

Perimeter blocks in different forms

– aspects of daylight and view

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Abstract. The perimeter blocks in cities are usually rectangular and follow the streets. The buildings are mostly of similar height within each block. However, perimeter blocks can be developed in many various forms. Geometric options such as chamfered corners, varied building heights and different positioned openings in a broken perimeter block are analyzed in this paper regarding the aspects of views and daylight in city planning. The choice of evaluation criteria is based on scientific discourse in the field of daylighting. As in the new European standard, “Daylight in Buildings”, the following three parameters are included in calculations: solar radiation, daylight level and view out. Computer-based daylighting simulations and calculations of view parameters are performed for different designs of the perimeter blocks with equal density, FAR = 1.33. The simulations have been carried out for Stockholm. That means roughly the same shadows as in Oslo, Helsinki, Tallinn, St Petersburg and Anchorage, all close to the same latitude (60°N). In lower latitudes, e.g. Southern and Central Europe the shadows are shorter. Nevertheless, the ranking of the alternatives will be similar. This study confirms that geometrical changes can improve the conditions for views and daylight in the perimeter blocks. The advantages in the tested urban design alternatives are considerable compared to the perimeter block of the standard type.

1. Introduction

Many different aspects shall be considered in the design of buildings. The famous old principle: “Form Follows Function” is important and has great relevance also in the construction of modern sustainable settlements.

However, in the pursuit of densification and economical optimization, the issues of views and daylight are missing in many projects. Those aspects are strongly dependent on the shape of buildings and their close surroundings. This study aims to show how the shapes of urban blocks can be developed to improve the daylight access and the views in urban settlements. The improved quality of daylight and view in the studied alternatives can be reached with the same density Floor Area Ratio (FAR) as for the conventional alternatives. The density is here defined as FAR, Floor Area Ratio = total floor area/plot area. A constant value of 1.33 has been chosen where the entire plot has been enclosed by 10 meters of street, which means a total area of 80 x 120 meters (1,33 corresponds to 2,13 counted on only the built plot of 60 x 100 meters). A Floor Area Ratio (FAR) of 1,33 is a relative low value for central districts but high in a suburban context.

In an economical assessment, based on prices on the market, the improvements in daylight should be weighed against the added cost for the improved building shape. Potential savings in energy consumption for the electric light must be calculated as well as other relevant values in the total economical overview.

2. The Alternative Types of Perimeter Blocks

The book *Urban Forms* (Panerai et al., 2004) describes the development of the urban block from the middle of the nineteenth hundred until now with many influential European examples and even some American new urbanist projects. The book raises questions how we can keep qualities from the old town districts in our contemporary developments. The French-British quartet of authors advise a detailed look at existing settlements considering their morphology including the scale, the streets and the shape of the buildings. Inspired by this book we examine some very typical urban layouts focusing at daylight and views.

An extensive investigation of the heat energy demand including the daylight aspect was done in 2014 with comparison of many different city districts in Berlin, Paris, London and Istanbul (Rode et al., 2014). The approach in this study is different; we consider only a few simplified configurations to quantify and explain the impact of the specific shapes. An important study by Mark DeKay describes how the different geometry of a standard atrium building impacts daylighting conditions (DeKay, 2010). Atrium buildings are often erected as perimeter blocks and DeKay touches on certain variations. We aim at extending the knowledge with research on some more shapes. 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 vs width of the block). The variation of the street grids within a town is smaller. The usual regulations for the urban blocks within a specific city district contain standardised measures of length and width.

This study looks to possible alternative regarding the shape to the conventional perimeter blocks in street grids. Following sustainable design recommendation, the blocks are oriented east-west. Different compass directions will be investigated in future research. Larger urban blocks have the advantage of being able to contain more complicated structures of buildings. Such blocks also create long facades, which is a disadvantage regarding uniformity and has been pointed out by urban theorists as e.g. architect Rob Krier. The assumed size of the blocks has dimensions which are easy to analyse; 100 meter in east-west direction and 60 meter in north-south direction. The scale is representative for the Nordic countries as well as the rest of Europe though the average size of blocks is larger.

