THE DAYLIGHTING OF THE STAVE CHURCH OF BORGUND

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Introduction

The stave churches are Norway's unique contribution to "the challenge of the medieval church". [1] (Figure 1).

How did architecture, structure and daylighting combine to reinforce the liturgy in the early church?

This paper attempts to show that the true spirit of Nordic lighting is to be found in the original *medieval* church. In winter, a mystic quality in the interior, associated with ritual, is achieved when the "weak light is split by roof work and sinks like a dim atmosphere into the room". [2] I demonstrate how"if the door is left open, as it commonly was in summer, then the whole space is lit up". [3]

Such architecture has been designed to reinforce the religious message being conveyed. The daylighting of the church is modulated by the architecture, itself a manifestation, technically, of a certain set of cultural and social imperatives. The interaction of structure, material and texture is a complex one. Why did the master craftsmen who built these churches build them the way they did? And how did that translate into the dramatic, atmospheric interiors that characterise such churches?

Much daylighting commentary is restricted to an assessment of average daylight factor in terms of adequacy and a description of the penetration of sunlight into the space. Recently developed techniques of cumulative daylight modelling are useful for sustainability judgements but rarely are qualitative assessments made of the characteristics of daylit interiors in sacred buildings.

1. Bugge G. *Stave-churches in Norway*, Dreyers Forlag A/S, Oslo (1983) p14.

Figure 1: Borgund stave church (www.wondermondo.com/Norway.htm [CC BY-SA 2.0)

2. Norberg-Schulz C. *Nightlands: Nordic Building.* The MIT Press (1996) p80 *citing* Hansen M A. *Orm go Tyr.* (1959) p377.

3. Blindheim M. *The Stave Church Paintings: Medieval Art from Norway.* UNESCO/Collins, London (1965) pp18–19.

The stave church of Borgund

A daylighting analysis is undertaken of one of the most characteristic stave churches, that of Borgund in Sogn, at a variety of *scales* of analysis.

A first analysis allows the exploration of the lighting of the church in its landscape setting. Next is a consideration of the atmosphere produced in the church by the arrangement of the fenestration and the final analysis demonstrates how the master carpenters that built the church were sensitive to the effects of light. Working at these different scales improves the characterisation of the lit interior.

The church at Borgund was chosen because it is the best preserved example of a stave church and has acted as a model for the reconstruction of other stave churches. The conclusion is that the true *spirit of Nordic lighting* is to be found in the early medieval

The English translation 'stave church' is a poor rendition of the Norwegian term *stavkirke* (sing.) or *stavkirker* (plur.).

church before it was swept away by the 'Gothic' accretions added to the church after the change in Norway to Lutheran doctrine [4]

4. Abrahamsen H. *Building in Norway.* The Royal Norwegian Ministry of Foreign Affairs (1959) p33.

This is what you see today (Figure 2).

Figure 2: The interior of the stave church at Borgund. (http://en.wikipedia.org/wiki/File:Stave_church_Borgund_interior.jpg [CC BY-SA 3.0])

This is what it would have been like in medieval times (Fig 16).

Figure 3: Possible appearance in summer (by the author).

The analysis

Around 20 or so stave churches remain in Norway, there being around 500–600 [5] (perhaps even 1000) [6] when they were first built. One of the best preserved is that of the church of Borgund in Sogn. It sits within a valley around 200km from Oslo in the province of Sogn in Western Norway (Figure 4).

5. Abrahamsen H. *op.cit.* p9.

6. Carli R and Paniccia R M. The Norwegian *stavkirke* and the *spazio anzi*: continuity and discontinuity in social representation and myth. *Rivista di Psicologia Clinica*, 2, (2011) p58.

