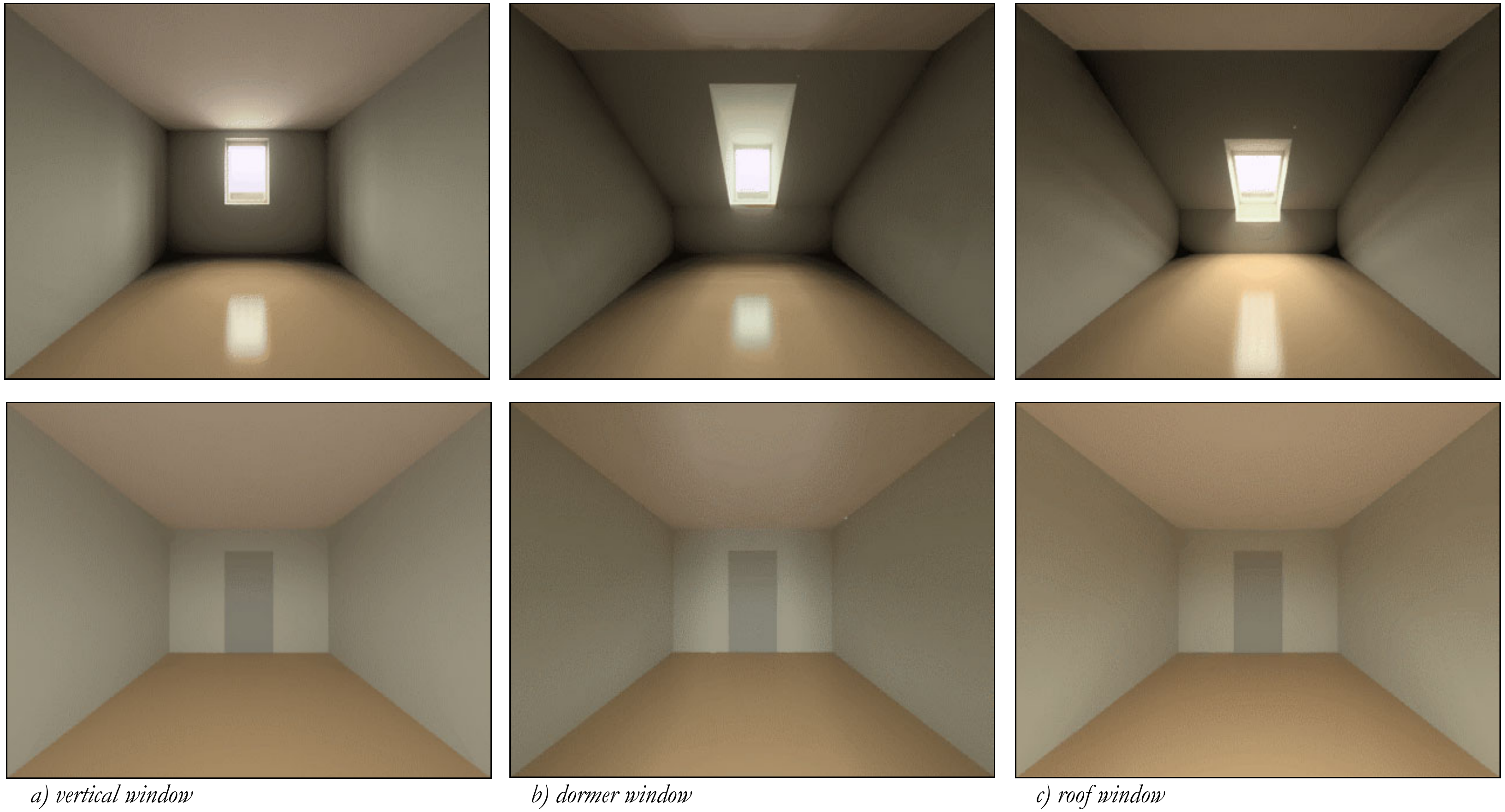


Figure A.1. Renderings mimicking the human vision. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, overcast sky conditions.

