



Report Title: The Impacts on Solar Access and Energy Demand of Different Building Masses in Linear Building Forms • <i>An Feasibility Study of Norwegian Suburb Sustainable Residential Community Project: Ådland, Bergen</i>	Date: 09.06.2012			
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Abstract: The main direction of the thesis is analyzing the impact on solar access and energy demand of different building mass in linear building forms. The study model of this work is a current ongoing project - a suburb sustainable residential community design project locates in Ådland, Bergen, Norway. The work mainly consists of two parts: theory and project analyses. Both two parts are focusing on reducing environmental impact of suburb sustainable residential communities. More specifically, the theory is aiming on finding out the critical design and energy issues for suburb sustainable residential communities. The project is aiming on using the strategies from theory part and analyzing critical design issues of solar access and energy issues of heating demand reduction with different building masses.
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Keywords:

1. <i>Suburb sustainable residential community</i>
2. <i>Reduction of environmental impact</i>
3. <i>Ensuring solar access</i>
4. <i>Reduction of heating demand</i>
5. <i>Renewable energy supply systems</i>

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1. Introduction

1.1 Research Field and Research Question

This work examines the impacts on energy demand and solar access of three different building masses in linear building forms. The study model of this work is a current ongoing suburb sustainable residential community design project in Ådland, Bergen, Norway.

The study focuses on a community scale. Three different building masses are named as site layout 1, site layout 2 and site layout 3. By designing and comparing these three site layouts, the study explores how solar access to the buildings, outdoor open spaces and their total heating demand are affected. This lead to the objective of the thesis is to find out the criteria for arranging the site with meeting both the needs of better solar access and lower total heating demand. The goal of the thesis is to give suggestions on further reduction of environmental impact from the feasibility study proposed by our supervisor [18].

Buildings and associated infrastructure cause approximately 30% of the energy and material flows and effects on the environment [1, 6]. If we can assume that climate change is the direct outcome of human activities, then the reduction of building energy consumption should be considered initially. So in another word, the objective of sustainability in the context of building sector is producing the least possible amount of energy to reduce the environmental impact. Regardless of the sources, the energy efficiency of buildings is considered as the initial task for any sustainable strategies. Being energy efficiency overall is to reduce operation energy use of a building by applying measure that primarily affects the building envelope and spatial design. Those measures are known as passive strategies, such as:

- Orientation of the building in related to microclimate, e.g.: solar heating, wind and etc;
- Insulating and air tightness for building envelope;
- Glazed openings design for providing appropriate natural day light, solar energy and etc.

Energy efficiency measures should be provided to different sustainable building design with the adjustability to different climate and surroundings. Basic elements in a residential community are a cluster of building blocks standing closely to each other. It could consists of hundreds blocks, some cases might be more, and some might be less. Thus, each building's location in the community will affect others surrounded. From a single building block view point, the orientation, the solar gain affected by other building surrounded, the building envelope efficiency measures are influencing the heating demand. From the whole community viewpoint, in order to receive relatively equal opportunity of the passive solar

usage, the arrangement of the building blocks with the consideration of terrain level and the distances among the blocks should be analyzed. *Grouping and joining units also promote savings in both construction and energy...* [13,148]. The reduction of external surface in contact with air can help to achieve less heat losses through the building envelope thus a reduction of total heating demand.

Therefore the research question is formed as *what are the impacts on solar access and energy demand of different building masses in linear building forms.*

1.2 Research Scope

Homes accounts for 40% electricity consumption in Norway [14, 20]. Due to this high energy consumption of residential buildings, it is necessary to analyze how to reduce the energy demand in the residential development field. Thus, firstly the scope of the thesis is limited to residential building type in Bergen climate.

Secondly, the scope of the analysis' scale is limited to suburb residential community. Due to the fast urban population and improving transportation technologies, it led the expansion growing towards suburbs. Suburbs emerge in the 1850s and have remained a popular alternative to the city even today. The traditional way of suburban sprawl leads to a higher consumption of fossil fuels. The desire for larger plots of land and the rural feel of the countryside, new developments are infringing upon more and more of the natural, uninhabited land [21]. In order to reduce the environmental impact of the new development residential community, the analyses of preserving existing nature as much as possible and providing the residents' daily needs on site or close to the site should be considered in the early design stage.

Since Ådland project is located in Bergen, Norway, the geographical land is limited to Ådland project development site. Due to the huge size of the plot, only part of it will be analyzed (see detailed information in chapter 3.1).

The aim of this feasibility study is to reduce the environmental impact. So the consideration of preserving of the topography and existing nature as much as possible are discussed in the design of three site layout. There are other issues related to the sustainable residential community residents' daily life, such as: affordable access to safe food and water, ensuring people can live without fear of crime, ensuring community participation in decision-making and etc. These considerations will not be set up as part of the scope.

The dates for solar access analysis are limited to: Dec. 21st, March, 21st, Jun. 21st. And the consideration of solar access is only limited on building facades, exclude the solar access to the interior space. The energy demand calculations are limited to the operational energy use. The energy of building's life cycle will not be considered here.

1.3 Research Methodology

This thesis contains mainly three parts: 1) theory, case study and reflections; 2) project analyses; 3) conclusions.

Since the Ådland project is aiming on developing a suburb residential community, before the study on three different site layouts' design and comparison carried out, the considerations of suburb sustainable residential community design criteria should be considered initially. These considerations have been discussed by answering the following questions sequentially:

- Why sustainability and sustainable buildings?
- Why sustainable development in suburbs?
- What a suburb sustainable residential community constitutes?

A suburb sustainable residential community case study will be analyzed after the theory discussion. It is aiming on learning from what has been done for reducing environmental impact in a sustainable residential community so that the similar strategies can be learn for Ådland project.

At last, Ådland project will be analyzed according to the steps present blow:

- Project site location, surroundings and microclimate
- Existing site nature
- Defining built area and green area
- Design of base unit and consideration of energy efficiency measures
- Design of three site layouts
- Energy demand calculation
- Design discussions and comparisons
- Energy discussions and comparisons

In the feasibility study provided by our supervisor also proposed concept of Zero Emission residential community. So the calculations of renewable energy supply systems will be discussed at last.

2. Design of Suburb Sustainable Residential Community

2.1 Sustainability and Built Environment

Summary:

2.1 includes five parts: 1) sustainable development and objectives; 2) climate changes and buildings; 3) energy use in buildings and energy efficiency strategies; 4) zero emission buildings; 5) use of renewable energy.

2.1 mainly answers the questions of why sustainability and sustainable buildings. And it also introduces the concept of passive house and Zero Emission Buildings.

Sustainable development and objectives

Due to the energy crises in the early 1970s, a rapid growth in understanding that modern development can cause worldwide environmental and social crises. And the contemporary concept of “sustainability” emerged in the same time for alternative modern development approaches that could be envisaged as enduring far into the future. *The definition coined by the Brundtland Commission in 1987 describes development as “sustainable” if it “meets the needs of the present without compromising the ability of future generations to meet their own needs”* [1, 8].

Sustainable development requires meeting four key objectives [2, 2]:

- *Social progress which recognizes the needs of everyone;*
- *Effective protection of the environment*
- *Prudent use of natural resources; and*
- *Maintenance of high and stable levels of economic growth and employment*

In another word, sustainability is focusing on addressing the environmental problem while retaining the balance among human equality and quality of life, economic and social criteria.

Climate changes and buildings

Perhaps today's one of the most imminent environmental problems is global warming. *The political world has, since the 1980s, been worrying about the impact on the Earth's climate of “greenhouse gas” released into the atmosphere through human activities...It is well known that the Earth has warmed and cooled naturally at intervals over its lifespan of billions of years. What is new and dangerous about the current phenomenon is the extraordinary speed with which the new warming seems to be happening* [3, 18]. For example, the impact of the global warming in Norwegian context is illustrated in figure1 [4, 23]. Only the temperatures are determined in heating needs in this analysis. Housing in Trondheim and

Oslo around year 2035 will have the same heating demand as Gothenburg today and about year 2085 the needs will be less than Copenhagen today.



Figure 1: Schematic illustration of the modified fuel needs for space heating when climate changes.

Building and construction industry field is considered as one of the largest “consumers” of man-made materials flows. A life cycle approach to building states: *today’s buildings and associated infrastructure cause approximately 30% of the energy and material flows and effects on the environment* [1, 6]. And specifically in Norwegian context, building sector consumes around 38% of the total energy consumption [Figure 2, 5, 48].

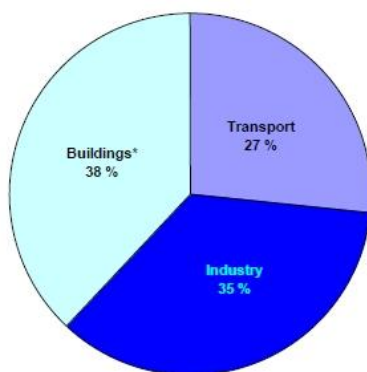


Figure 2: In Norway, buildings count for 38% of the total energy consumptions.

Thus, if we can assume that climate change is the direct outcome of human activities, the reduction of building energy consumption should be considered initially.

Climate changes and the fact of high energy consumption from building and construction sector lead to a serious of new challenges on: energy needs, environmental technologies and etc. The realization of the challenges has been extended into both continental and national. In EU Commission has formulated its 2020 target of a 20% reduction in energy consumption mainly through energy efficiency. And among EU member states, countries propose a comprehensive description of the progress towards very low energy buildings. For instance, Norway has pointed out as a major strategy in cutting CO₂ emissions while proposed passive house standard as the minimum energy performance from 2017 which will be further discussed in the following section [6, 1 and 4].

Energy use in buildings and energy efficiency strategies

Sustainable covers many issues, but none is as important as energy...this energy is mostly derived from fossil sources that produce the carbon dioxide that is the main cause of global warming. We must replace these polluting sources with clean, renewable energy source such as wind, solar energy and biomass, or we must increase the efficiency of our building stock so that it uses less energy [7, 2].

In general, energy associated with buildings includes the operational energy and the construction energy – known as embodied energy. The operational energy is the energy used for heating, cooling, ventilating, run appliances and equipment and providing domestic hot water in buildings. Regardless of the sources, the energy efficiency of buildings is considered as the initial task for any sustainable strategies. Being energy efficiency overall is to reduce operational energy use of a building by applying measures that primarily affects the building envelope and spatial design. Those measures are known as passive strategies, such as:

- Orientation of the building in related to microclimate, e.g.: solar heating, wind and etc;
- Insulating and air tightness for building envelope;
- Glazed openings design for providing appropriate natural day light, solar energy and etc.

Those energy efficiency measures can provide to different sustainable building design with the adjustability to different climate. For instance, usually residential buildings in cold climate such as Norway need higher heating demand. Thus, the passive strategies for diminishing of the heating demand have become significant in this case. The passive solar heating for allowing maximum solar radiation enters the interior space and well-insulated, airtight building envelope for retaining heat within the building is the common principles. (In the overheating period, solar avoidance – shading design might be needed as well.)

Nowadays, many buildings have successfully implemented the passive measures in order to reduce the energy demand. And it has been formalized as a design concept – Passive House. Definition of the passive house concept originally came from Germany: *a passive house is a building, for which thermal comfort can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions - without a need for additional recirculation of air* [8, 4]. Passive house has been considered as a further development of the low energy house since the requirement of passive house design has become stricter on most of the building component categories. In the Norwegian context, passive house concept has also been implemented into the national standard – NS3700 for residential passive house [9]. And the criteria in this standard can be summed as follow [8, 7 and 8]:

- Primary requirement: starting point of net heating needs for space heating is 15kWh/m²a.
- Secondary requirements: for overall heat losses and renewable energy share of heating and domestic hot water and the minimum requirements are for components and supply systems [see table1]. Maximum heat losses factor are between 0.60 and 0.50W/m²K.

Characteristic	Requirement	Ref.
U-value W/m ² K	Wall: ≤0.15 Roof: ≤0.13 Floor: ≤0.15 Windows: ≤0.80 Door: ≤0.80	NS3700
Normalized thermal bridge value W/m ² K	≤0.03	NS3700
Heat recovery	≥80%	NS3700
SPF-recovery factor kW/(m ² /s)	≤1.5	NS3700
Air leakage at 50Pa, n ₅₀	≤0.60h ⁻¹	NS3700

Table 1: Energy efficiency measures from NS 3700.

- In addition, due to the cold climate condition in Norway, climate adjustment is allowed: criteria for buildings in locations with annual mean temperatures lower than 6.3 °C, maximum requirement of annual heating energy demand and overall heat loss can be calculated by following formula in table 2. The maximum of heating demand requirement is allowed to be slightly higher [8, 11].

Building size	annual heating energy demand (net)		Overall heat loss factor, H*
	Annual average temperature (T _m)		
	≤ 6.3°C	>6.3°C	W/(m ² ·K)
Ah < 100m ²	15 + 5.4 x (250 - Ah)/100	15	0,60
Ah < 250m ²			0,55
Ah ≥ 250m ²	15 + 5.4 x (250-Ah)/100 + (2.1 + 0.59 x (250 - Ah)/100) x (6.3 - T _m)	15 + 2.1 x (6.3 - T _m)	0,50

T_m = annual average temperature outdoors
Ah = heated floor space (according to NS3940)

Table 2: Climate adjustment formula from NS 3700.

It can be read from the requirement of the passive house standard, most energy efficiency measures are part of the building fabric. In another word, they are the configuration and structure of the buildings. It is therefore important for addressing energy consideration at an early stage of the decision-making process in the planning, location and design of new building and construction.

Zero emission buildings

Due to the impact of the building on environment mentioned in the previous section and the emergence of concerns about the rapidly increasing CO₂ emissions, passive house concept has been further developed towards zero energy buildings (ZEB). *A passive house with complete balanced annual energy consumption and related equivalent CO₂ emissions is called ZEB. In Europe, ZEB is considered the logical continuation of a long chain of developments from low-energy houses towards passive houses [10, 12].* However, a clear definition of ZEB has not been attained. There are various definitions of ZEB. Torcellini et al. [11, 3]: *ZEB is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies* (to be discussed in the next section). And different countries also have its own understanding and target of a ZEB. For instance, in Germany, the focus will not be a zero energy building, but instead of “zero emission” or “climate neutrality”. In this case, “climate neutrality” means buildings have very low energy demand and the remaining energy demand can be covered by renewable energy sources. And in Switzerland, strategy called 2000-watt society has been developed in the late 1990s. *This Swiss rate will lead to a reduction of the total energy consumption per person from approximately 6500W today to 2000W, and of CO₂ emissions from 8.5 tons to 1 ton by 2150. And the 2000W primary energy per person is corresponding to current global average figures [see figure 3, 10, 14].*

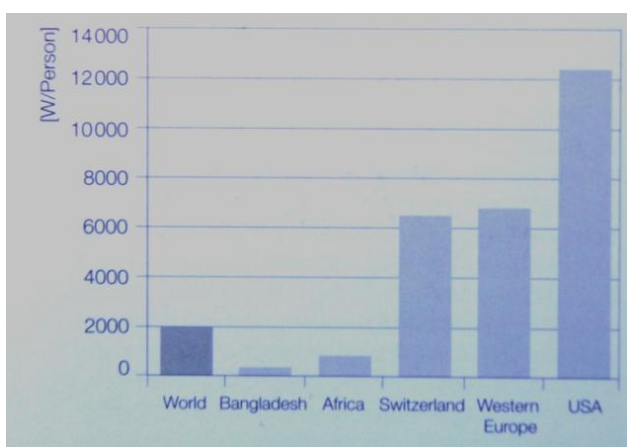


Figure 3: Current global average figures of primary energy per person.

In the Norwegian context, Dokka et al. [12, 2]: *In a Zero Emissions Building such balance is achieved not directly on the energy demand and generation but on the associated carbon equivalent emissions. The energy imported from the grids into the building is accountable for certain emissions. The export of renewable energy from the building to the grids is accountable for avoiding similar emissions by other (non-renewable) energy producers connected to the same energy grids.* Hereafter the balance period became one of the crucial discussion points. Dokka et al. [12, 8] suggested few options. The suggestion of calculating the balance of emissions over a year will be chosen for the energy balancing calculation. It has to be mentioned that carbon dioxide equivalent emissions will be used for measuring the balance between imported and exported energy. And carbon dioxide equivalent emissions will be shortened to CO₂ emissions in this thesis.

Use of renewable energy

As mentioned before, energy is one of the important issues of sustainability. And this energy is mostly derived from fossil sources that produce the carbon dioxide. Carbon dioxide is causing a gradual increase of the average air temperature at the earth's surface. *Concerns about the unsustainable mode of harvesting non-renewable energy resources and the damage that their use is causing to the environment makes the use of renewable resources relevant as well as economical, considering the mounting costs of energy. The British Renewable Energy Advisory Group (REAG) defined renewable energy sources as "Energy flows that occur naturally and repeatedly in the environment and can be harnessed for human benefit"* [13, 15]. And in terms of building energy use, even if a building is designed to provide a comfortable indoor environment annually through passive means, it will still require energy for lighting, running equipment and appliances, and to provide domestic hot water. Despite providing energy efficiency measures for minimizing the heating demand as much as possible, the rest of the energy demand is recommended to be covered by utilizing renewable energy.

In Norwegian context, *homes account for 40 percent of electricity consumption in Norway...* [14, 19]. *Using renewable energy to supply electricity to homes in Norway becomes a central issue. Photovoltaic (PV) – generated electricity is an almost ideal energy source. PV converts sunlight directly into electricity* [7, 205]. The PV production usually have mismatch between winter and summer due to higher solar radiation in summer period. It can be solved by connecting to the existing power grid. Excess PV power can be sold to the utility and drawn back when there is higher demand of the electricity. Norway has the world's largest hydropower production [20]. Electricity provided by Norwegian utility grid is produced by hydro power. Thus, it is also considered as the utilization of renewable energy.

Despite the electricity demand, heating demand should also be covered by renewable energy, such as solar energy. One of the most common systems in this case is solar thermal collector. Since its production is also related to solar radiation, the same mismatch similar to PV production appears. Usually solar thermal collector can be used in combination with, e.g.: ground source heat pump, micro combined heat and power (CHP) and etc. They can help to cover the rest of the heating demand. Heat pump is connected to the ground and makes the use of heat from the ground. *This renewable heat source has been harvested in a number of countries for residential use. The common technique is to drill deep holes through which pipes are inserted to take advantage of the high temperature underground... hot water is then extracted, brought to the surface and used as heat source* [13, 15]. *CHP fuses generation of electricity and production heat into one process. An alternative popular at the moment is to arrange for the electricity to be generated decentrally, directly at the consumer. This approach enables CHP to be incorporated directly into the energy concept of a building or neighbourhood* [16, 143]. Similar to PV systems, the excess electricity can be delivered to electricity grid. The fuel can be fill in to CHP could be, e.g.: biogas, diesel, wood, vegetable oil, natural gas and etc. *From the ecological viewpoint, renewable energy sources should be used whenever possible, e.g.: biomass, hydrogen, waste heat and etc.* [15, 143]. The parameters of CHP such as: the efficiency; the power to heat ratio – the amount of electrical energy generated per kilowatt-hour of heat emitted should be considered when choosing a CHP. Normally a CHP with biogas as energy production fuel, the efficiency is up to 85% and the power to heat ratio is 0.3-0.6 [15, 142].

Conclusion:

Due to the energy crises, sustainability emerged and it represents that meet the needs of the present without compromising the ability of future generations to meet their own needs.

Buildings and associated infrastructure cause approximately 30% of the energy and material flows and effects on the environment. If we can assume that climate change is the direct outcome of human activities, then the reduction of building energy consumption should be considered initially.

A passive house is the house with implementation of passive measures in order to reduce the energy demand. A passive house with complete balanced annual energy consumption and related equivalent CO₂ emissions is called ZEB.

Despite the use of energy efficiency measures, it is recommended to cover the rest of energy demand by utilizing renewable energy.

Thus, it is clear that in the context of building sector, the objective of sustainability is producing the least possible amount of energy to reduce the environmental impact. But the issues of maintaining or improving the life of the occupants living in the buildings should also be borne in mind. But it will not be further discussed in this thesis.

2.2 Issues Central to Suburb Sustainable Residential Community Design

Summary:

2.2 includes three main parts: 1) sustainable development of suburbs; 2) Sustainable residential community in suburbs; 3) design of suburbs sustainable community.

2.2 mainly answer two questions: 1) why sustainable development in suburbs; 2) what a suburb sustainable residential community is; 3) what a suburb sustainable residential community constitutes

At last, a case study will be analyzed in order to discuss the criteria for designing a suburb sustainable residential community.

Sustainable development of the city edges – suburbs

At the end of the twentieth century nearly half of the global population was living in cities, and this figure is expected to rise to 60% by 2030 [2, 16]. Due to the fast urban population and improving transportation technology, it led the expansion growing towards the edge of the cities – suburbs. Suburbs emerge in the 1850s and have remained a popular alternative to the city even today. Suburbs are the communities surrounding cities that are usually made up of single-family homes ...One issue arising from suburban growth is the disorganized, reckless manner in which neighbourhoods are built, called sprawl. Because of the desire for larger plots of land and the rural feel of the countryside, new developments are infringing upon more and more of the natural, uninhabited land. The unprecedented growth of population in the past century will continue to fuel expansion of suburbs in the coming years [21].

The traditional way of suburban sprawl leads a higher consumption of fossil fuels. People need vehicle to reach jobs, shopping area, leisure centres and etc. Gleeson et al. [3, 54] suggests new city extensions towards suburbs should aim for zero net greenhouse gas emissions. And it also mentioned for the sustainable development of suburbs residential community should contain a mixture of activities: affordable housing, workplace, shops, café, sports facilities, child-care centres, schools and etc. So considering how to reduce the environmental impacts of suburbs community is becoming the current challenge in built environment as well.

Sustainable residential community in suburb

Before continuous with the discussion of sustainable residential community design criteria, it is necessary to consider more about “*what a sustainable residential community is and what it constitutes*”.

Firstly, a residential community could be a cluster of building blocks with modest size which form up our daily inhabitable environment. Wheeler [16, 181] gave his understanding of a sustainable residential community: *...It could include a square mile or more, a large area containing hundreds of blocks and tens of thousands of residents or workers. But community may also denote a particular cultural or social grouping of people living in proximity to one another...typically the term has been applied to an area that a resident can easily traverse on foot – that is, with dimensions of one mile or less. This area should also possess some unifying social architectural, economic, historical, or physical characteristics.* This understanding reflected what mentioned in the previous paragraph: residential community should contain a mix of activities. It should be the place can fulfil the basic daily needs of the residents living there.

And Sassi [2, 181] gave a further understanding that *sustainable communities should develop sustainable solutions to meet the basic needs for homes, health, education, employment, an attractive and safe environment, a prosperous economy, good public services and open space.* So planning sustainable communities should not only aim on searching a specific architectural design and construction solution for each building, since sustainable community is about the way people live as well.

All the issues mentioned above should be well considered during the designing of a sustainable community. But not all the issues will be discussed in this thesis, the issues of a sustainable community design will be generally considered as two scales in the following section:

- Site scale: the choice of the site, the existing condition of the site, what the site needs
- Building scale: the adaptable building design for different users

In order to present two scales consideration in a clear manner, the following discussion will be alternate a case study and author's reflections.