Figure 4: Map of Norway

The expansion of Christianity into Norway took place between 995 and 1000 with a bishopric established in Bergen around 1070. [7] The stave churches were part of a great swathe of church building between 1100 and 1250. [8]

7. Barraclough G (ed.). *The Times Atlas of World History.* Times Books (1984) p101.

8. Abrahamsen H. *op.cit.* p13.

The churches were small needing only to accommodate a few worshippers from surrounding farms (perhaps serving around 300 people) [9] and they lie in parts of Norway that are mountainous, deeply cut by fjords, and surrounded by rolling forests. [10] They are built of wood, easily available, using the 'stav' technique—the vertical arrangement of staves held rigid by horizontal beams (in contrast to the 'laft' technique—the horizontal layering of timber dovetailed where they cross at the corners). [11]

9. `http://home.loopme.com/fortidsminneforeningen/sites/fortidsengelsk/go.cfm?id=66595` (*Society for the Preservation of Norwegian Ancient Monuments.)*

10. Abrahamsen H. *op.cit.* p6.

11. Abrahamsen H. *ibid.* p17.

One of the earliest churches still extant in England—that of Greensted in Essex (Figures 5 and 6)—uses the 'stav' technique in parts of its walls although the *stone* architecture developed later in Western Norway depended upon English and Norman masons, [12] the stone being more vulnerable to frost than the pine wood of the stave churches. Thus the stave church is Norway's unique contribution to architecture and is a highly ingenious architectural construction. Bugge states that "we must consider them *original works*—the Norwegian answer to the challenge of the medieval church". [13]

12. Abrahamsen H. *ibid.* p13.

13. Bugge G.*op.cit.* p14.

The church sits—remote—in a valley surrounded by steeply contoured mountains. This means that the church is sensitive only to zenithal light from the sky.

Figure 5: Greensted church, Essex *c.* 1013 (*World Architecture: An Illustrated History*, Hamlyn, London (1963) p194.)

Inspecting the the plan and two sections of the church (Figures 7 and 8), we see a square nave with rising timber columns—redolent of a forest—with a chancel leading off it. The columns define an ambulatory. Surrounding this inner core is an arcade. In section we can see a high attic window and then wind-eyes high up in the vault of the church (incidentally providing the temperature control necessary for the preservation of the wood). [14]

We can also see the steeple, the mysterious dragon heads and gable ends that decorate the church as it rises from its base. The whole is clad in sun-baked tiles (Figure 9).

Figure 6: The short-baulk timbers of Greensted church built of oak and elm.

14. Foster M. *Principles of Architecture.* New Burlington Books (1983) p58.

But these are 'Gothic' additions—when Norway officially abandoned Catholicism in 1536, the church gave its allegiance to Lutheran doctrine. The Lutherans wanted to remove the mysticism [15] so they added the attic window and built the gable ends and added the arcade. To reveal the true nature of the church we have to strip away the 'Gothic' additions and revert to its medieval core as shown in Figure 10.