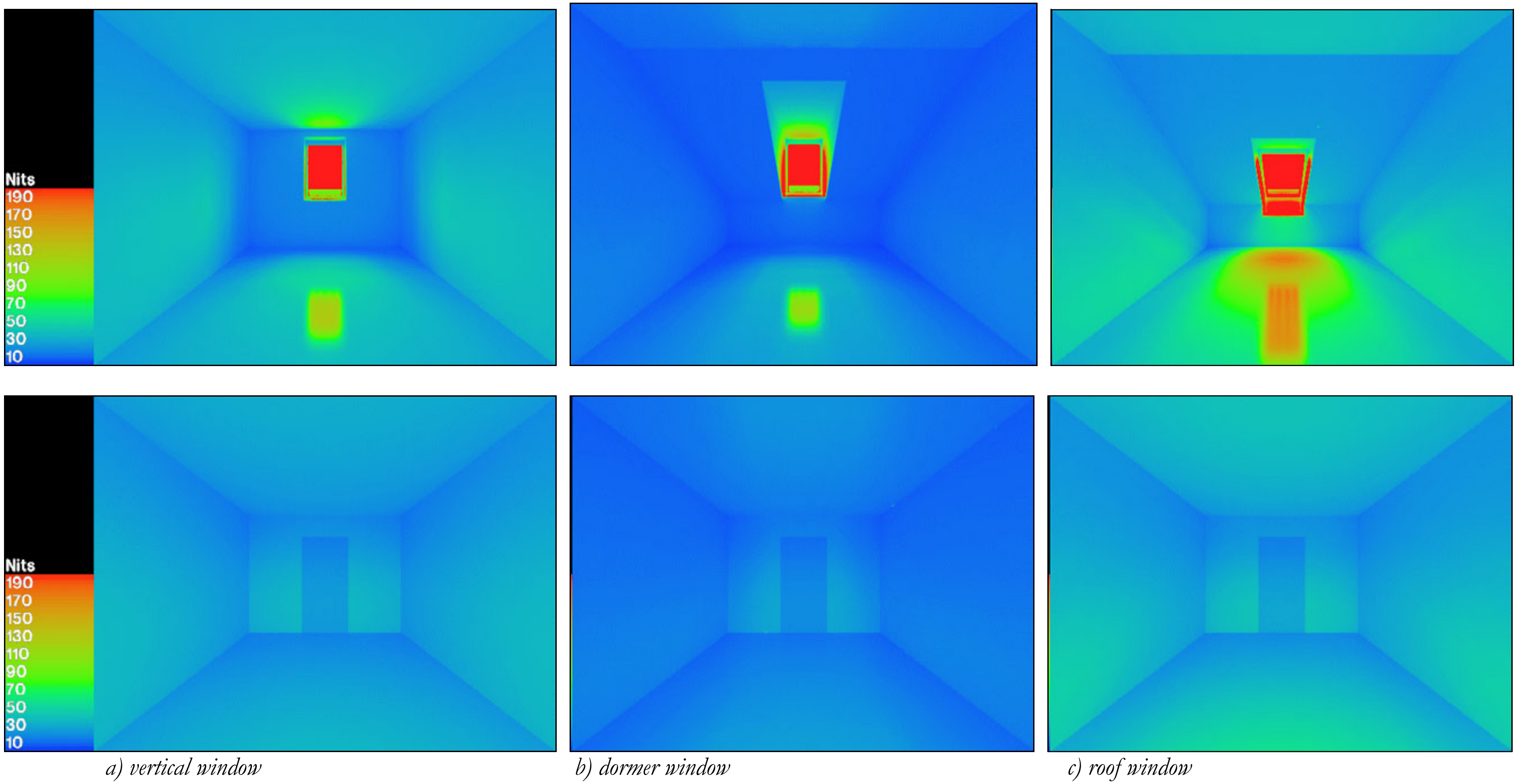


Figure A.2. False colour renderings. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, overcast sky conditions.

