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## Perimeter Blocks in Nordic Towns - How latitude affect daylighting

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# Perimeter Blocks in Nordic Towns - How latitude affect daylighting

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**Abstract:** One of the design principles for future sustainable towns is compactness. The densification of cities is very much needed, but it usually compromises the access of daylight. Densification is especially challenging in the Nordic region characterized by low angled sunlight, something that also limits daylight distribution and restricts its intensity. The higher the latitude, the greater is the difficulty in the distribution. Perimeter blocks give shelter from wind and often create semi-public courtyards which have been seen to be attractive in many Nordic settlements during history. In the present study, alternative design to the conventional perimeter blocks are explored and geometric options such as chamfered corners, strategically varied building heights and differently positioned openings in a broken perimeter block are analyzed. The yearly simulations as well as simulations for May 1<sup>st</sup> have been carried out for the same perimeter blocks located at four different latitudes (decimal coordinates):

1. **65.0** Oulu (similar to Mo i Rana 66.3, Jokkmokk 66.6 and Rovaniemi 66.5)
2. **63.4** Trondheim (similar to Reykjavik 64.1, Östersund 63.2 and Vaasa 63.1)
3. **59.3** Stockholm (similar to Oslo 59.9, Helsinki 60.2, Tallinn 59.4, Saint Petersburg 59.9 and Anchorage 61.2)
4. **55.7** Copenhagen (similar to Malmö 55.6, Glasgow 55.9 and Moscow 55.8)

The choice of evaluation criteria is based on scientific discourse in the field of daylighting. According to the new European standard, solar radiation is included. Computer-based daylighting simulations are performed for different designs of the perimeter blocks with equal density, FAR = 1.33. The further north a city is located, the lower the houses in a perimeter block must be to maintain a certain level of daylight. The study confirms that latitude affects daylighting and that geometrical change can improve the conditions for daylight in the perimeter blocks.

## 1. Introduction

Around 56 million people are living with the daylight conditions which in art and literature is denoted as the Nordic Light - from southern Denmark up to the geographic North Pole (about 54.0°N to 90.0°N). In the southern hemisphere, the corresponding latitudes with the same type of daylight, are not that much populated, only around 1000 people live there, mainly researchers at Antarctica. The most characteristic feature of the Nordic Light region is low angled sunlight that contributes also to long twilights and white nights in summer. This study aims to show how high latitudes hamper the daylight and how the shapes of urban blocks can be developed to improve daylighting in urban settlements.



This study about the impact of the latitude on daylighting is part of a series of studies; one article about visible access to the sky and the views in different perimeter blocks has been presented in an earlier paper<sup>2</sup>. Another article is planned about different compass directions and one about different variations of the heights in the blocks. Theoretical knowledge and practical experiences have been combined in the present study aiming to develop a method to compare town planning from different latitudes considering daylighting. For this purpose, alternative shapes of perimeter blocks have been developed. The research question was if improved quality of daylight can be reached with the same density Floor Area Ratio (FAR) as for the conventional perimeter block.

### *1.1 The impact of heights*

The height is a well-studied parameter. The higher the building, the longer are the shadows. Assumed height in the latitude simulations have been five floors (= 15 meters) except alternative 4 and 5 which has 4, 5, 6 and 7 floors, see figure 1.

### *1.2 The impact of configurations*

An important study by Mark DeKay describes how the different geometry of a standard atrium building impacts daylighting conditions [1]. A configuration study was presented in Graz by the actual research team [2]. The tested urban configuration alternatives have considerable advantages regarding daylight compared to more conventional blocks.

## **2. The Alternative Types of Perimeter Blocks**

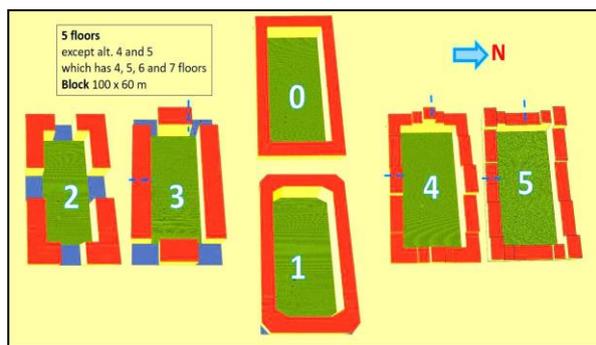
International comparisons over rectangular street grids show large variation from town to town. Some have quadratic shapes but most of the grids have rectangular shapes with considerably different dimensions (length versus width of the block). The variation of the street grids within a town is smaller. In specific city district the measures of length and width often are standardised.