Design of suburbs sustainable community

The community La Foret de Marie-Victorin located in Quebec area, Canada can well present the building design based on original natural landscape (reducing impact on the nature). Figure 4 illustrates *the La Foret de Marie-Victorin site is a 102 acre (41 hectare) plot of densely forested land* [13, 72]. It is adjacent to existing village residences on south-east corner. Its south side boundary is against a highway. On the north side boundary, it is facing a river.

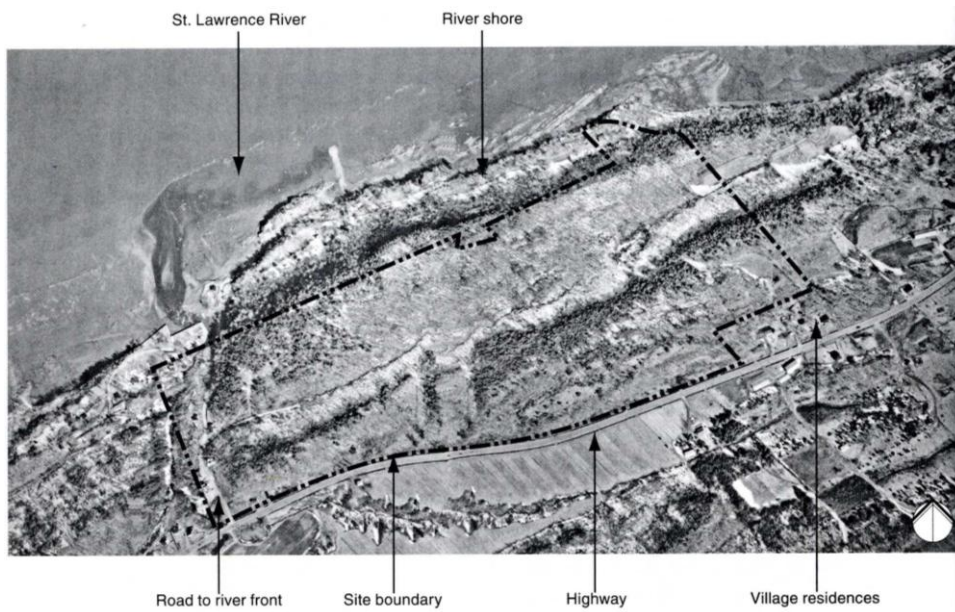


Figure 4: The site location and its surroundings.

The architects started the project with developing the master plan by studying regional and urban issues and their potential effect on the site. They have documented the location of amenities such as daycares, schools, medical clinics, and shops to determine whether such facilities would be needed on the site [13, 73].

The author's reflection 1:

Suburb residential community should change the traditional image of remote area from the city: the shops, working place, academic areas, leisure areas, medical clinics and etc. In order to reduce the dependence on fossil fuel on transportation, the sustainable residential community design should aim on meeting local needs locally if possible. If not, then the place can be reached within cycling distance or other transportation with no dependence on non-renewable energy such as electrical car and/or tram is also highly recommended. And a well arranged public transportation net work can also encourage residents to reduce the use of private vehicles. These above stated issues should be considered while choosing a suburb site for sustainable residential community development.

The second stage of La Foret de Marie-Victorin is the study of site nature and microclimate. The architects found out there are existing streams and a deep ravine crossed the site. They have also found out the temperatures fluctuation in the site area between winter lows of -15°C to -30°C in January, to summer highs of 26°C to 35°C. The sun at the site peaks at a relatively low 68 degrees on the summer solstice and only 21 degrees on the winter solstice. Except the solar reception, winds also affect the environment. Winds also affect it. On the site, north westerly winter winds strongly bluster while south easterly breezes cool summer time heat [13, 73]. But the coniferous forest on site actual as windbreak [Figure 5, 13, 74].

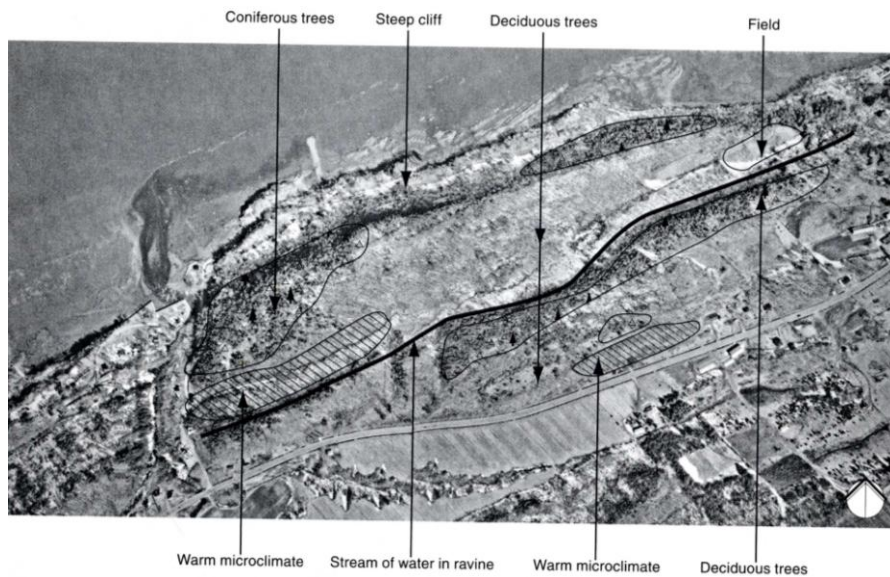


Figure 5: The La Foret de Marie-Victorin site has several areas with dense concentration of deciduous trees.

And architects also invited an expert to judge whether trees on site were worth preserving based on the age and diameter. In general, woodland cover 90 percent of the area and the flora is composed of mixed growth. Most of the trees are deciduous. Animal migration paths and large rock formation are also visible.

The author's reflection 2:

It is necessary to analyze the existing site conditions including: existing nature and the microclimate. In order to minimize impact of development on the environment, developing what we need and preserving what is not needed. Local nature usually not only consists of plant, sometimes there will be existing of fauna. The huge transform of the existing site will change the local ecosystem. And the analysis of the microclimate can provide better passive design of the local buildings. Site nature can brought good potential to serve a better microenvironment. Just as mentioned in the case above, woodland can act as windbreak in winter to prevent higher heat losses from the building. And as figure 4 illustrates there are existing of deciduous trees on site. Those trees can act as nature shading in summer and will allow the penetration of the winter sun.

After the site character analyses completed, the third stage of La Foret de Marie-Victorin is designing the roads and pedestrian paths. To keep the natural condition intact, we decided that circulation routes should be as short as possible. Also, unlike typical suburban streets measuring 12 meter wide, a 6 meters road was designed. An earlier tree survey revealed several patches with fewer, much younger trees. There areas were more suitable for roads rather than clearing areas with older trees [13, 75]. The street path was also routed according to the site elevations, by passing boulders refraining from clearing additional trees [Figure 6, 13, 76].

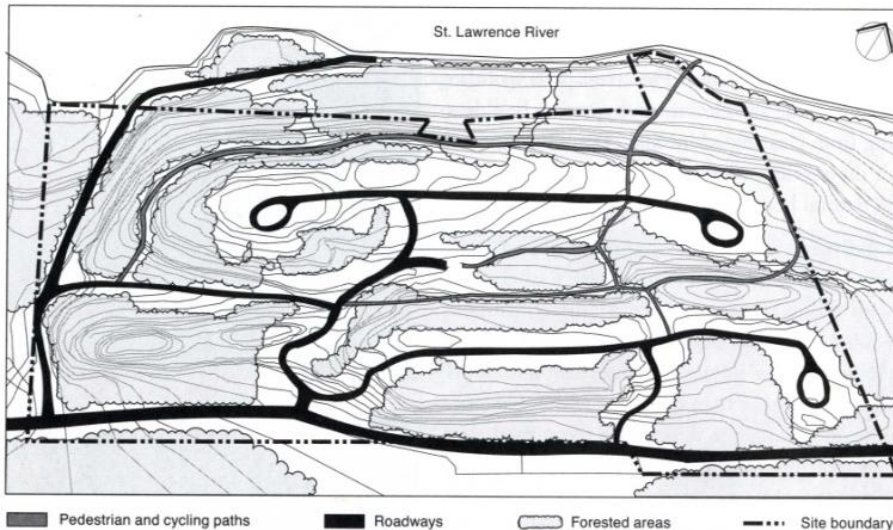


Figure 6: The routes of the roads and the pedestrian path were determined by the concentration of mature trees, the site's elevations, and locations of other natural features.

The author's reflection 3:

Despite the changing of existing nature on site as less as possible, the preserving of topography is also one of the issues should be borne in mind during designing the roads. The native natural landscape, flora and fauna create the distinct character. Similar as mentioned in the author's reflection 2, as soon as the changes of original nature have been down, the ecosystem on site has been changed and cannot be restored again. So roads should be constructed with respect to slopes and changes of site contours as much as possible. And the natural undulation can also remind the drivers on slowing down the speed and driving with care within the residential community.

The architects decided to create long, narrow parcels of each subdivision land in La Foret de Marie-Victorin project. They think smaller homes in denser configurations could be encouraged rather than dwellings with large footprints. And only the trees grew under the footprint of the home would be cut. The rest would be protected during construction and remain untouched [13, 75]. To preserve the site's natural state, homes were placed as close as possible to roads [Figure 7, 13, 76].

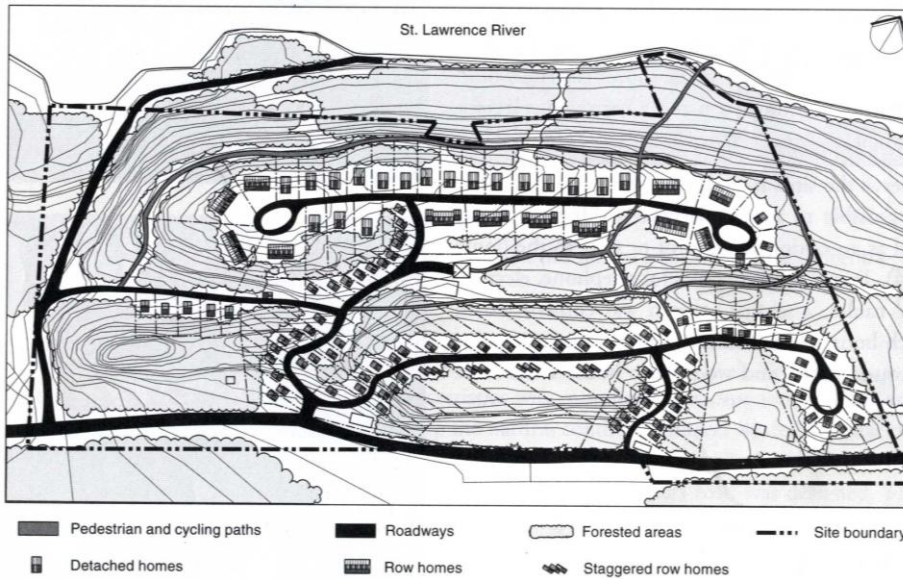


Figure 7: Narrow and long lots were introduced in the project, the homes were clustered near the road to prevent excessive tree clearing.

The author's reflection 4:

The project mentioned above has a clear concept of preserving the site natural as much as possible. And the native trees are protecting the buildings against the extreme weather in Quebec both in winter and summer. The strategy has been provided in this case is a good example of reducing environmental impact on site. But existing nature, microclimate and what exact the project needs for energy production should be analyzed carefully before other projects learn from it. In cold region such as Norway, the sun is much desired in winter and sometimes in summer as well. Due to the low sun angle and short period of sunrise, the dense forest might lead to less solar access problems. And if active solar will be used, such as PV, shadows from surrounded trees cast on PV panels will lead to low energy production, or worst case could be no production from the entire array of the panels. So the analysis method can be learnt but strategies are variable from different projects.

The quest for a home with a long and narrow footprint led to the design of a unit measuring 6 by 10 meters in La Foret de Marie-Victorin project. It created floors with a footprint of 64m², each of which could become a small self-contained, one-bedroom apartment [Figure 8, 19, 76]. The options created a possible scenario whereby the ground floor could be used as an independent dwelling unit to house an elderly member of the family. Alternatively, the floor could become a home office for a resident of the upper two floors. Developers expected that buyers would regard these options as a menu from which they would select their needed numbers of floors, desired interior layout, and suitable finishes [Figure 8, 13, 235 and 237]. To maximize the flexibility of the overall space arrangement, two front doors were designed. This enabled the structure to function as a single-or multi family home. It can be seen from figure 8 the service and mechanical functions are located along the north wall. This led the rest of the place for different interior design that fit the occupant's needs and budgets. The service place occupied north wall can help to reduce energy losses.

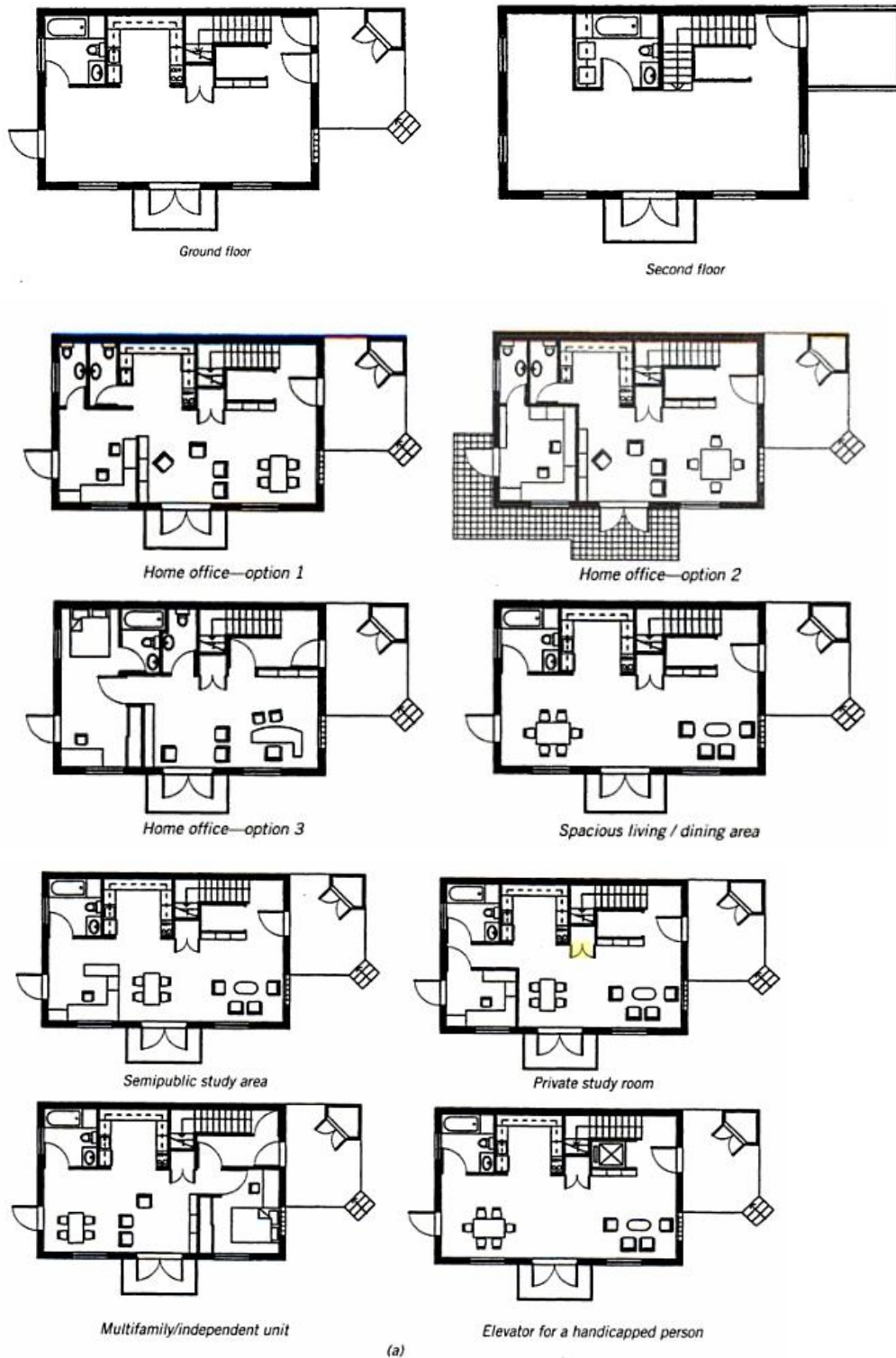


Figure 8: Flexibility interior spatial design for the unit.

The author's reflection 5:

From the design point of view, more flexible interior space can lead to various appropriate design for fitting different residents' needs and budget. From the energy point of view, the energy efficiency measures such as mentioned in chapter 5.1 should be applied to homes in

order to reduce the energy demand. From the materials choice point of view, the local and low emission materials are recommended. These considerations are needed for designing homes in a suburb sustainable residential community. (Due to the limited amount of time and size of the thesis, the impact of materials choice of a sustainable community on environment will not be discussed in this thesis.)

Conclusion:

Due to the fast urban population and improving transportation technology, it led the expansion growing towards suburbs. The traditional way of suburban sprawl leads to a higher consumption of fossil fuels. So sustainability should be implemented to suburb community.

Suburb sustainable residential community should include a serious of mix-functions which can provide residents' daily needs.

From the entire site viewpoint, site surroundings, site existing flora and fauna, microclimate should be carefully analyzed.

From a single apartment block viewpoint, the adaptable design of homes for different users and the appropriate design for future changes should be considered. The energy efficiency measures should also be concerned.

3. Ådland, Bergen - Zero Emission Suburb Residential Community

In chapter 2, strategies for designing a suburb sustainable residential community have been discussed. It has to be acknowledged that the discussion about the design issues of suburb sustainable residential community is not comprehensive. However, it still provides a guideline for Ådland project design.

3.1 Project Introduction

Summary:

3.1 includes two main parts: 1) project general information; 2) ZEB Research Center feasibility study proposal; 3) design of suburbs sustainable community.

Project general information includes site location, surroundings and microclimate.

ZEB Research Centre feasibility study of Ådland project includes design approach and design of different zones on site.

Project general information

The planning area is located on Ådland Ytrebygda in Bergen, Norway. Bergen municipality wishes to develop Ådland into a new residential area. The site is located on south east of Bergen (marked with yellow color in figure 9). It is close to two of Bergen's largest employment areas: Kokstad and Sandsli (marked with blue hatch in figure 9) [17, 4]. The site has a high potential for development and providing short cycling distance to areas of local employment.

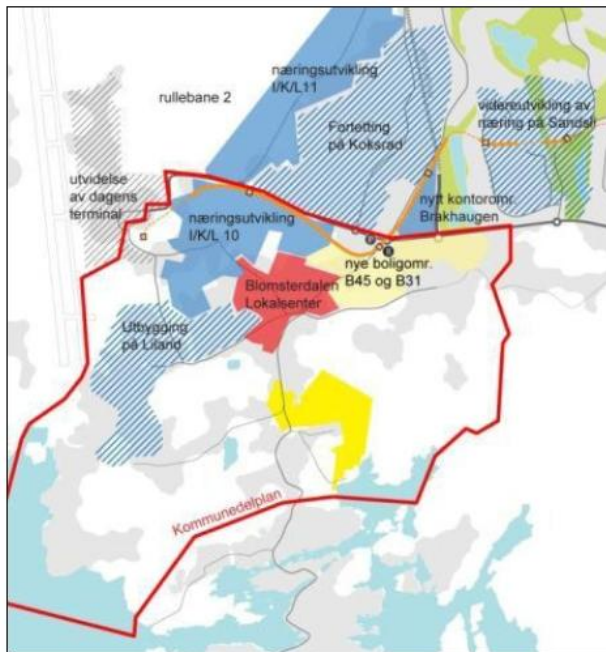


Figure 9: Location of Ådland site and its surroundings.

The west side of the plot is adjacent to Hjellestadvegen and is the entrance to the site [Figure10, 22]. Bus 525 Hjellestad runs near the site. Bergen municipality will prepare a zoning plan for pedestrian and cycling measures and improvement of Hjellestadvegen [17, 26]. North and east side of the planning area is pine forest and farmland.



Figure 10: Bird view map with the site boundary and the access road.

There are also other residential houses located adjacent to the site [See figure11, 17, 27]. They are mainly spread on north east and south west of the site. In additionally, there are few existing residential properties located on south area adjacent to the fjord. However, this area is not legally part of the planning area.



Figure 11: Existing residential housing type adjacent to Ådland site.

Ådland planning area is largely undeveloped. It is mainly covered by mature and young pine, birch, spruce forest and oak trees. There are large numbers nests of goshawks in the forest [17, 12]. On some parts of the site where partly undulating with a gentle slope, low-lying meadow with a creek and a marsh in the forest.

In general, the site has good solar access from the west and north. But solar access might be blocked by the dense forest area to the east and south [See figure12, 18, 11].

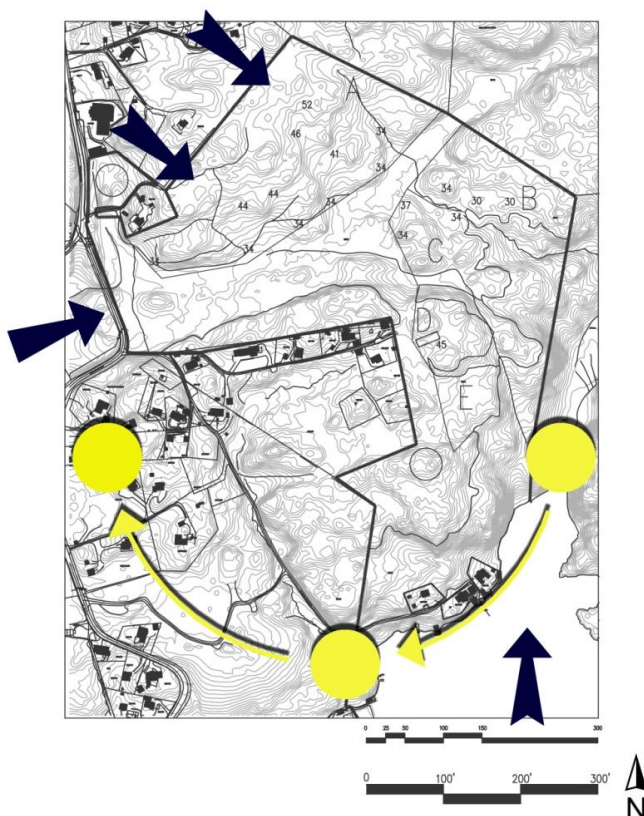


Figure 12: Sun path and prevailing wind directions.

The prevailing wind directions are predominately from the north westerly and southerly direction [See figure 13, 18, 54].