The famous study of different built forms by Martin and March had three alternatives: (a) 'pavilions', (b) 'streets', and (c) 'courts' (Martin and March, 1972). The third alternative consists of perimeter blocks. In this study differences between several alternatives of perimeter blocks are examined. We look more in detail to the town planning than common in urban studies. The first alternative to the standard perimeter block is the same block with chamfered corners, a modification which is often used. The most famous example is the large extension of the old city during the nineteenth hundred in Barcelona. Chamfered, instead of right-angled corners in the court yard have been used from time to time world-wide. The sizes of the chamfered corners in this study are based on functional aspects regarding the windows and following the principle of keeping the same floor area ratio as in the standard block. This principle is true in all alternatives.

Other options to develop the block are openings between the streets and the courtyard. The experience of the neighbourhood depends on how the openings are positioned, i.e. in the corners of the block or in the middle of the blocks. In frequent practical use these two types vary both in proportions and in scale. This study highlights the differences in daylight and sightlines. The two last alternatives with varied heights, 4 and 5, are developed within this project in an attempt to find new strategies. All alternatives have been developed in Sketch Up-drawing, see figure 1.

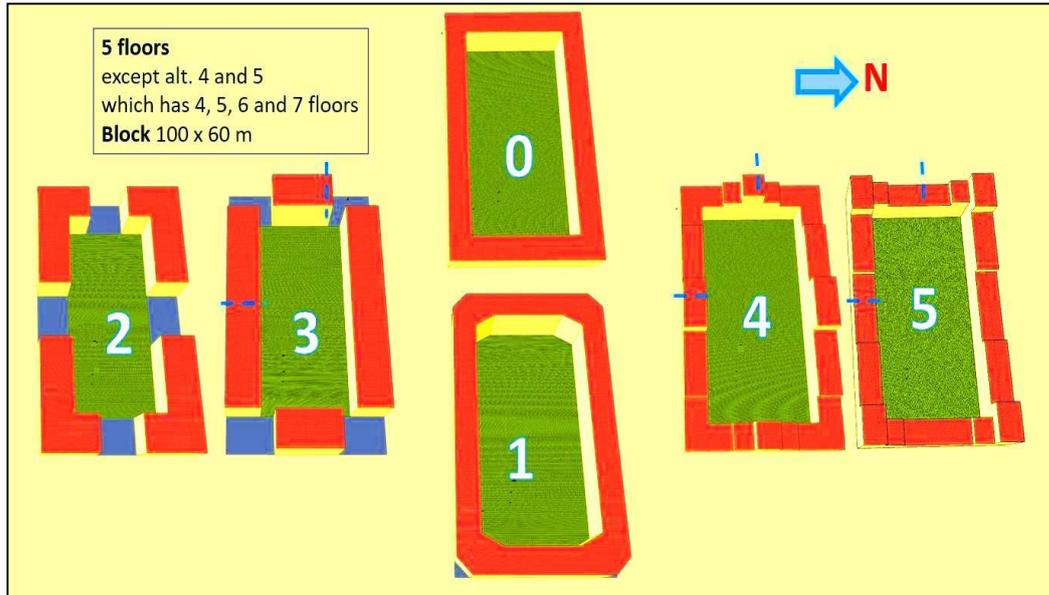


Figure 1. The six different types of urban blocks.

0. The conventional perimeter block (NULL) 0 is followed by five alternatives:
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.

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 as well as which parts of the day and the year. Especially difficult to handle is the sunlight at high altitudes 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 strategies for daylight 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. 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 studies between equinox and summer solstice. The classic Bioclimatic Chart is still relevant, it describes the limits for human outdoor comfort depending on temperature, humidity, air movement and solar radiation (Olgay, 2015). The outdoor temperature in most Nordic cities is not high enough to create comfort (temp. > 20° happens only occasionally) - compare the Chart with climate data as <https://climatecharts.net/>. Nevertheless, in the cities along the Oslo/Stockholm/Helsinki latitude, the period around May 1st is the time when people start to sit outdoors thanks to the direct sunshine, example on the Nordic climate see figure 2. To improve human

comfort by developing spaces with much sunshine/heat, sunlight strategies should be accurately tested. This study is intended to contribute to this development.