15. Abrahamsen H. *op.cit.* p33.

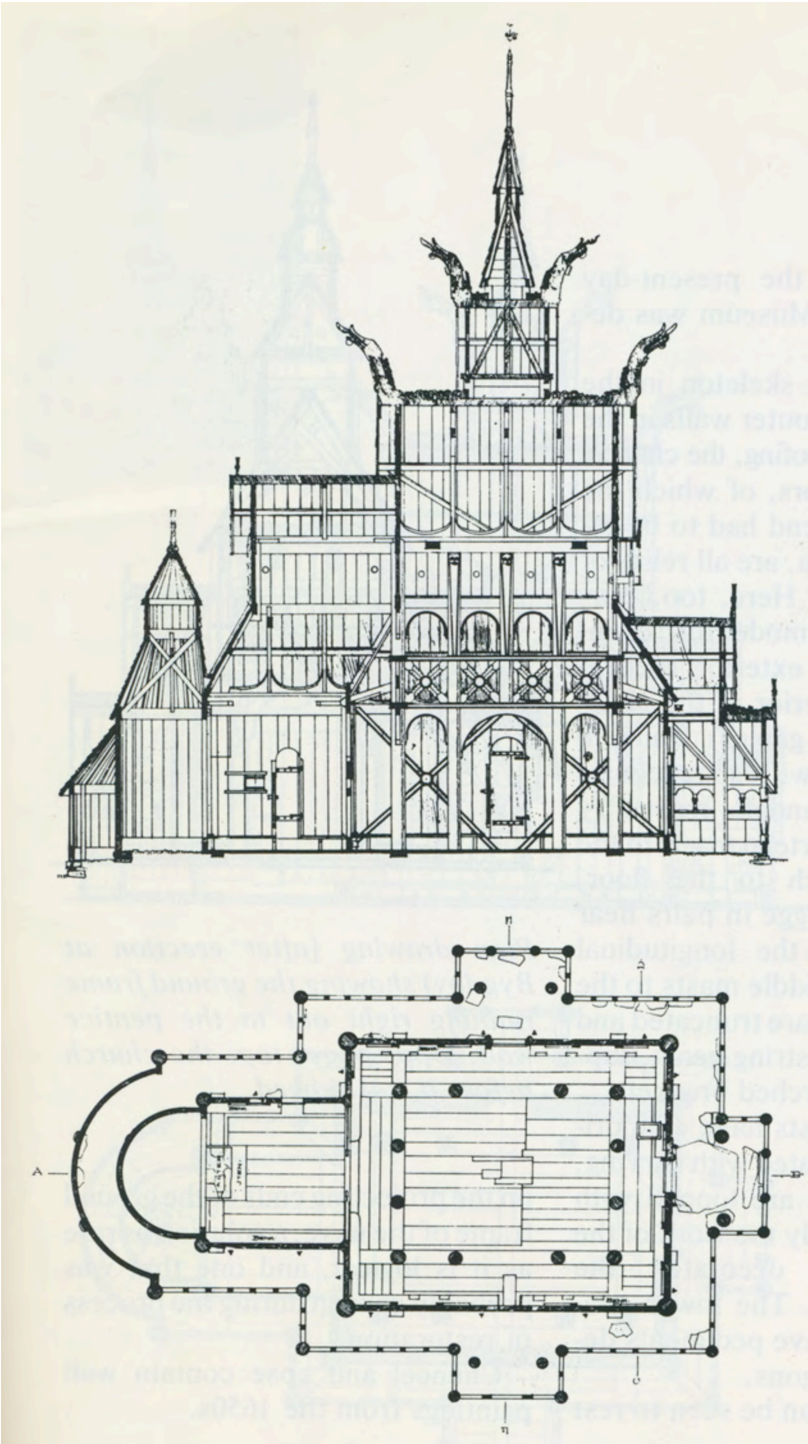

Figure 7: Borgund stave church: plan and long section. (Bugge G. *Stave-churches in Norway.* Dreyers Forlag A/S (1983) p65.)