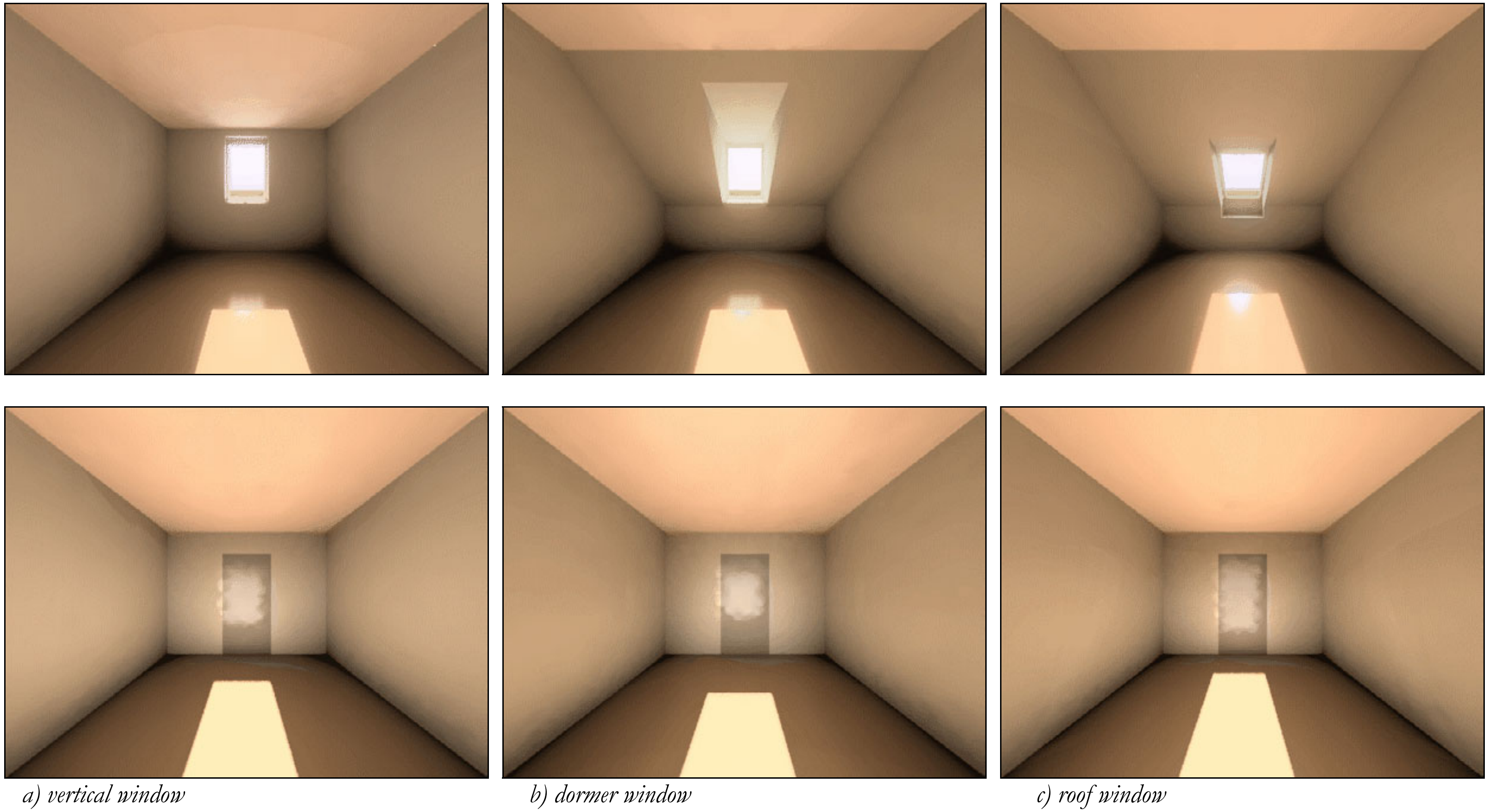


Figure A.3. Renderings mimicking the human vision. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, sunny sky, September 21, 12.00 hours.