Five alternatives to the conventional perimeter blocks in street grids are studied. Following sustainable design recommendation, the blocks are oriented east-west, see general guidelines as <https://greenpassivesolar.com>. The size of the blocks is 100 meter in east-west direction and 60 meter in north-south direction. The scale is common in the Nordic countries as well as the rest of Europe though the average size of blocks is larger.

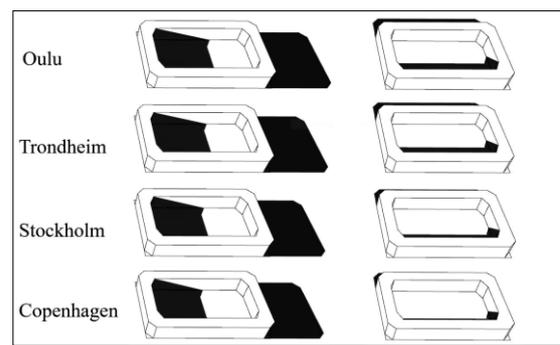
The design principle for all alternatives is keeping the same floor area ratio as in the standard block. The first alternative to the standard perimeter block is the same block with chamfered corners, a modification which is sometimes used in practise. Other options are blocks consisting of openings between the streets and the courtyard. The second alternative has openings positioned in the corners of the block and the third in the middle of the blocks. In frequent practical use these two types vary both in proportions and in scale. The two last alternatives with varied heights, 4 and 5, are developed within this project to find new strategies. All alternatives have been developed in Sketch Up-drawing, see figure 1 and later transformed to models for simulations in DIVA.

The total floor area is the same in all alternatives, which also means that it is possible to regard every block quarter as a module which can be combined with others to form new alternative hybrids. The Floor Area Ratio (FAR) is 1.33, which is a relative low value in an international context but relevant for most Nordic towns. The six alternatives are:

0. The conventional perimeter block (NULL), 0-alternative.
1. Chamfered corners in the outer corners of the building as well as in the courtyard.
2. Openings in a broken perimeter block positioned in the four midpoints of the building.
3. Openings in a broken perimeter block positioned in the four corners of the building.
4. Varied building heights around the courtyard with fewer floors in the corners of the block.
5. Varied building heights around the courtyard with more floors in the corners.



**Figure 1.** The six different types of urban blocks.



**Figure 2.** Shadows the 1<sup>st</sup> of May Alt. 1. Evening, sun in the west. Noon, sun in the south.

### 3. Daylighting Strategies in Urban Settlements

It is impossible to create satisfactory daylighting conditions during the whole day in dense settlements. It is always necessary to resolve the priorities between outdoor and indoor spaces and to consider which parts of the day and the year are most important. Especially difficult to handle is the sunlight at high latitudes due to the large variation of the azimuth angle (compass direction) during the day and across the seasons, as well as low average solar elevation angles through the year.

To develop good strategies requires a focus on the different times of the day. In people's every-day life the needs and desires vary depending on the type of buildings such as buildings for seniors, offices or kindergartens as well as the activity, underlined in a handbook for town planners [3]. A midwinter strategy leads to openings between the buildings in a North/South direction which is opposite to a strategy for the extended summer when the sunlight from east in the morning and west in the evening is highly appreciated. We have many possibilities to formulate goals and evaluation criteria connected to them, and it is easy to calculate many relevant metrics by computers. However, joining strategies together (e.g. making calculations on the yearly basis) often fails because the iterations will converge instead of diverge.

During many years' equinox studies have been very popular among practitioners as well as researchers. But the equinoxes are not suitable to analyze sunlight from east or west simply because in those two days the sun is positioned precisely at the east or west during sunrise or sunset, also it is on the horizon. That gives strong arguments for choosing other days between spring equinox and summer solstice. "The Sitting Outdoor – Period" in Nordic towns is roughly the warmest part of the year between late spring and early autumn. However, the temperature in the air is not high enough to bring comfort in most cases. The direct sunlight with its heating by solar radiation is also needed.