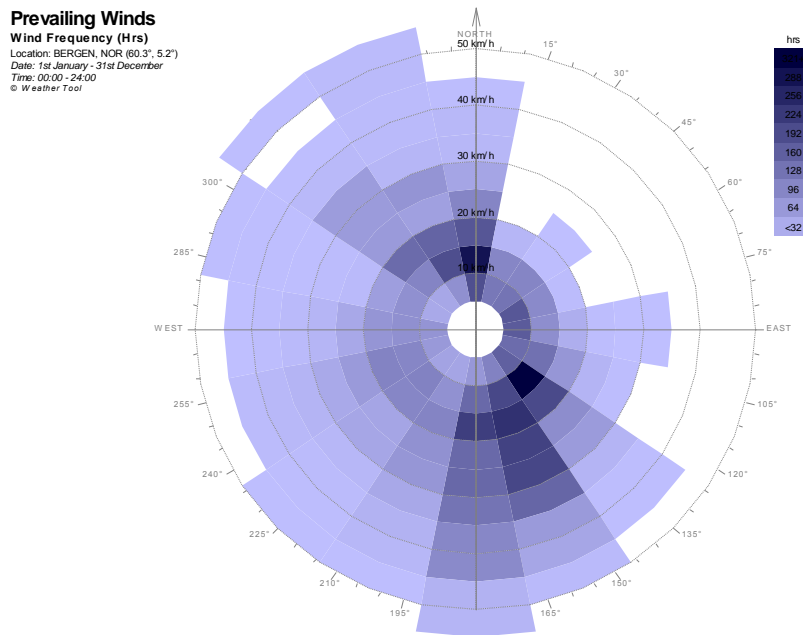


Figure 13: Prevailing wind rose map.

ZEB Research Centre feasibility study

As an input to Bergen municipality development, ZEB Research Centre has proposed a feasibility study for a possible ZEB pilot project of Ådland site. This was prepared by our supervisor. The key points of the project have been summarised as follow [18]:

- The design approach: buildings should follow the topography of the land as much as possible.
- The entrance of the site is located on the west of the plot adjacent to Hjellestadvegen (indicated with red spot on the site plan). The area indicated with the black spot is planned for kindergarten. There will be new proposed tram system from Blomsterdanlen to Bergen. It will be only 700 meters from Ådland site to tram station in Blomsterdanlen [See figure14, marked with red, 18, 8].



Figure 14: Zone A, zone B and zone C location on site.

- The site is divided into 2 implications:
 - 1) Different density of buildings layout [See figure 15, 18, 36]:

Identical rectangular blocks with the external dimensions of 10x30 meters are provided to all the building blocks in this feasibility study.

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. The buildings in this zone A is comprised of 6 of 2-storey, 9 of 3-storey and 11 of 4-storey apartments buildings. The total building area in zone A is 24900m².

Low density, smaller scale pavilions nestled in the dense woodland are located in zone B and C. Zone B contains three 3-storey and four 2-storey pavilions. And there are five 3-storey and two 2-storey houses in zone C. Total building area in zone B is 6300m² and in zone C is 5700m².



Figure 15: ZEB Research Centre feasibility study proposal.

2) Energy supply concepts [18, 45]:

Electricity demand and thermal demand is reduced as much as possible. Solar energy is harvested through building integrated solar thermal collectors and PV panels. The remaining electricity and thermal demand is covered by a centralised biogas fuelled CHP.

As stated above, zone B and zone C will be located in dense woodland. Due to lack of more detailed information about the exact heights, locations and types of the trees surrounding zone B and C, it would be hard to make an assumption for their solar access. For this reason, the area with least vegetation - zone A is chosen as the object of the following analyses. It has to be noticed that one of aims of this thesis is achieving a further reduction on environmental impact based on ZEB Research Centre's feasibility study. Thus, the total apartment building area of 24900m² will remain the same.

3.2 Design Options Similarities

Summary:

3.2 includes two parts: 1) built area and green area in zone A; 2) base unit design and construction;

In the scale of site, it elaborates the preservation of existing green area and the reselected built area.

In the scale of single building, it demonstrates two adaptable base unit designs for different users. And various energy efficiency measures will be provided to the base unit design.

Built area and green area

As mentioned in the project information section, Ådland planning area is largely undeveloped. It is mainly covered by forest. Zone A is divided into four areas, see figure 16 [18,10]:

- Area (1) is covered by pine forest.
- Area (2) is a deep valley and coated with pine forest. The area has humid microclimate and wet soil condition due to the stream crossing through the whole forest.
- Area (3) is covered by young pine forest.
- Area (4) is coated with few oak trees.

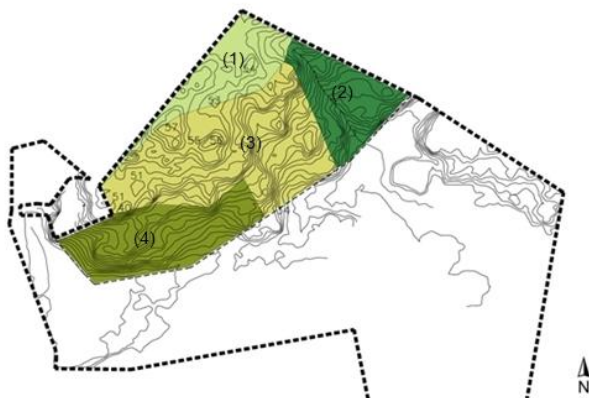


Figure 16: Zone A has been divided into 4 parts.

Pine forest which exists in area (1) can create a nature barrier for protecting the privacy of neighbour residential properties located on the northwest direction from a large developed community. Analyzing the winter average temperature of the prevailing wind, the lowest

temperature comes from north westerly. So the pine forest in area (1) can also act as protective screen from the coldest wind during winter time.

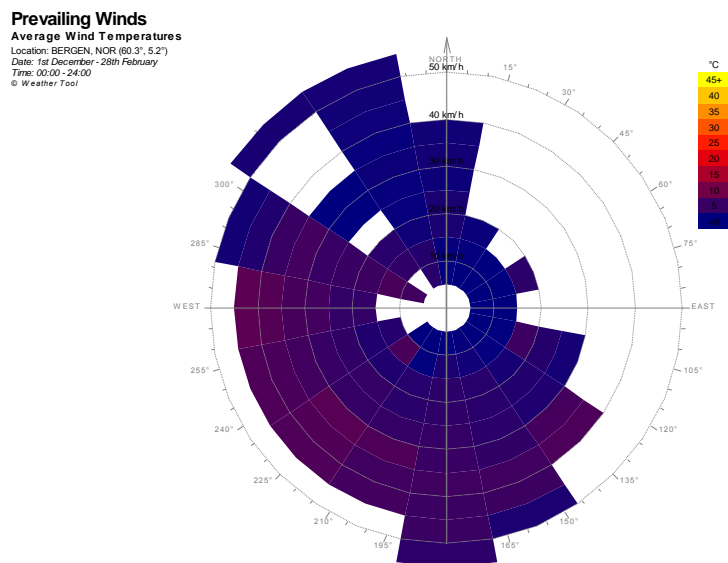


Figure17: Temperature of winter prevailing wind.

Area (2) is in a wet soil conditions and not suitable for construction purpose, and its beautiful nature with the creek and the mature forest is worth to keep, see figure 18 [17, 12].



Figure18: Picture is taken from area (2) in zone A with the forest and the creek.

Area (3) and (4) has sloped landscape which is suitable for slope housing type [see figure 19]. The nature slope can create better solar access for each lane of the buildings. And it can also provide opportunities for designing different heights of the blocks on site.

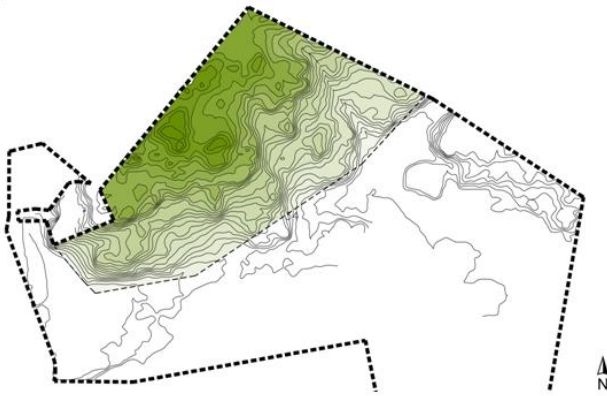


Figure19: Drawings indicates the level of the site. The greener the colour is, the more flat the area is.

So area (3) and (4) are defined as built zone. The young pine forest exists in area (3) has to be removed. Few oak trees in area (4) can be remained. Oak trees are usually deciduous species. Those trees can be rearranged so that they are not located on the footprint of the future buildings. They can be arranged along the future roads. In this case, they can help to absorb much rain water during the high rainfall day and protect the roads from over flooded. They can also help to create shadows to buildings for preventing overheating (in Jun, July and August) in the room. And in winter they will not influence the solar access to the buildings.

To conclude the site analysis, a sketch has been made to elaborate different areas on site [see figure 19]. Remaining forest area in zone A is indicated in green and the built zone is indicated in yellow in figure20. The entrance of the site and the kindergarten place for the whole community is remained the same as the feasibility study from ZEB Research Centre. In addition, two parking areas for residents in zone A are arranged outside zone A boundary (indicated in blue in figure 20). A suggested place for community centre could locate on the south edge of Ådland site (indicated in purple in figure 20).

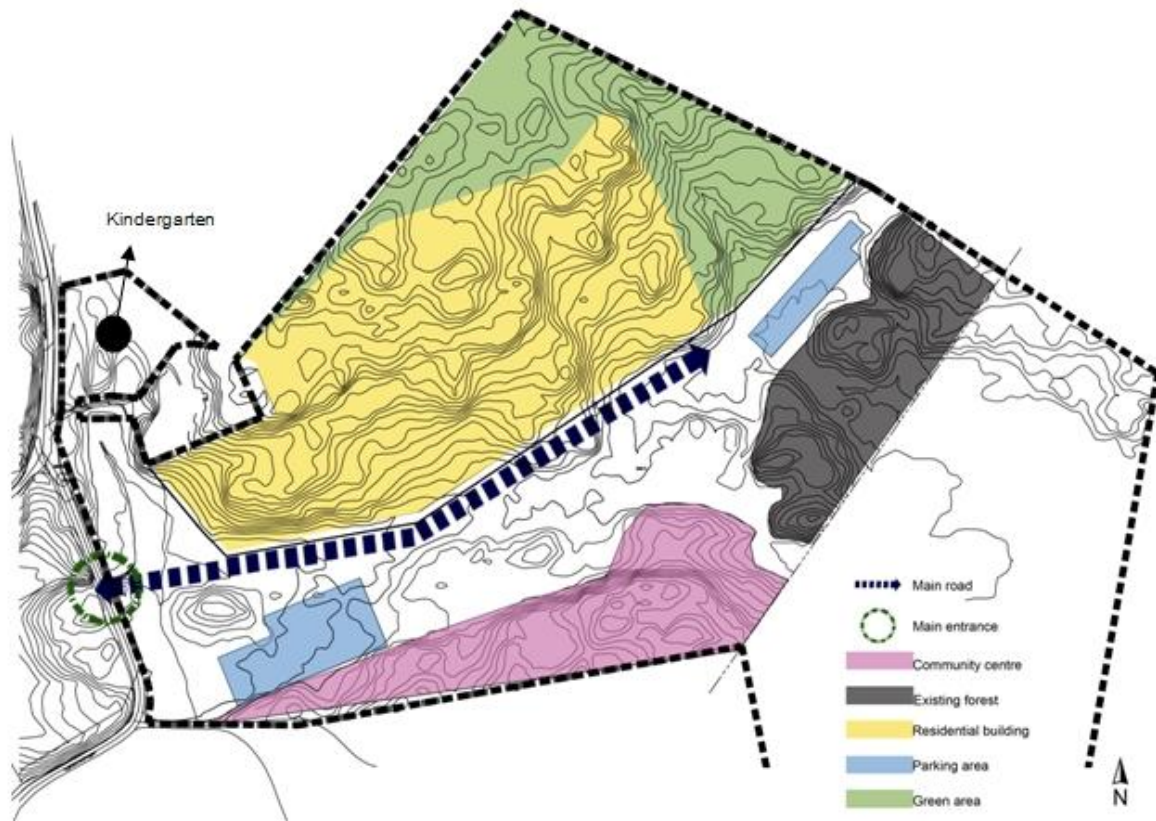


Figure 20: Site plan with the indication of built area, green area, parking, entrance and community centre.

As mentioned before, project analysis is aiming on achieving a further reduction on environmental impact based on ZEB Research Centre's feasibility study. The reduction of environmental impact is not only focusing on the preservation of the existing site as much as possible. The reduction of energy demands of the new constructed buildings on site should also be taken into account. Three types building massing of linear arrangements on site will be analyzed later on in order to compare their total energy demand. Before presenting these new arrangements of the buildings, it is necessary to introduce the base unit in the following section. The base unit in this project means the basic building unit for creating different storey height building blocks. The base unit is a one-storey building block in rectangular shape with flat roof. The base unit will be introduced from two directions: adaptable interior design and energy efficiency measures.

Base unit design and construction

The base unit has external dimension is 10 x 30 meters which is retained from the design dimension of ZEB Research Centre's feasibility study. 24m² windows are applied to both north and south facades. There are no windows on west and east. Various stories of building blocks are determined according to the number of base units use. For example, a 4-storey building block is clustered by four basic units in a vertical direction.

The purpose of setting up the base unit is:

In order to avoid repeating design and energy calculation work. The similarities of shape, function, construction of buildings provide a possibility to create one model which can represent all the others on site. (But the various orientations should be borne in mind).

And the design concept of the base unit is:

Designing building in the way that it is appropriate for different family types and having easily modifiable layouts.

The base unit design contains two elements:

- 1) Fix elements: element with building service systems, such as bathroom; element with public circulation purpose, such as staircase and elevator shaft; element contains building structure part, such as external building envelope.
- 2) Flexible elements: interior partition walls

Figure 21 illustrate the first design suggestion of the base unit. The plan drawing contains two apartments. The fix elements – two bathrooms are located against west and east wall. And the staircase and elevator shaft are located in between two apartments.

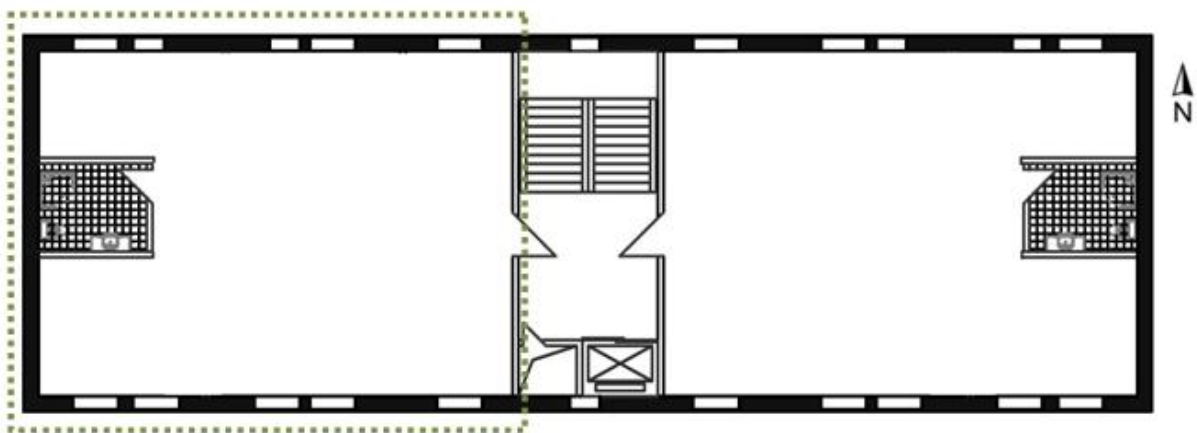


Figure 21: Plan drawing indicates the fix elements in the building.

Figure 22 illustrates the possible interior arrangement for one of the apartment. Kitchen and one of the bedrooms are located on north. One study room is located next to the north facing bedroom and it can be changed into an extra bedroom as well. One master bedroom, living room and dining room are located towards south. It is suitable for a family with two adults and one/two kids. These apartments can be sold with the purpose of long-term living.

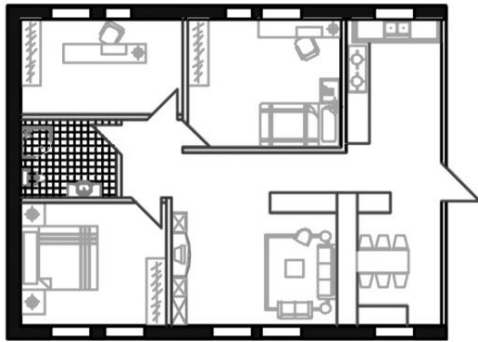


Figure 22: Drawing illustrate the possible interior space design with furniture.

Figure 23 illustrate the second design suggestions of the base unit. Fix element – circulation area remains the same position. But bathrooms are located relatively closer to the staircase area. And there are two small and two big apartments are designed into this base unit.

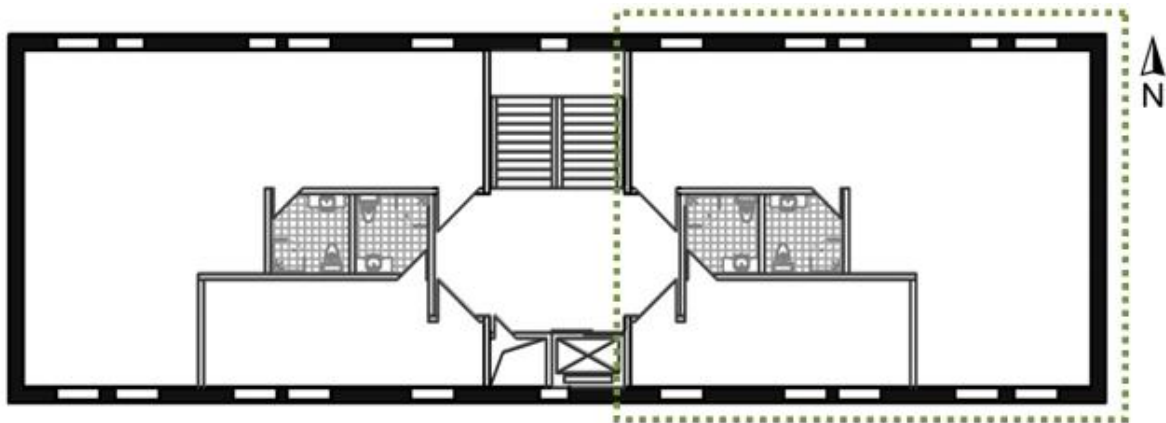


Figure 23: Plan drawing indicates the fix elements in the second design option.

Figure 24 illustrates possible interior arrangement of two different sizes apartments. These two apartments are separated in the plan drawing for the ease of understanding. The small apartment is an open plan apartment facing south. It can be used for renting. The tenant could be one student. And the bigger apartment has a south facing living room. Kitchen, dining room and two bedrooms are facing north. This apartment can be used for renting purpose as well. It is suitable for couples or couples with one kid. It can also be sold to young couples who will plan to have a family in the near future. And if the family grows, there will be needs for more spaces. Then the residence can choose to buy the smaller apartment together and combined two different sizes apartment into a bigger one.

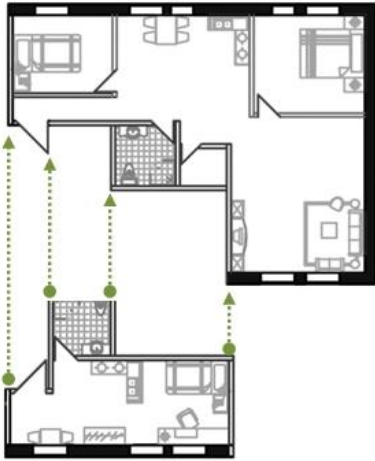


Figure 24: Plan drawing indicates one big apartment and one small apartment, when it is need, two apartments can be combined into one bigger family apartment.

Figure 25 illustrates the south and north elevation of an example of four base units clustered in vertical direction – a 4-storey building.

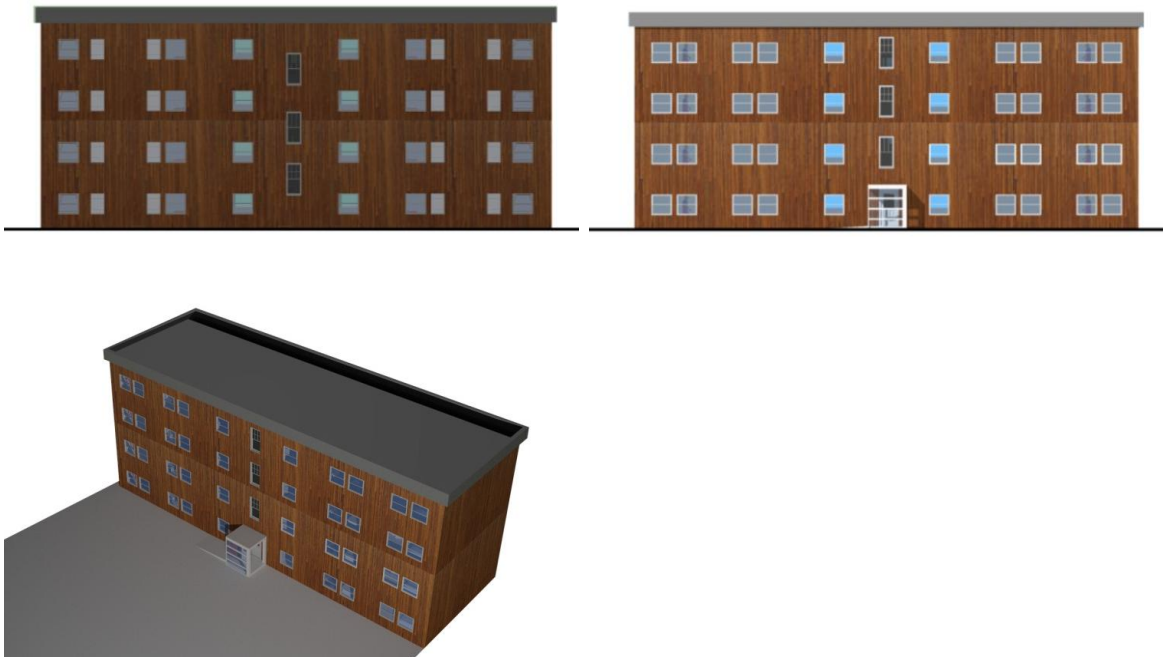


Figure 25: Sketches illustrate north façade (top-left), south façade (top-right) and isometric view of an example 4-storey building block.

However, there will be various flexible interior design solutions for base unit or even better ones than the design presented above. Changing the size and/or the amount of staircase module can bring more interior design options as well. Due to the limited time and the scope of the thesis, there are only two possibilities presented here. The purpose is to elaborate the

design for future and different users are the important development issues of a suburb sustainable residential community as well.

Highly insulated and air tight building envelope has been provided to the base unit. The U-values for different portion of the construction has illustrated in table 3. All the values are improved result of maximum requirements in Norwegian passive house standard requirement (NS3700) which has been discussed in table1 in chapter 2.