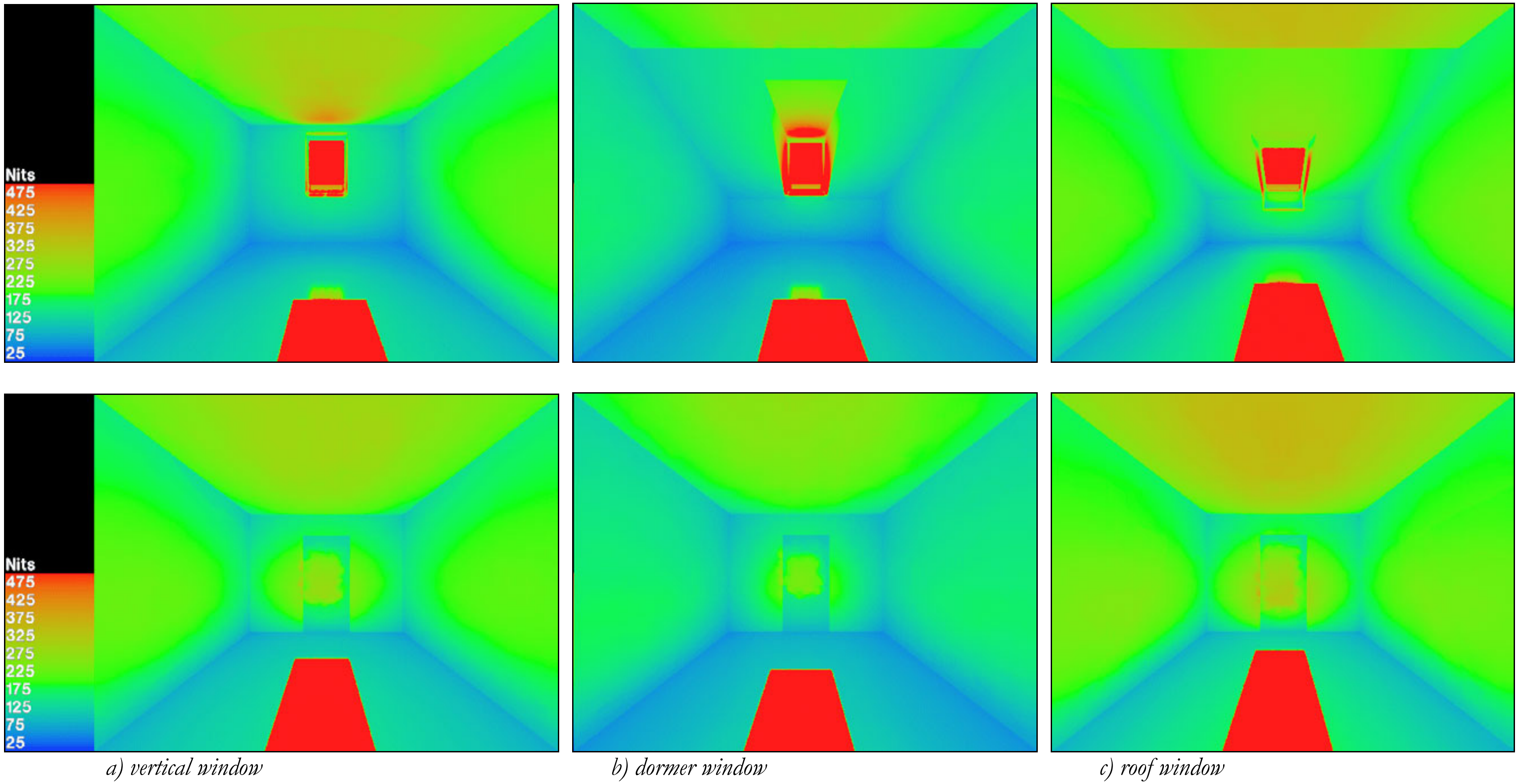