We look to a representative average place in the Nordic countries - the Oslo/Stockholm/Helsinki latitude. For that latitude the period around the 1<sup>st</sup> of May is the time when people start to sit outdoors during good weather. The 11<sup>th</sup> of August happens to be the point on the other side of the summer solstice. The period in between has good possibilities for outdoor activities due to good daylighting. However, the proposed period should not be regarded as an exact specification of the actual conditions. Since the shadows for the 1<sup>st</sup> of May also describe the conditions at the 11<sup>th</sup> of August, during the 101 days in between the sunlight distribution is better with a maximum at the summer solstice.

#### 3.1 The Shadow Maps

Shadow Maps are often used tools in town planning. The shadows from surrounding obstructions as mountains, trees and buildings affect the conditions at the outdoor spaces as well as in apartments. Most of the obstructions are permanent. The shape, size, orientation and position of the building must

therefore be developed during careful considerations. The shadow map also specifies surfaces on ground and facades which have sunlight qualities outdoors and indoors. That information can be used by planners to create daylight qualities for the residents.

The time of comfortable sitting outdoors in the sunshine on the balconies and in the courtyard can also be expanded by sunscreens in hot days and, in cold days by windscreens. The fundamental needs of daylight are different, both in quantity and quality, between different groups of people and even between individuals. Anyway, we may roughly agree that in residential areas interesting periods to study are in the morning and in the evening because almost all residents are at home, contrary to during noon when people are at work, schools and on weekend trips, etc. This is also the most difficult time for daylighting due to low sun angles. Besides the shadow maps for the western sun we also show the less critical shorter shadows in the middle of the day. The shadows from the western sun illustrates also the shadows in the morning because the shadows are equal although mirrored in the opposite direction (assuming symmetrical block shape). Depending on the clockwise movement of the sun the shadows also move. The minutes just before and just after the exact cardinal directions for the sun are especially interesting. All the facades orientated to the south can be in sunshine at 18:07 PM but on the contrary at 18:08 PM the facades orientated to the north are in sunshine (example from Stockholm, 1<sup>st</sup> of May, DST = Daylight Saving Time).

#### 4. Methodology

The three main steps in the research were: Constructions of the Urban Models, Calculations and Simulations of the Models and Comparisons, Analyses and Conclusions. The second step has two parts, sunlight radiation (shown in table 1 and 2) and shadow maps (shown in figure 2). According to the new European standard solar radiation should be included [4].

Part one: simulation of solar radiation at a specific day and for the whole year. Facades and courtyards. Comparison between the latitudes.

- Sunlight radiation on the first floor of the facades, average values for the 1<sup>st</sup> of May (kWh/m<sup>2</sup>) and for the whole year (kWh/m<sup>2</sup>).
- Sunlight radiation on courtyards, average values for the 1<sup>st</sup> of May (kWh/m<sup>2</sup>) and for the whole year (kWh/m<sup>2</sup>).

The simulations of the solar radiation are performed with DIVA for Rhino, an often-used tool for climate based and static daylighting calculations. The DIVA (Design, Iterate, Validate and Adapt). A plug-in for Rhinoceros software, enables effective calculations of daylight metrics, e.g. daylight factor, using the Radiance/Daysim engine. The facades on the upper floors have good distribution of sunlight in all alternatives. The challenge is to create settlements with good daylight for the worst cases, the facades along the first floors. To look only at the first floor means critical studies focusing on the worst case. We focus therefore on the differences and possible improvements. The studied model has been placed in a street grid with surrounding blocks performed in the same way. The street canyons have a width of twenty meters façade to façade.

Part two: Sunlight distribution on two different hours at a specific day. Shadow Maps of the 3D-models. Comparison between the latitudes.

- Simulations by SketchUp.

##### 4.1 Assumption of the facades as representative for the windows

The generated data is for the facades except for the ground values. Solar radiation on facades and daylight level on facades are values in our studies to describe conditions at the windows. We assumed

that the windows are evenly distributed along the facades. This assumption is common in general studies as ours because no special details are known.