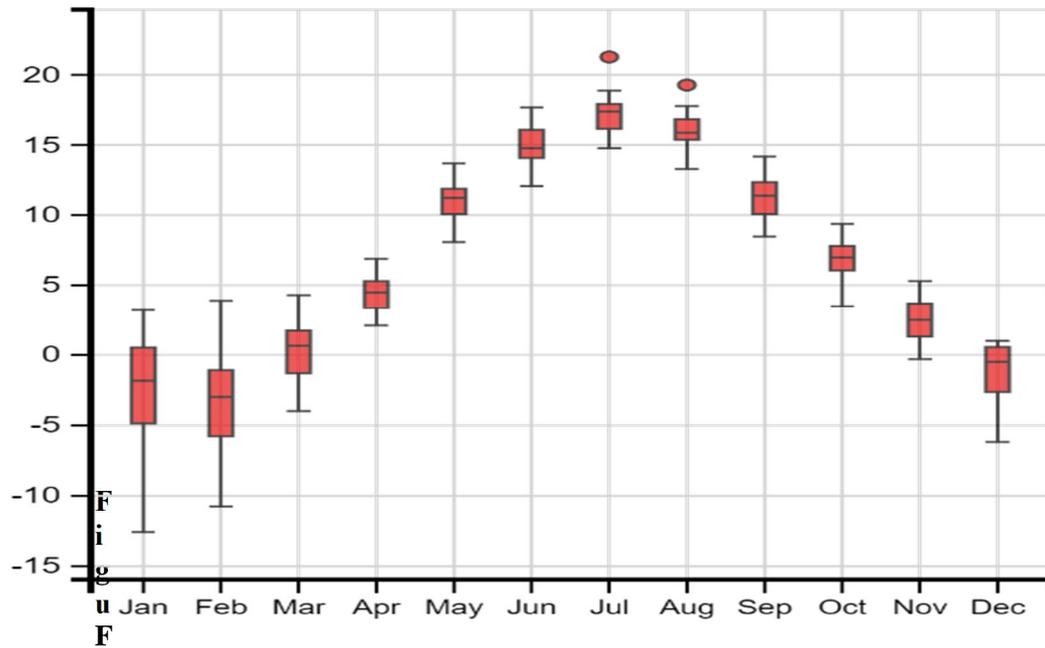


Figure 2. Distribution of monthly mean temperature (C°) Stockholm, Sweden. (data: www.ncdc.noaa.gov/ghcnm/distribution, © www.climatecharts.net)

3.1 The Shadow Maps

Shadow Maps are important 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 comfort zone for sitting outdoors in the sunshine on the balconies and in the courtyards can also expand by windscreens in cold days and by sunscreens in hot days. The needs of daylight vary, 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 lower sun angles than at noon. Besides the shadow maps for the western sun (representing even the eastern sun in the morning) we also show the less critical shorter shadows in the middle of the day. The western sun represents also the eastern sun in the morning because the shadows are the same although mirrored in the opposite direction.

All the blocks in the study are orientated in east-west direction. The position of the sun is in the west in the shadow patterns at the top, in the other six in the south, see figure 3. 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 (Stockholm, Latitude 59.3, 1st of May, DST = Daylight Saving Time). The shadows for the 1st of May also describe the conditions at the 11th of August. During the 101 days in between the sunlight distribution is better with a maximum at summer solstice.

