NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF ARCHITECTURE AND FINE ART
MSc in Sustainable Architecture

Report Title: The Impact of Building Morphology on Energy Consumption	Date: 08/06/2012 Number of pages (incl. appendices): 119			
	Master Thesis	√	Project Work	√
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Abstract:

This research uses Ådland project as a case study in order to investigates how the building morphology which is one aspect of the architectural quality will impact the heating demand of buildings. The research is based on the design which is ongoing in the Research Center on Zero Emission Buildings (ZEB).

There are mainly four parts in this research. In the first part, there is a literature study on energy-efficient building design. The second part describes the architectural design of Ådland project. In the third part, the methodology is explained, which uses ECOTECT as the simulation tool. At the end, the heating consumption of different building organizations are analysed.

The simulation results indicate that, with excption of Linear 1 organization and L-Shaped organizations, the heating demand differences of different building morphologies could almost be disregarded. The heating demand is not related to either the U-values of building components or different climates. However, the heating demand of the building is mainly related to the shape coefficient factor. In this context, the conclusion shows that both Linear 1 organization and L-Shaped organization are a preferable design solution for Ådland project.

Keywords:

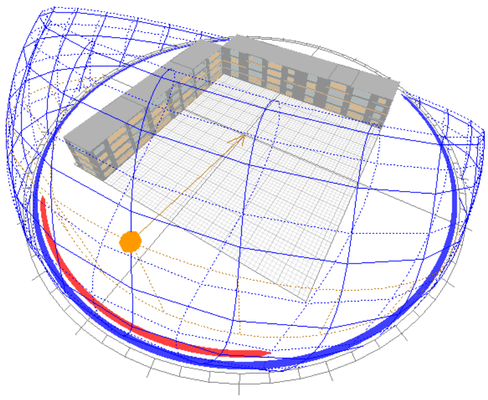
1. Building Morphology
2. Energy Consumption
3. ECOTECT
4. Zero Emission Buildings

The Impact of Building Morphology on Energy Consumption

By

Lin Du

Master in Sustainable Architecture



June, 2012

Summary

Buildings are responsible for 38% of energy use in Norway, about 64% of which is heating energy. Lacking of architectural design at the early design stage has adverse consequences on the climate and environmental efficiency of buildings, which is a burden for reducing the energy consumption of buildings. It means that the architectural quality plays a very important role on the energy consumption of buildings. This paper selects one aspect of these architectural qualities namely morphology as the focus of the research.

This research uses Ådland project as a case study in order to investigate the impact of different building morphology on the energy consumption. And it is part of the ongoing research in the Research Center on Zero Emission Buildings (ZEB). There are mainly four parts in this research. In the first part, it is the literature study on energy-efficient building design. The second part describes the architectural design of Ådland project. In the third part, the methodology is explained, which uses ECOTECT as the simulation tool. The simulations include the impacts of environmental factors such as solar radiation, shadow pattern, and daylighting availability. Apart from these factors, the wind flow around the buildings has also been sketched. Finally, all the influences from these environmental factors were added up to obtain the energy performance of selected buildings. It is noteworthy that the energy consumption here mainly refers to the heating demand of buildings. At the end of this research, several building morphologies have been selected for the Ådland project.

The objective of this research paper is to provide designers with general guidelines at the early design stage for selecting the most energy-efficient building morphologies from the perspective of the heating demand of buildings.

Keywords

Architectural Quality, Building Morphology, Energy Consumption, Solar Radiation, Shadow Pattern, Daylighting, Wind Flow, ECOTECT, Zero Emission Buildings (ZEB).

Acknowledgements

First and foremost I wish to offer my sincere gratitude and appreciation to my supervisor and dear friend Associate Professor Aoife Houlihan Wiberg. Thank you for your unwavering support and encouragement both professionally and personally.

I wish to thank Professor Matthias Haase for his untiring response to all my questions. I wish to offer my sincere gratitude to Dr. Fernanda Acre Pacheco without whom this thesis would never have come realized. A very special thank you goes to Professor Anne Grete Hestnes who has given a significant inspiration and guidance.

I would like to thank my dear classmates and friends, Alise Plavina，Michael Gruner and Noora Alinaghizadeh, who kindly give me various useful suggestions during the development of this master thesis. I wish to thank my dear old friend and partner, Chenchen Guo. Thank you for nice supporting and patient caring during two years. It is unforgettable to pass every difficulty together with you. Thank you to all classmates in this Master Science of Sustainable Architecture, it is amazing to meet all of you in my life.

I also wish to thank for the enthusiastic and kindly helping from NTNU Architecture Library. Thank you for booking me two important reference books immediately.

Words cannot express my gratitude to the incredible support and love of my great parents Haisheng and Xuping and my family without whom my life would not have been so beautiful.

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Glossary

Global Warming

Global warming describes the process by which greenhouse gases accumulate in the atmosphere in abnormally high amounts, trapping the Earth's radiation and causing its temperature to rise significantly. This is linked to environmental problems such as changes in rainfall pattern, rising sea levels and expansion of deserts (Sassi, 2006).

Architectural Quality

The definition of architectural quality can be divided into five categories. First, good architecture is a combination of form, function, and construction. Second, architectural quality is targeted to fit the context, the plot, and the surroundings. Third, the concept is linked to a mystical aesthetic feature in architecture. Forth, architectural quality is a matter of expressing timeless values in a way that is typical for its contemporaries. Fifth, architectural quality has a usability value. Here, aesthetics and techniques are combined and coordinated for a practical solution. Quality becomes a practical question of material, construction, sustainability, and usability as well as a test bed for how design corresponds to the spatial needs of particular activities and the users concerned (Rönn, 2011).

Building Morphology

The term morphology comes from antique Greek (morphe) and means shape or form. The general definition of morphology is "the study of form or pattern".

Energy Consumption

The energy consumption means the necessary energy to maintain the instruction temperature in the building (Depecker, Menezo, J. Virgone and Lepers, 2001). This temperature is usually estimated to be from 18^{o}C to 26^{o}C for the comfort of inhabitants, which is according to the Norwegian Passive House Standard.

ECOTECT

Autodesk® Ecotect® Analysis sustainable design analysis software is a comprehensive concept-to-detail sustainable building design tool. Ecotect Analysis offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs (Autodesk).

Zero Emission Buildings (ZEB)

Conceptually a Zero Emission Building (ZEB) is a building with greatly reduced energy demand and able to generate electricity (or other carriers) from renewable sources in order to achieve a carbon neutral balance (Sartori, Andresen and Dokka, 2010).

Daylighting Factor

The daylighting factor is the ratio of the illumination indoors to outdoors on an overcast day, which is an indication of the effectiveness of a design in bringing daylight indoors (Lechner, 2009).

1. Introduction

1.1 Research Question

The first aim of this research is to examine and understand how building morphology impact the energy performance of the buildings. The second aim of this paper is to select building morphologies which are suitable for the Ådland project.

The research is based on the design which is ongoing in the Research Center on Zero Emission Buildings (ZEB). The goal of zero emission buildings is to design buildings which not only minimize the energy consumption and the environmental impacts to the surroundings, but also meets the need of thermal comfort of human beings.

1.2 Context and Relevance

The building industry takes up 38% of energy consumption in total in Norway (Haase, 2010). This is one of the most important factors resulting in the global warming. Therefore, the research about the Zero Emission Buildings design is becoming significantly important.

Optimized architectural design in the initial conceptual phase would help reduce the energy consumption of buildings in an efficient way. This is because architectural qualities extensively affect the energy performance of a building in terms of orientation, compactness, building morphologies, building envelopes, materials, functions, etc. (Lauring and Marsh, n.d.)

This master paper only selects building morphology as the research topic, and the results could be a potentially guideline for architects to develop the Zero Emission Buildings.

The research takes the Ådland project as a case study to analyze the impact of building morpholoy on the energy consumption. At the beginning, there are 12 building morphologies designed according to the Ådland site. Then, ECOTECT is chosen as the simulation tool to analyze solar radiation, daylighting availability, shadow pattern and the heating demand of different building morphologies. In addition, the wind flow around the building is sketched roughly. At the end, several building morphologies are suggested for the Ådland project.

2. Background

2.1 Global Warming

Global warming is caused by increasing concentrations of greenhouse gases produced by human activities such as deforestation and the burning of fossil fuels.

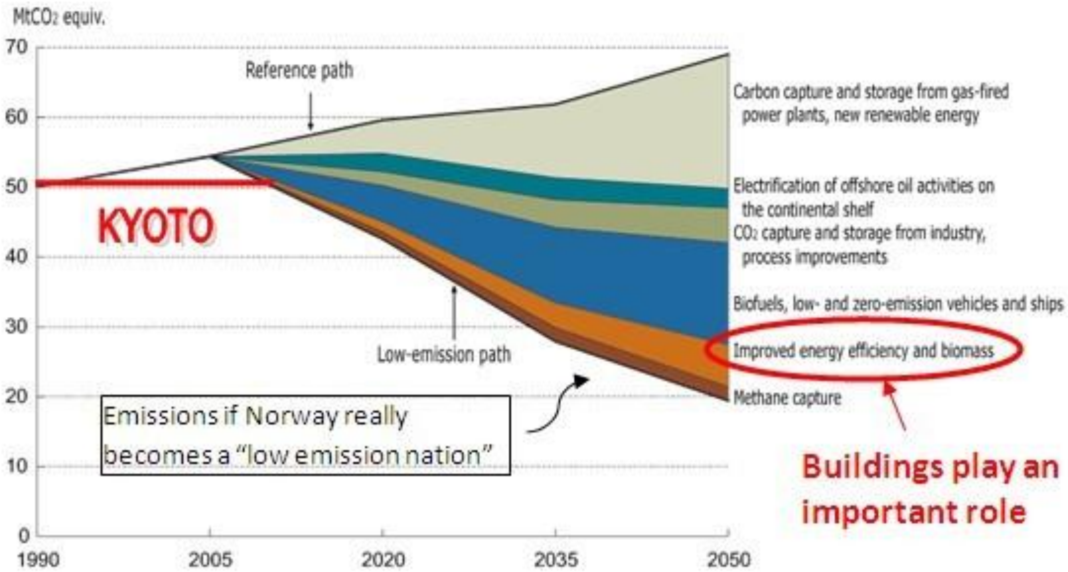


Figure 1: Low emission commission (Haase, 2010).

The Kyoto Protocol has set Norway's emissions target at one percent over 1990 levels for the first commitment period (2008–2012) (Tjernshaugen, 2002). Figure 1 illustrates that the general solution of low CO_2 emissions of different sectors. It shows that annual emissions of greenhouse gases in the past, in the Commission's reference path, and in the proposed low-emission path 1990–2050. We could see that buildings exert a significant role in climate change.

2.2 Energy and architecture

Because of global warming, it is now widely recognized that reducing the energy appetite of buildings is the number one green issue. In Norway, about 38% of energy consumption is from the building sector, as show in Figure 2.

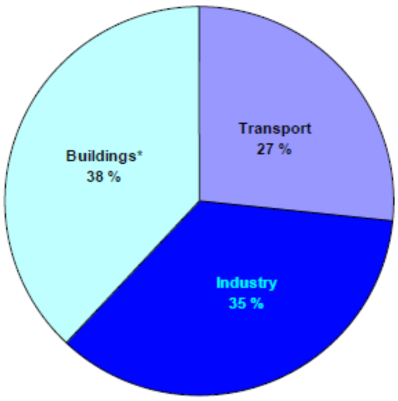


Figure 2: Energy consumption in Norway (Haase, 2010).

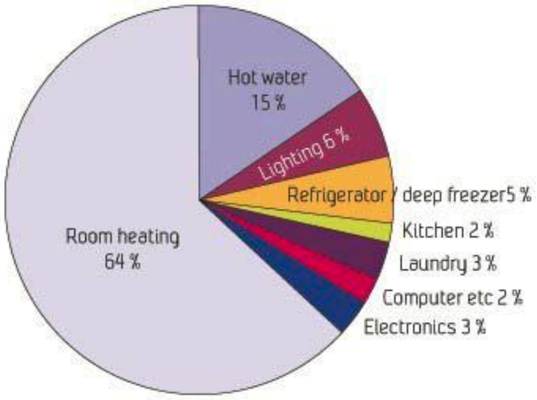


Figure 3: Distribution of electricity consumption in Norwegian residential units (SINTEF, 2008)

SINTEF states that the annual energy consumption in Norwegian residential units is mainly attributed to room heating, which accounts for 64% (See Figure 3). This paper will focus on the heating demand as a primary concern.

Since building industry takes 38% of energy consumption, architects have both the responsibility and the opportunity to design in an energy-conserving manner which can be at the same time comfortable, sustainable, humane, and aesthetically pleasing.

2.3 Building and Surroundings

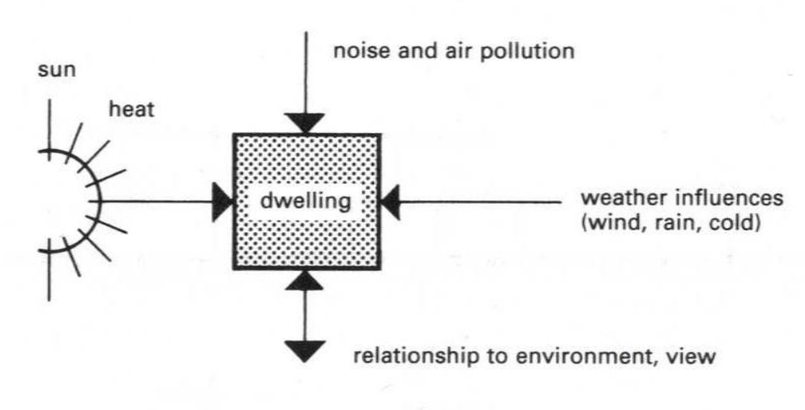


Figure 4: Relationship between a building and the environment (Baiche and Walliman,2000).

Before developing the energy-efficient buildings, it is important to understand which factor will influence the energy consumption of buildings. As Figure 4 shows, buildings are heated with the sun, cooled with the wind, lighted with the sky. It is apparent that the energy consumption of a building is affected by the solar access in terms of the heat and the light as well as the wind. In addition to these, the noise, air pollution, and view around the building are also important aspects of building design, which also should be considered at the early design stage even though they are not related to the energy consumption of a building.

Since the energy consumption is related to the solar access and the wind flow around buildings, before analyzing the impact of building morphology on the energy consumption, this research firstly analyzes the solar radiation, shadow pattern, daylighting availability and wind flow of different building morphologies, this will be discussed in Chapter 5 and 6.

2.4 Energy-Efficient Building Design

Architects are taking a responsibility to design the buildings as Zero Emissions Buildings. Conceptually, a Zero Emission Building (ZEB) is a building with greatly reduced energy demand and able to generate electricity (or other carriers) from renewable sources in order to achieve a carbon neutral balance (Sartori, Andresen and Dokka, 2010). There is a three-tier approach explaining the way to design energy-efficient building, which is one aspect of Zero Emission Buildings.

Figure 5: The three-tier approach to the sustainability design of heating, cooling and lighting (Lechner, n.d.).

In order to optimum the energy consumption of the buildings, it is important to know the right steps to design energy-efficient buildings. As Figure 5 illustrates, the first tier is the architectural design of the building, which can itself to minimize heat loss in the winter, to minimize heat gain in the summer, and to use light efficiently. Poor decisions at this point can easily double or triple the size of the mechanical equipment and energy eventually needed. On the other hand, making the right design choices in tier one can reduce the energy consumption of buildings as much as 60 percent. In this paper, the main research question is from this tier, which is about the impact of “Form” on the energy consumption of buildings. The second tier involves the use of natural energies through such methods as passive heating, cooling and daylighting systems. The proper decisions at this point can reduce the energy consumption another 20 percent. Thus, the strategies in tiers one and two, which are both purely architectural, can reduce the energy consumption of buildings up to 80 percent. Tier 3 consists of designing the mechanical equipment to be as efficient as possible. That effort could reduce energy consumption by another 8 percent. Thus, only 12 percent as much energy is needed as in a conventional building. That small amount of energy can be derived from renewable sources both on and off site (Lechner, 2009).

Above all, the energy demands of buildings are accomplished not just by mechanical equipment, but by the passive design strategies of the building and its site layout. The design decisions that affect these environmental controls have, for the most part, a strong effect on the form and aesthetics of buildings. Thus, through design, architects have the opportunity to simultaneously satisfy their need for aesthetic expression and to efficiently heat, cool and light buildings. Only through architectural design can buildings be heated, cooled and lit in a sustainable way.

Naturally, building morphology is one of important aspect of the passive design strategies of the buildings, and the research about the building morphology will promote the development of the Zero Emission Buildings.

2.5 Case Study: ZEB Pilot Project Ådland, Bergen

Bybo AS are the developers for the ZEB Pilot Project in Ådland. The project is an design phase. Ådland project was chosen as a case study and the research about the impacts of different building morphologies on the energy demand could potentially be used in development of this project.

2.5.1 Site Analysis

Site Layout

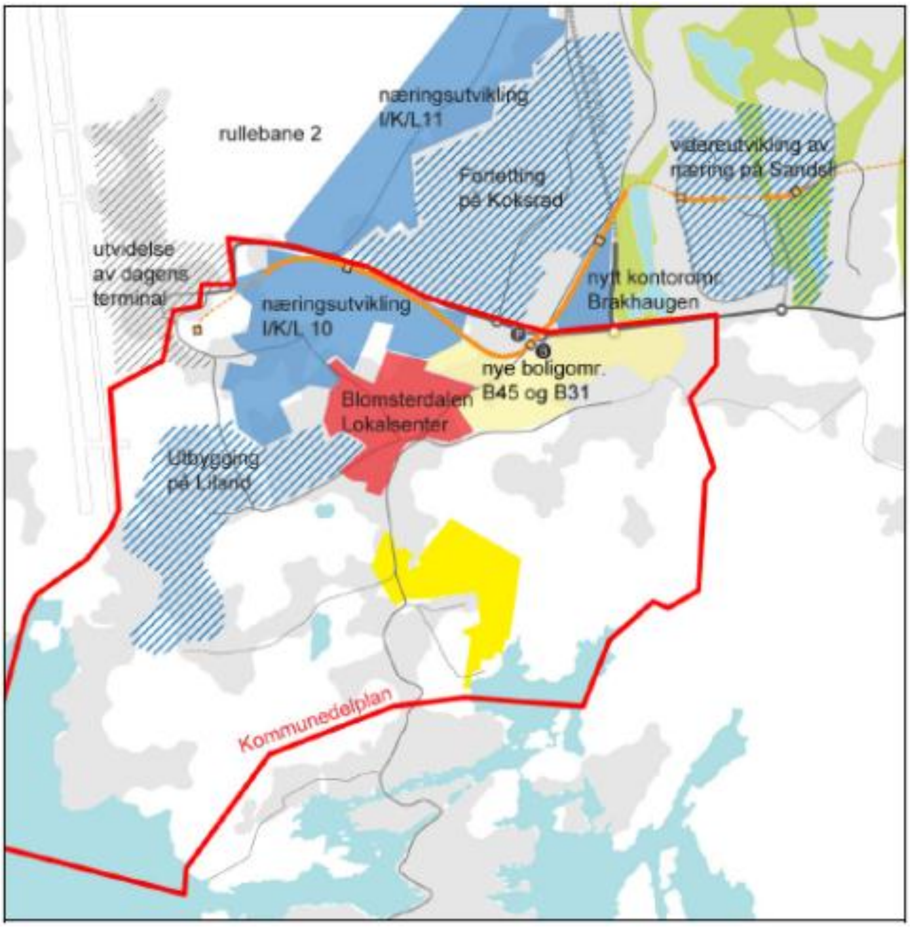


Figure 6: Ådland Site(Wiberg, n.d.).

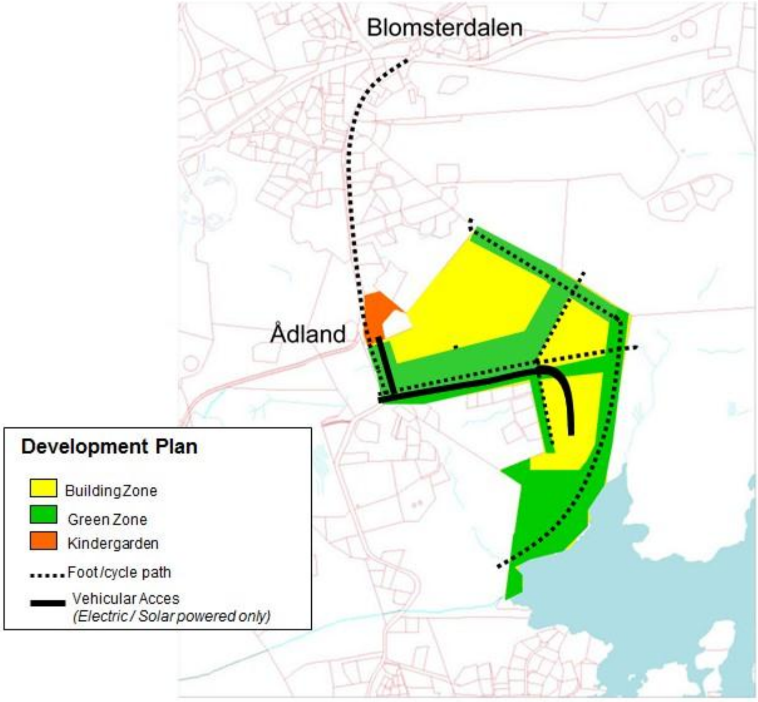


Figure 7: Development plan of Ådland site (Wiberg, n.d.).

The Ådland site is showed in Figure 6. The area (yellow) has good market attractiveness due to the site's proximity to two of Bergen's largest employment area's located in Kokstad / Sandsli (blue hatch). Figure 7 shows that the area of Ådland site is reduced in size and divided into concentrated building zones to minimise impact on nature and protect the fjord (south) and forest (east). Furthermore, paths through the area will be maintained and enhanced and will open up towards more dense forest and hiking terrain. It is envisaged that various modes of zero emission transportsw are used within and to or from the site. Roads and future bike routes are flat and well suited to cycling. The area is well within cycling distance to major employment zones (Wiberg, n.d.).

1. View on the ridge 2. View looking up to the ’sunny’ ridge

3. View from the ridge looking south across the plateau.

Figure 8: Ådland site views (Wiberg, n.d.).

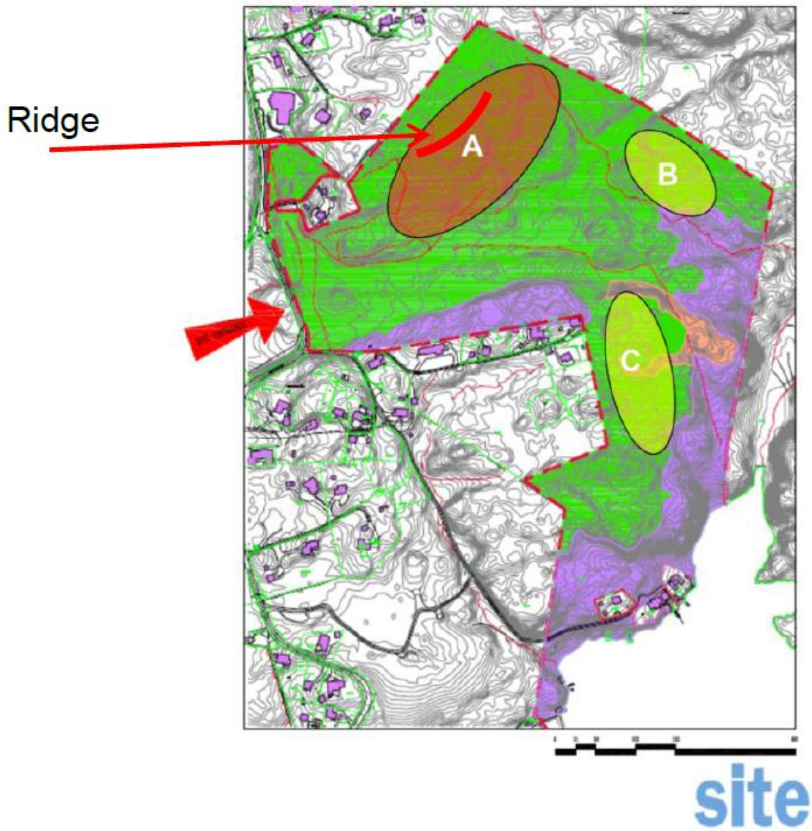


Figure 9: Site plan (Wiberg, n.d.).