#### *4.2 The impact of the latitudes on the daylight conditions*

To quantify the impact of the latitudes on the daylight conditions simulations of daylight have been done over a year and a day for towns located at four different latitudes. The rays from the sun at more northern latitudes have lower altitude angles but also larger range of azimuth angles. The investigation has been done with the specific angles from the actual latitude and all other parameters the same including the same clear sky type.

#### *4.3 Clear Sky simulations*

The parameter, Cloudiness, is dependent of the local climate in the calculated towns. The climates vary a lot depending on differences in topography, water surfaces, the surrounding physical geography, etc. In analyzing sunlight at different latitudes, we reduce distortions from different climate and amount of clouds in different cities by assuming one similar type of climate. Then we can study the changes in one parameter, the latitude. The alternative to handle the parameters by multi-regression analysis or similar method was rejected due to more complicated processes. The same climate means the same weather and cloudiness for all simulations. That can be created in many ways; as an average weather file representing the four cities (1) or a “clear sky” weather file without clouds (2). In this study the latter, “clear sky”, is chosen for three reasons;

- a. The choice of “clear sky”-simulations is prepared for a second step: impact of different cloud conditions.
- b. The Shadow Patterns are consistent with “clear sky”-simulations.
- c. “Clear sky” facilitates the analysis depending on it is precise.

The “Clear sky” weather files are epw-files made by Meteonorm 7 based on a clear sky for the whole year for respective city. The content of ozone and particles in the atmosphere (long distance transport from volcano eruption and other particles) gives small variation in radiations from year to year. However, the relative differences between the cities are about the same regardless which year. The Meteonorm software contains worldwide climate data. This can be an Excel file for specific analysis and be directly imported to photovoltaic, solar thermal or building simulation software. The data base contains observations from 8 325 weather stations and five geostationary satellites. On this basis, state of the art interpolation models provide data for every site with high accuracy. The clear sky radiations are calculated as maximum global radiation and corresponding diffuse radiation for clear days (cloudless sky) at hourly intervals. This affects the automatic selection of the clear day temperature model (warmest possible temperature). Eventual improvements of the method for clear sky can be done if a future evaluation will show a specific need for more precision.

#### *4.4 The impact of clouds*

A comparison between the simulations in Stockholm with or without climate factors shows:

- 15-19 % reduction of radiation in adding the clouds by a weather-file based on climate data for the actual place, see table 1.
- The same ranking order for the alternatives with the only a very small difference, that No. 1 and No.3 with local climate at the first-floor simulation came in split first place. The comparison shows that it is possible to use the “clear sky” result instead of the complicated climate simulation for the ranking of the best daylight strategies in Stockholm.
- It is probable that the conclusion about the “clear sky” is valid even for other towns - a reasonable conclusion even if a very odd distribution of clouds during day could affect the ranking in some way. Further test in other towns must be done to confirm the hypothesis (tests are planned in the autumn 2019).

<b>Radiation</b> (kWh/m <sup>2</sup> ) <b>Model:</b>	<b>Cloudy Sky.</b> <b>first floor.</b>	<b>Clear Sky.</b> <b>first floor.</b>	<b>Cloudy as</b> <b>% of Clear</b> <b>first floor</b>	<b>Cloudy Sky.</b> <b>Courtyard.</b>	<b>Clear Sky.</b> <b>Courtyard.</b>	<b>Cloudy as</b> <b>% of Clear</b> <b>Courtyard</b>
<b>Alt. 0</b>	2.41	2.96	81	3.42	4.02	85
<b>Alt. 1</b>	2.47	3.03	82	3.41	3.97	86
<b>Alt. 2</b>	2.45	2.98	82	3.65	4.29	85
<b>Alt. 3</b>	2.47	3.04	81	3.07	3.81	81
<b>Alt. 4</b>	2.32	2.85	81	3.32	3.88	86
<b>Alt. 5</b>	2.33	2.86	81	3.55	4.17	85

**Table 1.** Daylight Radiation. 1<sup>st</sup> of May in Stockholm. Cloudy and Clear Sky.

A single “Clear Sky” simulation is valid as such for every place along the actual latitude. If the hypothesis above about a strong covariance with “Cloudy Sky” simulation can be proved in detail or at least have few exceptions it will lead to a general conclusion;

- The ranking of the best daylight strategies at a specific place can be done from a “Clear Sky” simulation from every place along the same latitude.