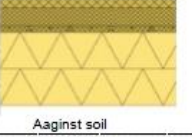
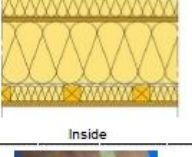

U-value (W/m ² K)	Drawings	Description
External wall 0.13	 <p>Outside</p> <p>Inside</p>	<p>From inside to outside</p> <ul style="list-style-type: none"> 2x13mm layers of gypsum board 45mm insulation between battens airtight layer 200mm insulation 15mm OSB 28mm airgap 28mm distance strip 22mm external wooden cladding
Ground support floor 0.10	 <p>Inside</p> <p>Against soil</p>	<p>From inside to outside</p> <ul style="list-style-type: none"> 140mm reinforced concrete floor 200mm XPS <p>Both ground support floor and foundation will be insulated</p>
Roof 0.10	 <p>Outside</p> <p>Inside</p>	<p>From inside to outside</p> <ul style="list-style-type: none"> 15mm wooden ceiling board 45mm insulation between battens airtight layer 200mm insulation 15mm OSB one layer of bitument felt minimum Two layers of roofing felt
Window 0.70		NORDAN triple glazing window
Heat recovery ventilation system		Efficiency 80%
Air leakage at 50Pa n ₅₀		≤0.60h ⁻¹
Thermal bridges		0.03 W/m ² K

Table 3: Energy efficiency measure provide to base unit.

Before continue with the design and energy consideration of Ådland project, the method of designing three different site layouts and calculation of their energy demand will be presented first in the following section.

3.3 Methodology

Summary:

This section includes three parts: 1) introduction of three site layouts design 2) simulation tools, input data and comparing total energy demands comparison of three site layouts; 3) Renewable energy supply systems options.

Single separated, transverse cluster, vertical cluster, three types of building massing will be presented as new three site layout design and compared from both solar design and energy demand point of view. And one of the site layouts will be chosen as the base case for renewable energy supply systems combination comparison with the objective of achieving ZEB.

The main aims of three site layouts design and energy calculations are:

- Ensuring solar envelope of the buildings
- Comparison of total energy demands among three site layouts
- At last, one of the site layout will be chosen as the base case for the analysis of renewable energy supply systems choices in order to achieve a zero emission community

The input data of energy efficiency measures [table 3, in section 3.2] in energy calculation got inspiration from NS3700. There are two reasons for applying the passive house standard energy efficiency measures to all the site layouts:

- In order to design a ZEB, it should be primarily energy efficiency.
- Norway has pointed out as a major strategy in cutting CO₂ emissions while proposed passive house standard as the minimum energy performance from 2017 [6]. Due the project current statue of feasibility study and research stage, design according to the NS3700 is considered as a logical choice.

But it has to be noted that only the chosen site layout will be further designed in order to achieve Norwegian passive house standard:

- 1) Primary requirement: specific heating demand for space heating purpose maximum 15kWh/m²
- 2) Second requirement: Overall heat losses between 0.50-0.60 W/m²K

And the renewable energy supply systems will be used for covering the rest of the energy demand.

Design of three site layouts

The project analysis will focus on Zone A. Total building area in Zone A is 24900m². This sum of square meter will be remained. As mentioned the previous section, the base unit has

external dimension of 10x30 meters. 24900 m² is equal to 83 base units. And this figure can be arranged as follow:

- Eleven 4-storey buildings
- Nine 3-storey buildings
- Six 2-storey buildings

The design approach for three site layouts is: buildings should follow the topography of the land as much as possible.

Three site layouts are designed as linear array distribution of the building blocks. In order to simplified the explanation process of building massing and energy demand calculations, different combination with different amount of base unit will be coded with a single letter and a number. The building with the combination of two base units, their code started with S (e.g: S1, S2, S3 and etc). The building with combination of three base units started with T (e.g.: T1, T2, T3 and etc). And the building with four combined base unites start with F (e.g: F1, F2, F3 and etc) [See table 4].

Description	Site layout 1 spread out individual blocks	Site layout 2 Transverse cluster of blocks	Site layout 3 Vertical cluster of blocks
2-storey building	S1,S2,S3,S4,S5,S6	S1+S2+S3, S4+S5+S6 (2-storey combi-3)	9-storey building:
Number of base units	12 units	12 units	63 units
Total number of buildings	6 buildings	2 buildings	7 buildings
Total external wall area	2880 m ²	2400 m ²	15120 m ²
3-storey building	T1,T2,T3,T4,T5,T6,T7,T8, T9	T1+T2,T6+T7,T8+T9 (3-storey combi-2) T3+T4+T5 (3-storey combi-3)	10-storey building:
Number of base units	27 units	27 units	20 units
Total number of buildings	9 buildings	4 buildings	2 buildings
Total external wall area	6480 m ²	5580 m ²	15120 m ²
4-storey building	F1,F2,F3,F4,F5,F6,F7,F8,F9,F10,F11	F1+F2+F3+F4 (4-storey combi-4) F5+F6+F7 (4-storey combi-3) F8+F9,F10+F11 (4-storey combi-2)	
Number of base units	44 units	44 units	
Total number of buildings	11 buildings	4 buildings	
Total external wall area	10560 m ²	7200 m ²	

Table 4: Explanation of different building masses in three site layouts.

Site layout 1 is designed with spread out single blocks [See figure 27]. Site layout 2 is based on the same amount of units as site layout 1. But it is the transverse cluster of blocks design. The entire new buildings in site layout 2 are the combinations of the adjacent blocks in site layout 1. Site layout 3 is the vertical clusters of base units. They are mid-rise buildings with 9-storey and 10-storey high [See table 4 and figure 27]. The designs of road among these three site layouts are quite similar. There are three distinct levels of the road design:

- Site entrance road, the main public street, two-way traffic, 5m wide
- Semi-public road, accessing different compound, two-way traffic, 3m wide
- Accessing path in front of each buildings

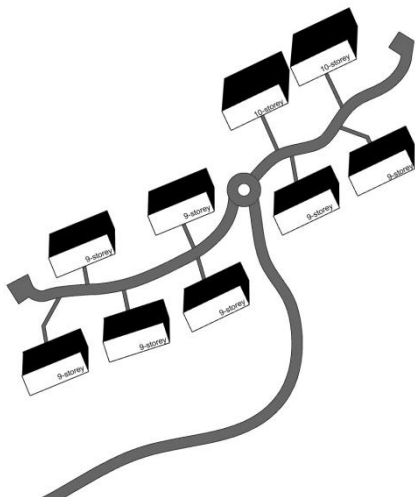
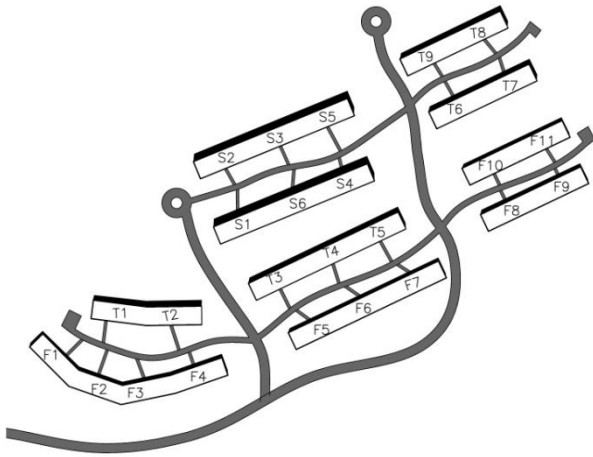
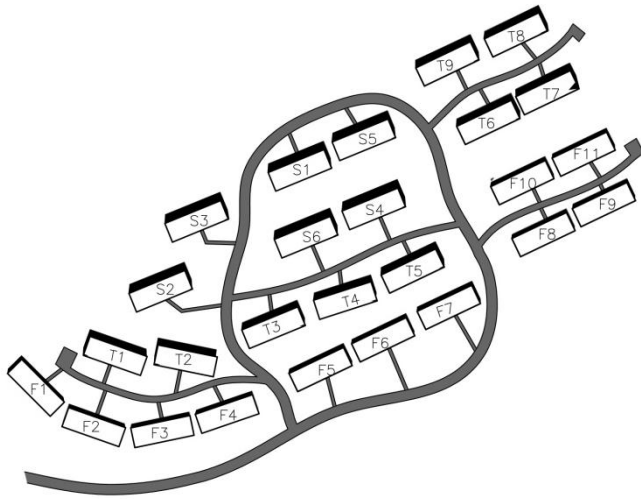


Figure 27: Site layout 1 plan (top), site layout 2 plan (middle), site layout 3 plan (down)

Simulation tools and input data

ECOTECH Analysis [23] is used for ensuring solar envelope of buildings. Ådland site is located closely to the Bergen airport. Since there is no available weather data for the specific site, in ECOTECH Analysis, the weather data is based on Bergen airport area.

The solar envelope analysis is based on three specific days:

- 21st of December
- 21st of March
- 21st of June

In December 21st, the analysis will focus on south façade. In March 21st and June 21st, the analysis will focus on south façades and the outdoor open spaces.

SIMIEN student version [24] is used for energy demand calculation. And the weather data in SIMIEN is set up as Bergen local weather file. The input data is:

- Heated floor area: it is equal to external dimension subtract the area of walls. The base unit heated floor area is 234m².
- Heated air volume (heated floor area multiply the height of the room).
- The orientation of all the facades and roof: since all the blocks are arranged to follow the topography, the orientations are various. The orientations of each facade in all building blocks are presented in the table below [See table 5].
- Size of all the windows and doors: determined according the base unit, south facing windows 24m², north facing windows and external doors 24m².
- U-values, air leakage and thermal bridges for each component of building envelope: can be found in table 3.
- The highly airtight and insulated part is only around the apartments. Figure 28 illustrate the airtight layer with dashed lines and highly insulated walls on a simple cross section sketch. The staircase will have much lower demand. Since it is not a heated space, the energy calculation will not take it into account.

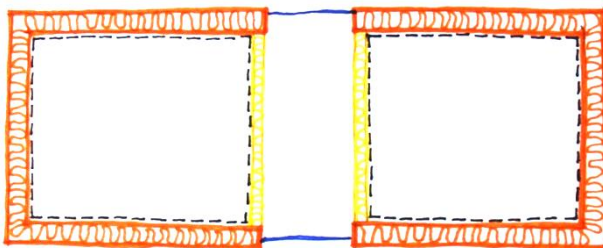


Figure 28: Cross section sketch indicates the portion with highly insulated and airtight building envelope.

- Information of ventilation heating system: 80% efficiency, 1.2 m³/hm² as maximum and minimum airflow rates for multi-storey residential building or row house, 1.5

kW/m³/s as specific fan power. Operational time is 24hour, 7 days a week the whole year round (52 weeks). That is equal to 8736 hrs [8].

- Internal gains for residential apartment building: average internal gain of 3.2 W/m² [8].

Buildings	North façade	South façade	West façade	East façade
	(°)	(°)	(°)	(°)
F1	135	315	405	225
F2	110	290	380	200
F3	78	258	348	168
F4	70	250	340	160
F5	65	245	335	155
F6	65	245	335	155
F7	65	245	335	155
F8	65	245	335	155
F9	65	245	335	155
F10	65	245	335	155
F11	65	245	335	155
T1	65	245	335	155
T2	65	245	335	155
T3	65	245	335	155
T4	70	250	340	160
T5	65	245	335	155
T6	65	245	335	155
T7	65	245	335	155
T8	65	245	335	155
T9	65	245	335	155
S1	65	245	335	155
S2	65	245	335	155
S3	65	245	335	155
S4	65	245	335	155
S5	65	245	335	155
S6	65	245	335	155
9-storey	65	245	335	155
10-storey	65	245	335	155

Table 5: Four facades orientations of all the building blocks.

Heating demand, electricity demand, net energy demand and heat loss factors are part of the output data from SIMIEN. Total heating energy demand will be compared among three site layout. Pros and cons of design and total energy demands will be pointed out.

Renewable energy supply systems

Three options are set up in order to compare different combination of renewable energy supply systems:

- Option 1: electricity is provided by PV + Grid, heating is provided by solar thermal collector + fuel cell CHP
- Option 2: electricity is provided by gas turbine CHP + Grid, heating is provided by solar thermal collector + gas turbine CHP

- Option 3: electricity is provided by PV + Grid, heating is provided by solar thermal collector + ground source heat pump (HP)

CO₂ emissions of operational energy are considered for measuring the balance between imported and exported energy.

3.4 Limitations

*Section summary:
Limitation will be pointed out in three parts: 1) Design of the site layouts and base unit
2) simulation data and calculation of energy demand 3) Renewable energy supply systems options*

Design of the site layouts and base unit

From the different building massing in different site layouts viewpoint, the common character of those three site layouts is linear building forms. There should be also other choices of site layouts worth to analyze during the feasibility study. The site can be designed with the consideration of both from architecture and the ensuring of solar envelope of each building view point.

From the base unit exterior morphology viewpoint, in this thesis only a common rectangular shape has been designed. There will be various choices for the shape of the building with variable shapes of the roof. The exterior shape can also create different choices of interior spaces. It is also worth for analyzing from the energy demand point of view.

From the flexible interior layout design of the base unit viewpoint, the presented plan drawings are not the only possibility. For example, changes of the staircase modular location could create other flexible interior arrangement. The sketch provided in this thesis cannot represent all different flexible design. It is only aiming at reminding architect, the adaptable interior design for different users is also part of the important issues for creating a suburbs sustainable residential community. In additionally, the interior design might influence the passive design strategy choices as well.

Simulation data and calculation of the energy demand

ECOTECT has been used to analyze the shadow range and ensure solar envelope of the buildings. Due to the lack of correct local data, the weather data of Bergen airport area has been imported to ECOTECT. The microclimate analysis of sun path and prevailing wind will

be a bit different than the real local site conditions. It suggested that an accurate local weather data should provide to architects in the preliminary design phase.

As mentioned in project information section, Ådland site is largely undeveloped and covered by dense forest. So the impact of the existing forest on site's solar access and wind patterns should not be ignored. There are no existing detailed data of the trees' height type and their exact locations. It is hard to take those features into the project analysis in this thesis. Therefore, the numerical results might be different than what have provided in this thesis. But it will not influence one of the aims of these analyses which are providing a possibility of further environmental impact reduction from the ZEB Research Centre's feasibility study.

Renewable energy supply systems options:

There are only three options of combination systems have been calculated here. There are various other renewable energy systems such as the use of wind power, hydro power and etc. Variable efficiency of CHP systems can also be used to compare. And the installation costs of the energy systems could be also interesting to be taken into account.

3.5 Site Layouts Design and Energy Demand Discussion and Comparison

Summary:

3.5 includes four main parts: 1) site layouts design 2) design discussion and comparison; 3) energy demand discussion and comparison

Site layouts design will introduce three site layouts building block locations.

Design discussion and comparison include the criteria such as: solar access to buildings and open space, surfaces against external air and for active solar purpose.

Energy demand discussion and comparisons includes: totally heating demand and heat loss factor.

At last comparison will be concluded. Pros and cons of three site layout design and energy demand will be discussed again.

Site layouts design

Site layout 1

Figure 29 is the plan drawing of site layout 1. Figure 30 is the 3D view of site layout 1 from south west. 4-storey buildings are mainly located in the lowest part of the site. The levels of the building locations are various. F1, F2, F3 and F4 are located between contour line 32 to

37. F5 and F6 are located between contour line 34 to 37. F7 is slightly higher. It is located in between contour line 38 to 40. F8 and F9 are located between contour line 33 to 35. F10 and F11 cannot be designed into the same lane as other 4-storey buildings due to the boundary of the built area. They are located on a higher level of F8 and F9, between contour line 37-40.

3-storey buildings are located upper level of 4-storey buildings. Most of the blocks are also distributed in a linear direction. T1 and T2 are located between contour line 40 to 43. T3, T4 and T5 are located between contour line 39 to 43. T6 and T7 are located in a higher level of F10 and F11 and between contour line 40 to 44. These two blocks are not located in the same lane as other 3-storey buildings. And T9 and T8 are located upper level of T6 and T7 and between contour line 44 to 49.

2-storey buildings are located on the highest level and relatively flat area of the plot. Six of 2-storey buildings cover the area between contour line 48 and 53.

There will be roads passing in front of each building lanes. Roads connected to the main access road are 5 meter wide and the smaller roads extend in front of the buildings are 3 meters wide.

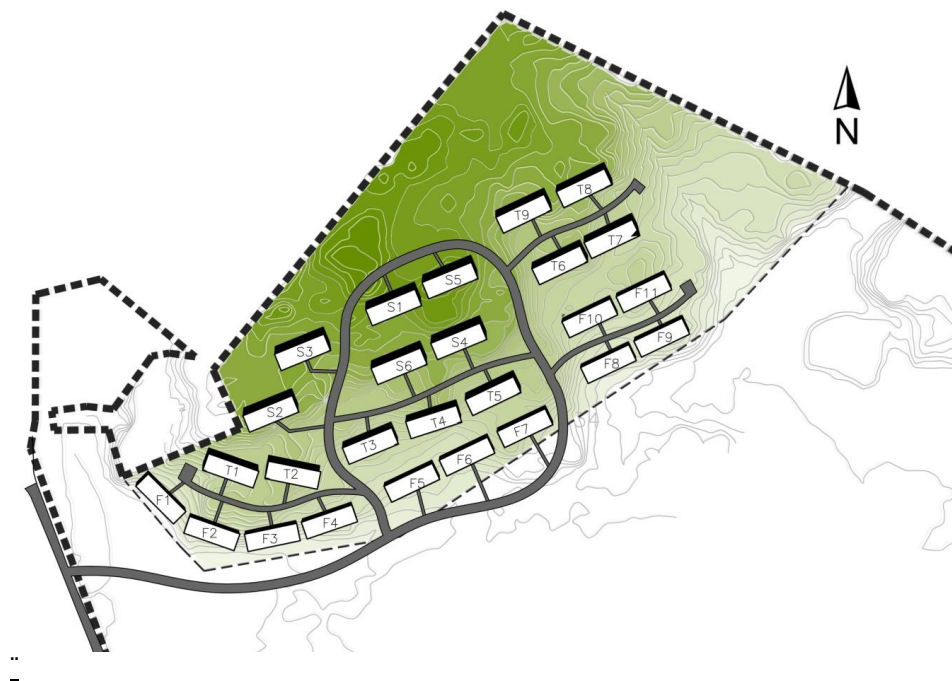


Figure 29: Plan drawings of site layout 1.

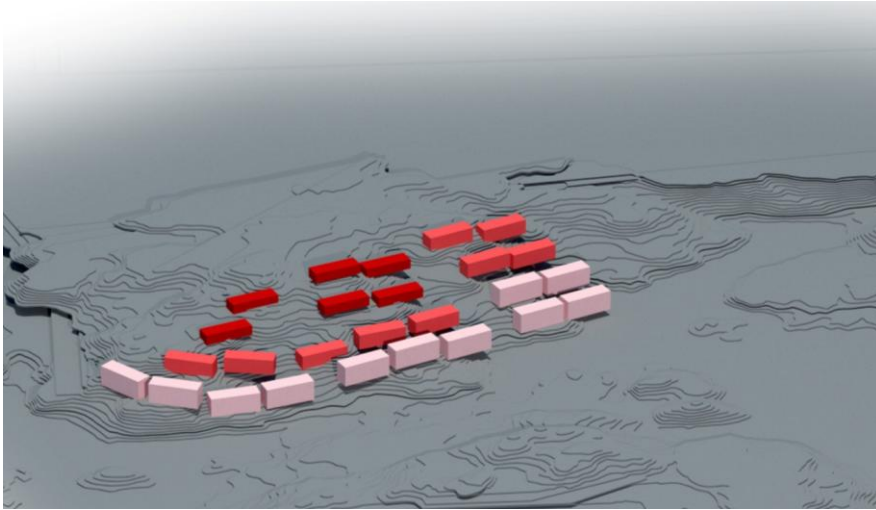


Figure 30: 3D view of site layout 1.

Site layout 2

Site layout 1 is similar to site layout 2 with the distance between different lanes remaining the same as well. However, difference is to combine the building blocks. New blocks are listed below [Figure 31, 32]:

- 1) F1+F2+F3+F4; 2) T1+T2; 3) S2+S3+S5; 4) S1+S6+S4; 5) T3+T4+T5; 6) F5+F6+F7;
- 7) T9+T8; 8) T6+T7; 9) F10+F11; 10) F8+F9

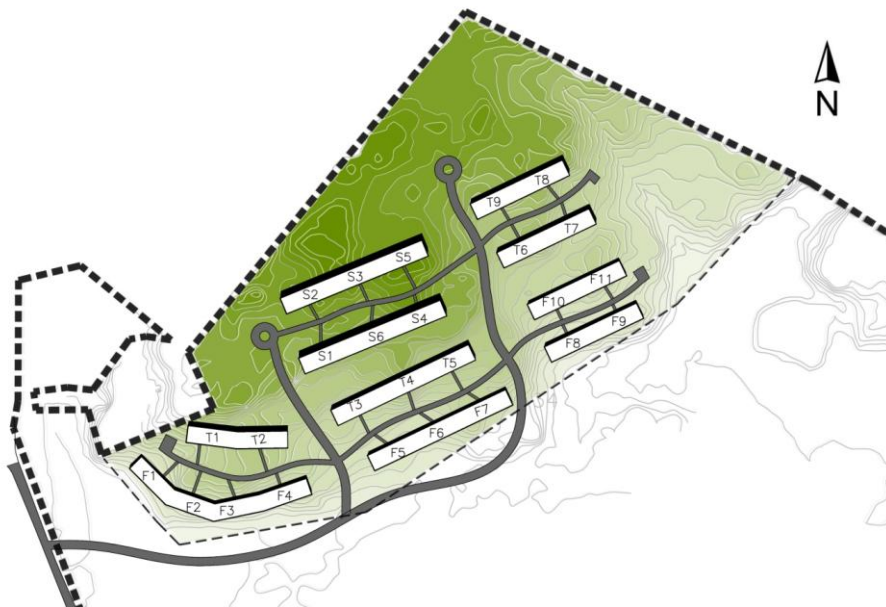


Figure 31: Plan drawing of site layout 2.

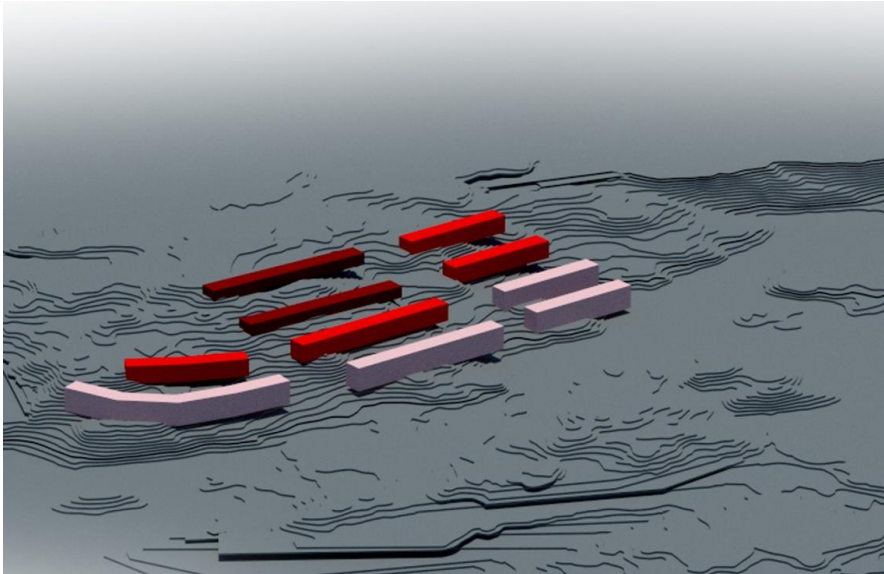


Figure 32: 3D view of site layout 2.