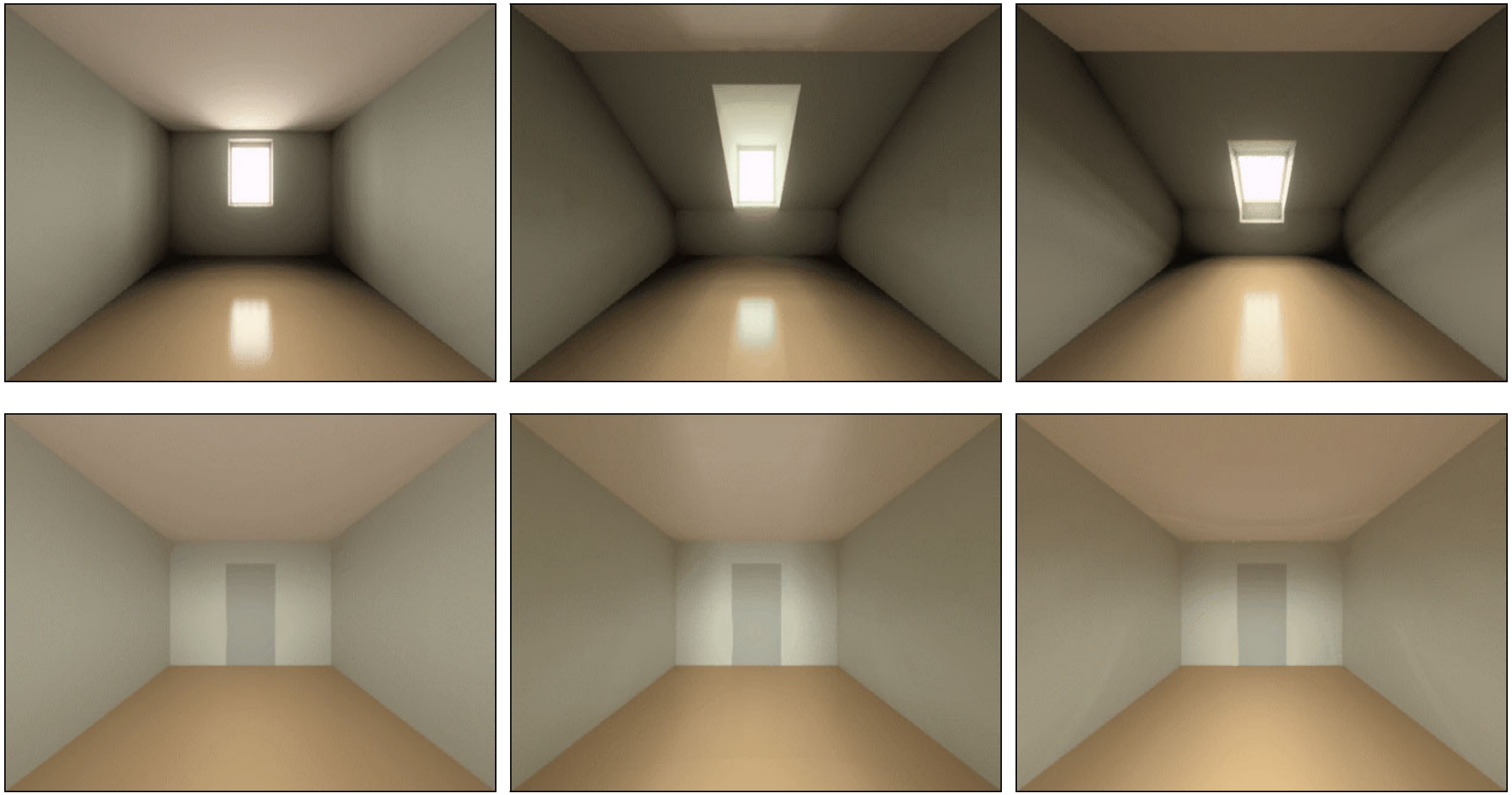