### 5. Results - The Daylight Values for different latitudes

The solar radiations are lower at higher latitudes which also are confirmed in the table below. The most important explanation is the lower sun angles. The two highest radiations for each town are presented on a blue background. The model with highest radiation is alternative 3 with openings in the corners. The differences between the models are relatively small which means that windy conditions and other aspects can be crucial. In windy cases the enclosed perimeter block is recommended, and it should be the chamfered version alternative 1 which has clearly higher radiation than alternative 0. Two deviations from the typical patterns are marked with stars and explained below.

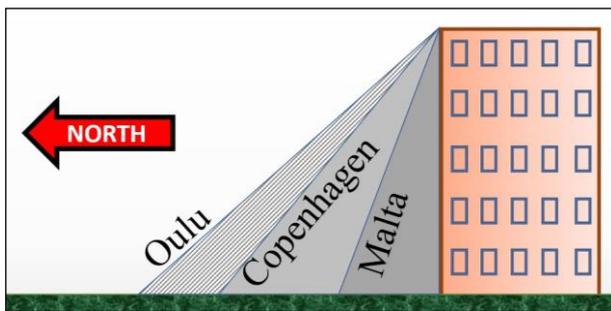
<b>Radiation (kWh/m<sup>2</sup>)</b>	<b>Model</b>	<b>1<sup>st</sup> of May</b>	<b>Year</b>
<b>Oulu</b> 65.0	Alt 0	2.63	519.69
	Alt 1	2.71	536.62
	Alt 2	2.67	538.09*
	Alt 3	2.72	551.63
	Alt 4	2.49	502.47
	Alt 5	2.52	499.38
<b>Trondheim</b> 63.4	Alt 0	2.88	570.37
	Alt 1	2.97	591.52
	Alt 2	2.92	596.92*
	Alt 3	2.98	613.73
	Alt 4	2.74	562.58
	Alt 5	2.77	561.55
<b>Stockholm</b> 59.3	Alt 0	2.96	613.1
	Alt 1	3.03	634.68
	Alt 2	2.98	629.27
	Alt 3	3.04	633.09
	Alt 4	2.85	611.17
	Alt 5	2.86	605.99
<b>Copenhagen</b> 55.7	Alt 0	2.85	650.75
	Alt 1	2.91	672.33
	Alt 2	2.86	669.85
	Alt 3	2.94	684.71
	Alt 4	2.82	632.59
	Alt 5	2.83	627.12

**Table 2.** Sunlight radiation – average values along the facades on the first floor

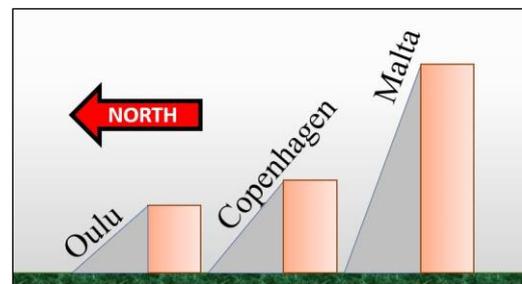
The ranking order considering high solar radiation of the different alternatives are the same for all towns with two unexpected exceptions. In the northern cities, Oulu and Trondheim, the yearly radiation at the first floor is higher for alternative 2 (\*) with central openings than for alternative 1 with chamfered corners. An explanation is the lower average altitude angle for the sun compared to more southern cities which will be especially difficult for alternative 1 with no openings. Although for the first of May and related period the alternative 1 is better than alternative 2 for all latitudes.

If the yearly values or the first of May and related period of 101 days should be in focus is a tricky question which depends on which conditions are most relevant for the people. But the figures above point at the same model except the second choice for Oulu and Trondheim. Looking to the whole year for northern cities, including the darkest part of the year - in contrast to the first of May with its higher sun angles - the alternative 2 is natural to prioritise before alternative 1. The local wind conditions must always be considered. At windy northern places the conclusion will be the opposite - the more closed alternative 1 is natural to prioritise before the more open alternative 2.