Site layout 3

In site layout 3, base units are combined in vertical direction. As mentioned in methodology section, there are 83 base units in total. Therefore, vertical cluster can be designed into [see figure 33, 34]:

- Seven 9-storey buildings
- Two 10-storey buildings

They are still located on site with a linear layout. First lane of 9-storey buildings is mainly located between contour line 35 to 41. The second lane of 9-storey buildings is located between contour line 48 to 52. The two 10-storey buildings are located between contour line 44 to 48 [see figure 33, 34]. The main entrance road are going half way through the site and a roundabout create two branch roads going towards west and east in order to create the entrance towards all the buildings. The roads width is still 5 meters. Since the buildings are much taller than the other two site layouts, the distance between the lanes are extended to 40 meters in average.

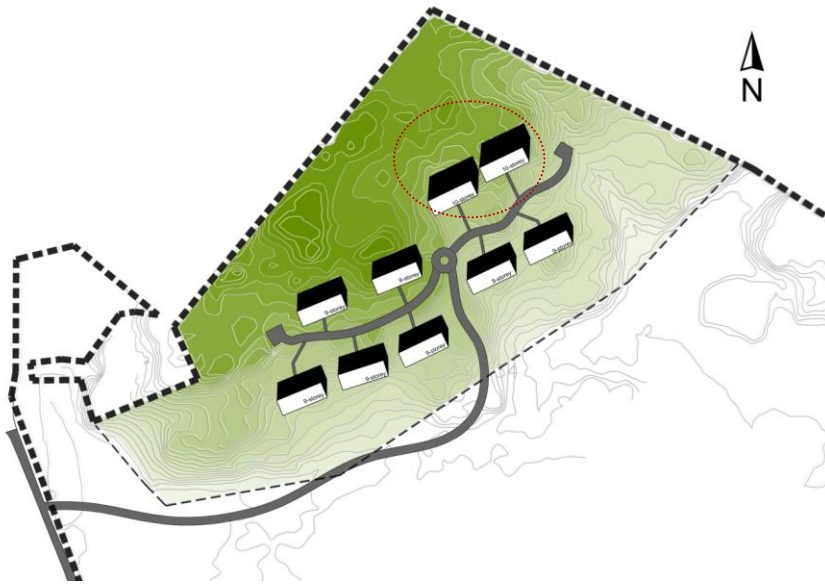


Figure 33: Plan drawing of site layout 3. Red circle indicate these two buildings are 10-storey ones and the rest models are all in 9-storey.

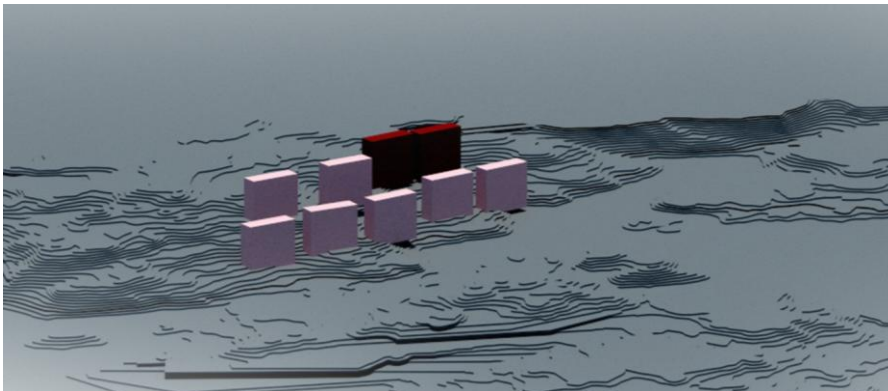


Figure 34: 3D view of site layout 3.

Design discussion and comparison

Solar access to buildings and open space cpmarison

On **Dec. 21st**, the area in site layout 1 [see attachment 1] which locates T1, T2, F1, F2, F3, and F4 has the similar total solar exposure hours as site layout 2 [see attachment 2]. But the distance between F1, F2, F3 and F4 in the linear direction make the changes. T1 and T2 have one more hour solar exposure than T1+T2 due to the distance among F1, F2, F3 and F4. There is almost no solar access to the open space, the little amount of solar access is

coming through the spaces among F1, F2, F3 and F4, and the time is between 12:00 till 15:00.

On **Mar. 21st**, due to the higher sun angle than in Dec., the total hours of south facades solar exposure are end with the same results both from site layout 1 and site layout 2:

- F1: 5.5 hours
- F2: 7 hours
- F3 and F4: 8 hours
- T1 and T2: 7 hours

And solar exposure on open space is 3 hours in total.

On **Jun. 21st**, even higher sun angle gives the same result both from site layout 1 and site layout 2. The total hours of south facades solar exposure are:

- F1: 15 hours
- F2: 15 hours
- F3 and F4: 10 hours
- T1 and T2: 14 hours

Design reflection 1:

- 1) *Distances between the different building lanes are in average 25 meters. This distance gives good solar envelope for the buildings locate on the second lane.*
 - 2) *Distance among the buildings in the linear direction can create different solar exposure hours both for the open space and the buildings locate on the second lane.*
 - 3) *First floor south facades of T1+T2 are always shaded in winter.*
 - 4) *Roofs are always having good solar access.*
 - 5) *Shading systems are needed.*
-

On **Dec. 21st**, the area in site layout 1 which locates S6, S4, T3, T4, T5, F5, F6, and F7 has similar solar exposure hours as in site layout 2. However, there are 1 hour differences existing between T3+T4+T5 and T3, T4, T5. This is due to the combined model F1+F2+F3+F4 cannot allow the low angle winter sun penetrate to the back lane. In site layout 3 [see attachment 3], 9-storey buildings on the first lane have total solar exposure hours on south facades for 5 hours and the second lane has 2 hours in total.

On **Mar. 21st**, from 8:00 till 12:00 the open space in site layout 1 between T3, T4, T5 and F5, F6, F7 will receive solar access. Site layout 2 has worth case due to the cluster of building

F5, F6 and F7. In this case, the influence is bigger than in Dec.21st. And the influence is not only on the total solar exposure hours, it is also considered from the viewpoint of shadow areas. Site layout 1 has less shadow area during the day than site layout 2. S6, S4 in site layout 1 and S1+S6+S4 has no solar envelope problems and good solar access during the day due to the higher terrain level. In site layout 3, the first lane of 9-storey buildings has good solar access, but they cast shadow on first and second floor in the second lane of 9-storey buildings. These two storeys will not receive morning sun from 7:00 till 11:00.

On **Jun. 21st**, S1, D6, D4, T3, T4, T5, F5, F6 and F7 are in good solar conditions. Total solar exposure hours on their south facades are 10 hours. Open space is also exposed to the sun. In site layout 2, the same good solar conditions appear. There are no problems on solar envelopes. And the only differences is quite similar to Mar. 21st, the shaded area on open space is bigger than in site layout 1. But due to the high sun angle, this problem seems insignificant. There are problems of solar envelopes of the second lane of 9-storey buildings in site layout 3. Open space in site layout 3 is also in a good solar access condition.

Design reflection 2:

- 1) *Areas where 2-storey buildings locate are the highest level on the whole site. This area has the best solar access.*
 - 2) *In general, the solar access of 9-storey buildings in site layout 3 has the least solar access in comparing with site layout 1 and 2. The second lane of 9-storey buildings is mostly in shade during the heating period.*
 - 3) *Due to the orientations, S1, S6, S4, T3, T4, T5, F5, F6 and F7 has better solar access in average in winter than T1, T2, F1, F2, F3 and F4.*
 - 4) *Roofs are always in good condition.*
 - 5) *Linear distance between F5, F5 and F7 will not have significant impact on solar access of open spaces most of the time.*
-

On **Dec. 21st**, the area in site layout 1 which locates T6, T7, F10, F11, F8 and F9 is receiving good winter sun in general. First floor apartments in F10, F11, T6 and T7 will not receive much sun during the day. Open spaces will be exposed to the sun for 2 hours. In site layout 2 has the similar condition as site layout 1. In site layout 3, half amount of the storeys in the second lane 10-storey buildings are in shaded from 10:15 till 13:00. Open space in site layout 3 has less than 2 hours' solar exposure which is one hour less than site layout 1 and 2.

On **Mar. 21st**, the total south facades solar exposure hours for each building block are listed below:

- F8 and F9: 6 hours
- F10 and F11: 5 hours
- T6 and T7: 4 hours

Site layout 1 and 2 has the similar condition. In site layout 3, total south facades solar exposure hours for first lane 9-storey buildings are 7 hours. South facades for second lane 10-storey buildings have solar exposure hours of 3 in total.

On **Jun. 21st**, in site layout 1, all the south facades from F8, F9, F10, F11, T6 and T7 receive sun from sunrise at 3:45 till 14:00. That is equal to approx.10 hours. Open spaces are in good conditions until 17:00. Due to the high sun angle, site layout 1 and site layout 2 has the similar situation. The south facades of the first lane of 9-storey buildings and the second lane of 10-storey buildings in site layout 3 have solar exposure hours of 10 hours. Open spaces are in good conditions until 17:00. On Jun.21st, three site layouts have similar south facades and open space solar exposure hours.

Design reflection 3:

- 1) *Areas where 2-storey buildings locate are the highest level on the whole site. This area has the best solar access.*
 - 2) *In general, the solar access of 9-storey buildings in site layout 3 has the least solar access in comparing with site layout 1 and 2. The second lane of 9-storey buildings is mostly in shade during the heating period.*
 - 3) *Due to the orientations, S1, S6, S4, T3, T4, T5, F5, F6 and F7 has better solar access in average in winter than T1, T2, F1, F2, F3 and F4.*
 - 4) *Roofs are always in good condition.*
 - 5) *Linear distance between F5, F5 and F7 will not have significant impact on solar access of open spaces most of the time.*
-

Surfaces against external air comparison

The total area of the surfaces against the external air for each sit layouts are listed below:

- Site layout 1: 27720 m²
- Site layout 2: 22303 m²
- Site layout 3: 19280 m²

Figure 35 illustrates that from site layout 1 to site layout 2, the surface area against air has reduced 5417m². From site layout 1 to site layout 3, the surface area against air has reduced 8440m².

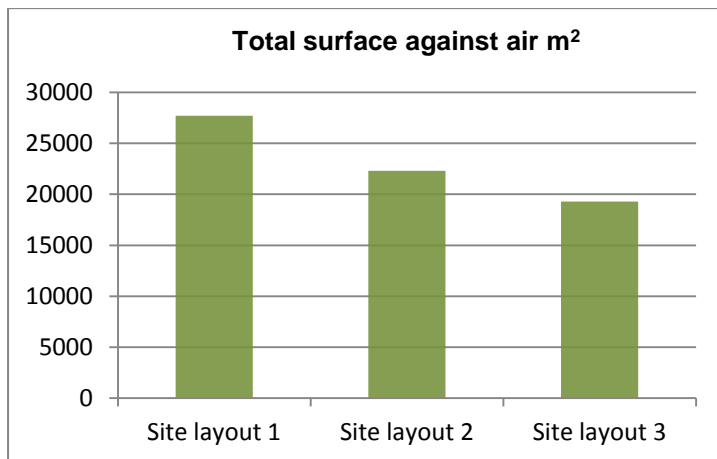


Figure 35: Comparison of total surface against air among three site layouts.

Surfaces for active solar comparison

Active solar systems such PV can be integrated into the building surfaces or install on the roof as the standing alone systems. According to the solar access analysis, the first lane of the building blocks from three site layouts always has good solar access. However, the second lane will have longer period in the shadow than the first lane, especially all the first floors.

If the building integrated PV will be preferred by the architects and clients, then the detailed analysis should be done in order to find out which surfaces are more suitable for creating a higher production from PV. It is suggested the area which locate F1, F2, F3 and F4 is not suitable for the building integrated PV due to it average low solar exposure during entire year. Site layout 3, especially the 9-storey and 10-storey buildings locate on the second lane is not an appropriate surface for building integrated PV.

It has stated in the Design reflection 1, 2 and 3 that roofs always have good solar exposure. So in this thesis, the standing alone PV systems is recommended. And the solar thermal collector for domestic hot production can be also arranged on the roof.

Energy demand discussion and comparison

Total heating demand comparison

Total heating demand for three site layouts is listed below [see figure 36]:

- Site layout 1: 322845 kWh
- Site layout 2: 291372 kWh

- Site layout 3: 280481 kWh

Site layout 2 has a reduction on heating demand of 10% from site layout 1. And site layout 3 has a reduction on heating demand of 13%.

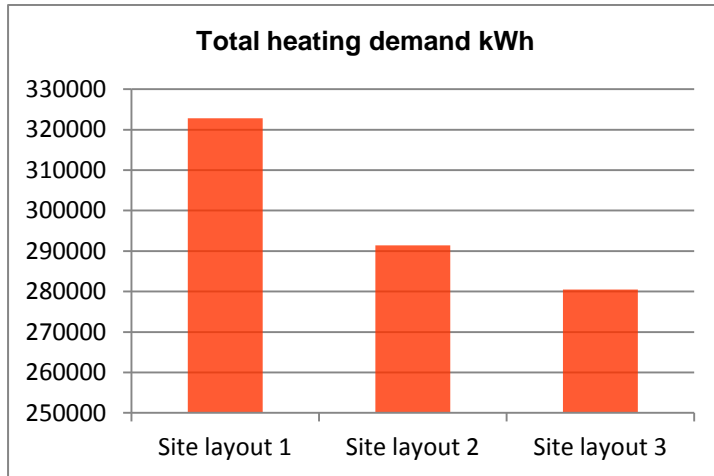


Figure 36: Comparison of total heating demand among three site layouts.

By changing building massing into different form in three site layouts ends with different heating demands. The reduction of external surfaces expose to air means the reduction of heat losses through building envelope. Therefore, site layout 2 can achieved lower heating demands than site layout 1. Usually the heat loss through roof is very considerable. In site layout 3, the dramatic reduction of the roof area brought a bigger reduction on heating demand from site layout 1.

Heat loss factor relate to room temperature comparison

Nowadays, applying well insulated and air tight building envelope is not a difficult technique anymore. Thus, the risk of high room temperature became critical due to the highly insulated and air tight building envelope. Due to the limit amount of time and size of the thesis, one single 4-storey building and one three 4-storey combined building blocks will be analyzed as an example. Figure 37 illustrates cross section sketches of one single 4-storey building and one three 4-storey combined building blocks. The red squares in figure37 Indicate the chosen apartments for room temperature analyses. They are on the same floor and same position, the only difference is the apartment in sketch on right is designed adjacent to another apartment.

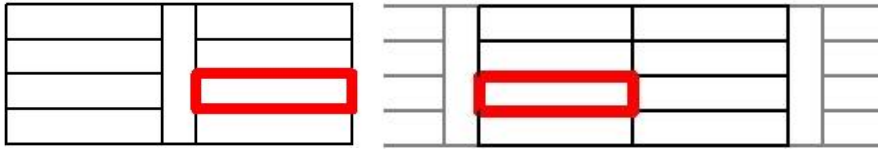


Figure 37: Cross section sketch of 4-storey apartment. Sketch on the left is a single block. Sketch on the right is the middle block of a cluster of 3 buildings. Red square indicates the chosen examine apartment.

As output data from SIMIEN, the heat loss factors for these two apartments are:

- The chosen apartment in single 4-storey building: $0.36 \text{ W/m}^2\text{K}$
- The chosen apartment in three 4-storey combined block: $0.33 \text{ W/m}^2\text{K}$

Thus, the apartment in three 4-storey combined block might have higher indoor temperature than the one in single 4-storey building. According to the dry bulb temperature from weather tool, the lowest temperature day in Bergen appears on 10th of February and hottest day is on 3rd of August [see figure 38]. The comfort temperature range in the coldest day is approx. between 18°C - 20°C . And the comfort zone in the hottest day is approx. between 20°C - 24°C .

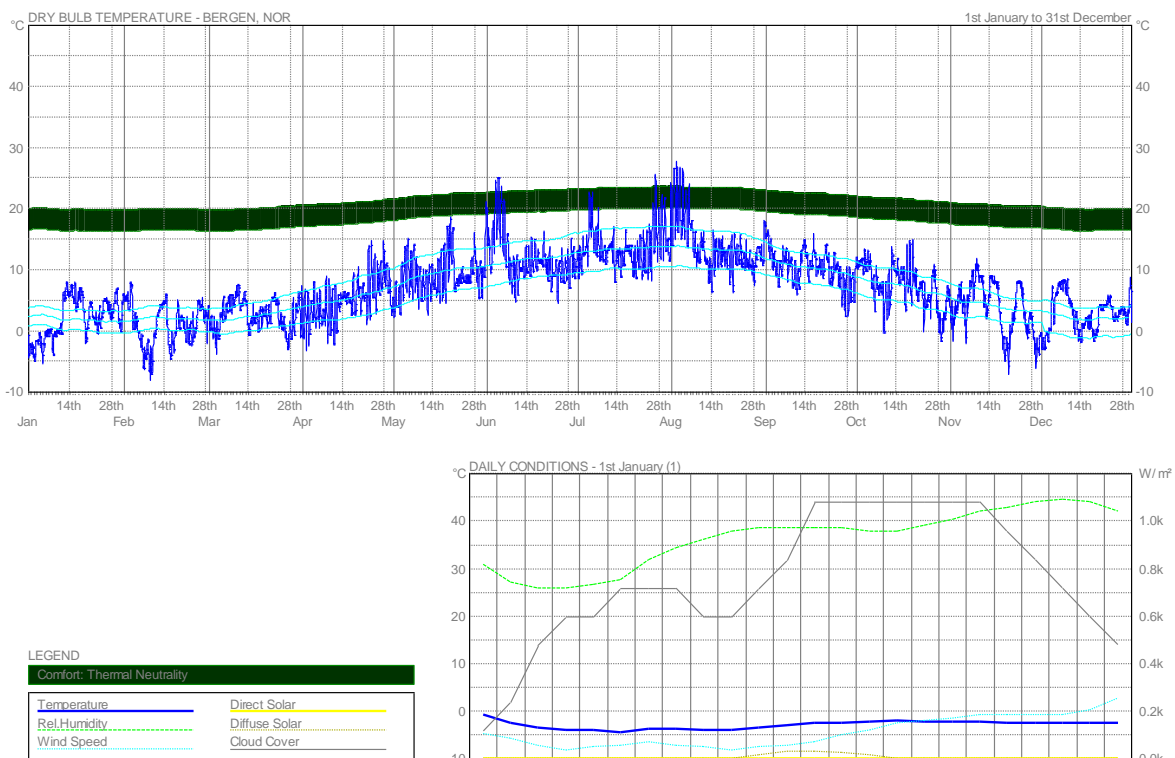


Figure 38: The table (on top) illustrate the fluctuation of the temperature in Bergen during the whole year. And the green band indicates the comfort temperature band.

According to SIMIEN's calculation, the indoor temperatures of exam apartment in three 4-storey combined blocks on 3rd of August and 10th of January are illustrated in figure 39.

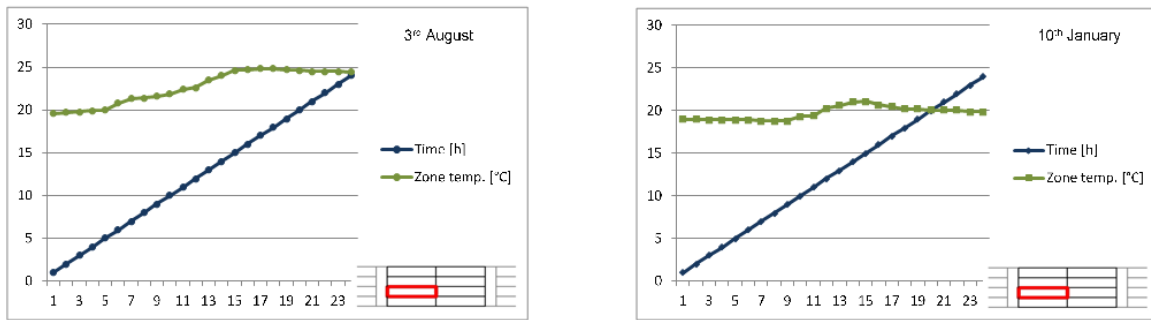


Figure 39: Fluctuations of temperatures through the whole day on 3rd of Aug and 10th of Jan.

On Aug. 3rd, indoor temperature of the apartment fluctuates between 20°C - 25°C which is 1°C degree higher than the comfort temperature band suggested by weather tool. On Jan. 10th, indoor temperature of the apartment fluctuates between 19°C - 22°C which is 2°C degree higher than the comfort temperature band suggested by weather tool. Seeing from the analysis above, there is not much exceeding temperatures. Thus, there will be no much over heating problems in the apartments by combing the building blocks together.

Comparison conclusions

There are a few comparison criteria discussed here [see table 6]:

1. Area in contact with external air: site layout 3 has least external surfaces that means it uses least materials on building structure.
2. Area in contact with soil: site layout 3 has least area in contact with soil that means use least land for building construction.
3. Solar envelope for the buildings: site layout 1 and 2 has least problems on solar envelope for the buildings.
4. Solar access to open place: site layout 1 and 2 has biggest solar access on open spaces.
5. Total heating demand: site layout 3 has the least heating demand.
6. Available active solar area on roofs: site layout 1 and 2 have advantages in this case.

Three site layouts have their pros and cons. By choosing site layout 3 might end with lower heating demand. It also has potential of extension since it used less land. But from a user viewpoint, he/she might lack of the feeling of shared green space on the ground level. From construction materials viewpoint, these kinds of mid-rise building might not be suitable to use timber construction. Heavy construction such concrete can be another choice. It might end with higher emissions from choosing heavy concrete construction. From the microclimate viewpoint, the detailed analysis of wind patterns should be analyzed in order to avoid wind

tunnels with fast wind speed penetration between the buildings. It will create an unpleasant open space.

Criteria	Site layout 1	Site layout 2	Site layout 3
Area in contact with external air			
Area in contact with soil			
Solar envelope for all the buildings			
Solar access to open space			
Total heating demand			
Available active solar area on roofs			

Table 6: The table indicates the advantage and disadvantage of the examine criteria.

Site layout 1 and 2 have similar situation on solar access to the buildings and open spaces. But site layout 2 has lower heating demand and less area in contact with external air. So site layout 2 is chosen for renewable energy supply systems analyses.