Figure 8 shows the photos which were taken from the site. Figure 9 illustrates the site was divided into 3 Zones, A, B and C, respectively. This paper mainly focuses on Zone A. Zone A is located on a south facing ridge which is sparsely vegetated compared to the rest of the site. The ridge is facing a dense woodland which provides a nice aspect for the buildings. The ridge faces onto a flat, open plateau and is therefore not over shadowed and is a perfect location to ensure maximum solar gain. Higher density building is located on the south facing ridge to the north of the site (Zone A) where there is the least vegetation thus minimizing the environmental impact of the site but also ensuring maximum solar access (Wiberg, n.d.).

It is noteworthy that the purple and orange zones indicates area where the vegetation remains untouched (Wiberg, n.d.).

2.5.2 Climate Analysis

Whenever processing the energy-efficient buildings design, the site climate analysis should always be the first step in the early design stage. However, a limitation is that often the only available data is not site specific. For example, the only available weather data is for Bergen, which is not exactly the weather data for site, specific for Ådland is therefore not precise.

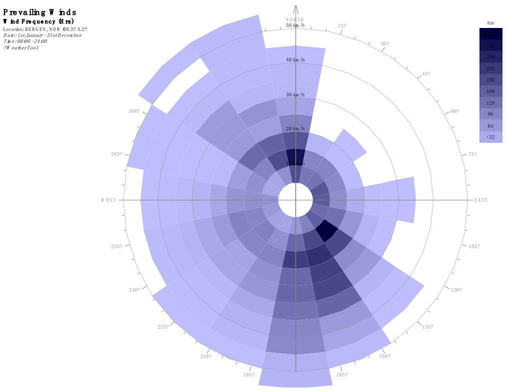


Figure 10: Annual wind rose all hours (ECOTECT)

Figure 10 shows a wind rose map, it gives detailed information about wind direction and frequency for a whole year. The diagram reveals that the prevailing wind in Bergen comes from both northwest and southeast, but the reality on the site is that the wind from the southeast would be blocked by the forest to the southeast of the site which is not easy to simulate. This would affect the heating demand of the buildings.

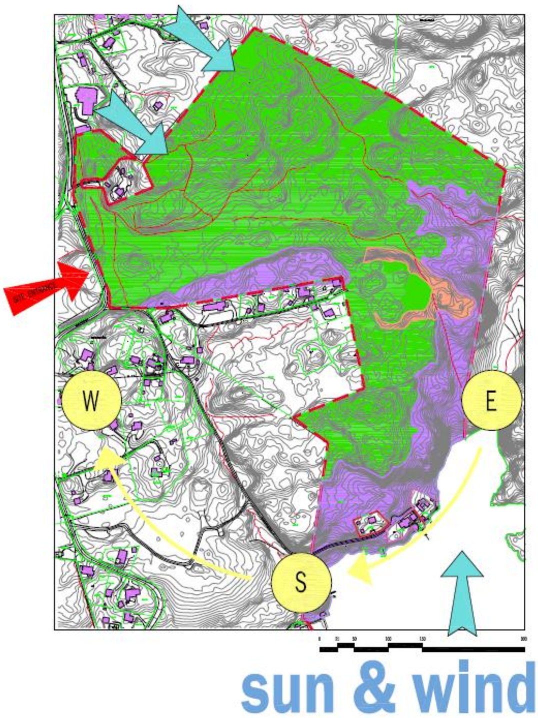


Figure 11: On site climate analysis (Wiberg, n.d.)

Sun

The site has good solar access to the west and north of the site. The east and south of the site is densely forested thus reducing solar access (Wiberg, n.d.).

Wind

See the last page.

2.5.3 Best orientation

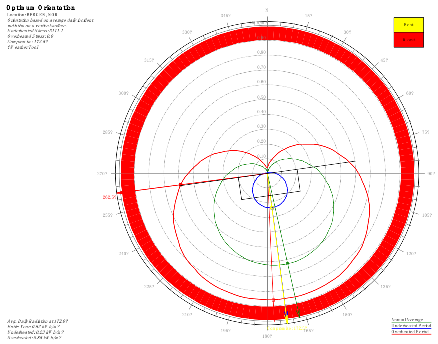


Figure 12: Best Orientation (ECOTECT)

The best orientation of the building would be to the south/south-east as shown in results from ECOTECT (see Figure 12). This is used to determine the most favorable range of orientations for passive solar heating, whilst still considering the effects of unwanted solar gains in summer. From the information, the best orientation is 172.5 ^{o} from the North to the South. However, it could be adjusted 30 ^{o} either from South to the East or from the South to the West for the maximum solar gain. In order to simplify the simulations, all buildings are assumed facing to the South in this paper.

The climate conditions both in Bergen and Madrid are illustrated in Table 1. The climate in Madrid is included for comparison as a sensitive analysis because to investigate the impact of hot climate on the energy consumption of different building morphologies. That means if there is much more solar radiation on the site, the results about the impacts of different building morphologies on energy consumptions may be different.

Table 1 Climate comparisons between Bergen and Madrid.

Category	**Name**	**Bergen**	**Madrid**
Solar altitude angle	Spring/Autumn Equinox	30 ^{o}	45 ^{o}
	Summer Solstice	50 ^{o}	66 ^{o}
	Winter Solstice	5 ^{o}	25 ^{o}
Average temperature	Low	1.0 ^{o} C	5.5 ^{o} C
	High	13.8 ^{o} C	25.5 ^{o} C
Temperature	Maximum temperature August	27.5 ^{o} C	38.8 ^{o} C
	Minimum temperature February	-5.7 ^{o} C	-3.2 ^{o} C
Humidity	Summer	63%	35%
	Winter	83%	56%

2.5.4 Passive Design Strategies

ECOTECT provides an initial analysis of passive design strategies based on Bergen Climate data. From Figure 13, we could see that through applying these passive strategies such as passive solar heating, thermal mass and natural ventilation, the thermal comfort percentage (red color) has been improved approximately twice compared to before which is shown in the yellow color.

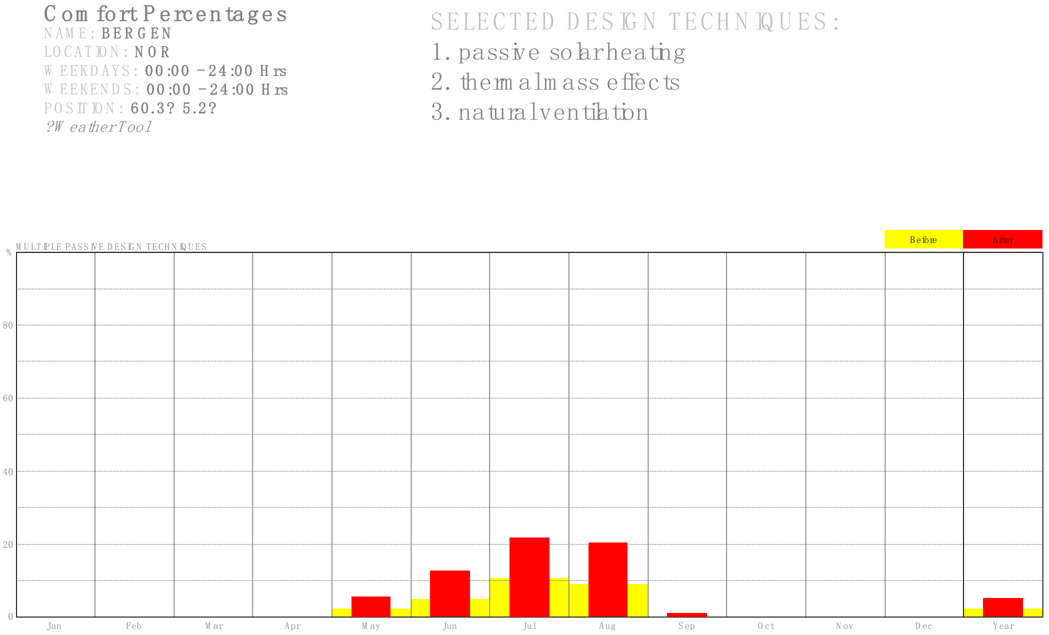


Figure 13: Expanded comfort zone due to passive strategies (ECOTECT).

3. Architectural Quality

We shape our buildings, and afterwards our buildings shape us.

— ***Winston S. Churchill, 1943***

The definition of architectural quality can be divided into five categories. First, good architecture is a combination of form, function, and construction. Second, architectural quality is targeted to fit the context, the plot, and the surroundings. Third, the concept is linked to a mystical aesthetic feature in architecture. Forth, architectural quality is a matter of expressing timeless values in a way that is typical for its contemporaries. Fifth, architectural quality has a usability value. Here, aesthetics and techniques are combined and coordinated for a practical solution. Quality becomes a practical question of material, construction, sustainability, and usability as well as a test bed for how design corresponds to the spatial needs of particular activities and the users concerned (Rönn, 2011).

This thesis focuses on the building morphology which is one aspect of the architectural quality. Here, the building morphology mainly means building form which is also defined as building organization in this research.

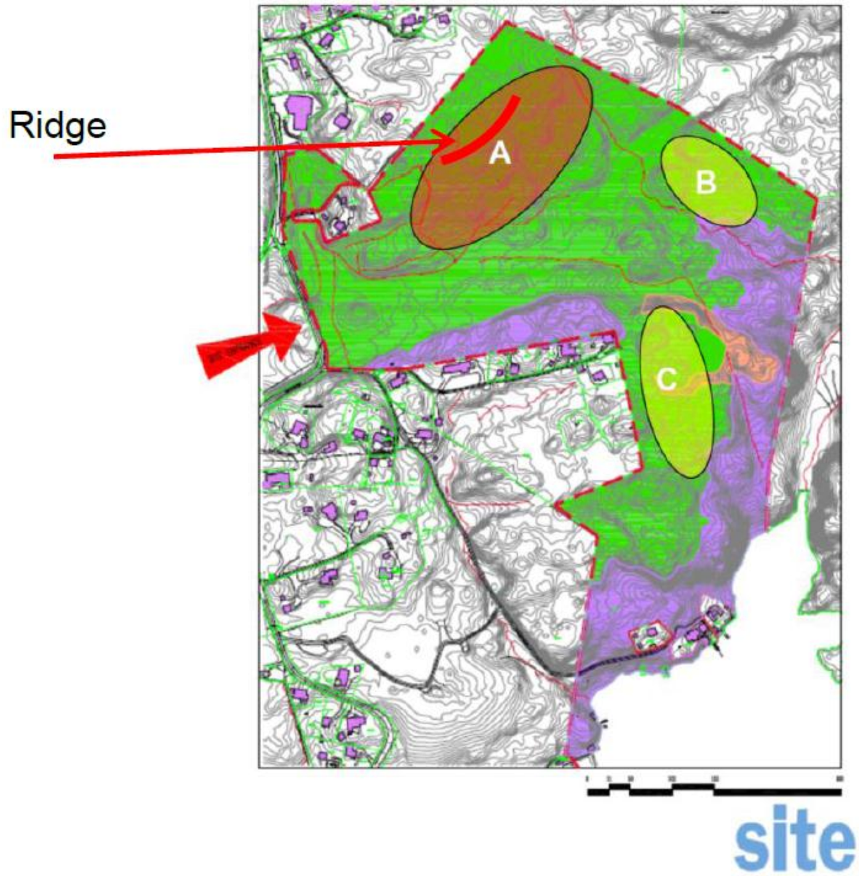
Nowadays, another important aspect of the architectural quality which should be considered is the architectural sustainability. Energy consumption is one core issue of sustainable architecture.

This research will investigate the impact of building morphology on energy consumption of buildings.

3.1 Design Principles

A key goal of zero emission buildings design is not only to minimize energy consumption of buildings and the environmental impacts to the surroundings, but also to meet the need of thermal comfort of inhabitants.

The design concept initially prepared by the ZEB center for Ådland project is ’Pavilions in the Wood’. The intention of the project is that the beauty and biodiversity of the site should remain intact to as great extent as possible. The design proposes minimizing the environmental impact by varying the density across the site. The design approach is such that the buildings should follow the topography of the land as much as possible (Wiberg, n.d.).



3.2 Concept

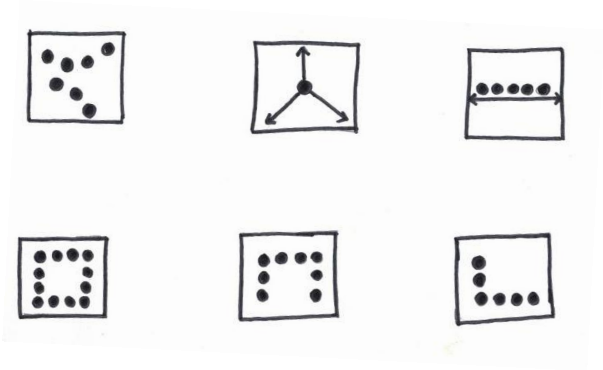


Figure 14: Design concept forms

The concept of the development of different building morphology comes from the diversity of form, space and order about the architecture. Six different possibilities of building morphologies are proposed and shown on Figure 14. They are clustered, radial, linear, square, U-shaped and L-shaped form. There will be more detailed descriptions about these forms in the chapter 3.3.

3.3 Building Model

The different building morphologies in this research are composed of 16 blocks which as shown in Figure 15 and 16. The massing block is shown below. Each block is 10 meters times 30 meters with 3 meters height (This number, 3 meters, is defined in ECOTECT).

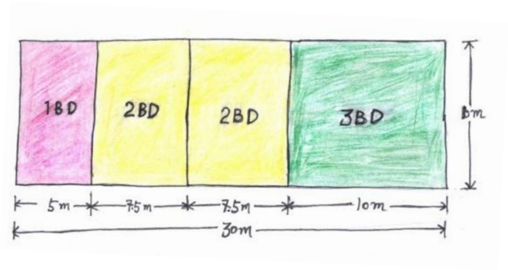


Figure 15: The plan of the block

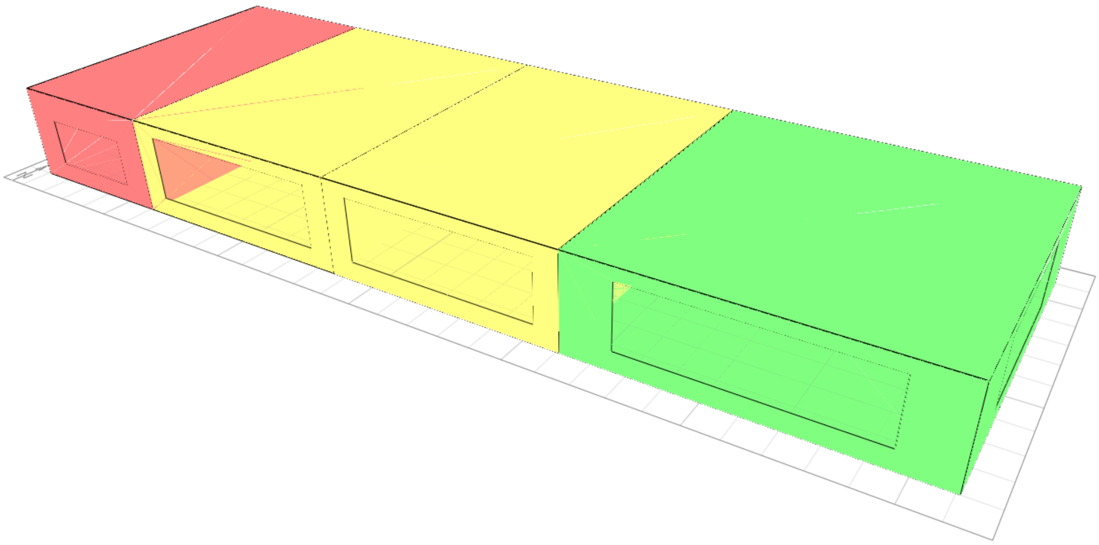


Figure 16: Block model from the ECOTECT

The 10m x 30m module is based on the areas used in the apartments in the Løvåshagen project (see Figure 17 and 18) which is the first passive and low energy housing project in Norway. Løvåshagen was also developed by Bybo AS and was selected as a ZEB case study. Apartments of different types can be combined resulting in longer or shorter modules depending on the site location. A generic 10m x 30m module includes a 1 bed, 2 x 2 bed and a 3 bed apartment as shown. This 10 m depth is especially beneficial for the execution of cross ventilation and daylighting strategy. There are 16 blocks in each building configuration and they are arranged in four stories. The total heated floor area is 4800 m^2. And every organization has 4 sections. Shading system is not included in this paper.

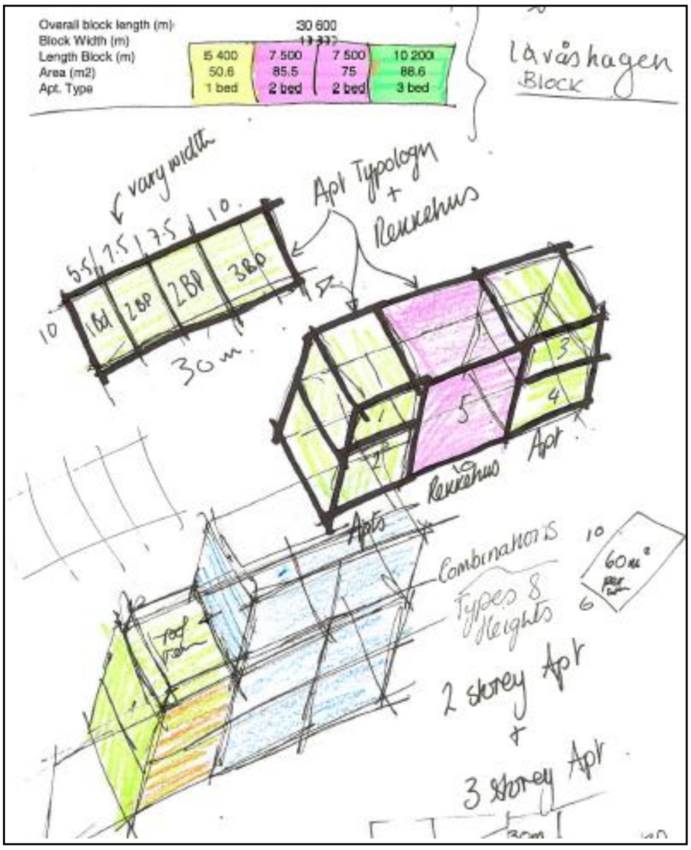


Figure 17: Sketches of models for Løvåshagen project (Wiberg, n.d.).

Figure 18: Løvåshagen project (Wiberg, n.d.).

Table 2 shows the window areas in the block model (see Figure 15). The area of window openings in the cold climate such as Bergen, is related to the heating demand and daylighting. More specifically, in order to use the daylighting as much as possible, the window openings should be designed as big as possible. This results in heat loss in the buildings and an increase in heating consumption, due to the low level of solar radiation in the winter in Bergen.

Table 2　Window areas: Width×Height

	South(m)	**West(m)**	**North(m)**	**East(m)**
1 Bedroom	3×1.5	5×1.5	2×1.5	—
2 Bedrooms	6×2	5×2	—	—
3 Bedrooms	7×2	—	3×2	5×2

In Norway, in order to optimum the balance of heating requirements and daylighting, there is a building regulation which is called TEK 10 defining about the window openings as follows:

$$\frac{A\ windows}{A\ heated\ floor\ areas} \times \textit{U-value} \leq\ 0.24 \text{ (TEK 10, 2010)}$$

If the U-value is 0.8, the ratio of window openings should be no more that 30% of heated floor areas. In this research, the window openings of the models are set to 30%. However, it is defined that this rule is only valid for non-residential buildings in this TEK 10. But if the buildings can be designed by satisfying the energy budget, this rule could be a good guide for residential buildings in terms of balancing solar heat loss and daylighting at the early design stage.

3.4 Building Morphologies

There are 12 building models which have been conceived according to the requirements of Ådland project. They are shown in Figure 19:

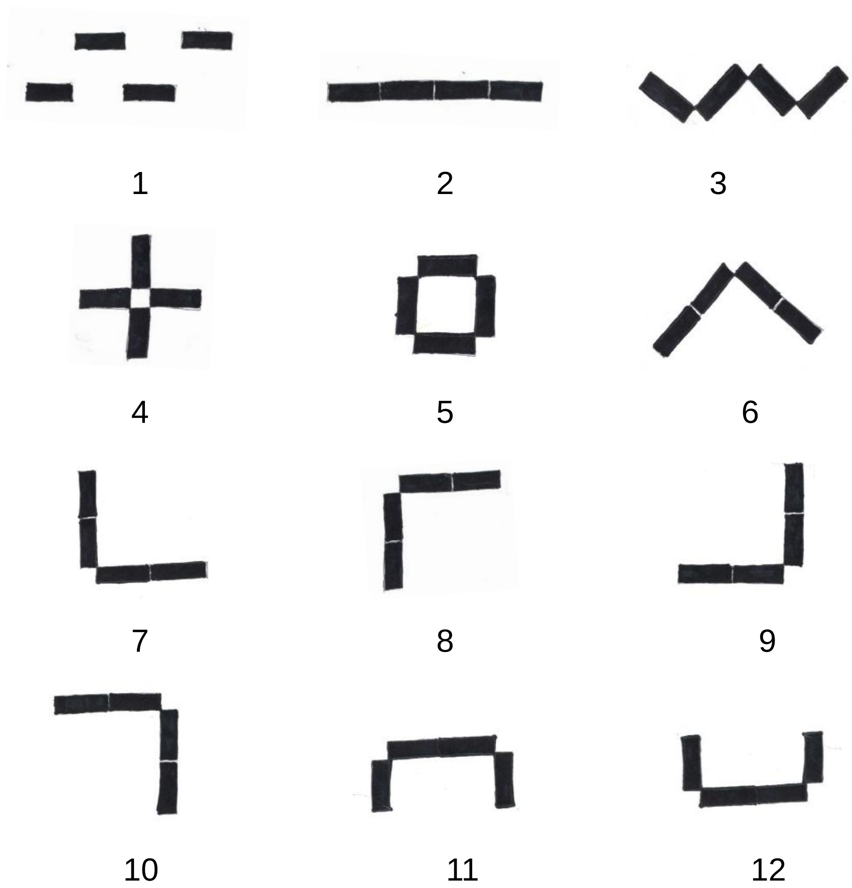


Figure 19: Building forms.

And then add height to these 12 models to give the shape a volume, which is about 12 meters in total. All of them are 4 stories. Finally, the 12 building morphologies are created, and they are also defined as building organizations in this paper. Among them, the initial proposal of Ådland project is No.1.

Clustered organization 

A clustered organization is grouped according to functional requirements of size, shape or proximity. In this model, building blocks have the same size and shape. One advantage of this organization is that each block could be optimized in terms of orientation and height, which is beneficial for reducing the energy consumption. In order to avoid over shadow between blocks, the distance between them from the North to the South is set as 21 m, and from the East to the West is 30m, which are calculated according to the average solar altitude angle in the spring. That is 30^{o}

A disadvantage of this organization is that due to the required distance between blocks to avoid overshadowing, this would result in a dispersed layout having a large impact on the site. Another disadvantage with clustered organization is lack of compactness (Ching, 2007).