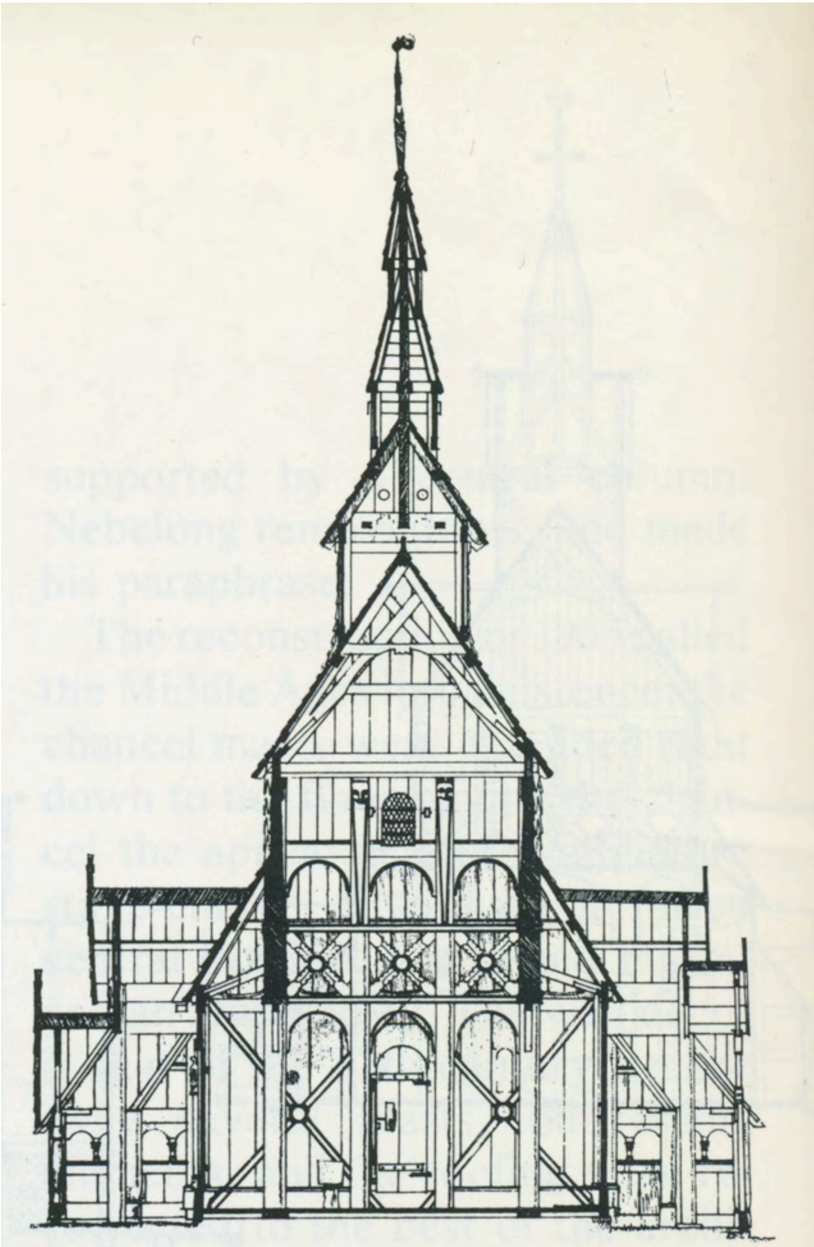

Figure 8: Borgund stave church: plan and long section. (Bugge G. *Stave-churches in Norway.* Dreyers Forlag A/S (1983) p64.)

Figure 9: Borgund stave church. (Kenneth Berger CC BY-NC 2.0)

What does that leave us with? Figures 11 and 12 show the limits of the medieval core (*Romanesque*). We have the nave with a screen to the chancel and the wind-eyes in the roof. There are doors to the south and west—very characteristic of these churches—and a door to the chancel. There is also a viewing slot onto the medieval stone altar. Maybe there would have been a couple of sperm whale candles on the altar flickering in the dark.

Figure 10: The Romanesque core of Borgund church. (Bugge G. *Stave-churches in Norway.* Dreyers Forlag A/S (1983) p18.)

I chose to explore the church in summer and winter at 3pm—the *hora nona* in the Catholic church—the ninth hour reckoned from 6 o'clock in the morning, marking the hour of Christ's death. [16]

Let us position a member of the congregation looking towards the altar. A second viewing position would be across the church looking up at the vault (Figure 11 and 12). It is possible to overlay the normal achromatic visual field to see what is in the field of view. The materials throughout are pinewood—boarded, shaped, carved...

Let us sample some measurement points in the field of view. In the view towards the altar there are 18 points sampled on the altar, the posts, the carvings...(Figure 13. In the view upward we look at the wind-eyes and their surrounds (Figure 14).

16. `http://home.loopme.com/fortidsminneforeningen/sites/fortidsengelsk/go.cfm?id=66595` (*Society for the Preservation of Norwegian Ancient Monuments.*)

Veitch has suggested that one of the psychobiological and psychological processes which refer to the 'affective' or 'emotional' response to lighting is that of *attention and appraisal*. [18] The term 'appraisal' in *attention and appraisal* has been described [19] using the theoretical framework shown in Table 1. It is proposed that there are 2 dimensions ("informational *outcomes*") to environmental preference: [20]

18. Veitch J A. 'Lighting Guidelines from Lighting Quality Research'. *Proceedings CIBSE/ILE Joint Conference*, University of York, 9–11 July (2000) p58.