3.6 Renewable Energy Supply Systems Options

Summary:

3.6 includes four main parts: 1) renewable energy supply systems option 1; 2) renewable energy supply systems option 2; 3) renewable energy supply systems option 3; 4) options comparison and conclusion

In order to achieve Norwegian passive house standard, the building should have space heating of $15\text{kWh/m}^2\text{a}$. All the buildings in site layout 2 have to reach this standard. In order to avoid repeating calculation work for energy budget and renewable energy supply systems, building S1+S6+S4 will be chosen for this analysis here. This will not influence the aim of the analysis which is finding out a better renewable energy supply systems for achieving a ZEB. The U-value of external walls has been further improved into $0.10\text{W/m}^2\text{K}$. The rest portion of the building envelope remains the same [see table 3, with U-value in design options similarities]. Three options are set up in order to compare different combination of renewable energy supply systems:

1. Option 1: electricity is provided by PV + Grid, heating is provided by solar thermal collector + fuel cell CHP
2. Option 2: electricity is provided by gas turbine CHP + Grid, heating is provided by solar thermal collector + gas turbine CHP
3. Option 3: electricity is provided by PV + Grid, heating is provided by solar thermal collector + ground source heat pump

Option 1

In option 1, PV and the national grid is mainly used to cover the electricity demand. Solar thermal collector is assumed to cover 30% of the heating demand and CHP will cover the rest. Fuel cell CHP with power-to-heat ratio of 0.3 - 0.7 will be chosen here [see table 7, 15, 142].

		i. c. engine	Diesel engine	Stirling engine	Fuel cell	Gas turbine
Electrical output	[kW]	1-5000	5-20000	1-40	1-250	30-250000'
Total degree of efficiency	[%]	up to 90	up to 90	up to 85	up to 90	up to 85
Elec. degree of efficiency	[%]	25-42	28-44	10-30	30-47	25-30
Power-to-heat ratio	[-]	0.4-1,1	0.5-1,1	0.4	0.3-0.7	0.3-0.6
Part-load behaviour		good	good	not so good	very good	not so good
Status of technology		proven	proven	small series	pilot plants	proven

Table 7: Table indicates the power to heat ratio of different types of CHP and their efficiency.

Table 8 illustrate the electricity balance between the production and demand.

Month	Electricity demand [kwh]	PV [kwh]	CHP electricity [kwh]	Grid supply [kwh]	Exported to grid [kwh]
Jan	3384	238	1847	-1299	
Feb	3056	638	1847	-571	
Mar	3384	1510	1847	-27	
Apr	3274	2340	1847		913
May	3384	2830	1847		1293
Jun	3274	3050	1847		1623
Jul	3384	2760	1847		1223
Aug	3384	2160	1847		623
Sep	3274	1520	1847		93
Oct	3384	759	1847	-778	
Nov	3274	301	1847	-1126	
Dec	3384	102	1847	-1435	
Total	39840	18208	22164	-5209	5768

Table 8: Table indicates the electricity demand and production from renewable energy systems.

Total area of PV is equal to approx. 250m². The table has been imported into column chart [see figure 40]. It can be seen that in Jan, Feb, Mar, Oct, Nov and Dec, the building needs extra electricity from the grid. However, from the whole year production viewpoint, electricity production covers the demand.

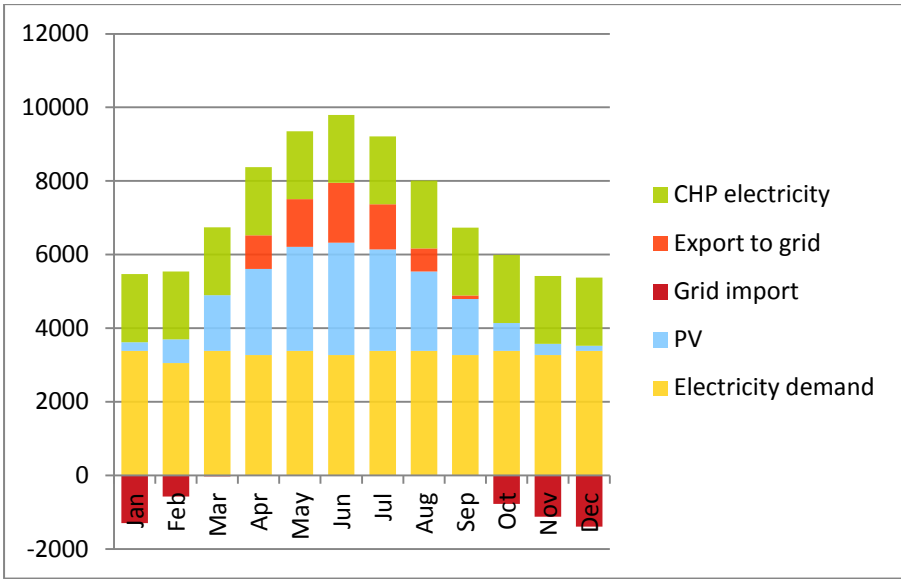


Figure 40: The electricity balance between the production and demand.

Table 9 illustrate the heating balance between the production and demand.

Month	Heating demand [kwh]	DHW demand [kwh]	Total monthly demand [kwh]	ST 30% HD [kwh]	Rest HD with CHP [kwh]
Jan	3737	3552	7289	165	7124
Feb	3359	3208	6567	440	6127
Mar	3323	3552	6875	1029	5846
Apr	1980	3437	5417	1590	3827
May	1138	3552	4690	1922	2768
Jun	302	3437	3739	2074	1665
July	37	3552	3589	1879	1710
Aug	38	3552	3590	1469	2121
Sep	440	3437	3877	1039	2839
Oct	1570	3552	5122	521	4601
Nov	2790	3437	6227	209	6018
Dec	3609	3552	7161	98	7063
Total	22323	41820	64143	12434	51709

Table 9: It presents the heating demand and renewable energy production.

Solar thermal collector covers 30% of heating demand. If it is assumed that 3.7m² solar thermal collector for a 100 m² dwelling, then the total amount of solar thermal collector are equal to approx. 50m² [18, 51]. Figure 41 illustrate the solar thermal collector production and the building's heating demand.

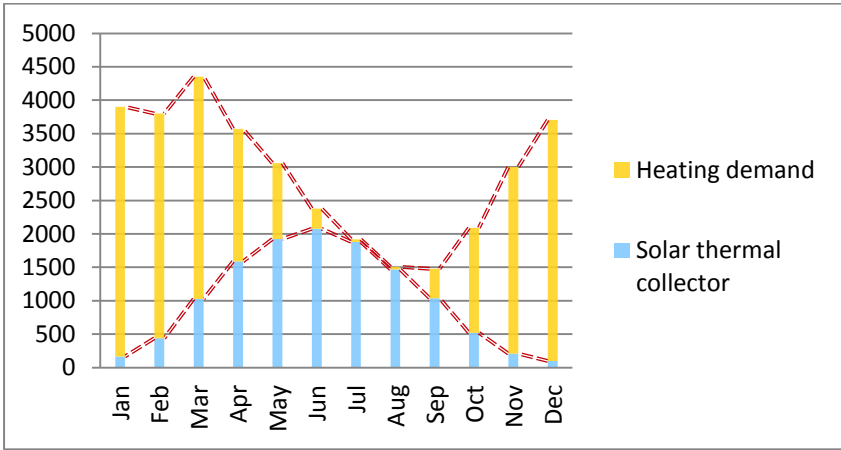


Figure 41: Solar thermal production through the whole year in comparing with heating demand.

Due to big mismatch of solar thermal collector production through the whole year, CHP will be used to cover the rest of the heating demand. The balance between the heating demand and solar thermal collector, CHP can be found in figure 42.

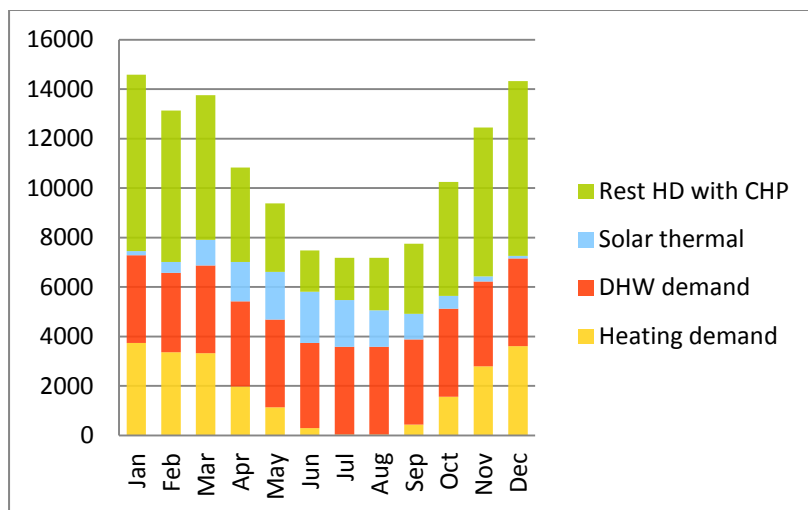


Figure 42: Heating demand and production balancing

Delivered energy [see table 10] is calculated as presented in the table below. Since solar thermal collector and PV all need electricity to run the systems, so the electricity CO₂ factor is taken the same as the national grid – 395g/kWh [12, 4]. The rest of the CO₂ emission factors are suggested by SIMIEN.

BRA: 1488m ²	Energy supply [kwh/a]	Efficiency	Delivered energy		CO2 factor [g/kWh]	CO2 emissions	
			[kwh/a]	[kwh/m ² a]		[kg]	[in kg/m ²]
Electricity							
Cristalline silicon PV	18208.0	100.0	182.1	0.12	395.0	71.9	0.05
Biofuel CHP	22164.0	0.98	22616.3	15.20	14.0	316.6	0.21
grid	-532.0	0.98	-542.9	-0.36	395.0	-214.4	-0.14
Total electricity	39840.0		22255.5	14.96		174.12	0.12
Heating							
Biofuel CHP	22323.0	0.84	26575.0	17.9	14.0	372.05	0.3
Total heating	22323.0		26575.0	17.9		372.1	0.3
DHW							
Solar thermal	12434.0	8.55	1454.3	0.98	395.0	574.4	0.39
Biofuel CHP	29386.0	0.84	34983.3	23.5	14.0	489.8	0.33
Total DHW	41820.0		36437.6	24.5		1064.2	0.7
Sum	103983.0		85268.2	57.3		1610.4	1.1

Table 10: Delivered energy for option 1.

The balance of monthly CO₂ emissions are calculated with delivered energy and its CO₂ factor. Table 11 shows the monthly balance of CO₂ emissions both for electricity and heating.

CO ₂ Emissions (Kg)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
PV	0.94	2.52	5.96	9.24	11.18	12.05	10.90	8.53	6.00	3.00	1.19	0.56	72.07
CHP electricity	26.39	26.39	26.39	26.39	26.39	26.39	26.39	26.39	26.39	26.39	26.39	26.39	316.68
Grid import	523.58	230.25	10.89							313.58	453.85	562.27	388.75
Export to grid				-368	-521.16	-654.17	-492.94	-251.11	-37.48				-2324.86
Solar thermal	7.62	20.33	47.54	73.46	88.79	95.82	86.81	67.87	48.00	24.07	9.66	4.53	574.50
CHP heating	118.73	102.12	97.43	63.78	46.13	27.75	28.50	35.35	47.32	76.68	100.03	117.72	861.54

Table 11: The balance of CO₂ emissions.

The numbers in table 11 has been imported to the column chart in order to visualize the balance in a clear way [see figure 43].

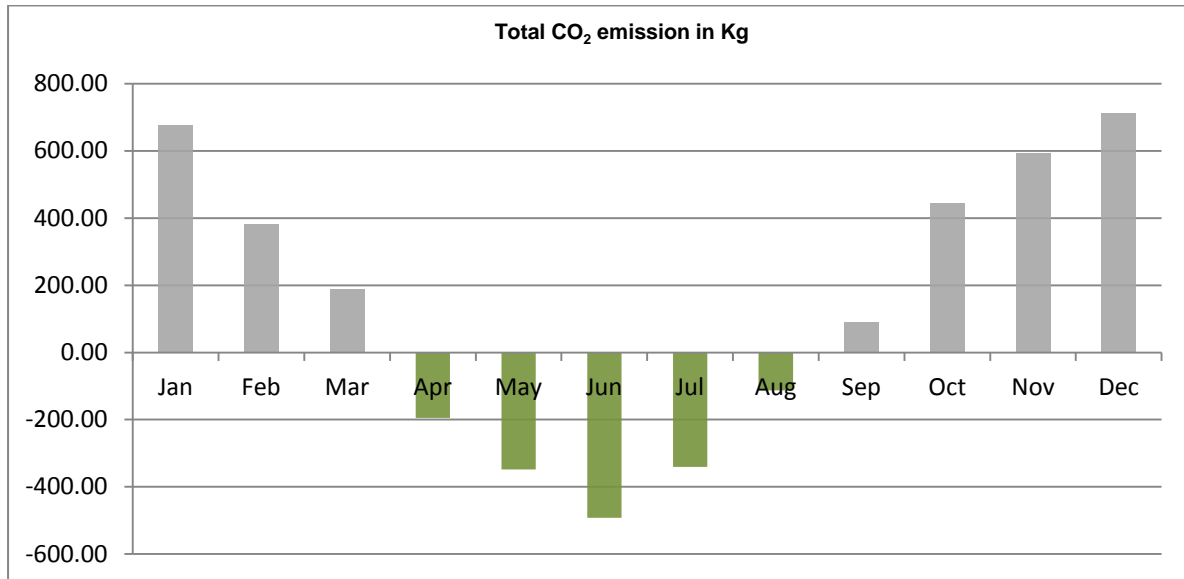


Figure 43: Balance of CO₂ emissions through the whole year.

Option 2

In option 2, CHP and the national grid is mainly used to cover the electricity demand. PV is used to cover the rest of the electricity demand for the energy balance purpose. Solar thermal collector is assumed to cover 30% of the heating demand and CHP will cover the rest. Gas turbine CHP with power-to-heat ratio of 0.3-0.6 will be chosen here [see table 12, 15, 142].

Table 12 illustrate the electricity balance between the production and demand.

Month	Electricity demand [kwh]	PV [kwh]	CHP electricity [kwh]	Grid supply [kwh]	Exported to gird [kwh]
Jan	3384	183	2155	-1046	
Feb	3056	491	2155	-410	
Mar	3384	1160	2155	-69	
Apr	3274	1800	2155		681
May	3384	2180	2155		951
Jun	3274	2350	2155		1231
Jul	3384	2120	2155		891
Aug	3384	1660	2155		431
Sep	3274	1170	2155		51
Oct	3384	584	2155	-645	
Nov	3274	232	2155	-887	
Dec	3384	109	2155	-1120	
Total	39840	14039	25860	-4108	4236

Table 12: It indicates the production of renewable energy systems and electricity demand of the building.

Total area of PV is equal to approx. 200m². The table has been imported into column chart [see figure 44]. It can be seen that in Jan, Feb, Mar, Oct, Nov and Dec, the building needs extra electricity from the grid. However, from the whole year production viewpoint, electricity production covers the demand.

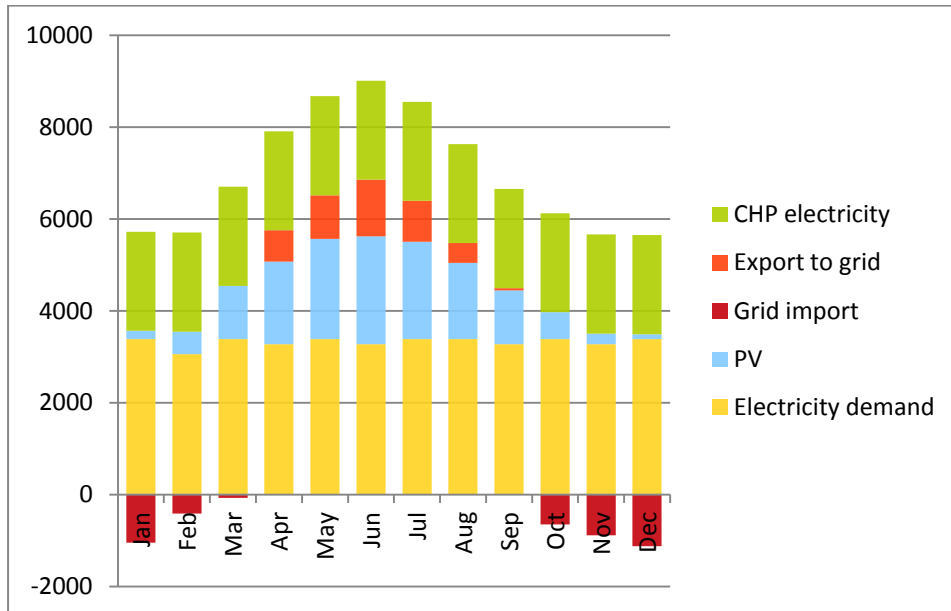


Figure 44: Energy production and demand of electricity.

Table 13 illustrates the heating balance between the production and demand.

Month	Heating demand [kwh]	DHW demand [kwh]	Total monthly demand [kwh]	ST 30% HD [kwh]	Rest HD with CHP [kwh]
Jan	3737	3552	7289	165	7124
Feb	3359	3208	6567	440	6127
Mar	3323	3552	6875	1029	5846
Apr	1980	3437	5417	1590	3827
May	1138	3552	4690	1922	2768
Jun	302	3437	3739	2074	1665
July	37	3552	3589	1879	1710
Aug	38	3552	3590	1469	2121
Sep	440	3437	3877	1039	2839
Oct	1570	3552	5122	521	4601
Nov	2790	3437	6227	209	6018
Dec	3609	3552	7161	98	7063
Total	22323	41820	64143	12434	51709

Table 13: It indicates the heating demand and the renewable energy production.

In this case, the heating demand balance is the same as in option 1, so the same information will not be repeated here. Delivered HD energy is calculated as presented in the table below.

BRA: 1488m ²	Energy supply		Delivered energy		CO2 factor [g/kWh]	CO2 emissions	
	[kwh/a]	Efficiency	[kwh/a]	[kwh/m ² a]		[kg]	[in kg/m ²]
Electricity							
Cristalline silicon PV	14039.0	100.0	140.4	0.09	395.0	55.5	0.04
Biogas CHP	25860.0	0.98	26387.8	17.73	14.0	369.4	0.25
grid	-59.0	0.98	-60.2	-0.04	395.0	-23.8	-0.02
Total electricity	39840.0		26467.9	17.79		401.10	0.27
Heating							
Biogas CHP	22323.0	0.84	26575.0	17.9	14.0	372.05	0.3
Total heating	22323.0		26575.0	17.9		372.1	0.3
DHW							
Solar thermal	12434.0	8.55	1454.3	0.98	395.0	574.4	0.39
Biogas CHP	29386.0	0.84	34983.3	23.5	14.0	489.8	0.33
Total DHW	41820.0		36437.6	24.5		1064.2	0.7
Sum	103983.0		89480.5	60.1		1837.4	1.2

Table 14: Delivered energy of option 2.

The balance of monthly CO₂ emissions are calculated with delivered energy and its CO₂ factor. Table 15 shows the monthly balance of CO₂ emissions both for electricity and heating.

CO ₂ Emissions (Kg)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
PV	0.72	1.94	4.58	7.11	8.61	9.28	8.37	6.56	4.62	2.31	0.92	0.43	55.45
Grid import	421.60	165.26	27.81							256.00	357.52	451.43	1679.62
Export to grid				-274.48	-383.31	-496.17	-359.13	-173.72	-20.56				-1707.37
CHP electricity	30.79	30.79	30.79	30.79	30.79	30.79	30.79	30.79	30.79	30.79	30.79	30.79	369.48
Solar thermal	7.62	20.33	47.54	73.46	88.79	95.82	86.81	67.87	48.00	24.07	9.66	4.53	574.50
CHP heating	118.73	102.12	97.43	63.78	46.13	27.75	28.50	35.35	47.32	76.68	100.03	117.72	861.54

Table 15: Table illustrated monthly CO₂ emissions.

The numbers in table 15 has been imported to the column chart in order to visualize the balance in a clear way.

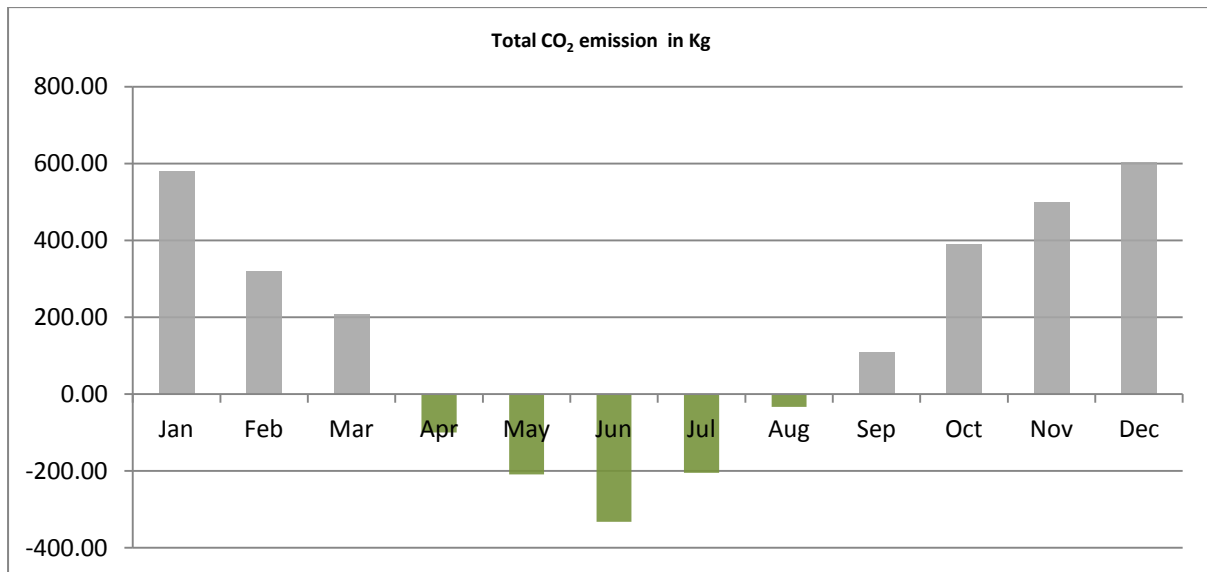


Figure 45: Monthly CO₂ emissions cannot be balanced in option 2.

It can be calculated from table 15 that CO₂ emissions cannot be balanced in this case even though the operational energy demand has been covered by renewable energy production. There are still remaining 1833.22 kg CO₂ emissions need to be covered by renewable energy. If PV will be chosen in this case to compensate these amounts of CO₂ emissions, then another 600m² will be needed.

Option 3

In option 3, PV and the national grid is used to cover the electricity demand. Solar thermal collector is assumed to cover 30% of the heating demand and ground source heat pump will cover the rest.

Table 16 illustrate the electricity balance between the production and demand.

Month	Electricity demand [kwh]	PV [kwh]	Grid supply [kwh]	Exported to grid [kwh]
Jan	3384	531	-2853	
Feb	3056	1420	-1636	
Mar	3384	3320	-64	
Apr	3274	5130		1856
May	3384	6200		2816
Jun	3274	6690		3416
Jul	3384	6060		2676
Aug	3384	4740		1356
Sep	3274	3350		76
Oct	3384	1680	-1704	
Nov	3274	674	-2600	
Dec	3384	102	-3282	
Total	39840	39897	-12139	12196

Table 16: Electricity demand and energy supply.