Linear organization 

This is a linear sequence of repetitive blocks. The form of a linear organization is inherently flexible and can respond readily to various conditions of its site. Linear organization can be segmented or curvilinear to respond to topography, vegetation, views or other features of a site. It can adapt to changes in topography, maneuver around a body of water or a stand of trees, or turn to orient spaces to capture sunlight and views. It can be straight, segmented, or curvilinear. It can run horizontally across its site, diagonally up a slope, or stand vertically as a tower. At the same time, linear forms front on or define exterior space. Because of their characteristic length, linear organizations express a direction and signify movement, extension and growth (Ching, 2007).

A disadvantage is that there is little or no differentiation of the external spaces around the buildings. However, it is very good for daylighting availability (Ching, 2007).

Radial organization 

A radial organization of space combines elements of both centralized and linear organizations. It consists of a dominant central space from which a number of linear organizations extend in a radial manner. The central atrium provides an articulated subservient function. A radial organization is an extroverted plan that reaches out to its context. Within its linear arms, it can extend and attach itself to specific elements or features of its site. Radial shape gives high occupancy densities. The external spaces within and around the building are clearly differentiated in relation to form and function (Ching, 2007).

There is one disadvantage about this radial organization. It can best be seen and understood from an aerial viewpoint. When viewed from ground level, its central core element may not be clearly visible and the radiating pattern of its linear arms may be obscured or distorted through perspective foreshortening (Ching, 2007).

Square organization 

The field is completely closed, and its space is naturally introverted. But the atrium in the middle is useful for daylighting and natural ventilation strategy.

L-shaped organization 

A L-shape configuration defines a field of space along a diagonal from its corner outward, while this field is strongly defined and enclosed at the corner of the configuration (Ching, 2007).

L-shaped configuration is stable and self-supporting and can stand alone in space. Because they are open-ended, they are flexible space-defining elements. They can be used in combination with one another or with other elements of form to define a rich variety of spaces. As Figure 20 shows,

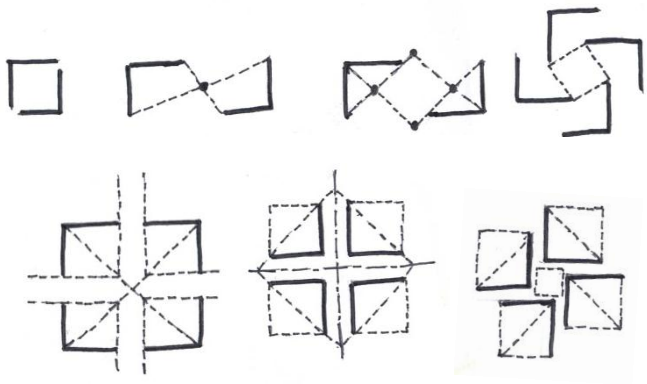


Figure 20: Different L-shaped Organizations (Ching, 2007).

The advantage of this type of layout is its provision of a private courtyard, sheltered by the building form and to which interior spaces can be directly related. A fairly high density is achieved with this type of unit, each with its own private outdoor space (Ching, 2007).

U-shaped organization 

A U-shaped configuration defines a field of space that has an inward focus as well as an outward orientation. At the closed end of the configuration, the field is well defined. Toward the open end of the configuration, the field becomes extroverted in nature (Ching, 2007).

U-shaped organization has the inherent ability to capture and define outdoor spaces. Their composition can be seen to consist essentially of linear forms. The corners of this configuration can be articulated as independent elements or can be incorporated into the body of the linear forms (Ching, 2007).

3.5 Architectural Sustainability

Contemporary architecture comes to a new phase; there are more and more requirements about the sustainability of the buildings due to the energy source scarcity and environmental problems. However, in the traditional architectural design, architects could present their design in terms of aesthetical quality and functional quality. For example, there is no existing data linking the energy performance of different building configurations. However, this paper provides a “Starting Guideline” for architects to certify the energy performance of their buildings. The reason for why it is called starting guideline is because this paper only focus on the heating demand, and there will be more and more detailed guidelines from other aspects about the energy performance of the buildings could be produced in the future, such as from the perspective of the electricity performance and the impact of urban density on the energy performance.

According to the steps of the energy-efficient building design which is described in Chapter 2, architectural design is the most efficient way to realize the sustainable architecture. This paper selects building morphology which is one aspect of architectural design as the research topic, and it is meaningful to investigate the impact of building morphology on the energy consumption of buildings for the realization of sustainability of buildings.

Building morphology which mainly means building configuration here, could affect the solar access of buildings and wind flow around the buildings. On the one hand, solar access refers to the amount of the sun’s energy available to a building. Good solar access means reduced energy requirements, improved comfort levels and environmental benefits (Sustainability Victoria, n.d.). Precisely, solar access is related to the solar radiation, shadow patterns and daylighting. Especially, using daylight instead of artificial lighting can save energy by two ways: from reduced electrical energy used by artificial lighting and from reduced heat gain from light fixtures. On the other hand, wind flow will impact the natural ventilation strategy of buildings. For example, in the cold climate such as Bergen, it is very important to consider about the wind environment around the building blocks in order to reduce the heat loss that infiltration causes.

Eventually, all of these factors would add up the influences on the energy performance of buildings.

4. Methodology

All the simulations in this thesis are from ECOTECT, including the analysis about the impacts of different morphologies on the solar radiation, shadow pattern, and daylighting availability. Apart from these, some principle sketches of the wind flow analysis are drawn. At the end, the total impacts on the heating demand will be calculated by ECOTECT.

Assumption:

1. The way of the volume and surfaces of the building are oriented also severely affect the energy consumption of a building. But in this paper, all blocks are assumed facing south.
2. The reason why the buildings do not overlap at the corners is that it shall be possible to make a direct comparison of the volumes.
3. The buildings in this Zone A are comprised of 2, 3 and 4 story apartments. However, since the research question of this paper is about the impact of building morphology on the energy consumption, for the comparison identity, only 4 story buildings are set as the examples. It is also interesting to investigate the differences of energy performance of 2, 3 and 4 story apartment in the future work.

4.1 Parameters

4.1.1 Definition of the Shape Coefficient Factor

In order to qualify the shape, a “shape coefficient” Cf is defined as follows:

$\mathrm{Cf} = \frac{Se}{V}$ (m^2/m^3)   (1) (Depecker, Menezo, Virgone and Lepers, 2001）

Where

Se is the envelope surface of the building, i.e. the external skin surfaces

V is the inner volume of the building.

4.1.2 Passive House Standard

In Norway, energy performance of buildings is calculated according to the Norwegian Passive House standard defined in NS 3700 (2010), see Table 3. The heating demand requirement in Norway is no more than 15 $\mathrm{Kwh/m^2}$.

Table 3 Minimum requirements for insulation and air tightness.

Characteristics	**NS3700**
U-value walls	≤0.15W/(m2·K)
U-value floor	≤0.15W/(m^2·K)
U-value roof	≤0.13W/(m^2·K)
U-value windows [a]	≤0.80W/(m^2·K)
U-value doors	≤0.80W/(m^2·K)
Normalized thermal bridge value, Ψ”	≤0.03W/(m^2·K)
System efficiency heat recovery,T[b]	≥80%
SFP-factor ventilation system	≤1.5kW/(m^3/s)
Air leakage at 50Pa,n_{50}	≤0.60h-1
[a] including frames	
[b] annual mean temperature efficiency	

4.1.3 Parameters in ECOTECT

Table 4 shows the parameters which have been utilized in ECOTECT. At the beginning, the simulation bases on the Norwegian Passive House Standard (NS3700), and then in order to check whether the U-value is one of the factor which affecting the energy performance of the buildings and make the results more convincible, the 2nd U-values and the 3rd U-values are also investigated.

Furthermore, there is a sensitive studying according to the Madrid Climate, and in this simulation, all parameters are from 3rd U-values.

Table 4 Parameters base on different U-values.

Name	**Unit**	**Passive house**	**2nd U-values**	**3rd U-values**
Roof/Ceiling	$W/m^2/K$	0.09	0.61	0.61
Walls	$W/m^2/K$	0.1	1.87	1.87
Windows	$W/m^2/K$	0.8	1.8	2.71
Floor	$W/m^2/K$	0.1	1.58	1.58
Infiltration rate	ach	0.14	0.14	0.14
Wind sensitivity	Ach/hour	0	0	0
Thermal comfort zone	^oC	18—26	18—26	18—26

5. Results

5.1 Solar Radiation Analysis

A house should be designed to respond to site conditions to maximize free solar energy. All forms of housing, including medium and high density housing, can save significantly on energy use for heating and cooling if solar access is good (Sustainability Victoria, n.d.).

Table 5 shows the minimum and maximum solar daily radiation of different building organizations. The maximum solar daily radiations from all different organizations are 2000 Wh/m^2, but the minimum solar daily radiations are different. More specifically, Clustered organization has the highest one which is 60 Wh/m^2. This means that Clustered organization could get more solar heat gain to the building elements compare to other organizations. Then the next one is Linear 2 organization which is 50 Wh/m^2, but in contrast, Linear 1 Organization only has 10Wh/m^2, this is because of the orientation, in the Linear 2 organization, the blocks have been turned 30 ^{o} either from the South to the East or from the South to the West. This would be beneficial for the solar heat gain from the morning sun or the evening sun. Both L-shaped and U-shaped organizations have the least minimum solar access compare to others.

Table 5 Solar daily radiation of different morphologies.

	Name	**Minimum (Wh/m^2)**	**Maximum (Wh/m^2)**
1	Clustered organization	60	2000
2	Linear 1 organization	10	2000
3	Linear 2 organization	50	2000
4	Radial organization	30	2000
5	Square organization	40	2000
6	L-Shaped 1 organization	20	2000
7	L-Shaped 2 organization	4	2000
8	L-Shaped 3 organization	6	2000
9	L-Shaped 4 organization	6	2000
10	L-Shaped 5 organization	4	2000
11	U-Shaped 1 organization	10	2000
12	U-Shaped 2 organization	10	2000

5.2 Shadow Pattern

When designing a complex of buildings or a whole development, shadow patterns are very useful for achieving solar access to all of the buildings. The shadow pattern, like the solar access boundary, affects the solar heat gain of buildings. Therefore, in order to maximum the solar access, the shadow pattern around the buildings should be analyzed (Lechner, 2009).

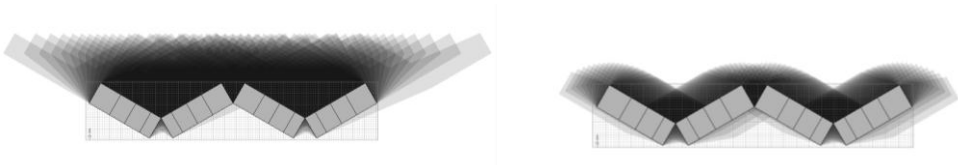
This chapter takes some examples about the shadow pattern ranges from ECOTECT. The results are presented from page 38 to page 40. Since there is completely no solar radiation in December, here it only takes examples from 9.00 to 17.00 both on 21st March/ September and on 21st June. From the results, we could see that it is obvious that the shadow cast on the site in March/September is larger than in June. This is because compare to June, there is lower solar altitude angle in March/September. On 21st March/September, all organizations have broad shading impacts on the site. But different building organization creates different shadow pattern. For example, there are atriums in the middle of No.4 Radial organization and No.5 Squared organization, and from the plan view, we could see that the atriums which have been signed in red circles are almost unusable no matter in terms of solar heat gain and daylight availability. If comparing about the shadow pattern ranges of L-Shaped organizations, No.8 and No.10 would be much better choices than No. 7 and No.9, the shadow patterns which have been signed in red circles in these organizations tell the reason about this. It is because the shadow will be casted on buildings themselves and this is not good in terms of the solar access. For U-shaped organizations, due to the same excuse as L-Shaped organization, No.11 is a much better choice comparing to No.12 from the shadow pattern perspective.

Shadow Pattern Analysis

21st March/ September | 21st June

1 Clustered organization

2 Linear 1 organization



3 Linear 2 organization

4 Radial organization

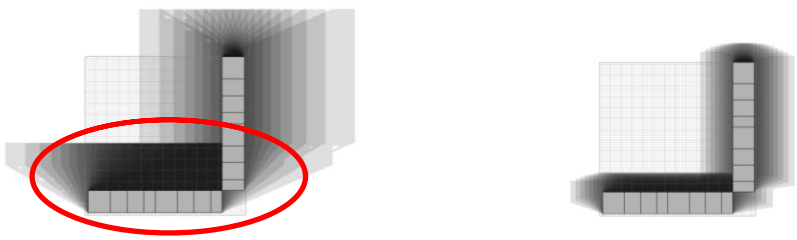
5 Squared organization

21st March/ September 21st June

6 L-Shaped 1 organization

7 L-Shaped 2 organization

8 L-Shaped 3 organization



9 L-Shaped 4 organization

10 L-Shaped 5 organization

21st March/ September 21st June

11 U-Shaped 1 organization

12 U-Shaped 2 organization

5.3 Daylighting

We were born of light. The seasons are felt through light.

We only know the world as it is evoked by light….

To me natural light is the only light, because it has mood-it provides

a ground of common agreement for man- it puts us in touch with the external.

Natural light is the only light that makes architecture architecture.

Louis I. Kahn

Daylighting is an important subject when dealing with energy-efficient buildings. On the one hand, if the design of the building does not allow for enough daylight, the residents will naturally turn to artificial lighting, which will increase the electricity consumption, ultimately arouse the augmenting of the energy demand. On the other hand, daylighting can also reduce the heating and cooling energy consumption because it can be cooler than electric lighting in the summer and it can passively heat a building in the winter.

Because of the impacts of different building morphologies on the solar access, the daylighting availability to the interior space of different building configurations is simulated in the ECOTECT, which is presented from page 45 to page 50. It is noteworthy that the research in this paper only takes the first floor area as examples.

Limitations:

1. In organization No. 2, 6, 7, 8, 9, 10, 11 and 12, the window openings in the side facades have been connected when the blocks attach with each other, this makes the exposed window areas to the outside have been reduced. But because it is difficult to calculate this situation, the analysis here assumes that the window areas to the outside are still treated as 30%.

2. The calculations are performed using ECOTECT Daylighting Analysis, but note that ECOTECT always considers the worst case scenario, with an overcast sky, and therefore does not distinguish the orientation as well. This could be showed by the results of organization No. 7, 8, 9 and 10. However, in the real practice, the results should be different by the different orientation, because the solar radiation in the different time in one day will be changed, and also it will be blocked by the building elements.

Table 6 lists the daylighting factors of the ground floor areas by different building morphologies.

Table 6 Typical Minimum Daylight Factors

Type of Space	Daylight Factor (%)
Kitchens	2
Living rooms	1
Bedrooms	0.5

All the daylighting factors in Table 7 are over minimum requirements which are shown in Table 6. However, this will result in the overheating and glare problem in the summer, so in the real project, the shading systems should be designed. Specifically, U-Shaped organizations, both No.11 and 12 have much higher average daylighting factors than other organizations, which are 61.25% and 61.28%, respectively. This is beneficial from the U shape, since the blocks could also accept the solar radiation from the morning and evening sun. The next higher average daylighting factor is No.1 Clustered organization, it's 60.21%, which is similar to No.2 Linear 1 organization, this indicates that the cluster and linear forms could get much more daylighting if they are not stopped by other obstacles. Another special number is 74%, which is from the maximum daylighting factor of organization No. 3, 11 and 12. The reason for this is because both U shape and V shape could get the solar radiation from the morning and evening sun.

The daylighting availability of the building also affects the heating demand of the buildings, and the total impacts will finally be added up to obtain the heating demand of buildings.

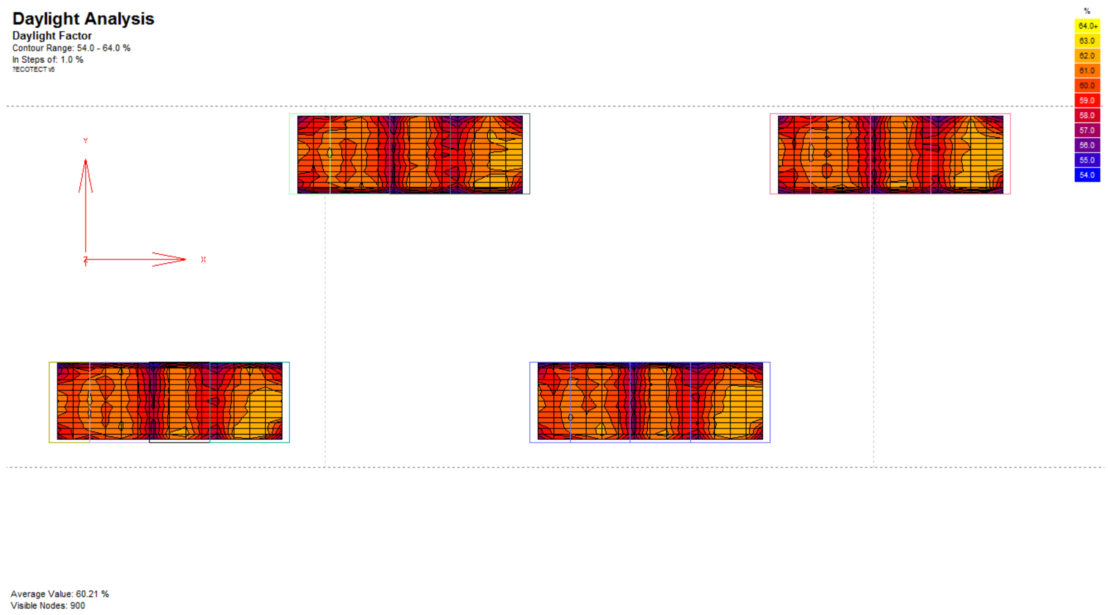
Table 7: Daylighting factor of different building morphologies

	DF / Name	Minimum	Average	Maximum
1	Clustered organization	54%	60.21%	64%
2	Linear 1 organization	54%	60.02%	64%
3	Linear 2 organization	54%	59.61%	74%
4	Radial organization	54%	59.75%	64%
5	Square organization	54%	59.56%	64%
6	L-Shaped 1 organization	54%	59.30%	64%
7	L-Shaped 2 organization	54%	59.49%	64%
8	L-Shaped 3 organization	54%	59.49%	64%
9	L-Shaped 4 organization	54%	59.49%	64%
10	L-Shaped 5 organization	54%	59.50%	64%
11	U-Shaped 1 organization	54%	61.25%	74%
12	U-Shaped 2 organization	54%	61.28%	74%

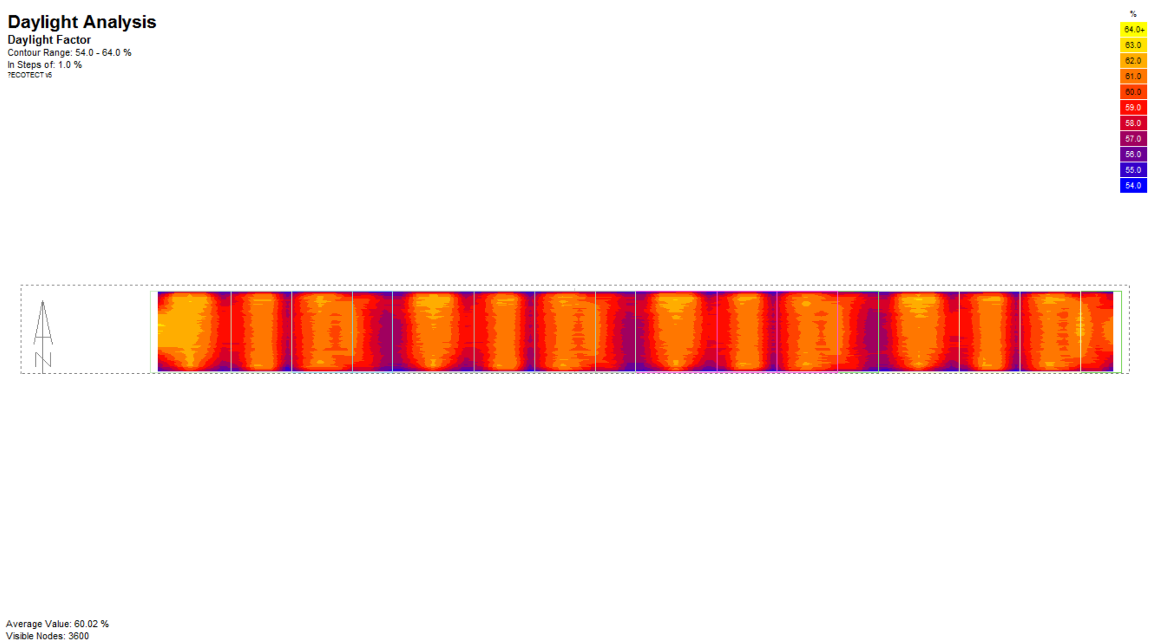
Note:

There are no shading systems in all simulation models here. Actually, shading could be an efficient complementary strategy for overheating, which could help both reduce the glare problem and the energy consumption. Since the shading is not related to the research question here, it is not considered in this thesis. But the shading design is a very important issue for the zero emission buildings.