19. Kaplan S. 'Aesthetics, Affect and Cognition: Environmental Preference from an Evolutionary perspective'. *Environment and Behavior*, Vol 19, No 1 (1987) pp3–32

20. Kaplan S. *ibid.* p10.

- UNDERSTANDING - "comprehending or making sense of a scene"
- EXPLORATION - "being held by the setting, being attracted by or pulled towards sources of additional information".

	UNDERSTANDING	EXPLORATION
IMMEDIATE	Coherence	Complexity
INFERRED, PREDICTED	Legibility	Mystery

Table 1: (*Adapted from Kaplan S; p12*)

In the church in winter the doors would be closed; often in summer the doors would be open. [17] We assume that the observer is fully adapted to the lit environment and therefore makes an *inferred* or *predicted* appraisal rather than one that is *immediate*.

17. Blindheim M. *op.cit.* pp18–19.

Calculating daylighting

What would be the sky condition at these two times of the year? Borgund is situated at approximately $61°N$ latitude and we can use climate data for Oslo ($59.9°N$) and Bergen ($60.3°N$) [18] to estimate

18. *Climate Consultant 5* software available from `http://www.energy design tools.aud.ucla.edu/`

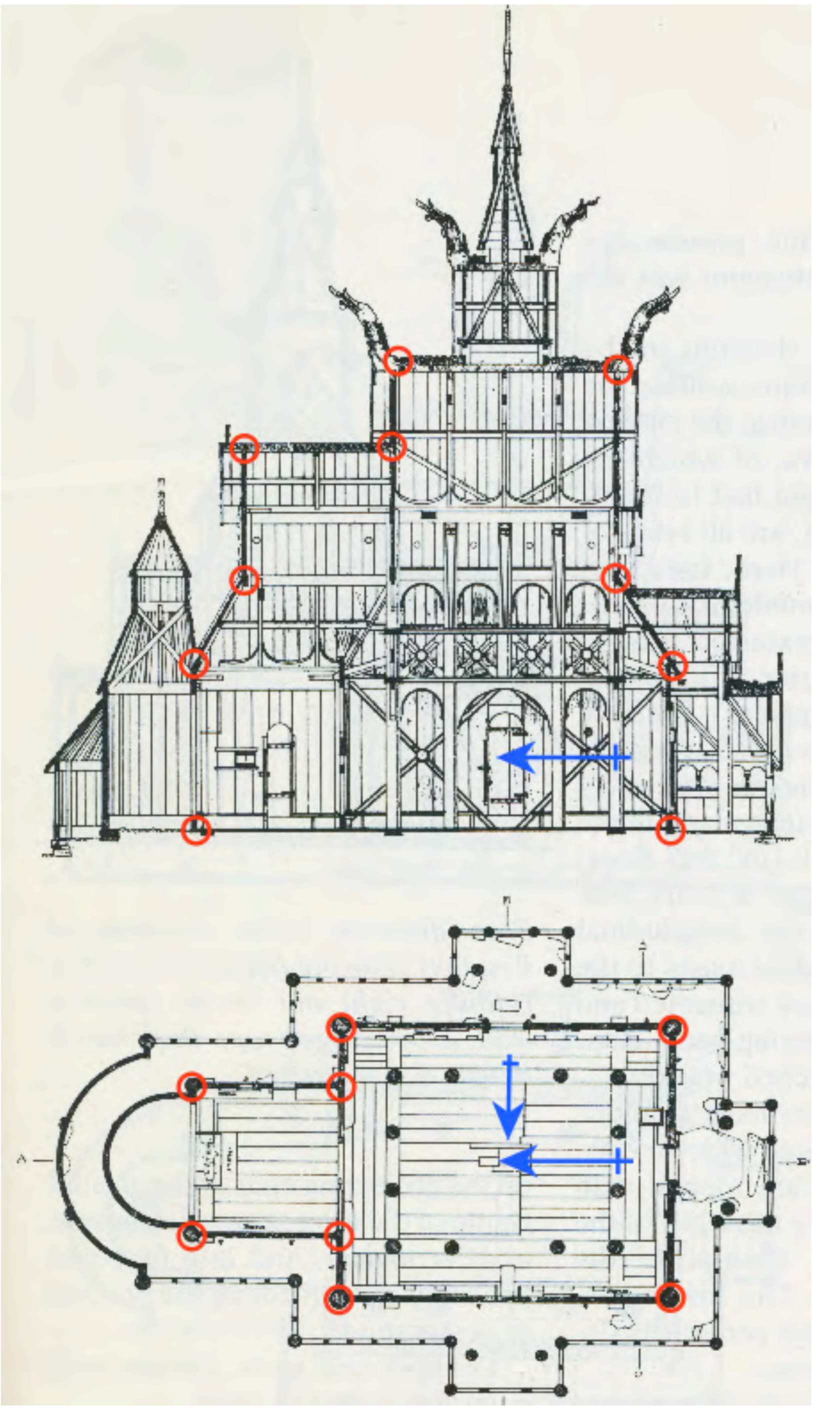

Figure 11: Borgund stave church: plan and long section. (Limits to the medieval core denoted by red circles.)

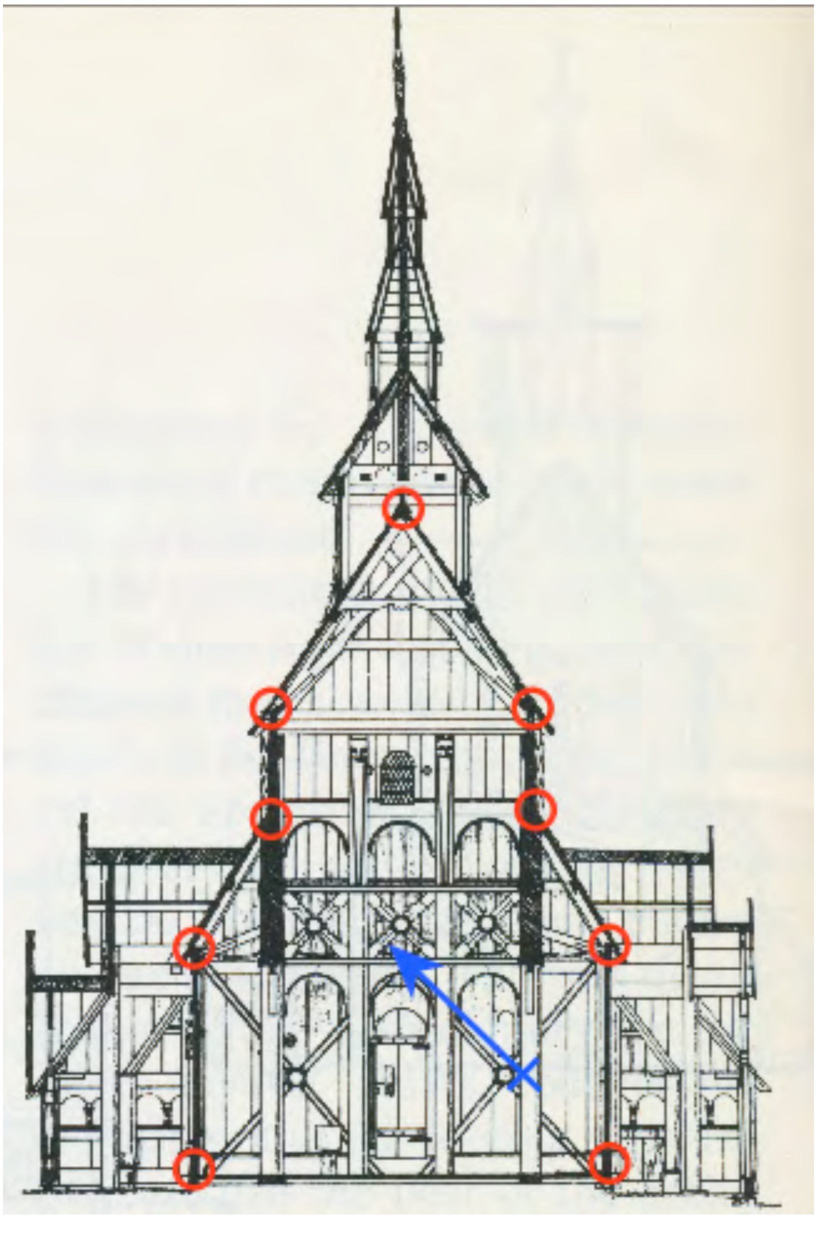

Figure 12: Borgund stave church: short. (Limits to the medieval core denoted by red circles.)(1983) p65.)