Total area of PV panels is approx. 600m². It can be seen that in Jan, Feb, Oct, Nov and Dec, the building needs extra electricity from the grid, see figure 46. However, from the whole year production viewpoint, electricity production covers the demand.

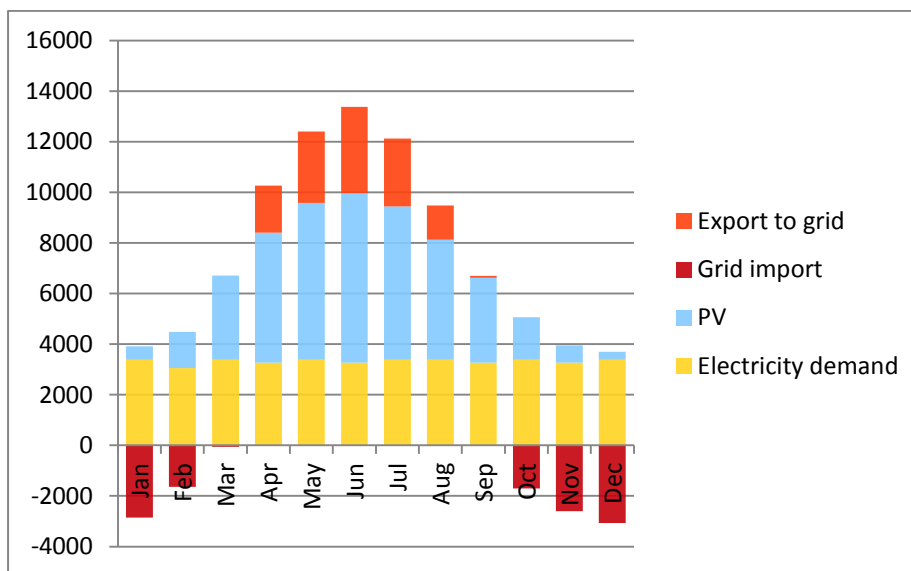


Figure 46: Electricity demand and electricity production.

Table 17 illustrates the heating balance between the production and demand.

Month	Heating demand [kwh]	DHW demand [kwh]	Total monthly demand [kwh]	ST 30% HD [kwh]	Rest HD with HP [kwh]
Jan	3737	3552	7289	165	7124
Feb	3359	3208	6567	440	6127
Mar	3323	3552	6875	1029	5846
Apr	1980	3437	5417	1590	3827
May	1138	3552	4690	1922	2768
Jun	302	3437	3739	2074	1665
July	37	3552	3589	1879	1710
Aug	38	3552	3590	1469	2121
Sep	440	3437	3877	1039	2839
Oct	1570	3552	5122	521	4601
Nov	2790	3437	6227	209	6018
Dec	3609	3552	7161	98	7063
Total	22323	41820	64143	12434	51709

Table 17: Heating demand and renewable energy supply.

Table 17 has been imported to the column chart. Figure 47 illustrates the balance between energy demand and production.

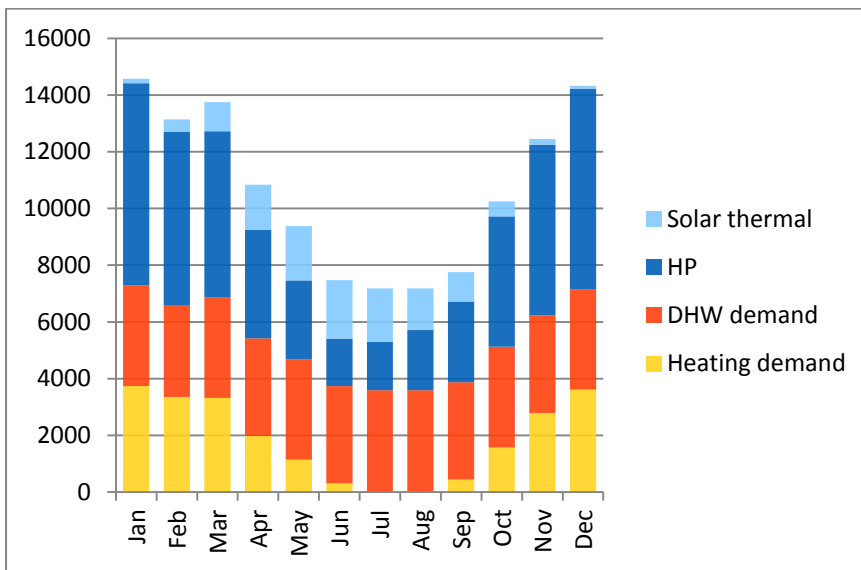


Figure 47: Electricity production and heating demand.

Delivered energy is calculated as presented in the table below.

BRA: 1488m ²	Energy supply [kwh/a]	Efficiency	Delivered energy [kwh/a] [kwh/m ² a]		CO2 factor [g/kWh]	CO2 emissions [kg] [in kg/m ²]		
Electricity								
Cristalline silicon PV	39897.0	100.0	399.0	0.27	395.0	157.6	0.11	
grid	-57.0	0.98	-58.2	-0.04	395.0	-23.0	-0.02	
Total electricity	39840.0		340.8	0.23		134.62	0.09	
Heating								
HP	22323.0	2.6	8585.8	5.8	395.0	3391.38	2.3	
Total heating	22323.0		8585.8	5.8		3391.4	2.3	
DHW								
Solar thermal	12434.0	8.55	1454.3	0.98	395.0	574.4	0.39	
HP	29386.0	2.60	11302.3	7.6	395.0	4464.4	3.00	
Total DHW	41820.0		12756.6	8.6		5038.8	3.4	
Sum	103983.0		21683.2	14.6		8564.8	5.8	

Table 18: Delivered energy for option 3.

The balance of monthly CO₂ emissions are calculated with delivered energy and its CO₂ factor. Table19 shows the monthly balance of CO₂ emissions both for electricity and heating.

CO ₂ Emissions (Kg)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
PV	13.37	12.07	13.37	12.93	13.37	12.93	13.37	13.37	12.93	13.37	12.93	13.37	157.37
Grid import	1149.93	659.41	25.80							686.82	1047.96	1236.59	4806.51
Export to grid				-748.08	-1135.02	-1376.86	-1078.59	-546.55	-30.63				-4915.73
HP	1082.30	930.83	888.14	581.05	420.52	252.95	259.79	322.23	431.31	699.00	914.27	1073.03	7855.44
Solar thermal	7.62	20.33	4.88	73.45	88.80	95.82	86.81	67.86	48.00	24.07	9.65	4.53	531.82

Table 19: Monthly CO₂ emissions for option 3.

The numbers in table 19 has been imported to the column chart in order to visualize the balance in a clear way, see figure 48.

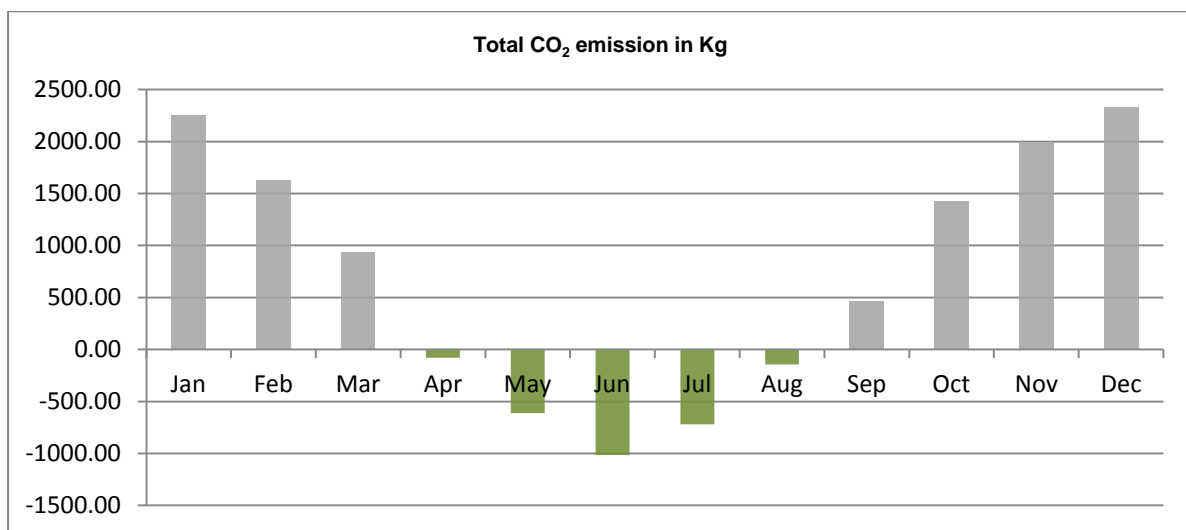


Figure 48: Monthly CO₂ emissions cannot be balanced.

It can be calculated from table 19 that CO₂ emissions cannot be balanced in this case even though the operational energy demand has been covered by renewable energy production. There are still remaining 1833.22 kg CO₂ emissions need to be covered by renewable energy. Using PV to cover these amounts of CO₂ emissions are not logical.

Comparison and conclusion

In option 1, using PV for main electricity production, the electricity from CHP considered as surplus. In this case, building can easily achieve an annual balance on CO₂ emissions. In option 2, using CHP for electricity purpose and the heat emitted from the process of electricity production cover part of the heating demand. In this case, an extra of approx. 600m² PV panels are need in order to achieve an annual balance on CO₂ emissions. In option 3, only using PV for electricity production and heat pump covers 70% of heating demand is not easy to achieve the CO₂ emissions annual balance.

Thus option 1 is the best choice among these three options. The fuel cell CHP are mainly operated using hydrogen obtained from natural gas at the moment. However, only prototypes have been built to date; a market launch is expected in the near future [15, 143]. If option 2 will be chosen, then the roof mounted PV will be 800m² in total. And the available roofing surface on S1+S6+S4 is 900m². Thus, among these three options, option 2 might be a better choice.

4. Conclusions and Future Work

Conclusions

The main research question in this thesis is:

What are the impacts on solar access and energy demand of different building masses in linear building forms?

The research question is formed up with the aim of providing a further reduction of environmental impact from Ådland suburb sustainable residential community feasibility study which is provided by our supervisor. The answers started from the discussion of few sub questions:

- Why sustainability and sustainable buildings?
- Why sustainable development in suburbs?
- What a suburb sustainable residential community constitutes?
- What the main environmental criteria for the design of suburb sustainable residential community?

Due to the energy crises, sustainability emerged and it represents that meet the needs of the present without compromising the ability of future generations to meet their own needs. Thus, sustainability is focusing on addressing the environmental problems while retaining the balance among human equality and quality of life, economic and social criteria. Buildings and associated infrastructure cause approximately 30% of the energy and material flows and effects on the environment. If we can assume that climate change is the direct outcome of human activities, then the reduction of building energy consumption should be considered initially. Sustainable covers many issues, but none is as important as energy. Regardless of the sources, the energy efficiency of building is considered as the initial task for any sustainable strategies. Despite the use of energy efficiency measures, it is recommended to cover the rest of energy demand by utilizing renewable energy. Therefore, it is clear that in the context of building sector, the objective of sustainability is producing the least possible amount of energy to reduce the environmental impact.

Due to the fast urban population and improving transportation technology, it led the expansion growing towards suburbs. The traditional way of suburban sprawl leads to a higher consumption of fossil fuels. So sustainability should be implemented to suburb community.

Suburb sustainable residential community should include a serious of mix-functions which can provide residents' daily needs.

From the entire site viewpoint, site surroundings, site existing flora and fauna, microclimate should be carefully analyzed.

From a single apartment block viewpoint, the adaptable design of homes for different users and the appropriate design for future changes should be considered. The energy efficiency measures should also be concerned.

Learning from the theory, the built area and green area on Ådland site has been reselected with the approach of preserving the nature and native topography as much as possible. Three site layouts design have been done based on new built area. Discussions due to the solar access are carried out in three parts:

- **Affected by the building mass and building lanes:** firstly, roofs are always having good solar access. With the separated building layout on site can bring a better solar access to the open spaces. First floors in the building located on the second lane also have less risk of casted in shade. By clustering the building in transverse direction, simply closing the gaps between buildings, the open space will not have better solar access in March and Dec. The first floors in buildings located on the second lane will have higher risk of longer shaded hours in March and Dec. But this risk seems negligible according to the sun path analyses. By clustering the buildings in vertical direction, lower floors in the buildings located in second lane cannot ensure solar access in Dec. If the different height of building blocks will be arranged on site, then the buildings with less storey should located on the upper level. Approximately average 25 meters between building lanes in site layout1 and 2 are the minimum distance for ensuring better solar access to all the buildings. And in order to ensure the buildings get better solar access from the second lane in site layout 3, the distance between the lanes should be more than 40 meter.
- **Orientations of the buildings:** most of the buildings on site have similar orientations, and their solar access is in a good condition. But the buildings have

north façade orientation of 110° till 135° is worse than other buildings in terms of south façade solar exposure. These two types of orientations should be avoided.

- **Area on site:** the area against south side is in a good solar condition since it is the highest level on site. The area against west side has the deepest slope on site. So the buildings and open spaces can be easily shaded not only by the buildings surrounded but also the nature terrain. So this area might not be suitable to construct buildings with the approach of following the native topography.

From the solar access viewpoint, site layout 1 will have better solar access both to the buildings and open spaces in general.

From the total heating demand view point, site layout 2 has a reduction on heating demand of 10% from site layout 1. And site layout 3 has a reduction on heating demand of 13%. The reduction from site layout 2 to site layout 3 is insignificant. So considering about reduction of heating demand in terms of different building masses from site layout 1, the most significant reduction is site layout 2.

At last, three options of renewable energy supply systems have been introduced in order to achieve a Zero Emission residential community. It is suggested that gas turbine CHP with biogas as input fuel and national grid can be used for electricity supply, PV should be used to cover the rest of electricity demand while producing the surplus in order to compensate the extra CO₂ emissions from operational energy. Solar thermal collector can be used for covering 30% of heating demand and the rest will be covered by biogas CHP.

Future work

The work is focusing on reducing the environmental impact in a suburb sustainable community scale. And more specifically for the Ådland project study, ensuring solar access and heat demand reduction with different building masses have been analyzed.

In the theory part, it is focusing on introducing strategies on how to analyze and design the site so that the new development will have least environment impact on the site. Those strategies have been carefully discussed in *the author's reflection box*. It can be used by architecture students to get a quick understanding and check points of the issues central to the development of the site in the early design stage.

In Ådland project analyses chapter, the work can be provided as a new feasibility study of Ådland project development. From the design viewpoint, it can provide relatively detailed information about the impact on solar access of different building blocks locate in different places on site. This can be further developed into the concept of different locations on site might have different appropriate configurations of housings. It can work as a base case for further development of variable exterior morphology in terms of different shapes of the roof and their impact on solar access of the open spaces and heating demand.

From the materials choices viewpoint, there is a possibility of further discussion about relationship between building envelope materials saving and total energy use of the buildings from a life cycle perspective.

Renewable energy supply systems can be further analyzed with the consideration of system installed cost. From the client point of view, cost might be one of the important considerations in terms of system choices.

Acknowledgement

I am really grateful to my supervisor Aoife Houlihan Wiberg's help. Without her useful guidance and encouragement, I could not manage to finish the thesis within three-month short period.

I appreciate the help from Matthias Haase for valuable advice and helpful information on energy calculations.

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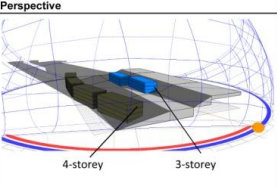
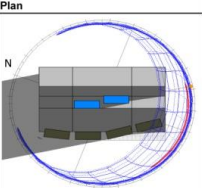
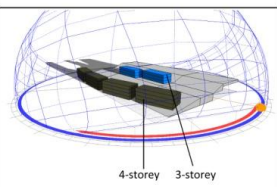
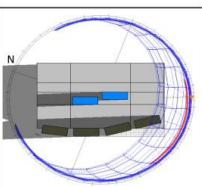
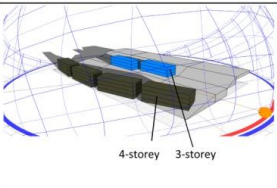
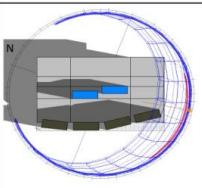
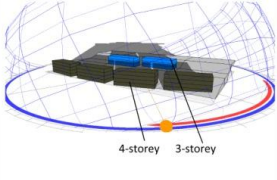
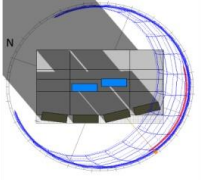
[24] **SIMIEN student version.** ProgramByggerne . Retrieved 10.05.2012, from

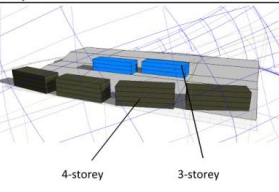
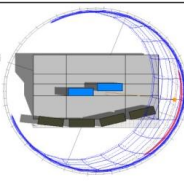
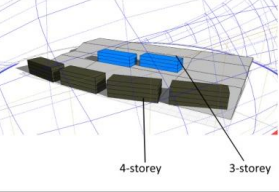
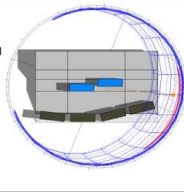
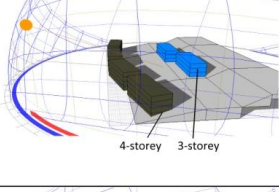
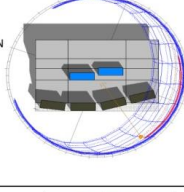
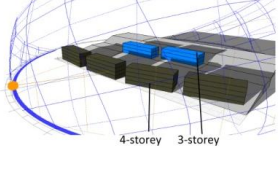
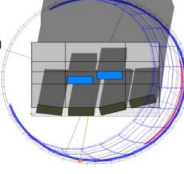
<http://www.programbyggerne.no/>

Attachment 1: Site layout 1 solar access analyses

F1, F2, F3, F4, T1, T2

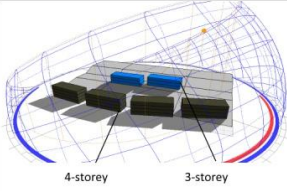
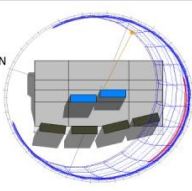
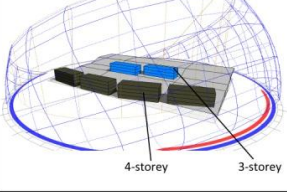
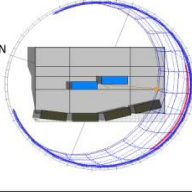
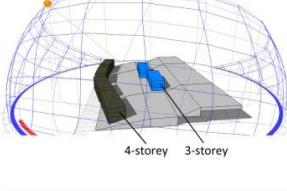
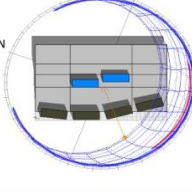
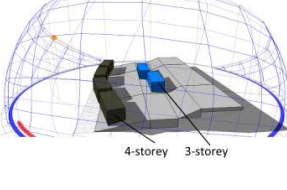
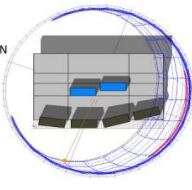
Building F1, F2, T1 and T2 will not receive the morning sun at 10:15 on **Dec.21st** (sunrise on Dec.21st). Only south facades of F3 and F4 will receive morning sun. All the roofs exposed to the sun. At 12:00, south facades in all the buildings in the simulation models are exposed to the sun. And at 15:00, half hour before sunset, south facades in F1, F2, F3 and F4 are exposed to the sun. South facades on third floor in T1 and T2 will expose to the sun. Roofs receive solar gain 5 hours in total. South facades in F1, F2, F3 and F4 will expose to the sun approx. 5 hours in total. South facades in T1 and T2 will receive approx. 2 hours sun.

Time	Views	
21 st Dec	Perspective	Plan
10:15		
11:00		
12:00		
15:00		

Time	Views	Plan
21 st Mar 08:00		
12:00		
15:00		
18:00		

At 8:00 on **Mar. 21st**, north facades of F3 and F4 are 100% exposed to the morning sun. Starting at 10:45, south facades from F3 and F4 are exposed to the sun. From 11:45, F2, T1 and T2 start to receive the sun. From 12:00 till 17:15, all the buildings' south facades are exposed to the sun. From 12:00 till 15:00, the open space is also least shaded. Roofs from F3, F4, T1 and T2 have the most solar exposure hours. It is approximately six and an half hours on Mar.21st. Total south facades solar exposures of each building block are listed below:

- F1: 5½ hours
- F2: 7 hours
- F3 and F4: 8 hours
- T1 and T2: 7 hours

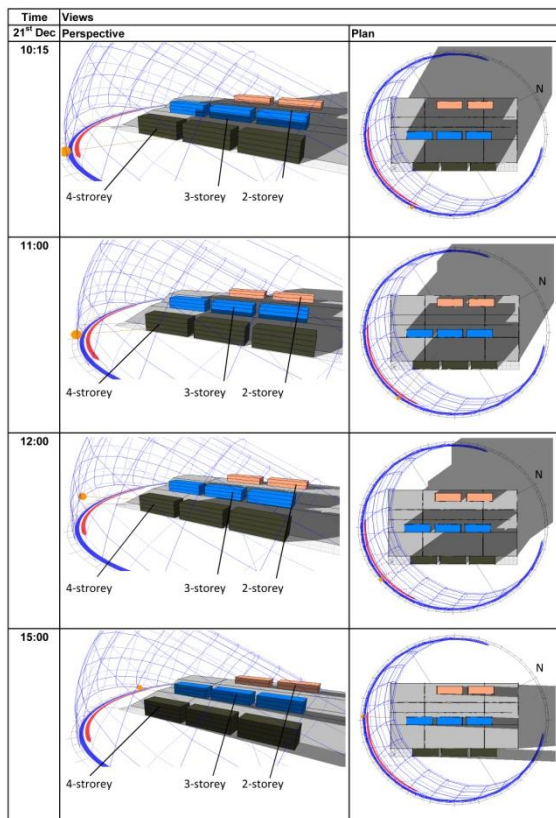
Time	Views	
21 st Jun	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

At 8:00 on **Jun.21st**, north and west façades receive morning sun. At 12:00, despite the south façade of F1, the other blocks are exposed to the sun. From noon till 15:00, all the south façades are exposed to the sun. This situation will continue until 18:00. Open spaces between the lanes are always exposed to the sun from noon until 20:30. The hours of roof solar exposure starts from 04:30 till 20:0. It is equal to 16 hours. Total south facades solar exposures of each building block are listed below:

- F1: 15 hours
- F2: 15 hours
- F3 and F4: 10 hours
- T1 and T2: 14 hours

All the south facades need shading devices.

S4, S6, T3, T4, T5, F5, F6 and F7



S4, S6, T3, T4, T5, F5, F6 and F7 are located on separated three lanes [see figure ?]. The average distance between each lane is 25 meters.