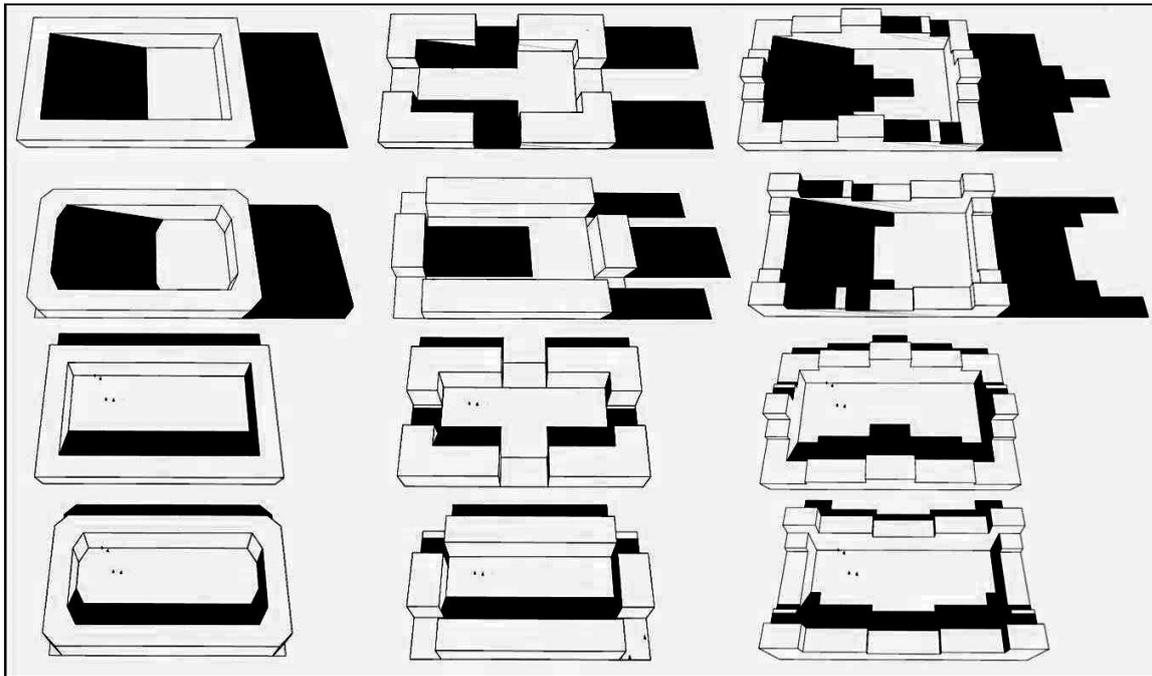


Figure 3. Shadows the 1st of May. Latitude 59,3. The six evening patterns at the top has sun in the west, the six lower patterns are at noon and has sun in the south.

The alternative with its chamfered corners (alt. 1) has very similar shadow patterns as the conventional perimeter block (alt. 0). Both alternatives have advantages. The best in the alternative 1 is the orientation of the windows in the chamfered corners. They result in more diffuse daylight and longer sightlines see table 1 and 2. Considering openings to the courtyard, it is better with the openings in the corners of the block (alt. 3) than in the middle (alt. 2) regarding the facades and its windows. The alternative with lower heights in the corners (alt. 4) has better daylight condition on the windows than the conventional perimeter block with five floors all around. In the alternative with higher heights in the corners (alt. 5) the advantage is a sunny spot in the middle of the courtyard.

4. 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 or local conditions are known.

5. The Daylight simulations

The methodology of the daylight simulations is based on the scientific discourse in the field of daylighting with origin from an early European collaboration (Baker et al., 2013) and recently formulated in the EU standard (CEN, 2019). Each alternative of settlement has been analyzed in a cluster of 3 x 3 blocks, all the same type. The daylight conditions in the six alternatives are described in the following way:

- Sunlight radiation on façades and on plots, average values, during the 1st of May from sunrise to sunset (kWh/m²).
- Sunlight radiation on the first floor of all facades, average values.
- Vertical Sky Component on the first floor of all façades (VSC), average values. 50% is the maximum value.
- Sky Component on the plot area (SC), average across the plot; 100% is the maximum value including visual access to the whole hemisphere.