Figure 13: The measurement points

Figure 14: The measurement points in the vault view. (*Image* `http://timtyson.us/archives/2009/09/ah norway such a beautiful place/` [CC BY-NC-SA 3.0]

the average monthly percentage sky cover. In June the sky cover range is 58–62% and in Dec 74%. So we are justified in using the CIE standard overcast sky luminance distribution as the basis for our investigation.

Using Moore's dot charts [19] we can compute Sky Component (SC) and Externally Reflected Component (ERC) at each point in Figures 13 and 14 and use the BRE split-flux formula to calculate average Internally Reflected Component (IRC).

19. Moore F. *Concepts and Practice of Architectural Daylighting.* Van Nostrand Reinhold, New York (1991) p225.

Average IRC = $\frac{0.85W}{A(1-R)} \times (CR_{fw} + 5R_{cw})$

where

W = area of windows

A = total area of ceilings, walls and floor inc. window area

R = average reflectance of ceiling, floor and all walls including window expressed as a fraction

R_{fw} = average reflectance of floor and those parts of the wall above the plane of the mid-height of the window (excluding window wall)

R_{cw} = average reflectance of ceiling and those parts of the wall above the plane of the mid-height of the window (excluding window wall)

C = coefficient having values dependent upon the obstruction outside the window.

We can compute the luminance at each point using the formula $L = \frac{\rho E}{\pi}$, assuming that pine wood has a reflectance of about 0.4.

These luminances can be converted into apparent brightness using the curves developed by Hopkinson and used by Waldram in his *Designed Appearance* method. [20] The procedure also requires the estimation of the adaptation luminance by a worshipper which Waldram considered was set by the local field within 6° of the object of regard.

20. Waldram J M. 'Studies in Interior Lighting'. *Transactions of the Illuminating Engineering Society (London)*, Vol 19, No 4 (1954) pp95-124

Tabulated calculation steps to determine apparent brightness for winter and summer at 3pm are shown in Tables 2 and 3.

An attempt at visualising these conditions is shown in Figures 15 and 16. Perhaps this analysis gives some indication of the qualities of the lighting within a typical stave church as described by Blindheim: [21]

21. Blindheim M. *op.cit.* pp18-19

> The first impression inside a stave church is one of almost complete darkness. Then a wealth of detail begins to emerge in the trickle of light which filters through the small round holes at the height of the triforium. If the door is left open, as it commonly was in summer, then the whole space is lit up. The modest floor dimensions, coupled with the considerable height, give these churches a remarkably personal and intimate effect and the texture of the wood adds warmth to the whole.

If the worshipper looks towards the vault from the second viewing position, they obtain a direct view of the wind-eyes (Figure 17). In the summer at 3pm, it is worth estimating the luminance of the sky from the viewing position (in winter, it will be almost dark at 3pm). An expression for the zenithal luminance of the sky is: [22]

22. Krochmann J and Seidl M. 'Quantitative Data on Daylight for Illuminating Engineering'. *Lighting Research and Technology*, Vol 6, No3 (1974).

Table 2: Apparent brightness in winter.

Illuminance from sky (winter at 3pm) = 3995 lx. Adaptation luminance = 0.6 asb. Measurement point	L (cd/m^2)	L (asb)	Apparent brightness
F	0.01	0.03	2
V	0.01	0.03	2
CU	1	3.14	18
TC	0.01	0.03	2
TL	2	6.3	24
TR	2	6.3	24
AL	1.5	4.7	21
AR	1.5	4.7	21
W	0.01	0.03	2
A	0.01	0.03	2
PLI	2	6.3	24
PLO	2	6.3	24
PRI	2	6.3	24
PRO	2	6.3	24
PLC	1.5	4.7	21
PRC	1.5	4.7	21

Table 3: Apparent brightness in summer.