The higher the latitude, the greater are the shadows is a basic fact, but despite of that, often forgotten in town planning. In the development of northern city districts, the practice from southern projects is often used. The height of the perimeter blocks in the figure 2 are five floors (= 15 meters). To keep the same size of shadow in Oulu as in Copenhagen requires a significantly lower building 3.6 floors instead of 5.0 floors. For Malta it is 11.2 floors. For comparison across latitudes, see figures 3 and 4.



**Figure 3.** The length of the shadows depends on the latitude (17,6 m, 12,8 m and 5,7 m).



**Figure 4.** The heights on the buildings at different latitudes for equal length of shadows (3.6, 5.0 and 11.2 floors with three meters each).

Some efforts can be done to support daylight at the “dark” northern latitudes:

1. A mathematical guideline - with the latitude as input - limiting the heights of the buildings gradually the further north has relevance. However, more important than a specific formula, is a restrictive approach to higher buildings at the northern latitudes.
2. To preserve openings in the settlements against the sky and, if possible, against the horizon.
3. To choose types of settlements with configurations which give much daylight outdoor (e.g. alt. 2 and 5) and indoor (e.g. alt. 3 and 1).
4. To develop town districts of such settlements with configurations in each block which are synchronized to the next and give long openings for low angled sunlight.
5. To prioritize light colours and well-reflective material for all surfaces in the towns especially ground and facades.

## 6. Design Strategies

The construction of the different alternatives in the project was based on the interests to analyse the impacts of different shapes. Using the experiences from this study and other tests it is possible to develop more design strategies than the five efforts mentioned above. The design process, often including iterations, has been investigated by Donald Schön and others. In a famous study he mapped the important steps in design [5]. To improve the design of the urban blocks and adapt it to a specific

location the iterative process of Create > Test > Analyse > Create >...is often used. The creations of the blocks can be done in strategic sketches or by programmes as Grasshopper using parametric design testing hundreds of possibilities. A third way is to optimise shapes and configurations by algebraic operations.

## 7. Energy Aspects

Many aspects of well-being are created by daylight. However, the most fundamental result of the alternative urban blocks is probably the increase of the direct sunlight in the urban settlements. The total potential of solar energy along the facades are showed in the yearly figures of radiations, see table 2. There is up to 7% difference between the most sunlit alternative - Alt 3 - and Alt. 0. In the sustainable compact city with high and dense urban blocks much of the sunlight is obstructed. Strategical geometry for the buildings has a special relevance here. In an earlier study the energy savings for the electric lighting was 13 % comparing an ordinary cranked street with a street with strategically positioned openings in the buildings [6].

The heat loss in buildings is to the large degree dependent on the shape of the building envelope (facades and the roof together). In the Nordic region, having negative heating energy balance, increasing of compactness causes a decrease of energy consumption for heating. In this respect, the ideal shape of a building is a sphere. Modifying the shape to a cube helps to lower construction costs with still high efficiency [7], stretching the shape to a linear form has a negative effect. On the other side, too large compactness means larger distance to windows (reduced view and well-being) and can have negative effect on energy consumption for lighting as the daylight level decreases dramatically with the distance from the window. Comparison of the studied alternatives in terms of compactness points at the alt. 3 as having highest compactness (lowest energy use for heating).

## 8. Conclusions

The same type of settlements as in southern Europe erected in the Nordic countries gives more darkness due to low sun at high latitudes. With lower heights of the buildings it is possible to adapt to the low sun angles at a price of decreased utilization of the plot. Other possibilities are to plan openings in the settlements and choose light colours and well-reflective materials for all surfaces in the towns. Settlements with configurations as chamfered corners and with openings in the corners of the perimeter block are supporting the daylight distribution and are therefore of special interest for the Nordic countries. Accurate general guidelines improve the implementation of knowledge a lot and save money and time for calculations. A guideline – as one example - limiting the heights of the buildings gradually the further north is relevant. However, general guidelines are never enough. It is always important with adaptations to local conditions as wind, noise, topography, etc.

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