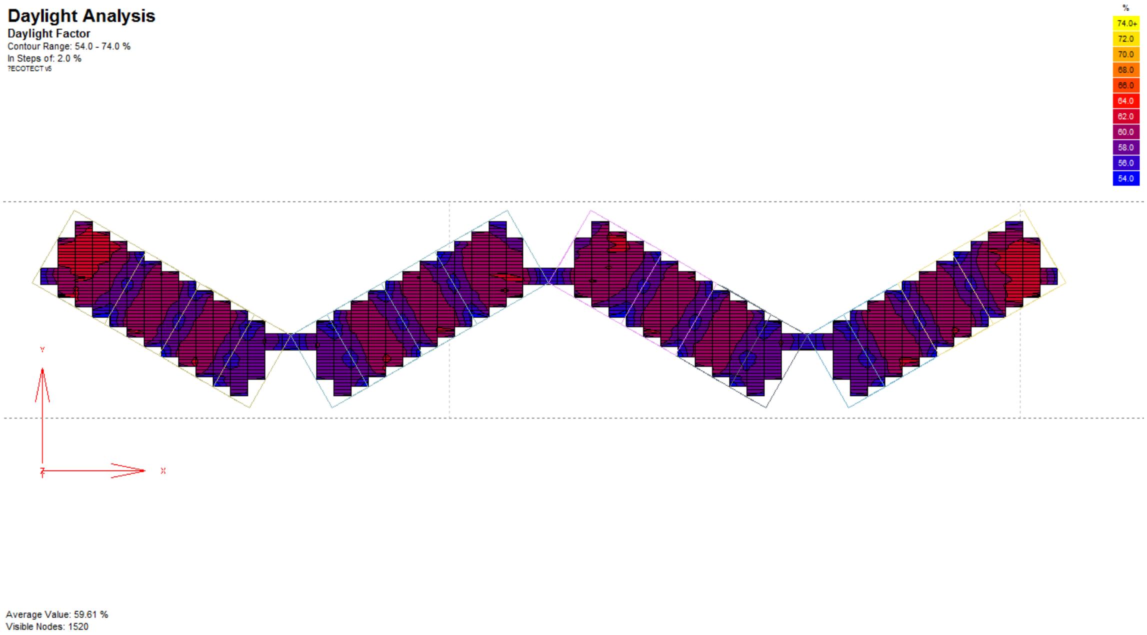
Daylighting Analysis



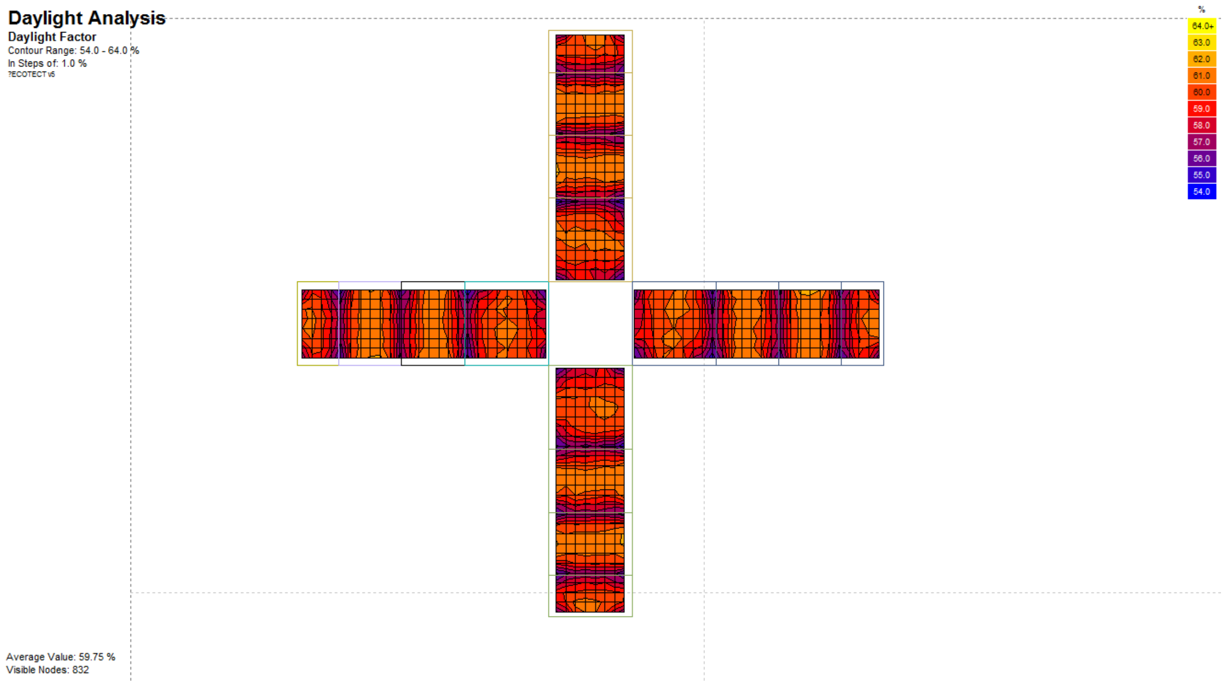
1 Clustered organization



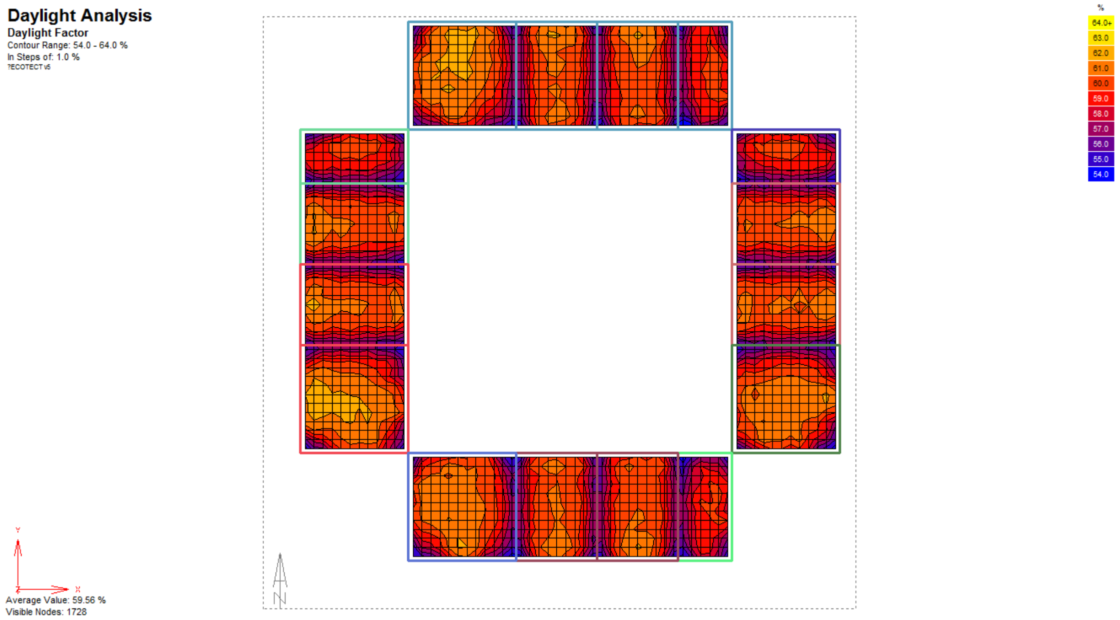
2 Linear 1 organization



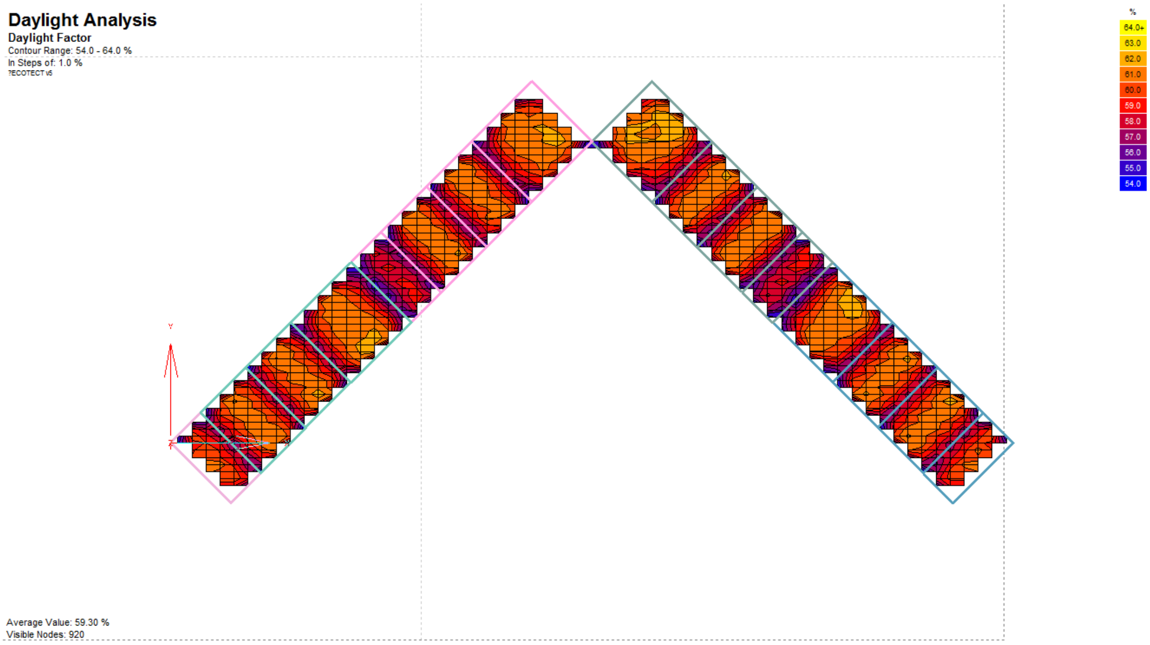
3 Linear 2 organization



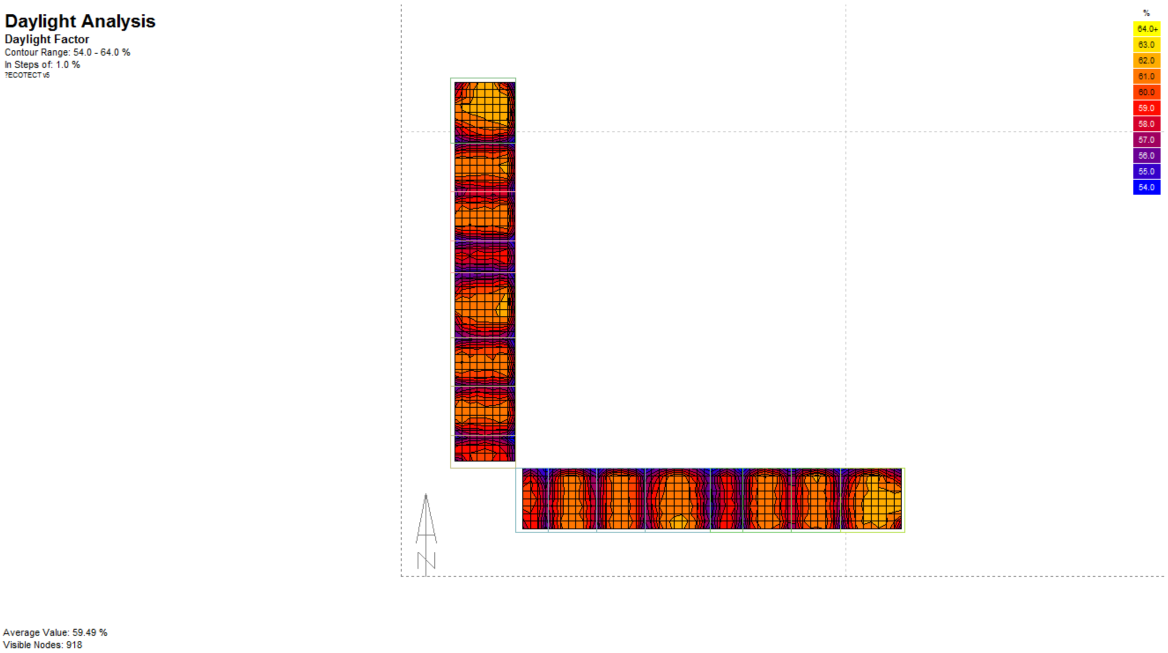
4 Radial organization



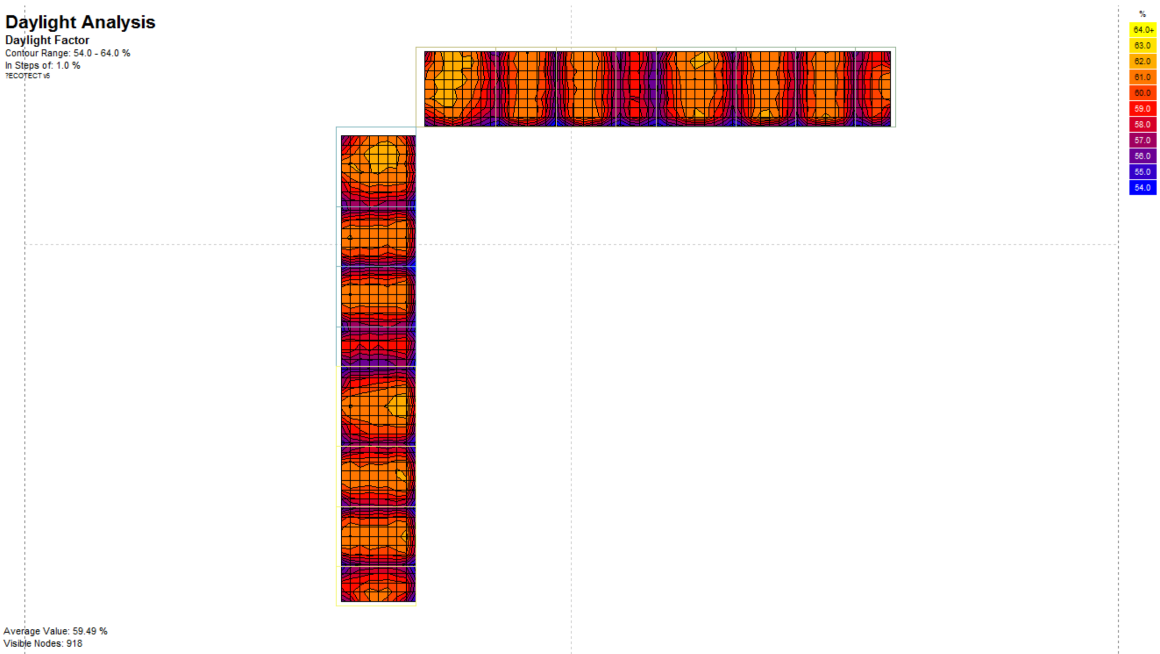
5 Square organization



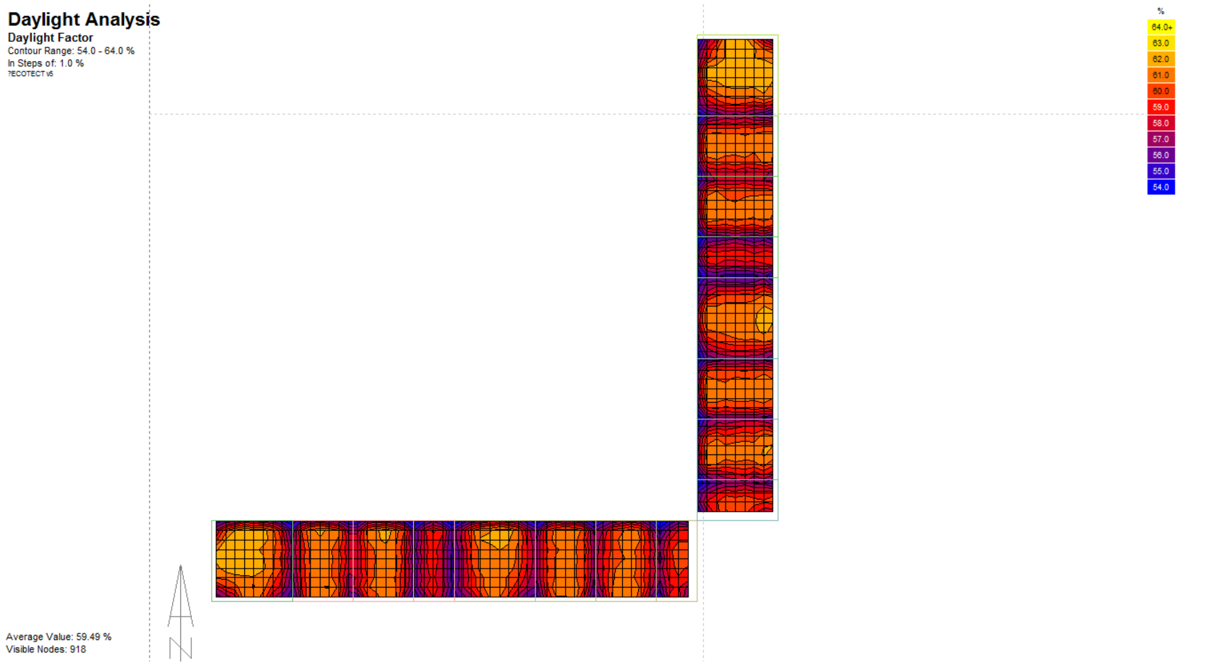
6 L-Shaped 1 organization



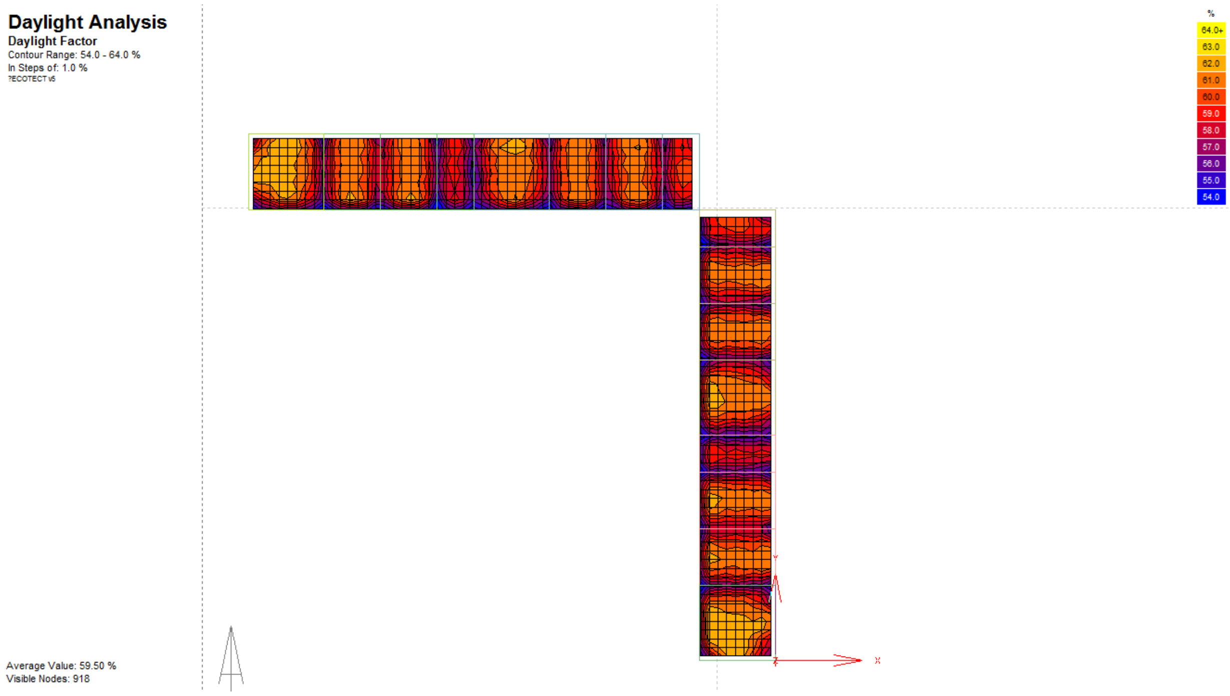
7 L-Shaped 2 organization



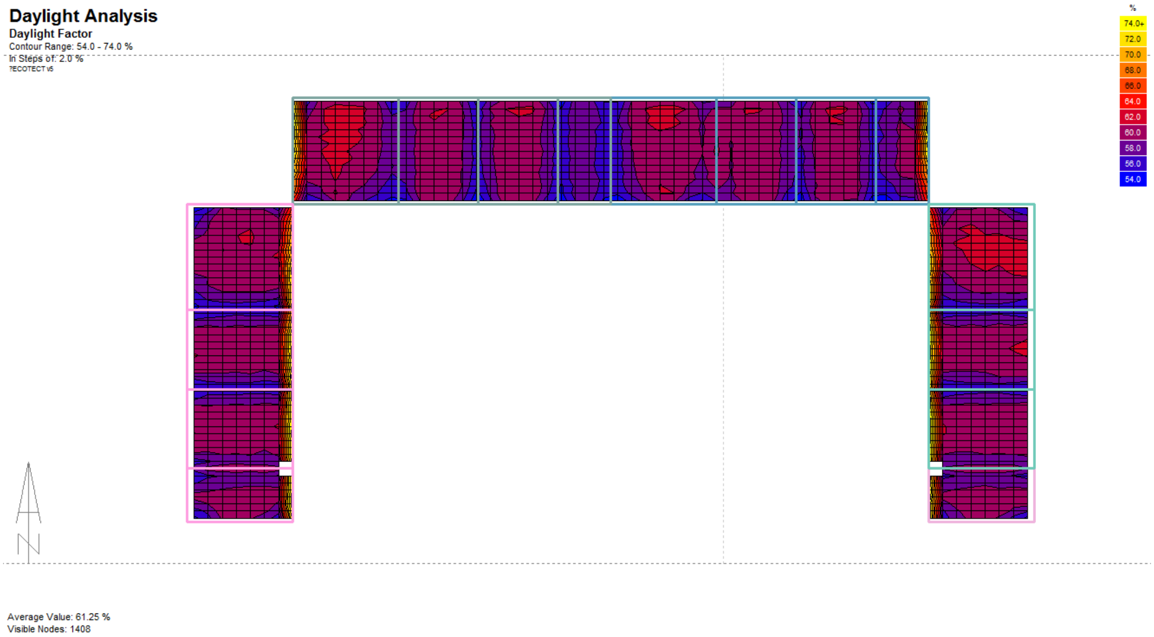
8 L-Shaped 3 organization



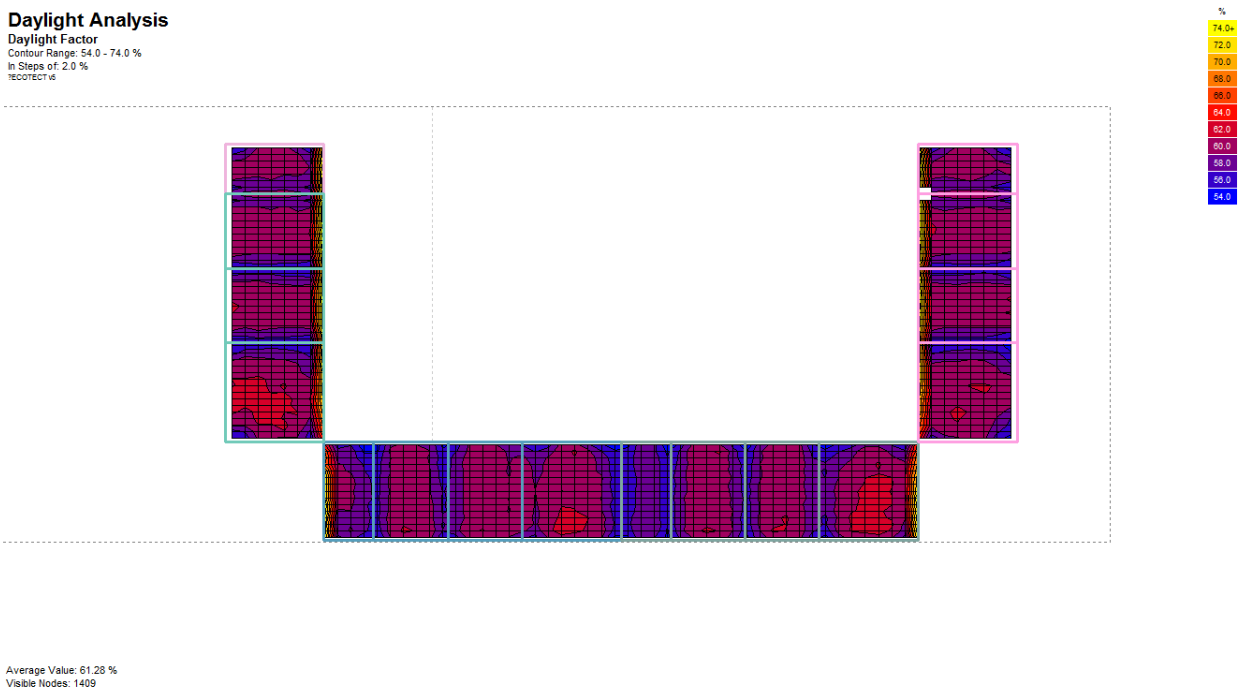
9 L-Shaped 4 organization



10 L-Shaped 5 organization



11 U-Shaped 1 organization



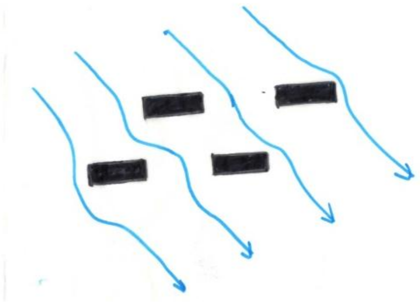
12 U-Shaped 2 organization

5.4 Wind

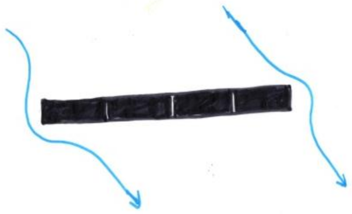
The wind around the buildings has to be considered in conjunction with built forms, as the built patterns could modify the open spaces outside the buildings which can increase, decrease and modify air speeds and result in the increase of the heat loss or gain. As a result, they can make hot, cold or humid conditions more bearable or more unbearable. The wind is an asset in the summer and a liability in winter. In the winter, the main purpose of blocking the wind is to reduce the heat loss that infiltration causes. When applying natural ventilation in a building, it is important to take the wind environments around the building into consideration (Lechner, 2009).