Illuminance from sky (summer at 3pm) = 35005 lx. Adaptation luminance = 21 asb. Measurement point	L (cd/m^2)	L (asb)	Apparent brightness
F	55.7	174.9	90
V	2.23	7	11
CU	11.15	35	38
TC	2.23	7	11
TL	20.1	63.1	53
TR	20.1	63.1	53
AL	15.6	48.9	49
AR	2.23	7	11
W	6.69	21	29
A	2.23	7	11
PLI	20.1	63.1	53
PLO	20.1	63.1	53
PRI	20.1	63.1	53
PRO	24.5	77	58
PLC	33.4	104.9	80
PRC	127.1	399	150

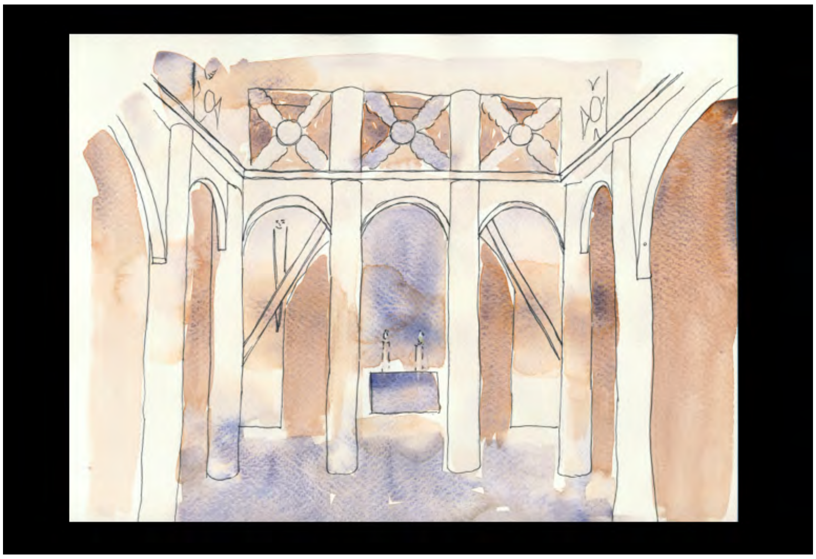

Figure 15: Apparent brightness in winter (by the author).

Figure 16: Apparent brightness in summer (by the author).

$L_o = 3990 \times (1 + \frac{3 \sin g}{2}) \sin g$
where
g = altitude of the sun.

This can be substituted into the following expression: [23]

23. Moore F. *op.cit.* App. G

$L_p = L_o \times \frac{1+2\cos P_{al}}{3}$
where
L_p = sky luminance at point P
L_o = sky luminance at zenith
P_{al} = altitude of point P above horizon.

This allows us to calculate the luminance of the sky through the wind-eye at around 4200 cd/m^2. Here we are seeing the expanse of sky in the *aperture* mode rather than the *surface* mode and the fact that the sky luminance is so much greater than the background luminance (of around 20 cd/m^2) suggests how the "... light ... sinks like a dim atmosphere into the room".

Figure 17: A view of the wind-eyes from the second viewing position

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The wind-eye shown in another stave church shows how it is possible to appraise the wind-eye in the *illumination* mode where attention is focused on the composition of the incident light (Figure 18) revealing the directional character of the daylighting.

Figure 18: The wind-eye in the *illumination* mode.

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I warmly acknowledge all those architects and writers who have studied the stave churches; and to those who have visited the church and have shared their images which I could use as a reference.

The weakness of my approach is not to have actually had the opportunity to visit the church although the vast amount of reference images and videos available do allow you to experience the church vicariously. Remember that if you actually visit the church you will see a modified lit environment. The one that was truly intended and has been so interestingly described by various writers was swept away by the Reformation.

The findings above refer to a stave church with staves and an elevated central portion (Type B in Bugge's classification). It would be interesting to explore whether similar characteristics are found in those stave churches of Type A with no staves under a single roof.