Figure A.4. False colour renderings. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, sunny sky, September 21, 12.00 hours.



a) vertical window

b) dormer window

c) roof window

Figure A.5. Renderings mimicking the human vision. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, sunny sky, September 21, 12.00 hours, with a shading screen.

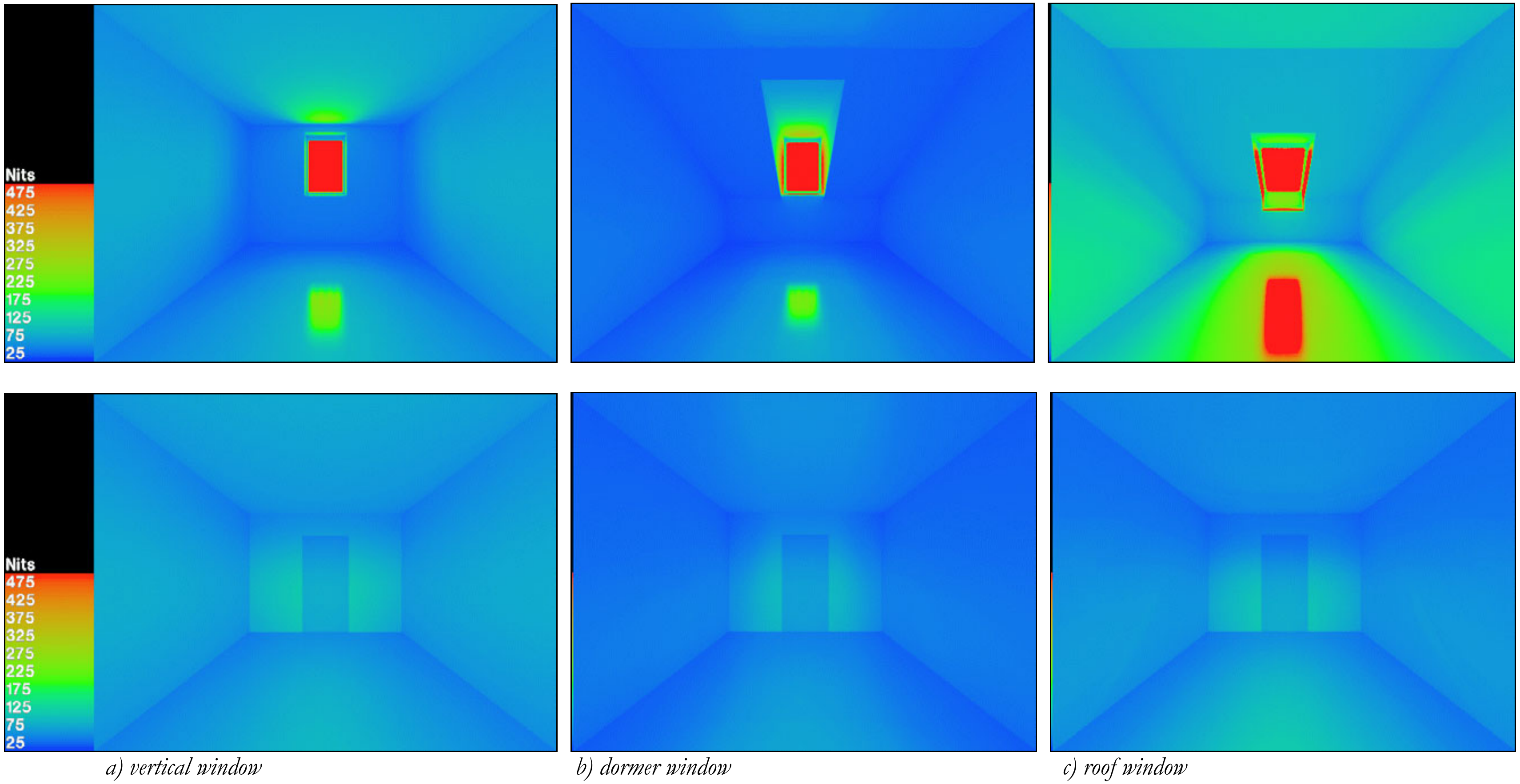
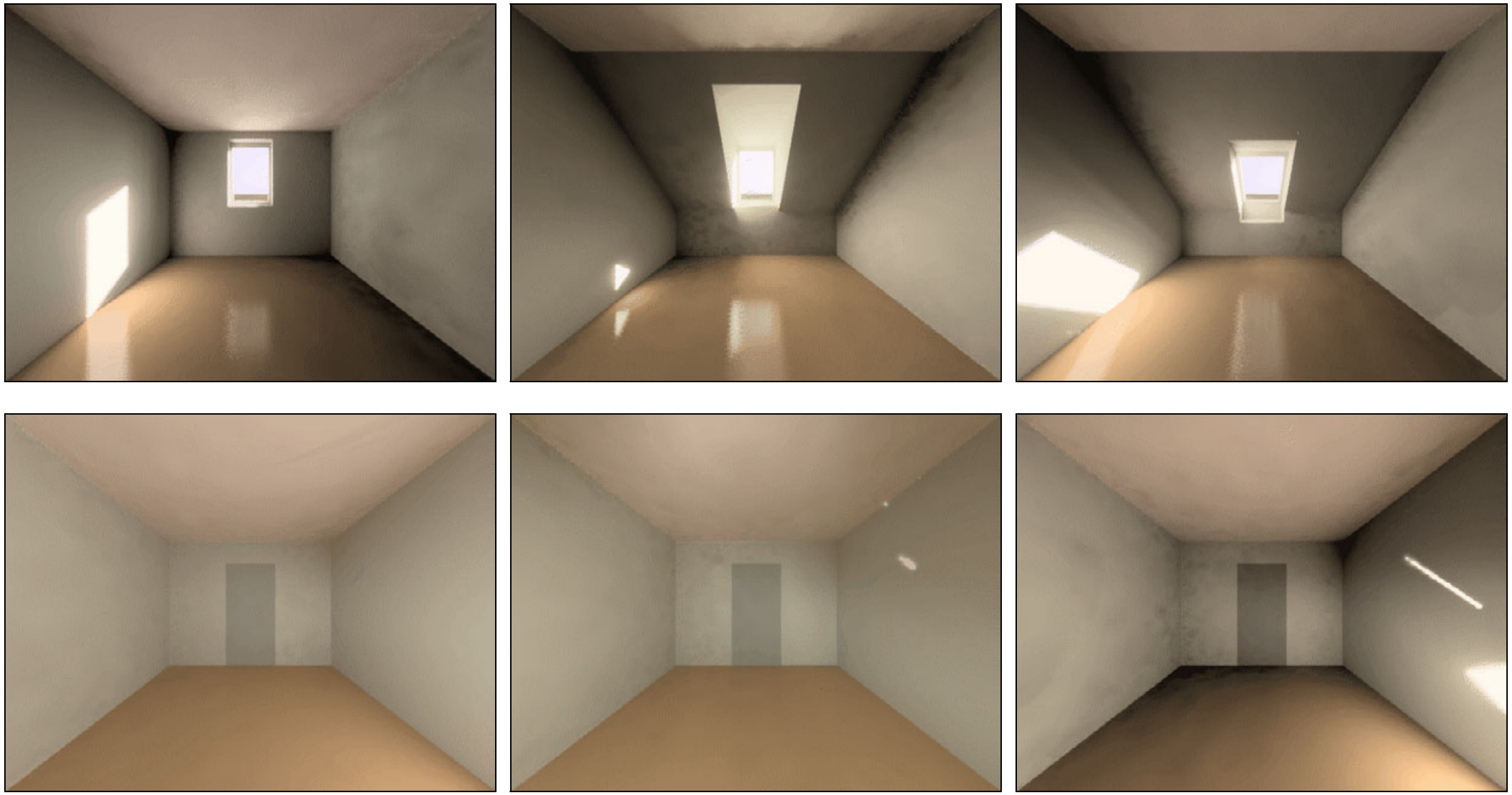