Page 52 and 53 are some simple sketches about the wind flow based on the different building morphologies. Among them, No.1 Clustered organization is suitable in hot and humid climates, because in these climates, buildings should be staggered to promote natural ventilation. No.2 the Linear 1 organization is good for the cold climate since this linear shape composing a protection which could against the wind around the buildings; this could help reduce the heat loss of buildings. Both No.3 Linear 2 organization and No.4 Radial organization will create the turbulence by the wind flow. One advantage of L-shaped organizations and U-shaped organizations is they create wind breaks by themselves, which defines private inside courtyard for buildings at the same time. There are some advantages about windbreaks. Firstly, wind breaks can be used to create edges that shelter buildings and open spaces. Secondly, wind breaks can be used to protect both buildings and outside areas from hot and cold winds. In cold climates wind breaks can reduce the heat loss in buildings by reducing wind flow over the buildings, thereby reducing infiltration and convection losses.

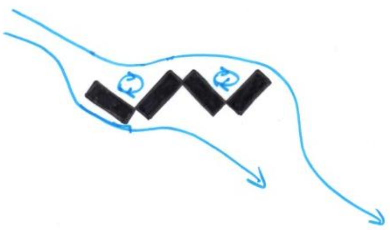
Wind Flow Analysis



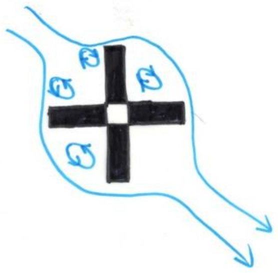
1 Clustered organization



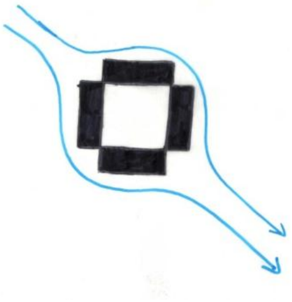
2 Linear 1 organization



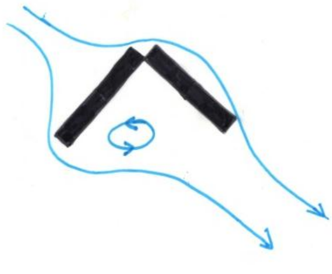
3 Linear 2 organization



4 Radial organization

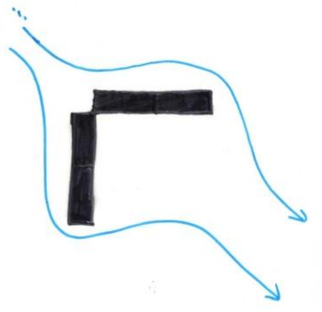


5 Square organization

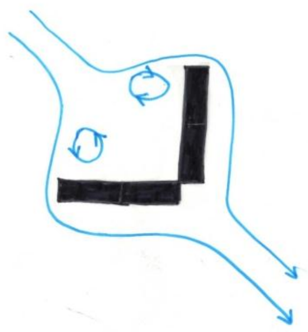


6 L-Shaped 1 organization

7 L-Shaped 2 organization

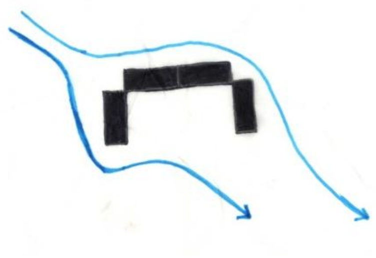


8 L-Shaped 3 organization

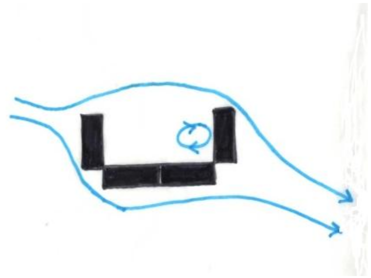


9 L-Shaped 4 organization

10 L-Shaped 5 organization



11 U-Shaped 1 organization



12 U-Shaped 2 organization

5.5 Shape Coefficient Factor

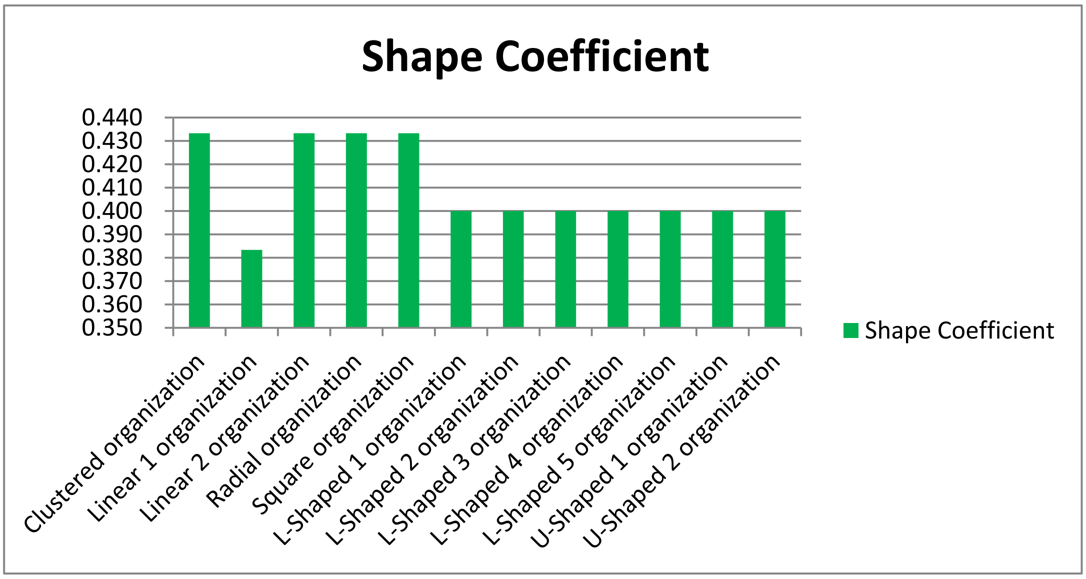


Figure 21: Shape coefficient factor.

Figure 21 shows the shape coefficient of different building morphologies. It is a very important factor which will affect the heating consumption of buildings. Among them, Linear 1 organization has the smallest shape coefficient, which is 0.383. Clustered organization, Linear 2 organization, Radial organization and Square organization have the same shape coefficient factor, which is 0.433. Besides, the shape coefficient factor of all L-Shaped organizations and U-Shaped organizations is 0.400.

5.6 Heating Demand

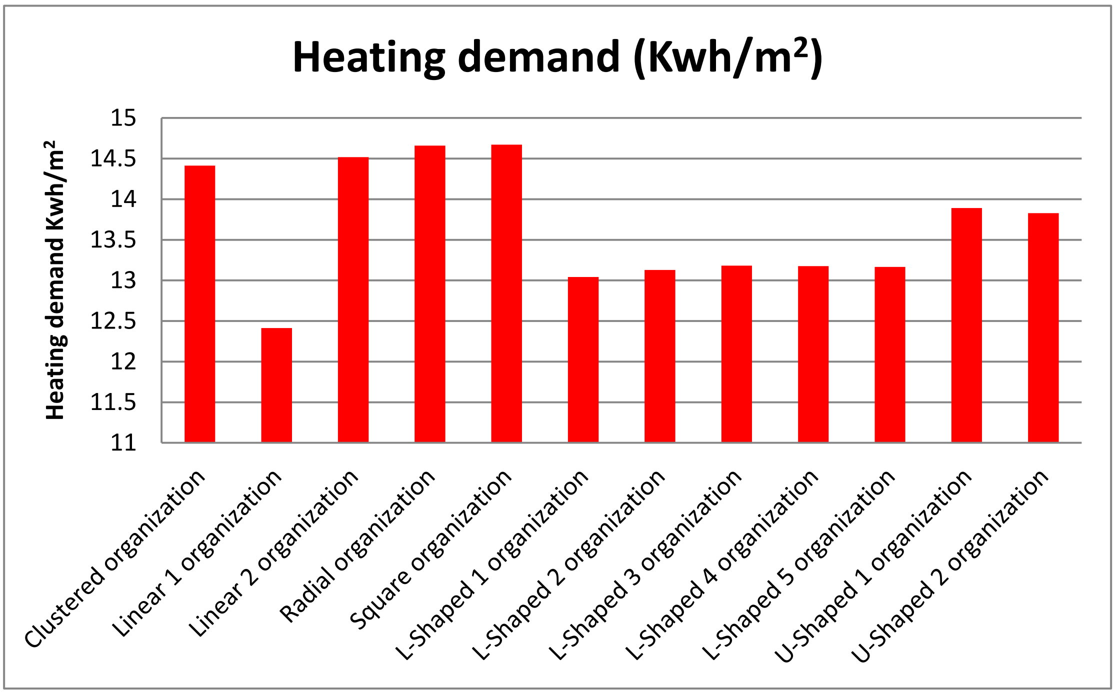


Figure 22: Heating demand according to Passive House Standard

Figure 22 illustrates the heating demand of different building morphologies; we could see that all of them are no more than 15 Kwh/m^2, which meet the Norwegian Passive House Standard. Linear 1 organization has the lowest heating demand, which is only 12.414 Kwh/m^2. The heating demand of Linear 1 organization has been reduced by 13.9% compare to Clustered organization. Then the next higher heating demands are around 13 Kwh/m^2, which are from all L-Shaped organizations, and the reduction is around 10% compare to Clustered organization. Compare with all of them, the heating consumption of Square organization is the largest, which is 14.672 Kwh/m^2. Actually, the heating consumption differences among Clustered organization, Linear 2 organization, Radial organization and Square organization almost could be negligible.

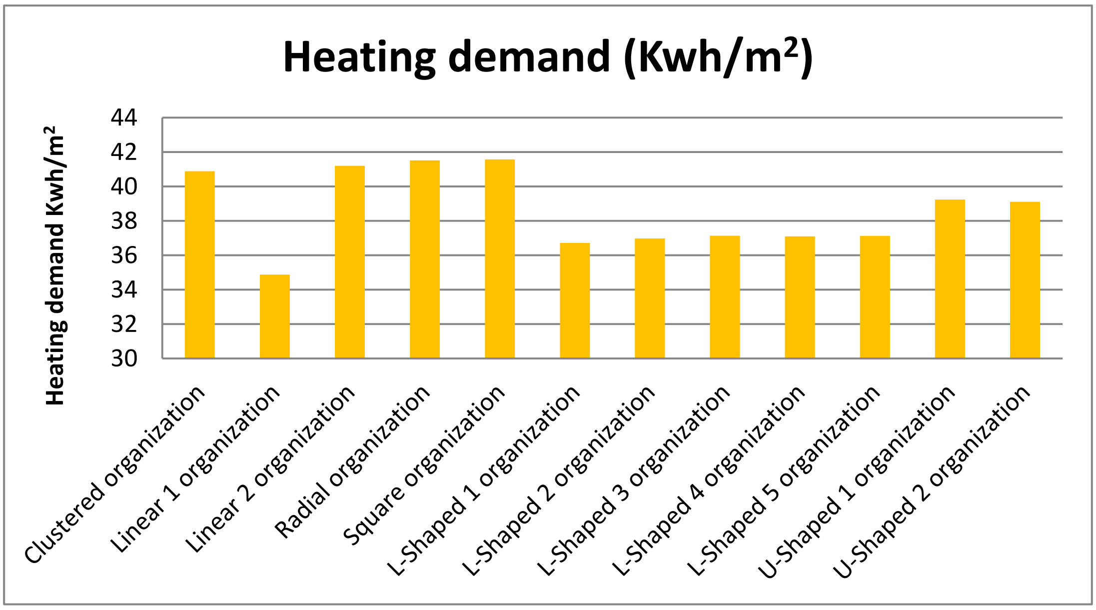


Figure 23: Heating demand bases on the 2nd U-value

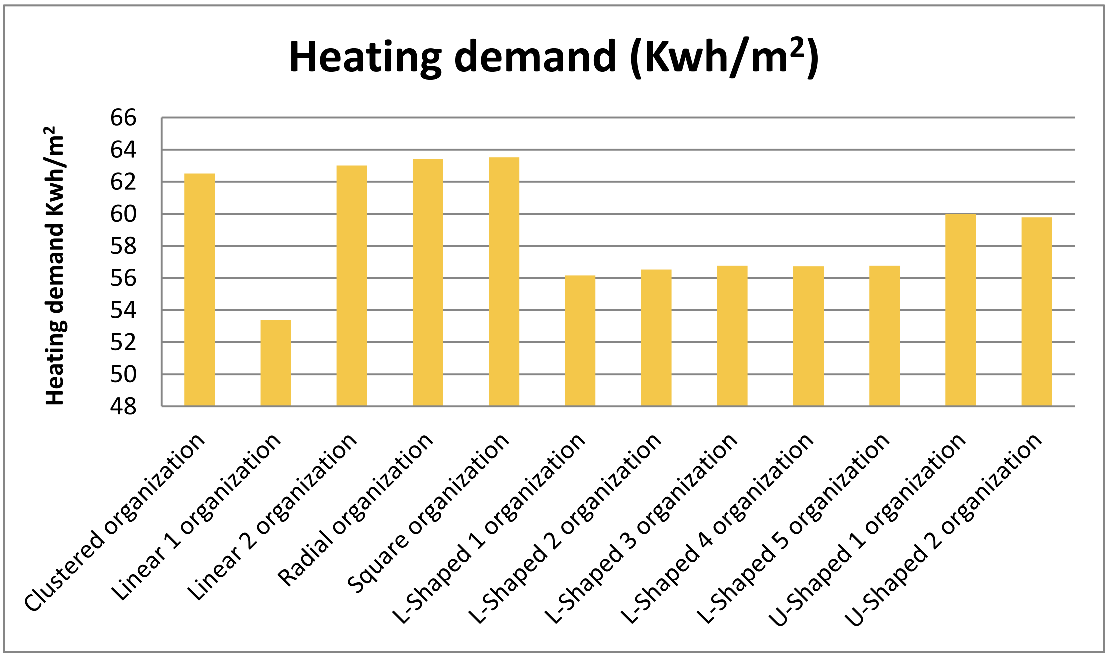


Figure 24: Heating demand bases on the 3rd U-value

Figure 23 and Figure 24 show the heating demand of different morphologies bases on the 2nd and 3rd U-value, respectively. We could see that they have the similar trend with the trend of the shape coefficient factor (see Figure 21), and the difference is that they have higher heating demand since the U-values are higher.

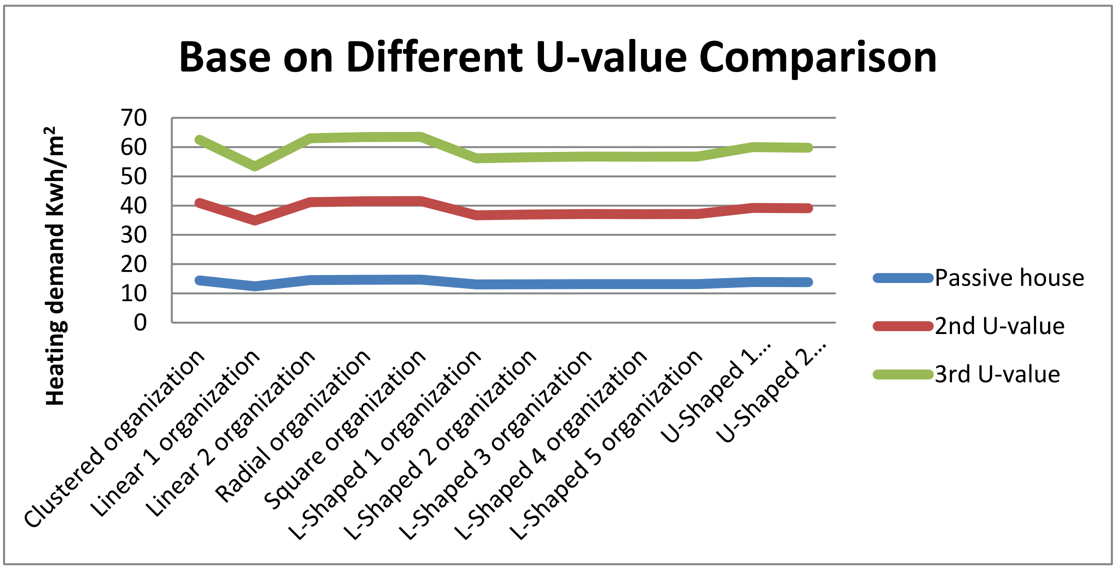


Figure 25: The comparison bases on the different U-values

As can be seen from the Figure 25, three curves indicate the similar fluctuation on heating demand of different building organizations. They are more or less stable. If the U-values are higher, the curve would be slightly more changeable.

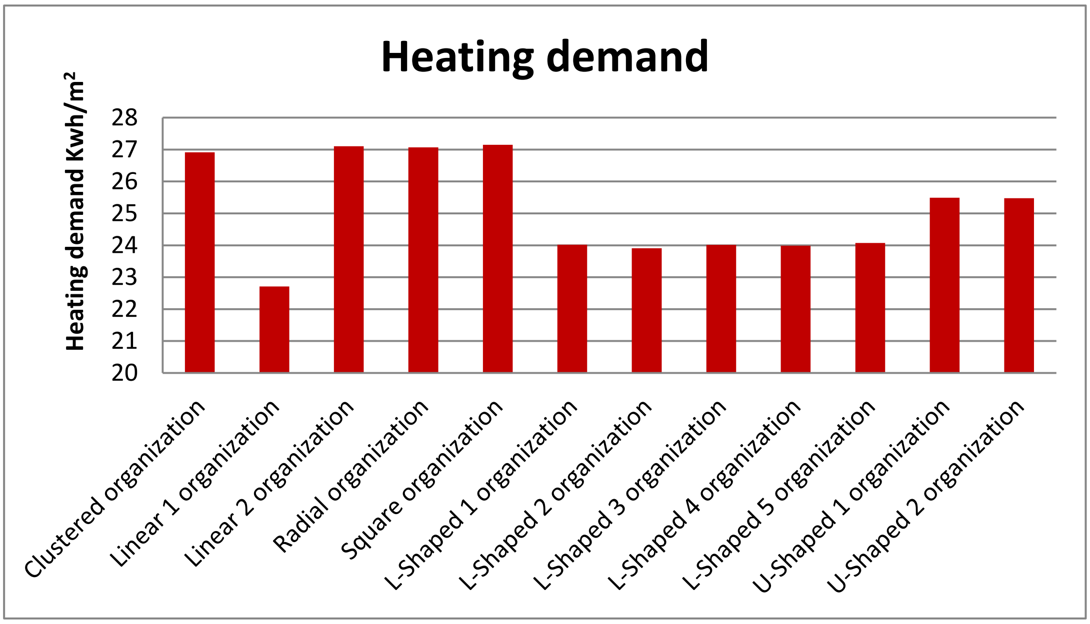


Figure 26: Heating demand bases on the 3rd U-value in the Madrid Climate

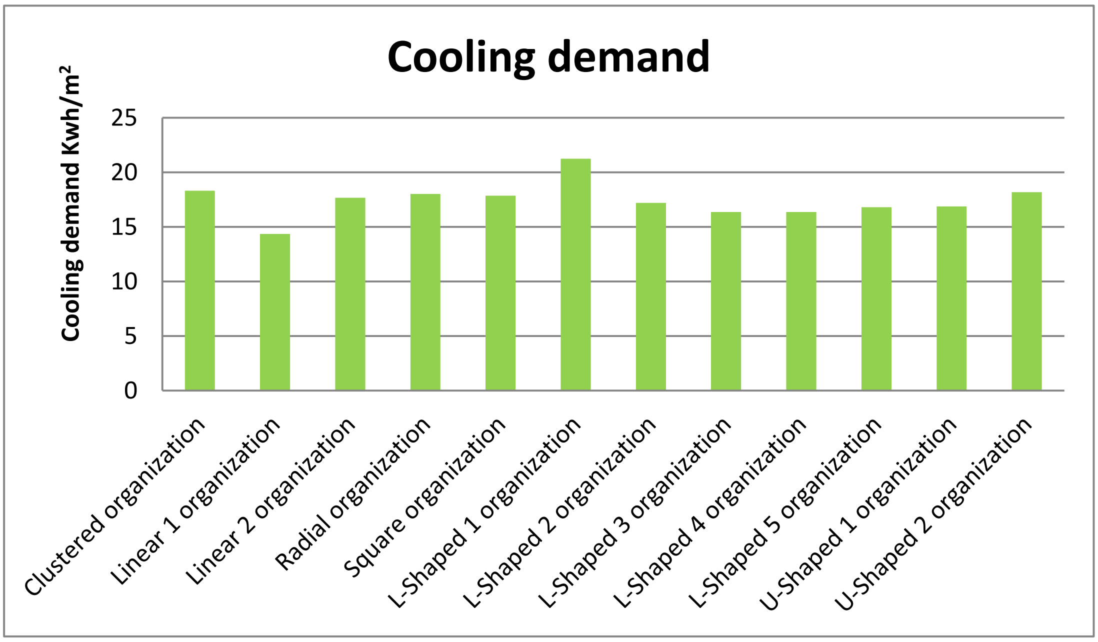


Figure 27: Cooling demand bases on the 3rd U-value in the Madrid Climate

Figure 26 shows the heating demand of different morphologies basing on the 3rd U-value in the Madrid Climate. It still has the similar trend as Figure 21 illustrates. But the cooling consumption of different organizations are very close to each other, see Figure 27. One interesting thing about this sensitive studying is that the cooling demand of L-Shaped 1 organization is the highest one among all organizations.

6. Discussion

6.1 Discussion on heating demand

The results about the heating consumption of different building morphologies are shown in Chapter 5.6. From the results, we could see that except Linear 1 organization and L-Shaped organizations, the differences among different building organizations are so slight that it almost could be negligible. But there are still some interesting findings.

Firstly, the trend of the diagrams between Heating Demand and shape coefficient factor is extremely similar. This means that the heating demand of the building is closely affected by the shape coefficient factor.

Secondly, the differences of heating consumption of different building morphologies will not be affected by U-values of building elements. After the building elements have been changed into much higher U-values, the heating demand of different building morphologies would also change according to the same scale (See Figure 25).

Thirdly, according to the sensitive studying in Madrid, the impact of different building morphology on the energy consumption will not be changed after changing into another climate. Even in the hot climate such as Madrid, the differences of heating demand among different building morphologies still follow the same trend. So the impact is not related to the solar radiation. But, another exciting result is about the cooling demand in Madrid, the result is not following the trend of shape coefficient factor (see Figure 21 and 27), surprisingly, L-Shaped 1 organizations has the highest cooling demand, it is interesting to investigate the reason for this in the future work.

6.2 Different building morphologies in Ådland Project

The final objective of this research is to investigate the impact of different building morphologies on the heating demand and choose the optimum building morphology for the Ådland project. This chapter introduces the features of different building organizations.

The initial proposal for Ådland project is Clustered organization. According to the Norwegian Passive House Standard, the heating demand of this morphology is 14.414 Kwh/m^2. Clustered organization has the good solar access in terms of solar heat gain and daylighting availability. But from the wind perspective, Clustered organization is much suitable for the hot and humid climate, since this organization will promote the wind flow around the building, which will increase the heat loss of buildings. However, there is one disadvantage about this Clustered organization, since the blocks are dispersed from each other, in order to get the same area, the site would be very crowded compare to other organizations. The view will be stopped by the neighbors (see Figure 28). People wanted to come to Ådland for closing to the nature and live in a sustainable neighborhood, but this Clustered organization would make people feel like live in a building forest, which does not make sense to develop Ådland area as a sustainable site.