The facades on the upper floors have good distribution of sunlight in all alternatives. The challenge is to create good daylight even for the worst cases, that is the first floors. Therefore, we have separate calculations for the first floors regarding both radiations and vertical sky component.

All the simulations are performed with DIVA for Rhino, a well-recognized 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 climate data for Stockholm was used as well as its geographical location. By keeping the reflection factor of the block surfaces and the ground close to zero (0,01%) the daylight factor script in DIVA was used to calculate SC and VSC.

Table 1. Results of the Daylight Simulations

Model	Radiation, first floor (kWh/m²)	Radiation, façade (kWh/m²)	Radiation, courtyard (kWh/m²)	VSC, 1st floor (%)	SC, courtyard (%)
Alt. 0	2.41	2.72	3.42	34.40	70.91
Alt. 1	2.47	2.77	3.41	35.28	69.98
Alt. 2	2.45	2.75	3.65	35.28	73.17
Alt. 3	2.47	2.78	3.07	35.35	65.73
Alt. 4	2.32	2.73	3.32	33.85	69.54
Alt. 5	2.33	2.72	3.55	33.70	72.39

The following observations may be done based on the simulation results. With chamfered corners (alt 1) the solar radiation on the facades and the vertical sky component are higher compared to the alternative conventional perimeter block (alt 0). Regarding the courtyard the result are the opposite, higher for the conventional perimeter block (alt 0) due to slightly lower obstruction angles.

With openings to the courtyard (alt 2 and 3) the solar radiation on the facades and the vertical sky component are both higher compared to the alternative conventional perimeter block (alt 0). Regarding the courtyard the result is the highest for openings to the courtyard in the middle (alt 2) and the lowest for openings in the corners (alt 3).

With the same height of all parts of the building (alt 0) the solar radiation on the facades are almost the same compared to the alternatives with varied heights (alt 4, 5) except for the first floor where it is higher. The shadows are slightly smaller along the facades with lower heights in the corners of the block (alt 4) and slightly smaller in the courtyard with higher heights in the corners of the block (alt 5). Further studies are needed to explain all results regarding variations of the height.

6. The Views in the Urban Areas

The quality of views in the outdoor environment depends on people's visual experience. Qualitative details such as beautiful streets with well-designed outdoor furniture and decorative façades are important elements of the visual perception. A good example on opinions and desires about the view from a window is a study at an office from 2015 (Matusiak and Klöckner, 2016). Beautiful distant views were not highly ranked as expected which show how important it is to investigate the actual specific situation because human perception is complex. Town planners must exploit opportunities relying on development of the architectural details of high quality. Anyhow, the length of the sightlines is regarded as the positive contributor of the view quality and is reviewed in this research. It may give a basis for the layouts of attractive views.

6.1 The View Calculations

The views in the six settlements of different urban blocks have been compared. That means that the distances of the horizontal sightlines from each window were calculated regarding the obstructing surrounding buildings using the Grasshopper software. All distances are in meters. Two types of distances have been calculated for each window:

1. Average distance to obstructing facades.
2. Perpendicular distance to obstructing facades.

Then the averages from all windows for the whole block have been processed for both values. All distances to the obstructing facades in the surrounding buildings are measured within a 138-degree cone except for the perpendicular distances. The cone represents the average visibility from a window considering the reduction caused by the obstructions in the window frame. In an earlier study about Tower Blocks we calculated that angle (Sundborg et al., 2018).

Limitations and assumptions for the calculations of the alternatives (see figure 1) are:

- For the first four block alternatives, model 0-3, all facades have been analyzed in 2D regarding maximum free view, minimal free view, perpendicular view and average free view (m) for one floor (all five floors have the same conditions). For options 4 and 5, all facades have been analyzed in 2D regarding maximum free view, minimal free view, perpendicular view and average free view (m) for all seven floors.
- Each block structure has been analyzed in a cluster of 25 x 25 blocks where the center block refers to the block on which the measurements were made. Each quarter's façade has been served with measuring points at ~ 2 meters intervals and all facades have been analyzed. Each measuring point has 416 (1080 for 360 degrees) range measurements in the 138-degree cone.
- All analyzes of the view have taken place in 2D along the horizontal plane. Max length for free view is set to 1000 m. 90% of the length of the façade has been analyzed, so as not to create measurement points directly adjacent to the building's corners.