Figure A.6. False colour renderings. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, sunny sky, September 21, 12.00 hours, with a shading screen.



a) vertical window *b) dormer window* *c) roof window*

Figure A.7. Renderings mimicking the human vision. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, sunny sky, September 21, 15.00 hours.

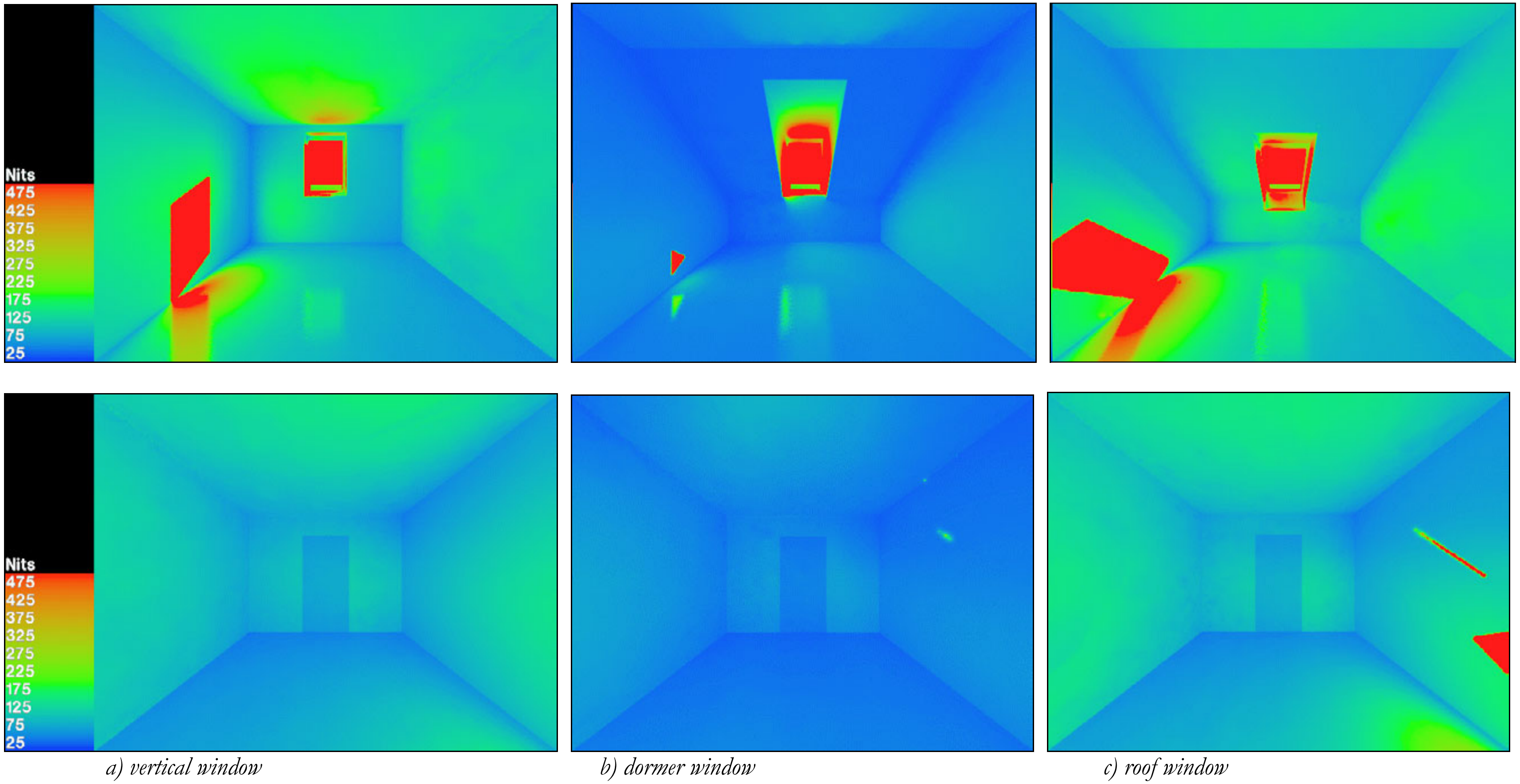


Figure A.8. False colour renderings. The first row presents the renderings of the view towards the window wall. The second row shows the renderings of the view towards the back (north) wall, sunny sky, September 21, 15.00 hours.

Table A.2. Rendering options used in the calculations.

Perspective renderings

	Vertical window				Dormer window				Roof window			
	O	S 12	S 12s	S 15	O	S 12	S 12s	S 15	O	S 12	S 12s	S 15
-dp	2048	2048	2048	2048	2048	2048	2048	2048	2048	2048	2048	2048
-ar	39	39	40	39	50	50	50	39	40	40	44	40
-ms	0.041	0.041	0.041	0.041	0.042	0.042	0.042	0.041	0.042	0.042	0.041	0.042
-ds	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
-dj	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
-dt	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
-dc	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
-dr	3	3	3	3	3	3	3	3	3	3	3	3
-sj	1	1	1	1	1	1	1	1	1	1	1	1
-st	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
-ab	6	6	6	6	6	6	6	6	6	6	6	6
-aa	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
-ad	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
-as	512	512	512	512	512	512	512	512	512	512	512	512
-av	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
-lr	12	12	12	12	12	12	12	12	12	12	12	12
-lw	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
-av	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0

Plane renderings (illuminance)

	Vertical window				Dormer window				Roof window			
	O	S 12	S 12s	S 15	O	S 12	S 12s	S 15	O	S 12	S 12s	S 15
-dp	2048	2048	2048	2048	2048	2048	2048	2048	2048	2048	2048	2048
-ar	39	39	40	39	50	50	50	39	40	40	44	40
-ms	0.041	0.041	0.041	0.041	0.042	0.042	0.042	0.041	0.042	0.042	0.041	0.042
-ds	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
-dj	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
-dt	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
-dc	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
-dr	3	3	3	3	3	3	3	3	3	3	3	3
-sj	1	1	1	1	1	1	1	1	1	1	1	1
-st	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
-ab	6	6	6	6	6	6	6	6	6	6	6	6
-aa	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
-ad	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
-as	512	512	512	512	512	512	512	512	512	512	512	512
-lr	12	12	12	12	12	12	12	12	12	12	12	12
-lw	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
-av	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0

The report describes the results of a pilot study on daylight conditions in simple rooms of residential buildings. As a tool for the analyses the Radiance Lighting Simulation System was used to simulate one room with three different window configurations, a vertical window, a dormer window, and a roof window. The simulations were performed for overcast sky conditions and under one sunny sky, for two different times of the day. The study shows that the window configuration affects the daylight conditions (distribution and intensity) significantly. The roof window results in a higher (average) daylight factor on a horizontal plane, i.e. more than twice as high compared with the vertical window, and more than triple as high compared with the dormer window.

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Impact of three window configurations on daylight conditions

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