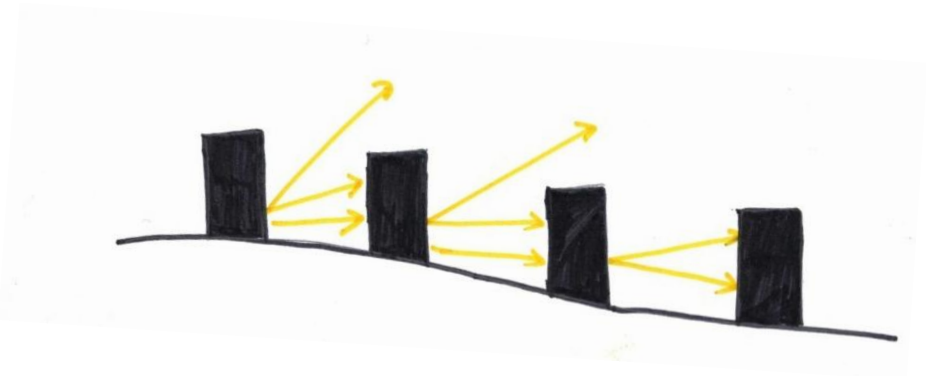


Figure 28: View is stopped with each other by using Clustered organization.

According to the results, Linear 1 organization has the lowest heating demand, which is 13.9% less than Clustered organization. This is because that the linear shape has lowest shape coefficient factor compare to other building morphologies. Specifically, from the daylighting perspective, Linear 1 organization has good solar access, which is beneficial for the reduction of electricity consumption. From the wind perspective, Linear 1 organization could against the wind around the buildings and help reduce the heat loss of buildings. Unfortunately, the minimum solar radiation of Linear 1 organization is less than Clustered organization, which means less solar heat gain, but this will not affect too much about the heating demand of the building, since the heat loss is also less compare with other organizations. So Linear 1 organization is preferred in Ådland project. Moreover, the architectural feature of Linear 1 organization is apparent. Especially, it is flexible and it can respond readily to various conditions of its site. It can adapt to changes in topography, maneuver around a body of water or a stand of trees, or turn to orient spaces to capture sunlight and views. And it is not difficult to get high density site with Linear organization. In contrast, the heating demand of Linear 2 organization is 14.518 Kwh/m^2, which is even more than Cluster organization (14.414 Kwh/m^2), this is because of the shape coefficient and the obstacles of neighbor blocks. Therefore, if choosing the linear shape as the building form, in order to reduce the energy consumption, the blocks should be connected with each other.

Radial organization and Square organization have quite similar heating demand; they are 14.659 Kwh/m^2 and 14.672 Kwh/m^2, respectively. In terms of solar access, both of them are not so good, because parts of the building will be extensively shaded by building itself. Besides, the atrium of the square shape is beneficial for the daylighting and ventilation strategy, but at the same time, this shape really takes a large area, which is not good for achieving a high density area. Radial shape gives high occupancy densities, but the people who live in the north of the block could not see the beautiful view from the south fjord. This is a disadvantage of this building morphology.

All heating demands of L-Shaped organizations are similar to each other, and they are around 13 Kwh/m^2. That means if changing the direction of L-Shaped organization, the heating demand will not be changed too much. In contrast with Clustered organization, the heating consumption of L-Shaped organization decreases by 10%. In the cold climate, this shape provides a private courtyard and also seems like a natural wind break, which could help reduce the heat loss of the building. From the architectural feature, L-Shaped could be organized in different ways (see Figure 21). A fairly high density is achieved with this type of unit.

For U-Shaped organizations, both of them, no matter facing the south or the north, the heating demand of them is around 13.9 Kwh/m^2. Compared to Clustered organization, U-Shaped organization is also a much better solution, even though it is just improved a little. The most exciting point is that U-Shaped organization has the highest daylighting availability among all building organizations, which will reduce the energy consumption. But U-Shaped 1 organization is much better than U-Shaped 2 organization, because the second one creates an extensive shadow pattern at the back of the building, which is not good for the solar radiation. Besides, the first one could protect the building from the wind, when the second one will create the turbulence at the north of the building, which arouses more heat loss.

In conclusion, for Ådland Project, in order to achieving the goal of zero emission buildings, the building shape should be designed as efficient as possible, if only choosing the optimum building configuration from the heating demand perspective, Linear 1 organization and L-Shaped organization should be preferred, not only because could they provide high density, but also because they could reduce the energy consumption of buildings. Compared with Clustered organization, the heating demand of them is reduced by 13.9% and 10%, respectively. Both organizations are very appropriate in the cold climate, since they create the wind break by themselves which reduce the heat loss of the building and then the heating demand. The next one is U-Shaped organization, even though it is just a little bit less heating demands than Clustered organization, it is worth to use this building morphology, especially when there is strong requirement on the daylighting availability.

However, it would be very interesting to have a combination of three building organizations together. Then after building organizations are combined together, the impact of the building morphology from neighborhood scale on the energy consumption should be investigated in the future.

On the contrary, Radial organization and Square organization are not suitable for Ådland project, because they consume slightly more heating demand than Clustered organization. Furthermore, though the radial shape gives high occupancy densities, the people who live in the north of the block will not be satisfied without the beautiful view from the south fjord. And the atrium of the square shape is beneficial for the daylighting and ventilation strategy, but at the same time, this shape takes a large area, which is not good for achieving a high density area.

7. Conclusion

Part of the year the sun is our friend, and part of the year it is our enemy. (Drawing by Le Corbusier: Oevre Complete, 1938-1944, Vol. 4, by W. Boesiger, 7th ed. Verlag fuer Architektur Artemis, 1977.)

It is the mission of modern architecture to concern itself with the sun.

Le Corbusier

From a letter to Sert.

In Norway, buildings behave an important role on solving the global warming problem. Since,

- Buildings use 38% of all energy.
- Space heating uses 64% of the energy consumed in buildings.

The research on the zero emission buildings design becomes substantially important. According to the three-tier approach to the sustainability design, the building design which reacts to the environmental factors such as the sun and the wind has a great impact on the energy consumption of buildings. Through design, architects have the opportunity to simultaneously satisfy their need for aesthetic expression and to efficiently heat, cool and light buildings.

This paper investigates how the building morphology which is one aspect of the architectural quality will impact the heating demand of buildings.

The final results indicate that the building morphology does have impacts on the energy performance of buildings. For example, compare to Clustered organization, the heating demand of Linear 1 organization could be reduced by 13.9%. And for L-Shaped organizations, it is 10%. But the heating demand differences of other building morphologies almost could be disregarded, and it is not related to either the U-values of building components or different climates. However, the heating demand of the building is mainly related to the shape coefficient factor.

This research also provides the suggestions for Ådland project. That is both Linear 1 organization and L-Shaped organizations are preferred, since the heating consumption of them are 13.9% and 10% less than Clustered organization, respectively. Both organizations are very appropriate in the cold climate, since they create the wind break by themselves which reduce the heat loss of the building and then the heating demand. Besides, compared with the clustered organization, both of them could achieve a high density with less site influence. Furthermore, U-Shaped organization is also a nice choice, even though it only saves by 3.6% of heating demand compare to Clustered organization, especially, if there is a high requirement on the daylighting availability. In fact, the further work could be the development of three organizations together in Ådland project.

In addition, the results of this research could be a “Starting Guideline” which helps architects to design buildings which significant energy-saving and less environmental impact.

8. Future Development

This research about the impact of building morphology on the energy consumption of buildings, raises more new research questions which should be investigated in the future work.

Initially, this research only examines the four story building types as examples, but the differences on energy performance of 2, 3 and 4 story apartments should also be investigated.

Secondly, this paper focuses on the impact of building morphology on the heating demand of buildings, and results show that there are slight differences among the heating consumption of different building morphologies. However, it is possible that there are influences on the electricity consumption by different building morphologies. This should be explored in the future work.

Thirdly, another interesting result is about the cooling demand in Madrid. The result does not follow the trend of shape coefficient factor. Furthermore, it was found that L-Shaped 1 organization has the highest cooling demand the reasons for this should be investigated further.

Finally, the relationship between energy consumption and the density at neighborhood scale should be examined in future work.

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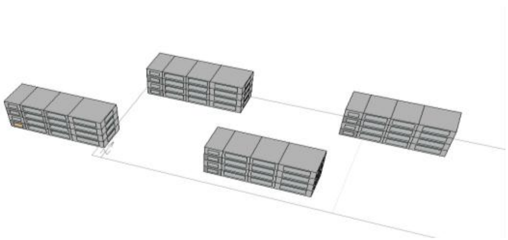
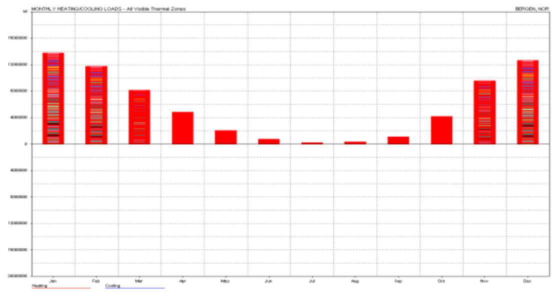
Appendix I

Passive House Standard

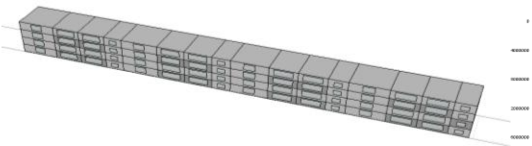
1 Clustered organization

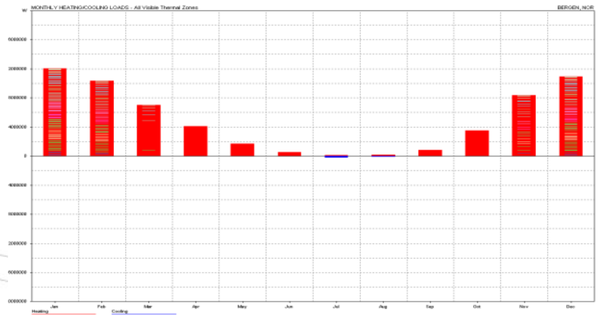




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 50822 W at 08:00 on 8th February			
Max Cooling: 0.0 C - No Cooling.			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	13751515	0	13751515
Feb	11756066	0	11756066
Mar	8107876	0	8107876
Apr	4817724	0	4817724
May	2062136	0	2062136
Jun	712801	0	712801
Jul	190163	0	190163
Aug	310294	0	310294
Sep	1088973	0	1088973
Oct	4198166	0	4198166
Nov	9582036	0	9582036
Dec	12608149	0	12608149
TOTAL	**69185896**	**0**	**69185896**
PER M²	**14414**	**0**	**14414**
Floor Area:	**4800 m^2**		

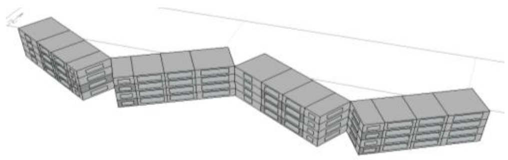
2 Linear 1 organization

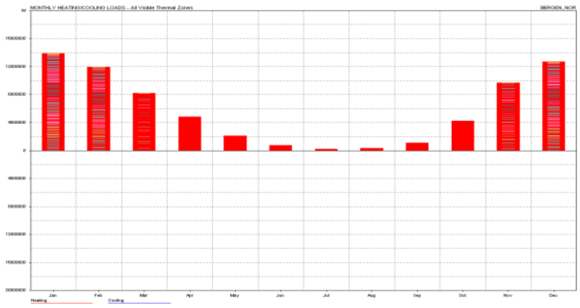




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 46513 W at 08:00 on 8th February			
Max Cooling: 24434 W at 15:00 on 7th July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	12032963	0	12032963
Feb	10325872	0	10325872
Mar	6978432	0	6978432
Apr	4081155	0	4081155
May	1707448	0	1707448
Jun	539970	0	539970
Jul	109049	224227	333275
Aug	192260	105014	297274
Sep	833441	0	833441
Oct	3510438	0	3510438
Nov	8325300	0	8325300
Dec	10948628	0	10948628
TOTAL	**59584952**	**329240**	**59914192**
PER M²	**12414**	**69**	**12482**
Floor Area:	**4800 m^2**		

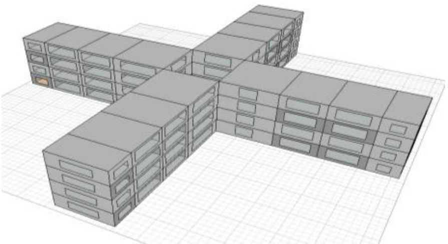
3 Linear 2 organization

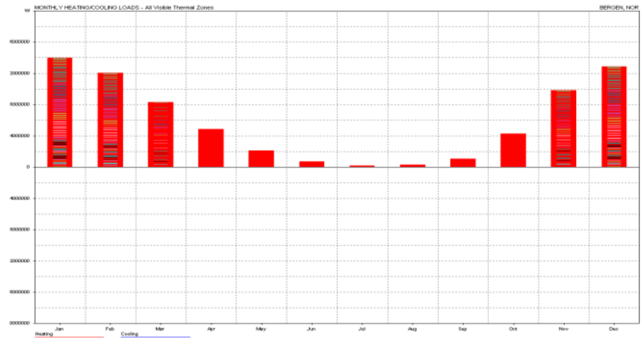




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 50798 W at 08:00 on 8th February			
Max Cooling: 0.0 C - No Cooling.			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	13830005	0	13830005
Feb	11908379	0	11908379
Mar	8173814	0	8173814
Apr	4824797	0	4824797
May	2066827	0	2066827
Jun	716403	0	716403
Jul	192394	0	192394
Aug	303704	0	303704
Sep	1085522	0	1085522
Oct	4227526	0	4227526
Nov	9673460	0	9673460
Dec	12685558	0	12685558
TOTAL	**69688384**	**0**	**69688384**
PER M^2	**14518**	**0**	**14518**
Floor Area:	**4800 m^2**		

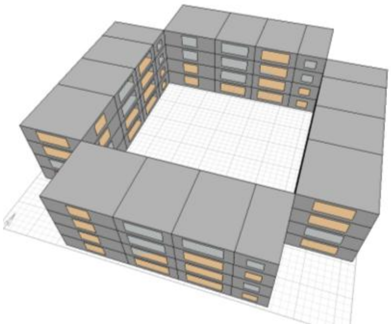
4 Radial organization

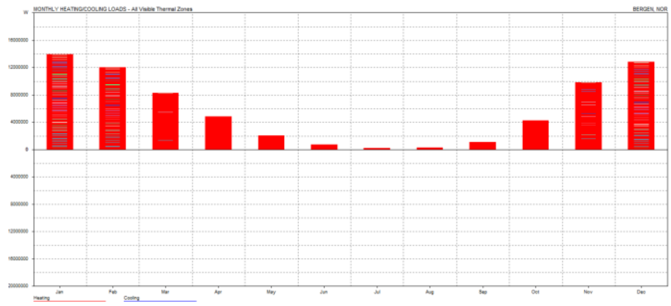




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 50820 W at 08:00 on 8th February			
Max Cooling: 0.0 C - No Cooling.			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	13958323	0	13958323
Feb	12032446	0	12032446
Mar	8277194	0	8277194
Apr	4872594	0	4872594
May	2073238	0	2073238
Jun	717937	0	717937
Jul	184112	0	184112
Aug	301777	0	301777
Sep	1078568	0	1078568
Oct	4258990	0	4258990
Nov	9788971	0	9788971
Dec	12820646	0	12820646
TOTAL	**70364792**	**0**	**70364792**
PER M²	**14659**	**0**	**14659**
Floor Area:	**4800m²**		

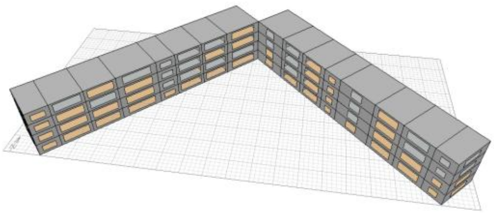
5 Square organization

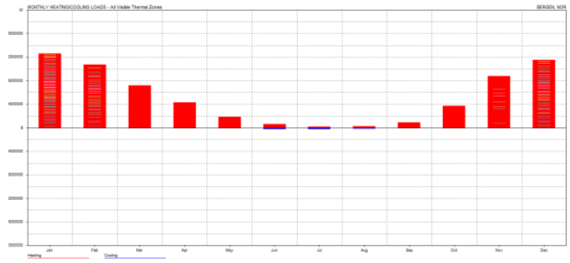




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 50828 W at 08:00 on 8th February			
Max Cooling: 0.0 C - No Cooling.			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	13971287	0	13971287
Feb	12052068	0	12052068
Mar	8266068	0	8266068
Apr	4866238	0	4866238
May	2071449	0	2071449
Jun	718912	0	718912
Jul	188333	0	188333
Aug	307428	0	307428
Sep	1089253	0	1089253
Oct	4259400	0	4259400
Nov	9800379	0	9800379
Dec	12837088	0	12837088
TOTAL	**70427904**	**0**	**70427904**
PER M^2	**14672**	**0**	**14672**
Floor Area:	**4800 m^2**		

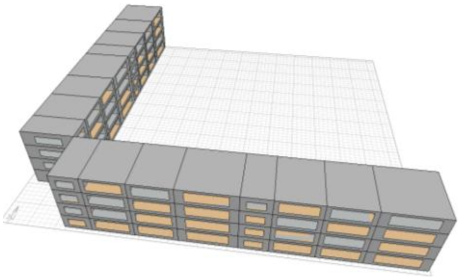
6 L-Shaped 1 organization

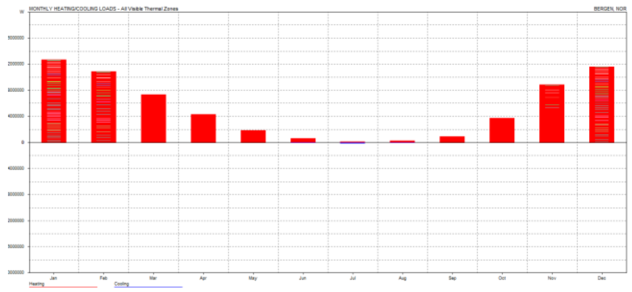




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 48002 W at 08:00 on 8th February			
Max Cooling: 52260 W at 11:00 on 8th June			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	12613803	0	12613803
Feb	10749377	0	10749377
Mar	7207444	0	7207444
Apr	4285777	0	4285777
May	1835429	0	1835429
Jun	606125	273827	879951
Jul	152871	279818	432688
Aug	241956	189280	431236
Sep	922069	7774	929843
Oct	3699376	0	3699376
Nov	8750891	0	8750891
Dec	11531778	0	11531778
TOTAL	**62596896**	**750698**	**63347596**
PER M^2	**13041**	**156**	**13197**
Floor Area:	**4800 m^2**		

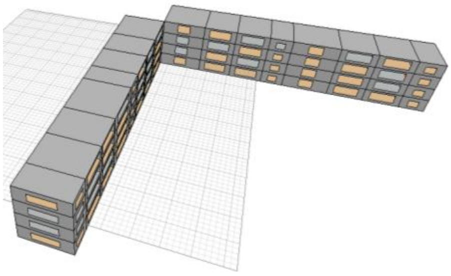
7 Linear 2 organization

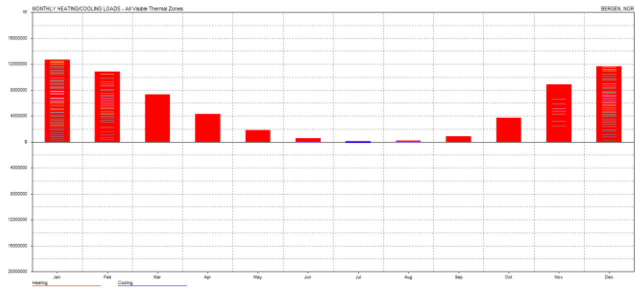




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 47909 W at 08:00 on 8th February			
Max Cooling: 17167 W at 15:00 on 7th July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	12679653	0	12679653
Feb	10834299	0	10834299
Mar	7318940	0	7318940
Apr	4320624	0	4320624
May	1833406	0	1833406
Jun	599998	80691	680689
Jul	135704	188094	323798
Aug	233976	107837	341813
Sep	916658	0	916658
Oct	3736865	0	3736865
Nov	8811444	0	8811444
Dec	11592159	0	11592159
TOTAL	**63013728**	**376622**	**63390352**
PER M^2	**13128**	**78**	**13206**
Floor Area:	**4800 m^2**		

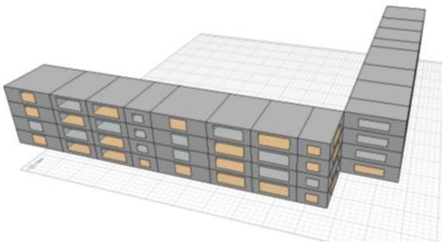
8 L-Shaped 3 organization

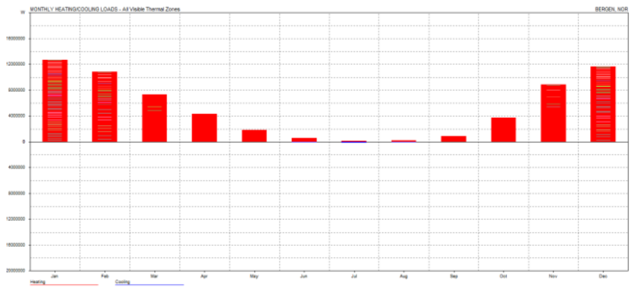




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 47939 W at 08:00 on 8th February			
Max Cooling: 16226 W at 15:00 on 7th July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	12732690	0	12732690
Feb	10898503	0	10898503
Mar	7349286	0	7349286
Apr	4325808	0	4325808
May	1828487	0	1828487
Jun	599664	37740	637405
Jul	134738	157430	292167
Aug	230417	63875	294293
Sep	913469	0	913469
Oct	3746012	0	3746012
Nov	8861372	0	8861372
Dec	11649912	0	11649912
TOTAL	**63270356**	**259045**	**63529400**
PER M^2	**13181**	**54**	**13235**
Floor Area:	**4800m^2**		

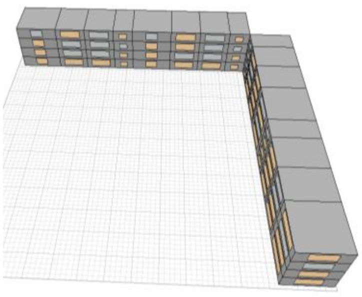
9 L-Shaped 4 organization

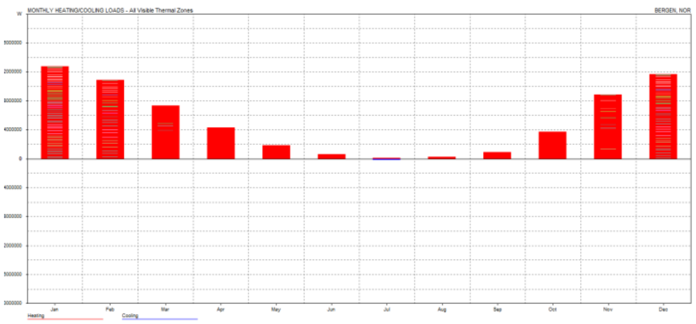




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 47933 W at 08:00 on 8th February			
Max Cooling: 16180 W at 15:00 on 7th July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	12725798	0	12725798
Feb	10887924	0	10887924
Mar	7344668	0	7344668
Apr	4326301	0	4326301
May	1831552	0	1831552
Jun	601686	37794	639479
Jul	135662	156882	292544
Aug	232081	63564	295645
Sep	917307	0	917307
Oct	3744722	0	3744722
Nov	8854782	0	8854782
Dec	11644571	0	11644571
TOTAL	**63247052**	**258240**	**63505292**
PER M^2	**13176**	**54**	**13230**
Floor Area:	**4800 m^2**		