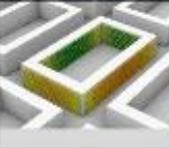
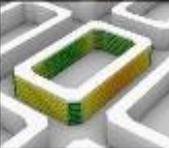
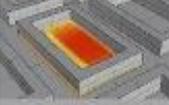
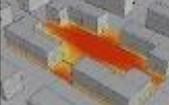
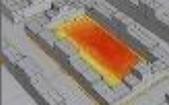
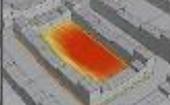
Table 2. Results of the View Simulations

Model	138° width obstruction distance, average (m)	Perpendicular obstruction distance, average (m)
Alt. 0	36.56	35.67
Alt. 1	39.24	37.23
Alt. 2	41.13	26.78
Alt. 3	43.98	36.47
Alt. 4	55.68	39.61
Alt. 5	55.01	35.41

In the case of a closed perimeter block it is better for the views to develop chamfered corners (1 better than 0). In addition, when building a closed perimeter block it is also better for the views to develop a variation in heights (4 and 5 is better than 0) because it offers long sightlines. In the case of a perimeter block with openings, the openings in the corners give longer views. (3 is better than 2). The average distances to the opposite façade are illustrated by colours in table 3 in the first row. The steps are from the EU standard, the chapter for view recommendations:

EU standard: 6 m ≤ **Minimum**, RED < 20 m ≤ **Medium**, YELLOW < 50 m ≤ **High**, GREEN

Table 3. Perspectives of obstruction distances and solar radiation.

Model	Alt 0	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
138° Width obstruction distance, average (m)						
Solar Radiation, (kWh/m2)						

7. Conclusions

The research shows advantages regarding views and daylight for most alternatives compared to the conventional perimeter blocks. It is quite understandable that openings to the courtyards are effective but the choice between openings in the corners or in the middle of the block depends on the local urban context and actual preferences. If it is the view from the windows and the daylight indoors together with the conditions along the facades which really matters, the first choice is therefore openings in the corners. If there are some conditions in the central part of the courtyard which are important, then the best choice is openings in the middle of the block.

The chamfered corners of the building in the courtyard and in the crossings increases the daylight on the facades compared to the conventional rectangular perimeter block even if the changes are relatively small. The average views are the best in the alternatives with varied height, 4 and 5.

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References

- Baker, N. V., Fanchiotti, A. & Steemers, K. 2013. *Daylighting in architecture: a European reference book*, new and expanded edition, Routledge.
- CEN 2019. Daylight in buildings NS-EN 17037:2018 2018 *European committee for standardization*.
- DeKay, M. 2010. Daylighting and urban form: an urban fabric of light. *Journal of Architectural and Planning Research*, 35-56.
- Martin, L. & March, L. 1972. *Urban space and structures*, Cambridge University Press.
- Matusiak, B. S. & Klöckner, C. A. 2016. How we evaluate the view out through the window. *Architectural Science Review*, 59, 203-211.
- Olgyay, V. 2015. *Design with Climate: Bioclimatic Approach to Architectural Regionalism* New and expanded Edition, Princeton University Press.
- Panerai, P., Castex, J., Depaule, J.-C. & Samuels, I. 2004. *Urban forms: the death and life of the urban block*, Routledge.
- Rode, P., Keim, C., Robazza, G., Viejo, P. & Schofield, J. 2014. Cities and energy: urban morphology and residential heat-energy demand. *Environment and Planning B: Planning and Design*, 41, 138-162.
- Sundborg, B., Matusiak, B. S. & Arbab, S. 2018. Tower Blocks In Different Configurations. *Smart and Sustainable Built Environments (SASBE)*. Sydney.