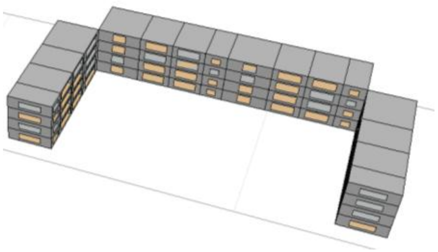
10 L-Shaped 5 organization

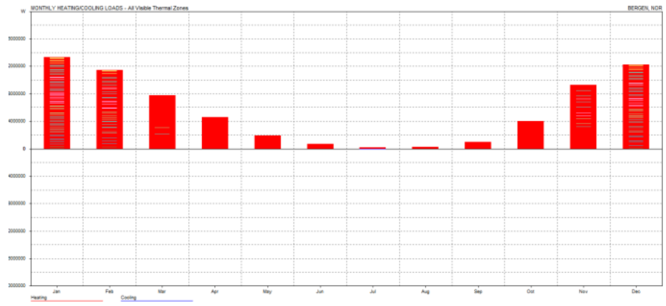




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 47909 W at 08:00 on 8th February			
Max Cooling: 17409 W at 15:00 on 7th July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	12710523	0	12710523
Feb	10894235	0	10894235
Mar	7344551	0	7344551
Apr	4321480	0	4321480
May	1829507	0	1829507
Jun	601851	28097	629948
Jul	135331	158066	293397
Aug	231199	58187	289387
Sep	917775	0	917775
Oct	3740926	0	3740926
Nov	8844839	0	8844839
Dec	11630132	0	11630132
TOTAL	**63202356**	**244350**	**63446704**
PER M^2	**13167**	**51**	**13218**
Floor Area:	**4800 m^2**		

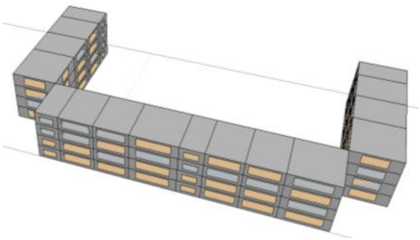
11 U-Shaped 1 organization

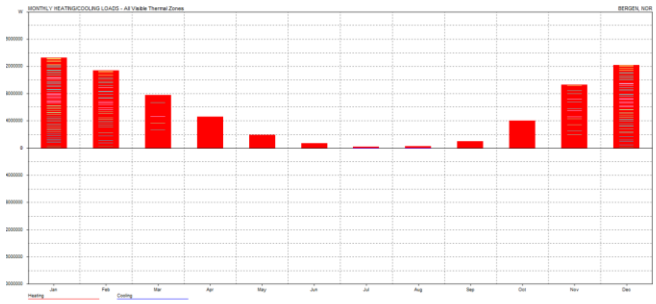




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 49392 W at 08:00 on 8th February			
Max Cooling: 8087 W at 15:00 on 7th July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	13338820	0	13338820
Feb	11429676	0	11429676
Mar	7766701	0	7766701
Apr	4582784	0	4582784
May	1944896	0	1944896
Jun	657916	0	657916
Jul	161823	74119	235942
Aug	265478	34713	300191
Sep	998395	0	998395
Oct	3987659	0	3987659
Nov	9312058	0	9312058
Dec	12235965	0	12235965
TOTAL	**66682172**	**108832**	**66791004**
PER M^2	**13892**	**23**	**13915**
Floor Area:	**4800 m^2**		

12 U-Shaped 2 organization

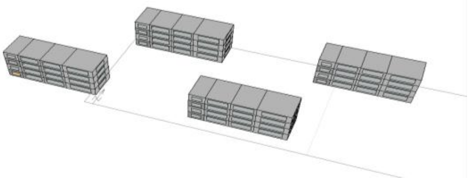


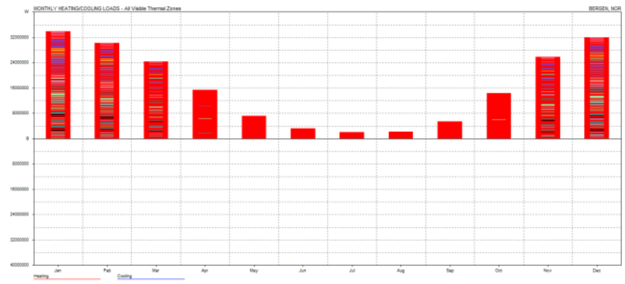


MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 49353 W at 08:00 on 8th February			
Max Cooling: 11360 W at 12:00 on 31st July			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	13269439	0	13269439
Feb	11370630	0	11370630
Mar	7741847	0	7741847
Apr	4573926	0	4573926
May	1945543	0	1945543
Jun	660346	42992	703337
Jul	161501	105362	266862
Aug	271677	78949	350626
Sep	1002133	0	1002133
Oct	3977810	0	3977810
Nov	9247681	0	9247681
Dec	12157449	0	12157449
TOTAL	**66379972**	**227302**	**66607276**
PER M^2	**13829**	**47**	**13877**
Floor Area:	**4800 m^2**		

2nd U-values

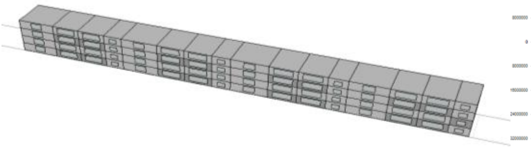
1 Clustered organization

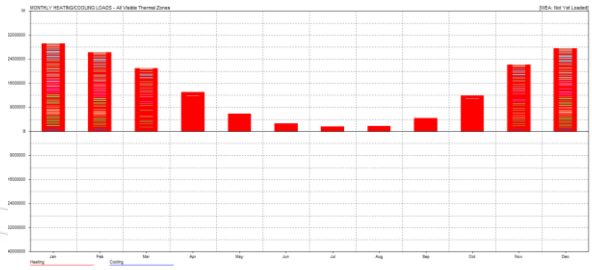




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 93523 W at 08:00 on 10th February			
Max Cooling: 21417 W at 11:00 on 3rd August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	33892300	0	33892300
Feb	30302148	0	30302148
Mar	24305528	0	24305528
Apr	15389658	0	15389658
May	7212144	0	7212144
Jun	3291851	0	3291851
Jul	2026920	0	2026920
Aug	2244043	21417	2265460
Sep	5454772	0	5454772
Oct	14321503	0	14321503
Nov	25793496	0	25793496
Dec	32040430	0	32040430
TOTAL	**1.96E+08**	**21417**	**196296192**
PER M^2	**40891**	**4**	**40895**
Floor Area:	**4800 m^2**		

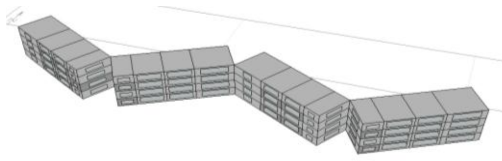
2 Linear 1 organization





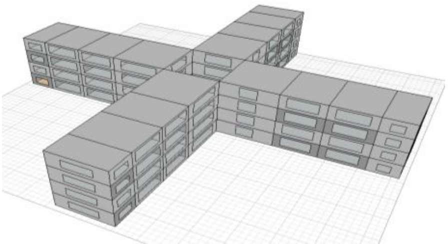
MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 82741 W at 08:00 on 10th February			
Max Cooling: 7130 W at 12:00 on 5th August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	29264584	0	29264584
Feb	26314882	0	26314882
Mar	20942014	0	20942014
Apr	13033714	0	13033714
May	5902250	0	5902250
Jun	2643377	0	2643377
Jul	1581321	0	1581321
Aug	1742637	7130	1749767
Sep	4336450	0	4336450
Oct	11945081	0	11945081
Nov	22131642	0	22131642
Dec	27588574	0	27588574
TOTAL	**1.67E+08**	**7130**	**167433664**
PER M^2	**34881**	**1**	**34882**
Floor Area:	**4800 m^2**		

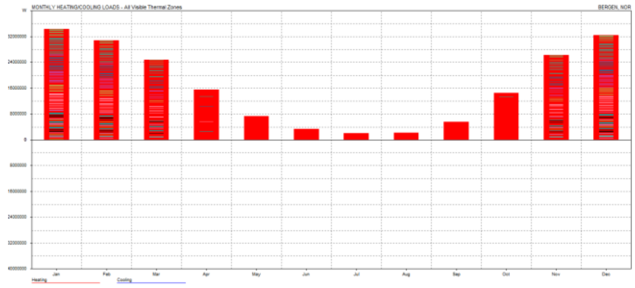
3 Linear 2 organization



MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 93498 W at 08:00 on 10th February			
Max Cooling: 0.0 C - No Cooling.			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	34072632	0	34072632
Feb	30634440	0	30634440
Mar	24628756	0	24628756
Apr	15389056	0	15389056
May	7265878	0	7265878
Jun	3308046	0	3308046
Jul	2031653	0	2031653
Aug	2254684	0	2254684
Sep	5487965	0	5487965
Oct	14458081	0	14458081
Nov	26028590	0	26028590
Dec	32216516	0	32216516
TOTAL	**1.98E+08**	**0**	**197776304**
PER M^2	**41203**	**0**	**41203**
Floor Area:	**4800 m^2**		

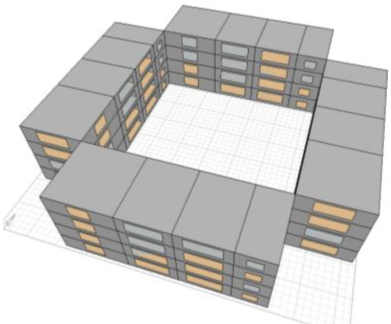
4 Radial organization

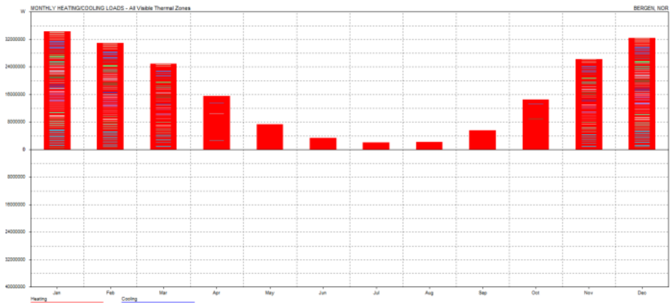




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 93509 W at 08:00 on 10th February			
Max Cooling: 5280 W at 11:00 on 3rd August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	34297036	0	34297036
Feb	30876516	0	30876516
Mar	24847484	0	24847484
Apr	15602094	0	15602094
May	7320157	0	7320157
Jun	3323100	0	3323100
Jul	2035598	0	2035598
Aug	2263860	5280	2269140
Sep	5532897	0	5532897
Oct	14549646	0	14549646
Nov	26254128	0	26254128
Dec	32390808	0	32390808
TOTAL	**1.99E+08**	**5280**	**199298624**
PER M^2	**41519**	**1**	**41521**
Floor Area:	**4800 m^2**		

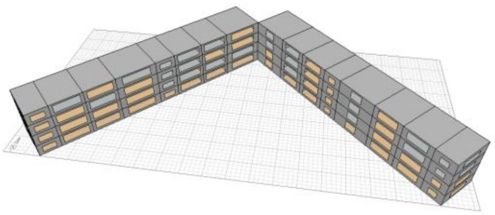
5 Square organization

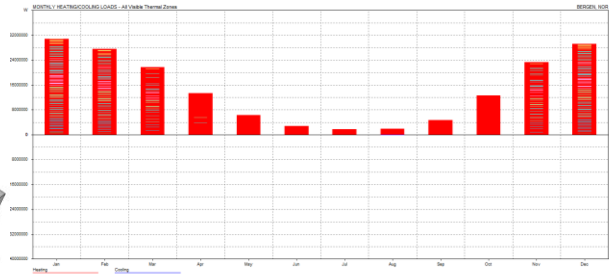




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 93529 W at 08:00 on 10th February			
Max Cooling: 0.0 C - No Cooling.			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	34340100	0	34340100
Feb	30940632	0	30940632
Mar	24895022	0	24895022
Apr	15618379	0	15618379
May	7306292	0	7306292
Jun	3322253	0	3322253
Jul	2035569	0	2035569
Aug	2262713	0	2262713
Sep	5529884	0	5529884
Oct	14559531	0	14559531
Nov	26313778	0	26313778
Dec	32447230	0	32447230
TOTAL	**2E+08**	**0**	**199571376**
PER M^2	**41577**	**0**	**41577**
Floor Area:	**4800 m^2**		

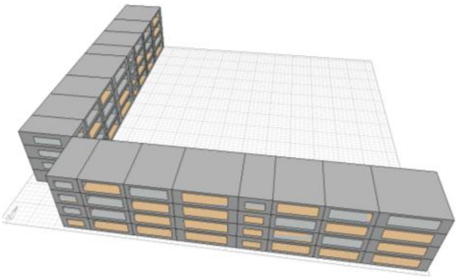
6 L-Shaped 1 organization

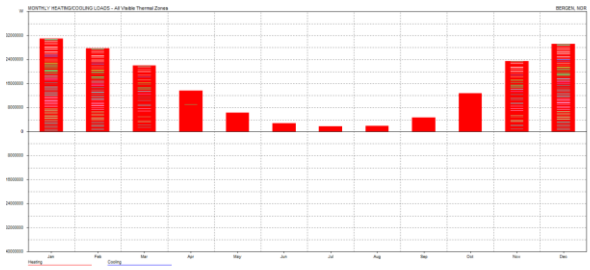




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 86390 W at 08:00 on 10th February			
Max Cooling: 25219 W at 12:00 on 3rd August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	30881878	0	30881878
Feb	27640102	0	27640102
Mar	21710444	0	21710444
Apr	13395024	0	13395024
May	6261704	0	6261704
Jun	2841822	0	2841822
Jul	1725334	0	1725334
Aug	1908212	88136	1996349
Sep	4663086	0	4663086
Oct	12659450	0	12659450
Nov	23404426	0	23404426
Dec	29159410	0	29159410
TOTAL	**1.76E+08**	**88136**	**1.76E+08**
PER M?	**36719**	**18**	**36737**
Floor Area:	**4800 m^2**		

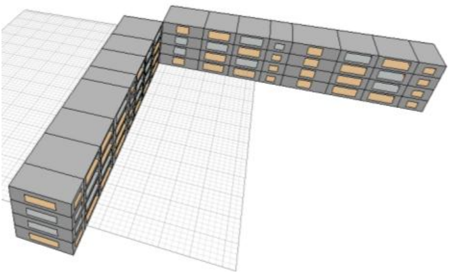
7 Linear 2 organization

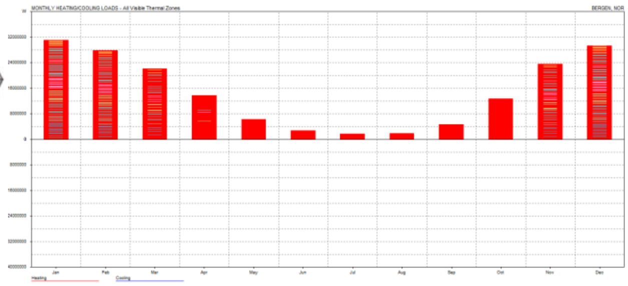




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 86291 W at 08:00 on 10th February			
Max Cooling: 5360 W at 11:00 on 3rd August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	30984658	0	30984658
Feb	27796584	0	27796584
Mar	22012300	0	22012300
Apr	13689817	0	13689817
May	6341890	0	6341890
Jun	2861374	0	2861374
Jul	1730001	0	1730001
Aug	1912286	21475	1933762
Sep	4708590	0	4708590
Oct	12761034	0	12761034
Nov	23499060	0	23499060
Dec	29182952	0	29182952
TOTAL	**1.77E+08**	**21475**	**1.78E+08**
PER M^2	**36975**	**4**	**36980**
Floor Area:	**4800 m^2**		

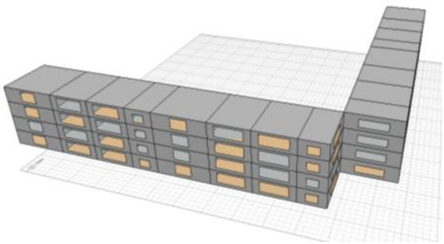
8 L-Shaped 3 organization

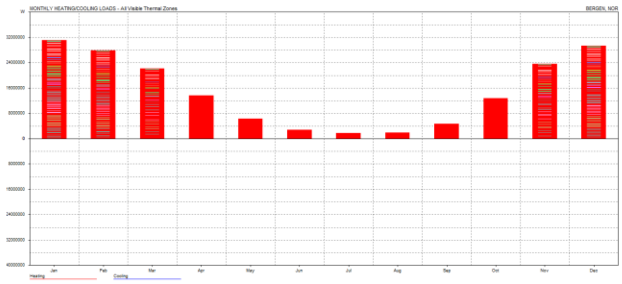




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 86335 W at 08:00 on 10th February			
Max Cooling: 4656 W at 12:00 on 5th August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	31098072	0	31098072
Feb	27950866	0	27950866
Mar	22143080	0	22143080
Apr	13736734	0	13736734
May	6338072	0	6338072
Jun	2862276	0	2862276
Jul	1731346	0	1731346
Aug	1912497	4656	1917153
Sep	4715228	0	4715228
Oct	12807208	0	12807208
Nov	23639694	0	23639694
Dec	29315282	0	29315282
TOTAL	**1.78E+08**	**4656**	**1.78E+08**
PER M^2	**37135**	**1**	**37136**
Floor Area:	**4800 m^2**		

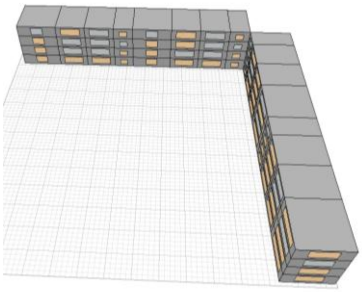
9 L-Shaped 4 organization

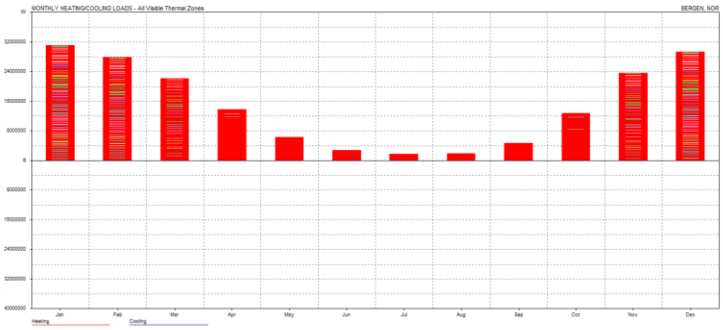




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 86291 W at 08:00 on 10th February			
Max Cooling: 4656 W at 12:00 on 5th August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	31072550	0	31072550
Feb	27918638	0	27918638
Mar	22103312	0	22103312
Apr	13719922	0	13719922
May	6333035	0	6333035
Jun	2860909	0	2860909
Jul	1729452	0	1729452
Aug	1911843	4656	1916499
Sep	4710520	0	4710520
Oct	12790043	0	12790043
Nov	23616202	0	23616202
Dec	29293622	0	29293622
TOTAL	**1.78E+08**	**4656**	**1.78E+08**
PER M^2	**37096**	**1**	**37097**
Floor Area:	**4800 m^2**		

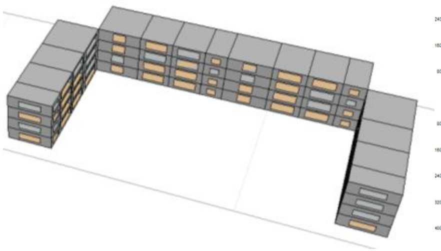
10 L-Shaped 5 organization

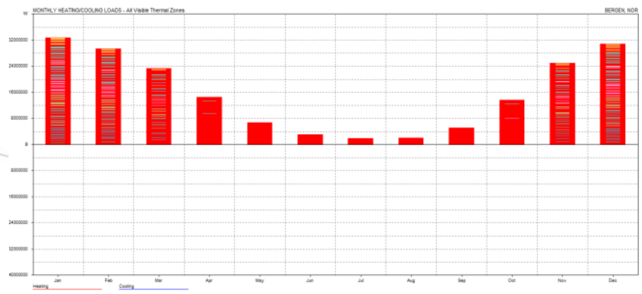




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 86291 W at 08:00 on 10th February			
Max Cooling: 2376 W at 12:00 on 5th August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	31071024	0	31071024
Feb	27947732	0	27947732
Mar	22154456	0	22154456
Apr	13750204	0	13750204
May	6342741	0	6342741
Jun	2861400	0	2861400
Jul	1729695	0	1729695
Aug	1911802	2376	1914179
Sep	4714502	0	4714502
Oct	12797829	0	12797829
Nov	23625626	0	23625626
Dec	29290548	0	29290548
TOTAL	**1.78E+08**	**2376**	**1.78E+08**
PER M^2	**37124**	**0**	**37125**
Floor Area:	**4800 m^2**		

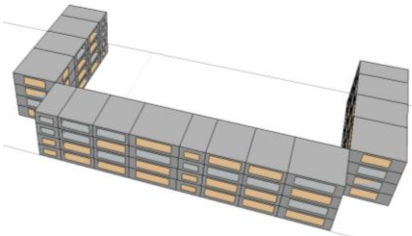
11 U-Shaped 1 organization

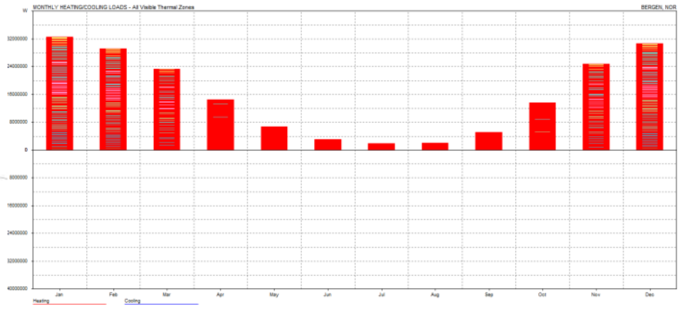




MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 89903 W at 08:00 on 10th February			
Max Cooling: 2377 W at 12:00 on 5th August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	32683808	0	32683808
Feb	29367836	0	29367836
Mar	23378590	0	23378590
Apr	14583554	0	14583554
May	6780833	0	6780833
Jun	3081382	0	3081382
Jul	1879595	0	1879595
Aug	2080858	2377	2083234
Sep	5096091	0	5096091
Oct	13631637	0	13631637
Nov	24925178	0	24925178
Dec	30847432	0	30847432
TOTAL	**1.88E+08**	**2377**	**1.88E+08**
PER M^2	**39237**	**0**	**39237**
Floor Area:	**4800 m^2**		

12 U-Shaped 2 organization





MONTHLY HEATING/COOLING LOADS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
Max Heating: 89894 W at 08:00 on 10th February			
Max Cooling: 5335 W at 11:00 on 3rd August			
	HEATING	**COOLING**	**TOTAL**
MONTH	**(Wh)**	**(Wh)**	**(Wh)**
Jan	32562132	0	32562132
Feb	29230684	0	29230684
Mar	23304452	0	23304452
Apr	14585298	0	14585298
May	6801374	0	6801374
Jun	3081860	0	3081860
Jul	1880211	0	1880211
Aug	2080481	19171	2099651
Sep	5097567	0	5097567
Oct	13597621	0	13597621
Nov	24789404	0	24789404
Dec	30718878	0	30718878
TOTAL	**1.88E+08**	**19171**	**1.88E+08**
PER M2	**39110**	**4**	**39114**
Floor Area:	**4800 m^2**		

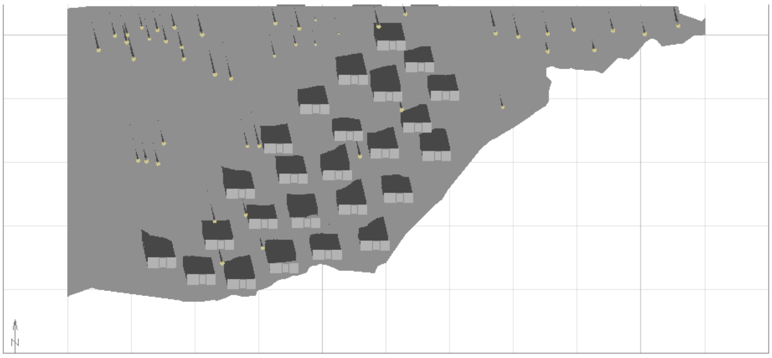
Appendix II

Supplement Study

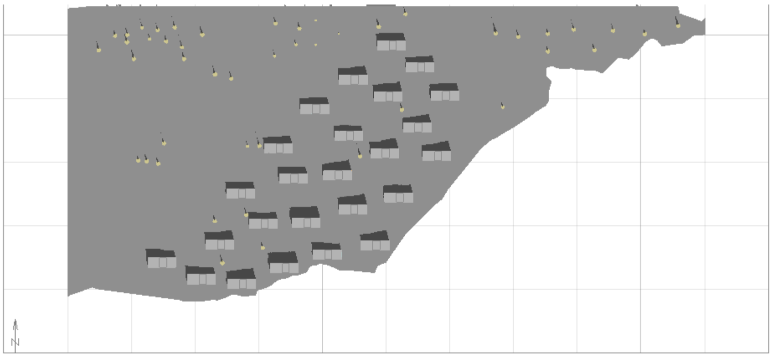
This appendix shows that ECOTECT also could do shadow pattern analysis of buildings in a neighborhood scale. The results here would be useful for the future research on the impact of the site density on the energy consumption of buildings.

1 Clustered organization

21st March/Autumn



21st June



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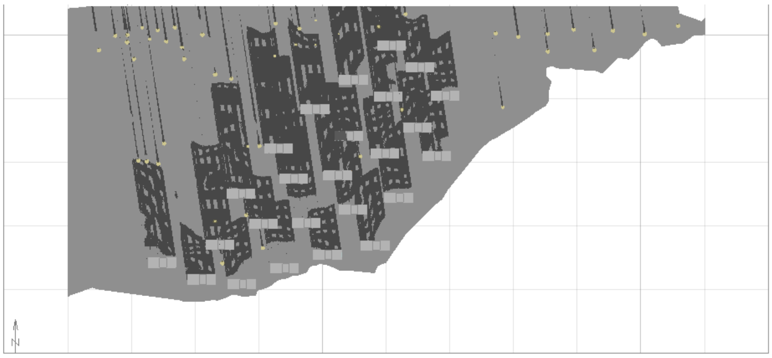
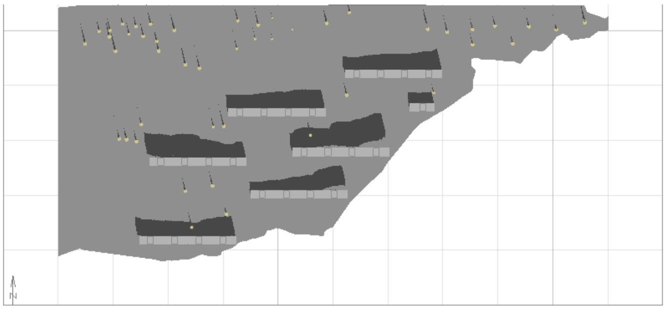


2 Linear 1 organization

21st March/Autumn



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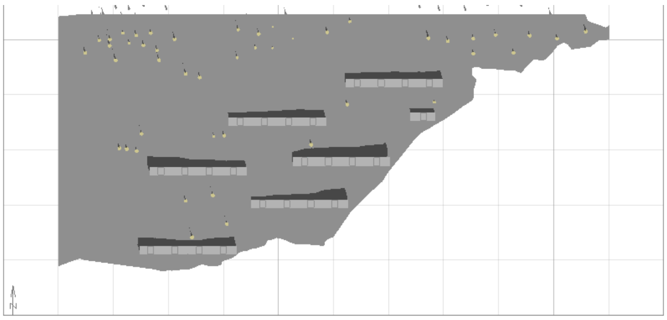

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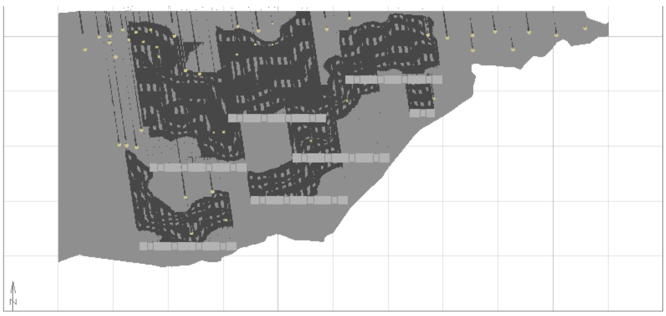
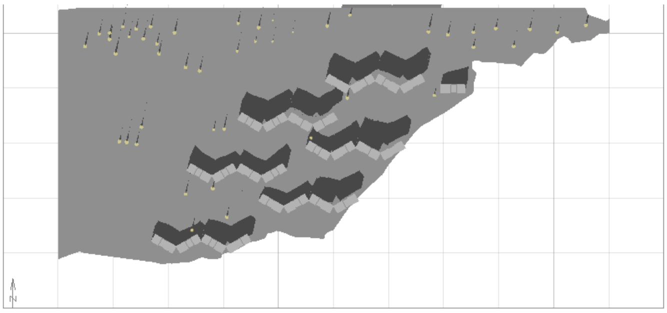


3 Linear 2 organization

21st March/Autumn



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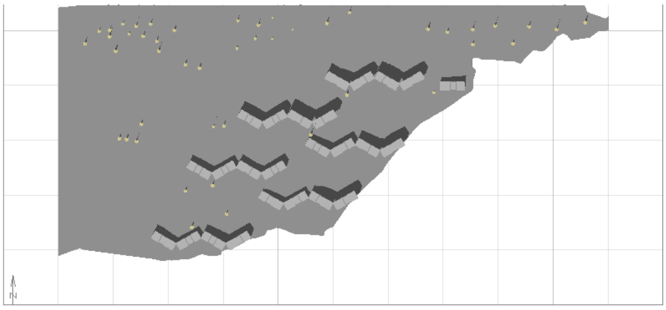

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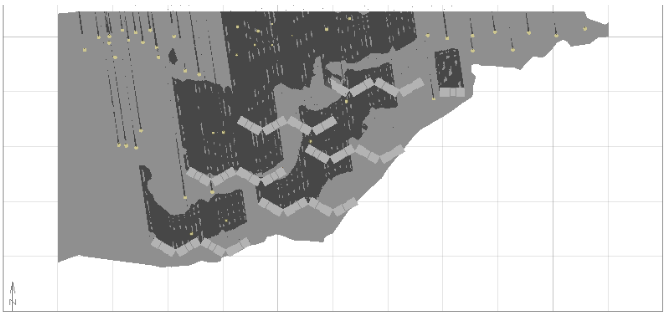
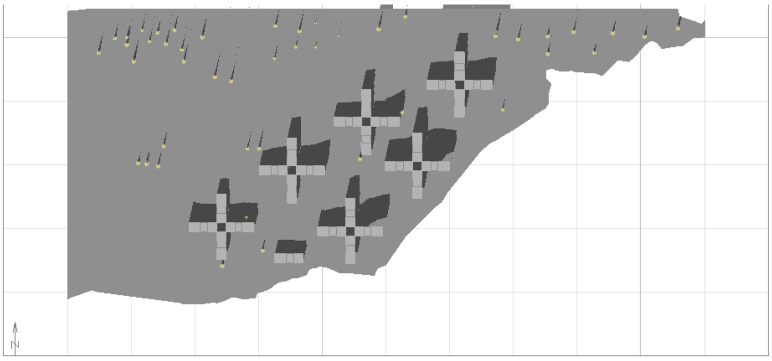


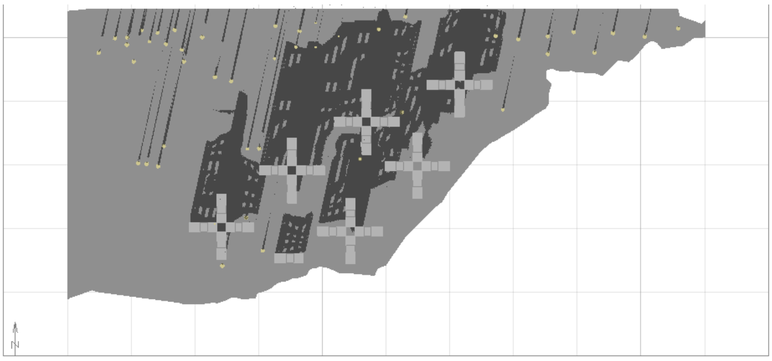
4 Radial organization

21st March/Autumn



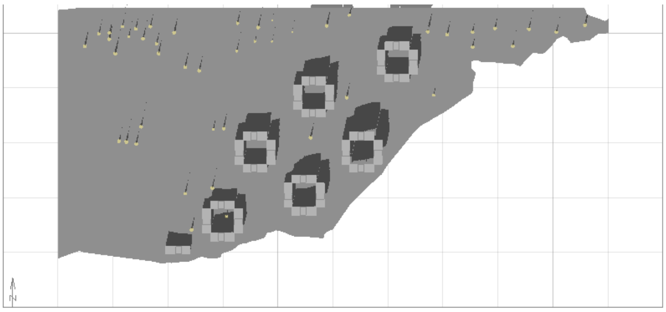
21st June

21st December



5 Square organization

21st March/Autumn



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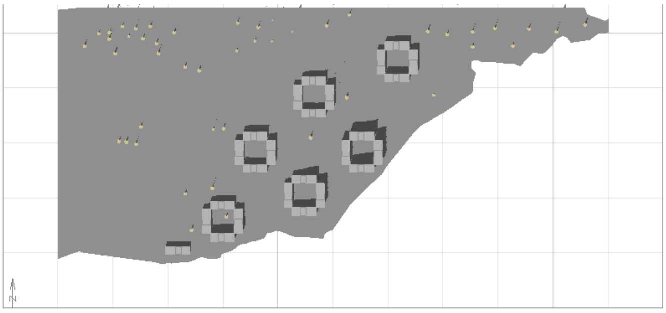

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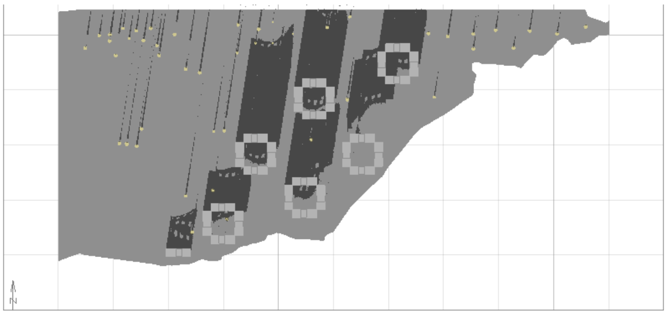
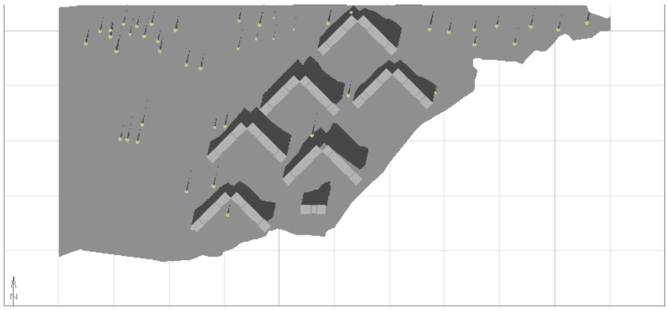


6 L-Shaped 1 organization

21st March/Autumn



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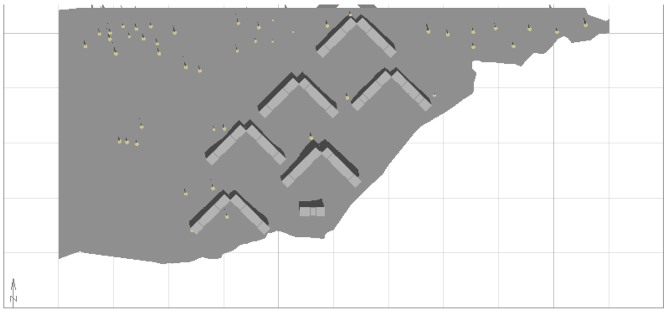

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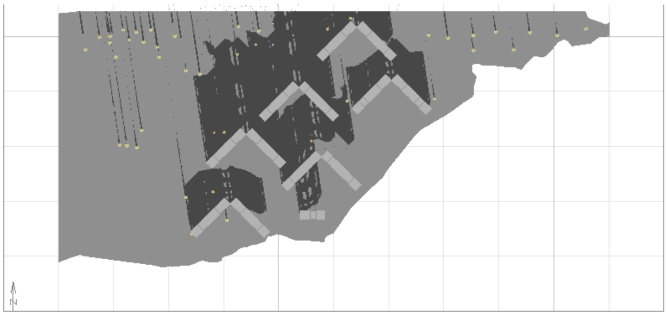
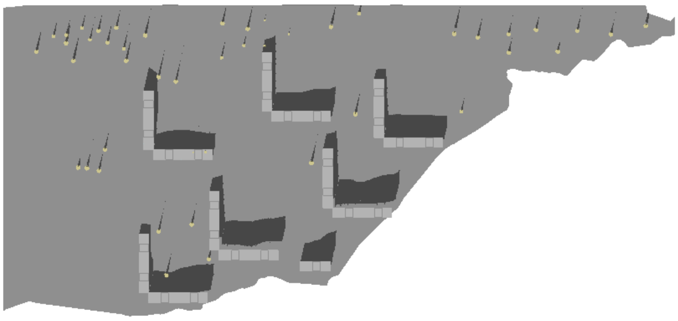


7 L-Shaped 2 organization

21st March/Autumn



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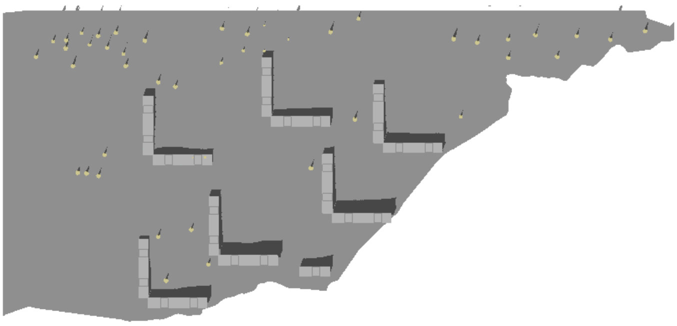
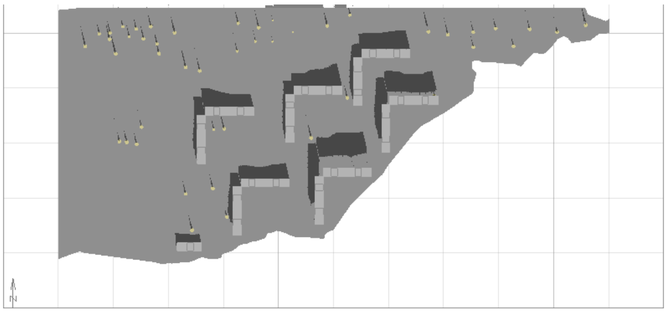


21st December

8 L-Shaped 3 organization

21st March/Autumn



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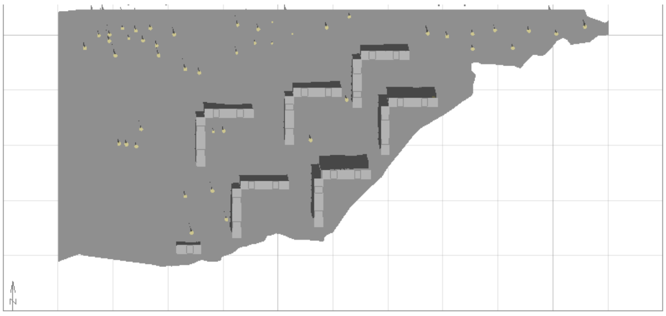

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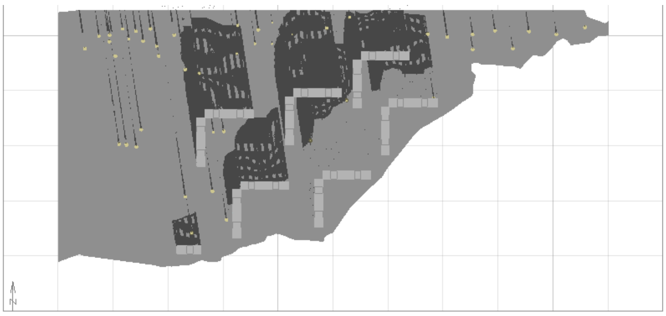
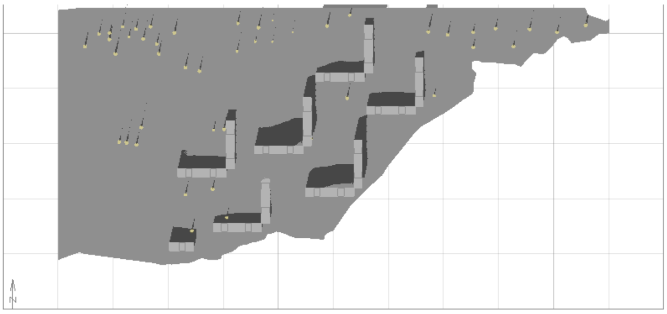


9 L-Shaped 4 organization

21st March/Autumn



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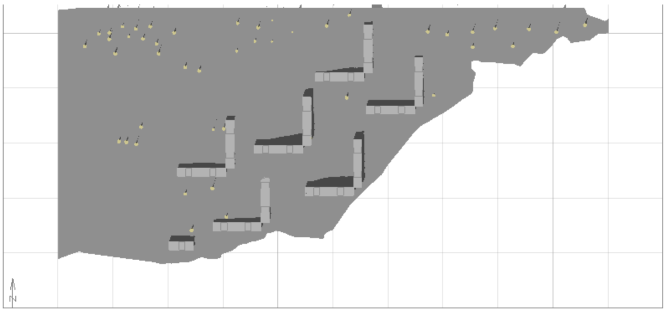

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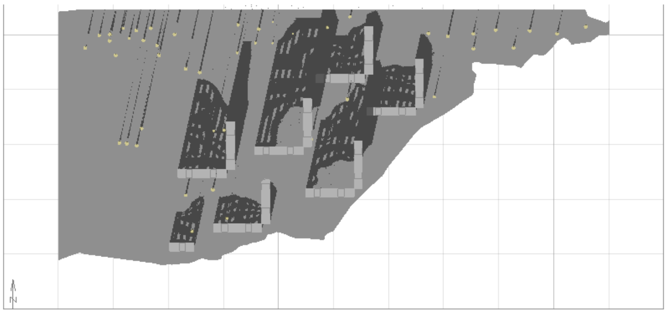
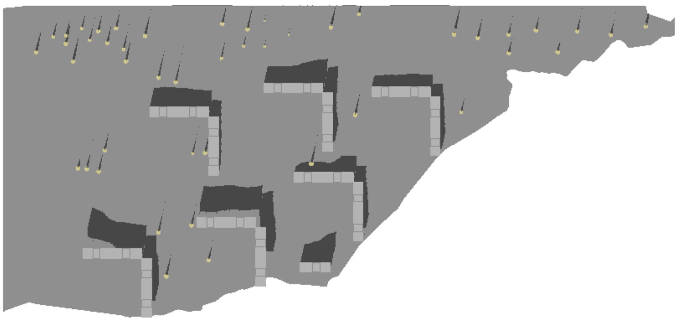


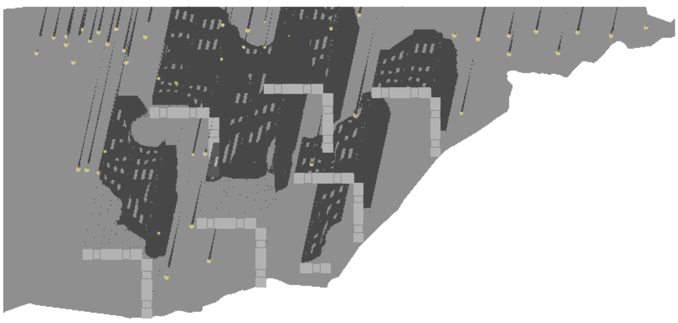
10 L-Shaped 5 organization

21st March/Autumn



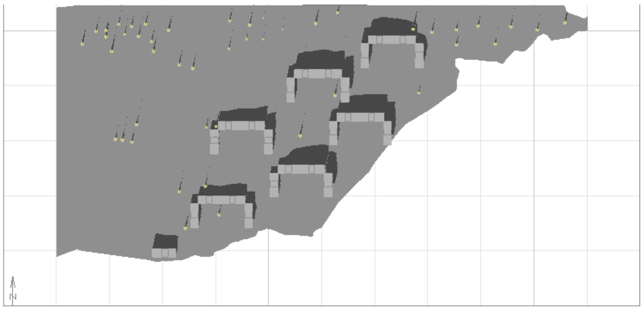
21st June

21st December



11 U-Shaped 1 organization

21st March/Autumn



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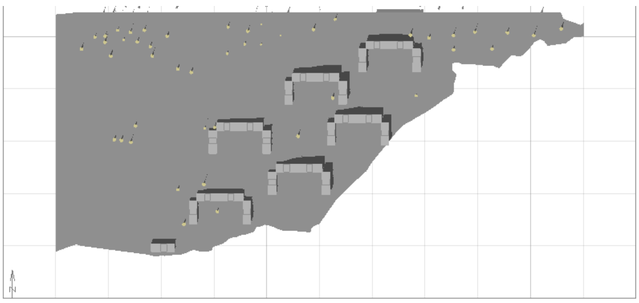

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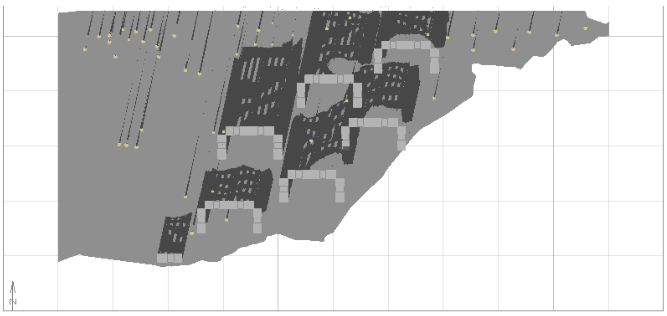
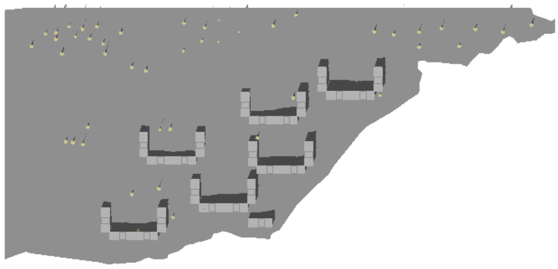


12 U-Shaped 2 organization

21st March/Autumn

21st June



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