At 10:15 on **21st Dec**, south façade of F5, F6 and F7 receive morning sun. First floor in T4, T5, S6, and S4 are in shade. From 12:00, all the south facades are in a good solar access condition. And this condition continuously extended till 14:30. From sunrise at 10:15 till sunset at 15:15, the total hours of the roofs solar exposure is all in all 5 hours. Total hours of solar exposure on south facades are listed below:

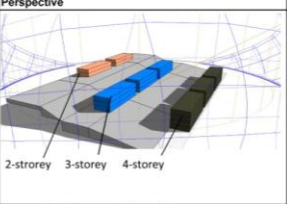
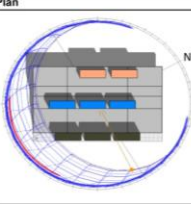
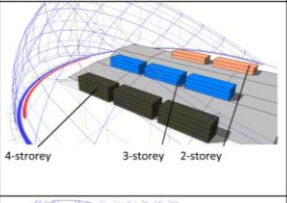
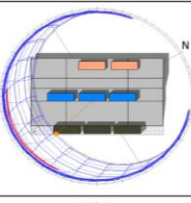
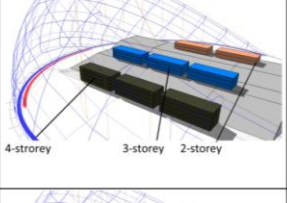
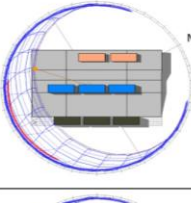
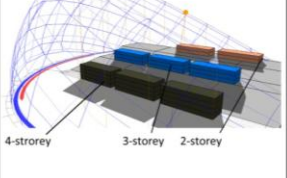
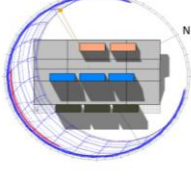
- F5, F6 and F7: 5 hours
- T3, T4, and T5: 2 hours
- S4 and S6: 2 hours

Time	Views	
21 st Mar	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

All the south facades in this simulation model are in good morning sun condition at 8:00 on **21st of Mar**. From 8:00 till 12:00, both outdoor spaces and buildings south facades are exposed to the sun between approx. 7:00 and 18:00. Solar exposure of roofs is 10 hours in total which is 50% increased from Dec.21st. Total hours of solar exposure on south facades are listed below:

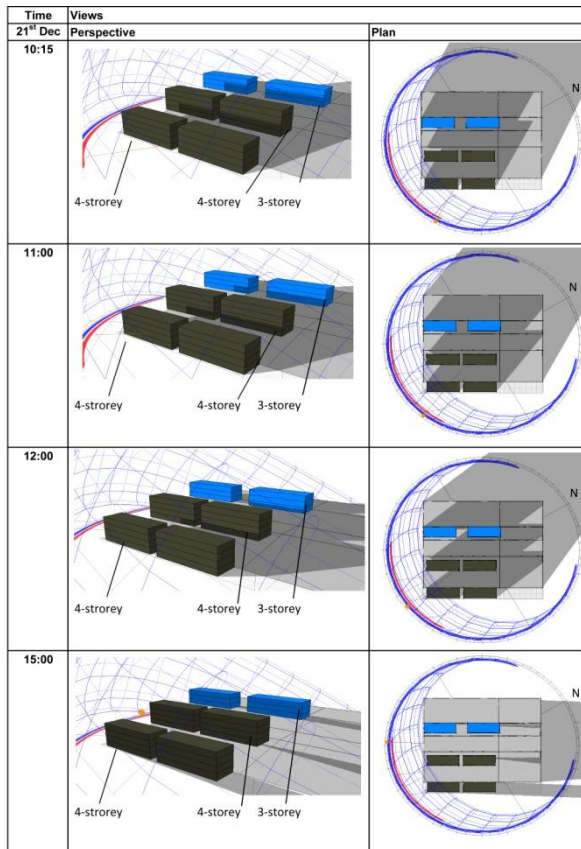
- F5, F6 and F7: 7 hours
- T3, T4, and T5: 6 hours
- S4 and S6: 7 hours

Due to the higher location of S4 and S6, they have 1 more hour's solar exposure on south façade than T3, T4 and T5. Shading might also need to be provided in this case.

Time	Views	
21 st Jun	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

All the south facades receive morning sun on **Jun. 21st**. This good condition of solar access on south façade will not be changed until 14:00. South façade exposure hours are approx. from sun rise at 4:00 till 14:00. That is equal to 10 hours in total. The outdoor open space starts to receive large amount of shadow from the building at approx. 17:00. The roofs are exposed to the sun from 4:00 till 20:30. In another word, that is approx.16 hour's solar exposures on the roof. On Jun.21st, all the south facades are receiving 11 hours solar exposures. Shadings are needed.

F8, F9, F10, F11, T6 and T7

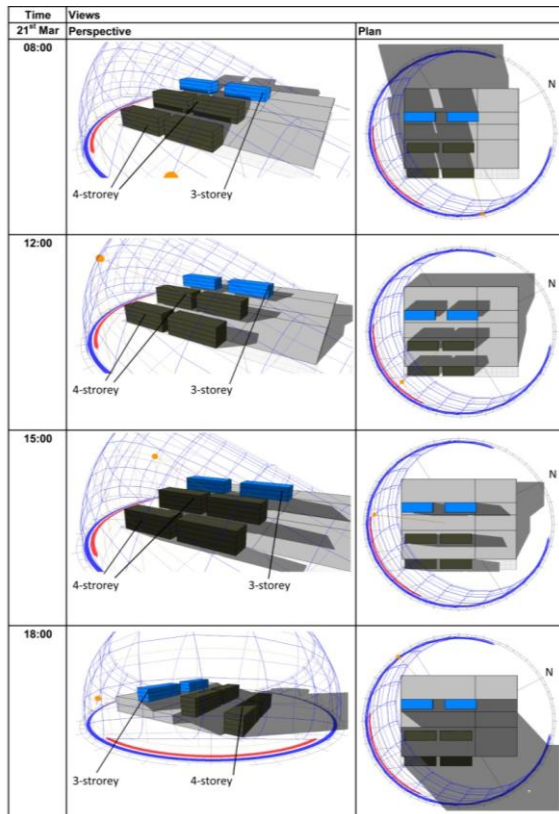


F8, F9, F10, F11, T6 and T7 are located next to the forest against east of the site [see figure ?].

At 10:15 on **Dec. 21st**, except first floor in F10, F11, T6 and T7, the rest of the buildings will receive morning sun. At 12:00, shadows started to move towards North West direction. All the blocks will expose to the winter sun in the afternoon before sunset (at 15:30). Total solar exposure hours of roofs are 5 hours. Total solar exposure hours are listed below:

- F8 and F9: 5 hours
- F10 and F11: 2 hours
- T6 and T7: 2 hours

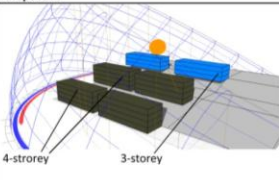
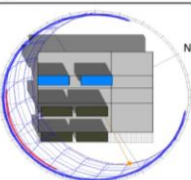
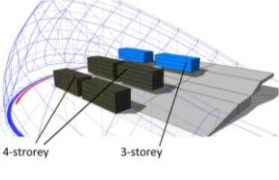
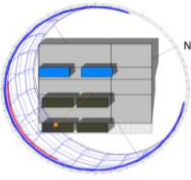
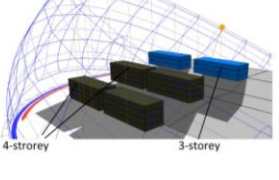
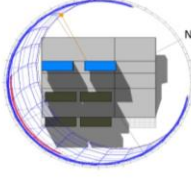
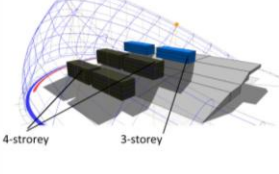
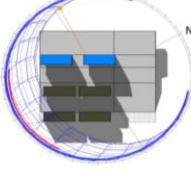
In winter, the solar access to the buildings will not influenced by the forest surrounded from northwest and northeast. But the forest located on south might reduce the solar access to the buildings.



Except first floor in F10, F11, T6 and T7, the rest of the buildings will receive morning sun at 8:00 on **Mar. 21st**. From 9:30 till 11:00, all the buildings' south facades exposed to the sun. The outdoor spaces are totally covered by shadow. From 12:00, the shaded area on the open spaces is getting smaller. South facades will be shaded from 15:00. North facades of F10, F11, F8 and F9 are shaded at 18:00. By this time, roof on building F9 and partly roof on F8, F9 and F10 are shaded. Theoretically, the roof in this model will receive approx 10 hours (from 7:00 till 17:00) solar exposure in average. Total solar exposure hours are listed below:

- F8 and F9: 6 hours
- F10 and F11: 5 hours
- T6 and T7: 4 hours

But due to the real situation, this area is surrounded trees from north east and north west direction. The average hours stated above might be reduced.

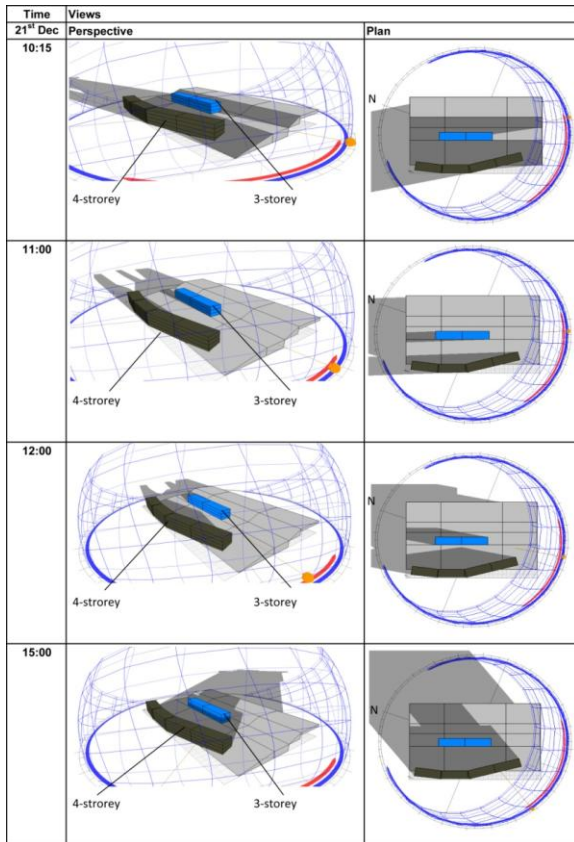
Time	Views	
21 st Jun	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

From 3:45 sun rise on **Jun.21st**, all the facades exposed to the sun. From 9:00 till 15:00, open spaces between buildings are in good solar condition. From 14:00 all the north facades will expose to the sun. Roofs are exposed to the sun from 3:45 till 18:30. That is equal to 15 hours. All the south facades will expose to the sun for 10 hours during the whole day. Those total hours will be reduced due to the real situation of the surrounded forest.

Attachment 2: Site layout 2 solar access analyses

F1+F2+F3+F4

F1+F2+F3+F4 always have good solar good access on **Dec.21st**. First floor in **T1+T2** is shaded for the whole day. In site layout 1, first floors in T1 and T2 are in better solar condition. The gaps among F1, F2, F3 and F4 allow the sun penetration to the open space and T1 and T2. With the combined model of F1, F2, F3, F4, the T1+T2 has problem on solar envelope. There is approx. 1 hour solar exposure time during whole day. It is 1 hour less then site layout 1. So the distances among the buildings located in the same lane also influencing the solar access on the open spaces and the building surrounded.



Time	Views
21 st Mar	Perspective
08:00	Plan
12:00	
15:00	
18:00	

On **Mar.21st**, due to the higher solar angle, the situation is quite similar to site layout 1.

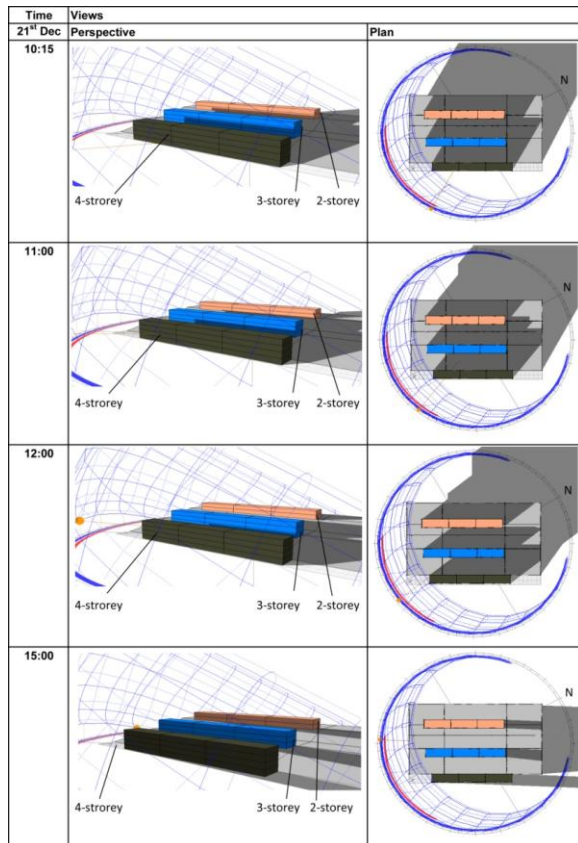
Time	Views
21 st Jun	Perspective
08:00	Plan
12:00	
15:00	
18:00	

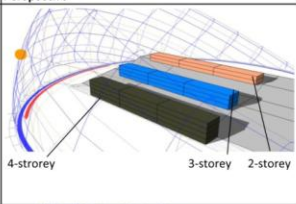
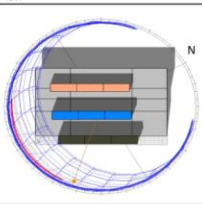
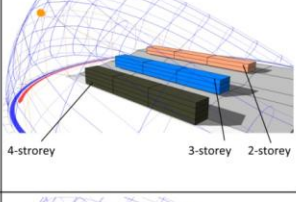
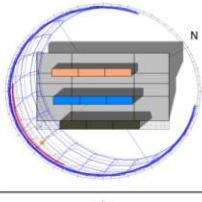
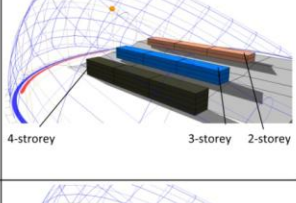
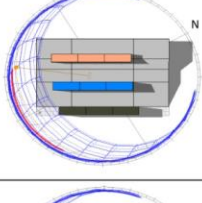
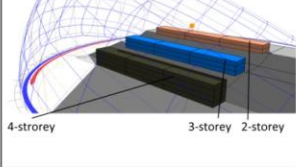
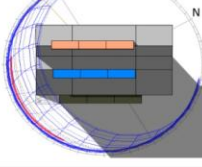
On **Jun.21st**, due to the higher solar angle, the situation is quite similar to site layout 1.

S2+S6+S4, T3+T4+T5 and F5+F6+F7

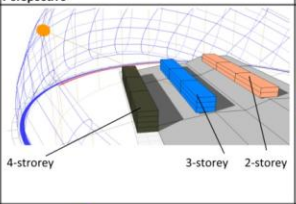
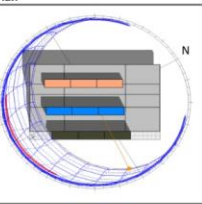
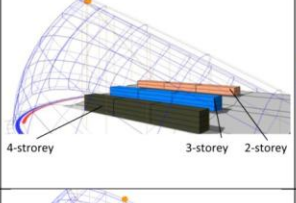
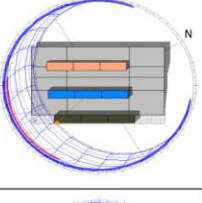
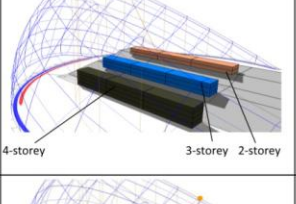
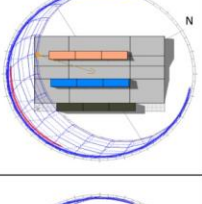
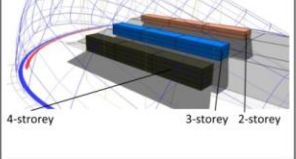
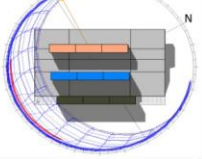
S2+S6+S4, T3+T4+T5 and F5+F6+F7 are located on three different lanes and remaining the average distance of 25 meters from site layout 1.

On **Dec.21st**, the solar envelope and solar access is similar to site layout 1. There might be 1 hour less solar exposure of south façades on T3+T4+T5. It is due to combined model F6+F6+F7 cannot allow the sun with low angle penetrate to the back lane. So similar to the model F1+F2+F3+F4, the gaps among the buildings in the same lane have impact on solar access of the lane behind. However, the differences are not much.



Time	Views	
21 st Mar	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

On Mar.21st, due to the higher solar angle, the situation is quite similar to site layout 1

Time	Views	
21 st Jun	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

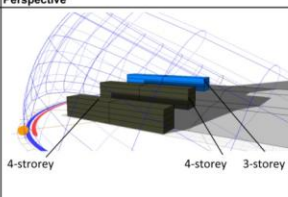
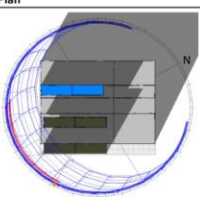
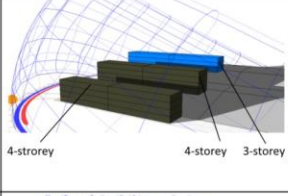
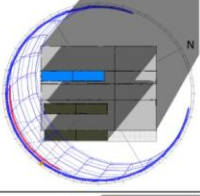
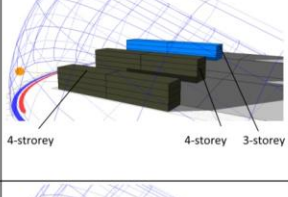
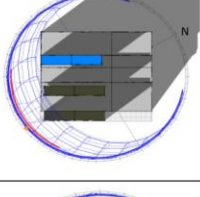
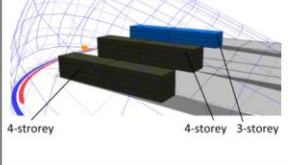
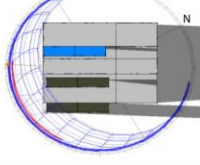
On Jun.21st, due to the higher solar angle, the situation is quite similar to site layout 1

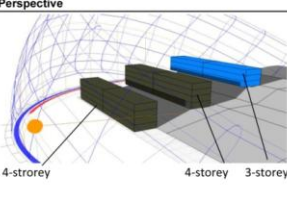
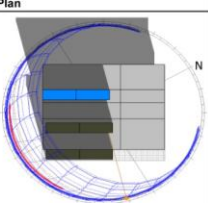
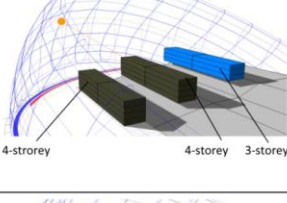
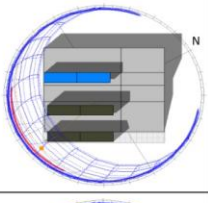
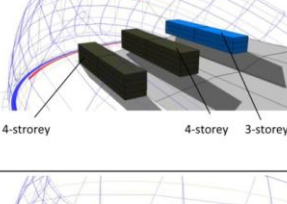
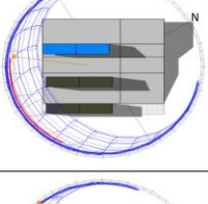
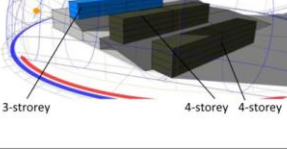
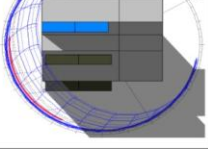
F8 +F9, F10 +F11, T6 +T7

F8 +F9, F10 +F11, T6 +T7, three combined building blocks will exam here. On **Dec. 21st** at 10:15, F8+F9 receive morning sun. First and second floors in F10+F11 and T6+T7 will be in shade. From 10:15 till 14:45, south facades of F8+F9 expose to the sun. From 13:15-14:45, south facades of F10+F11, T6+T7 are totally exposed to the sun. Total hours of solar exposures for the building blocks are listed as follow:

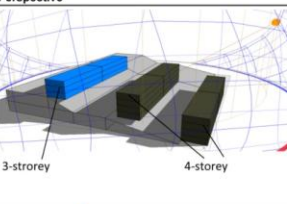
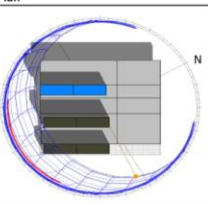
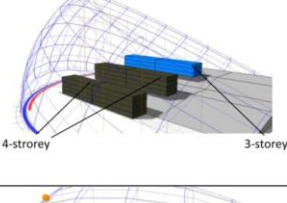
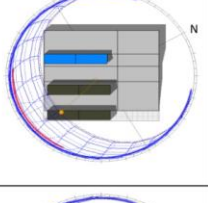
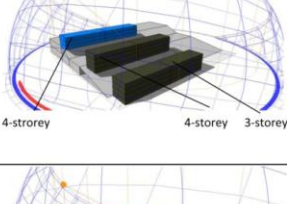
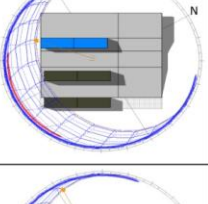
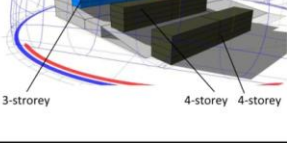
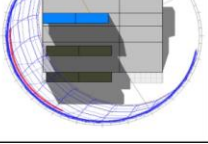
- F8+F9: 5 hours
- F10+F11: 2 hours
- T6+T7: 2 hours

First second floors in T6 and F10 are in better solar access condition then the building blocks in this simulation. Same reasons appears that the distance between the buildings located on the same lane will have slightly impact on the solar access to the lane behind.

Time	Views	Plan
21 st Dec 10:15		
11:00		
12:00		
15:00		

Time	Views	
21 st Mar	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

On Mar.21st, the situation is the same as in site layout 1

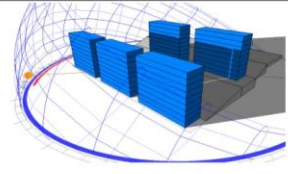
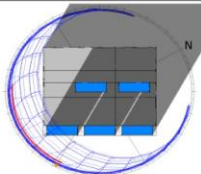
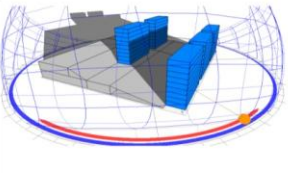
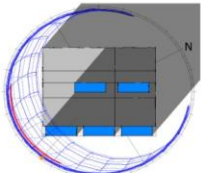
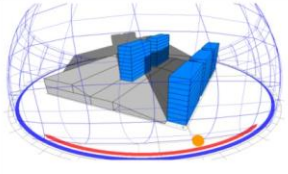
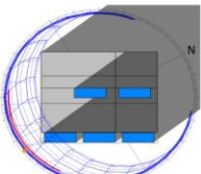
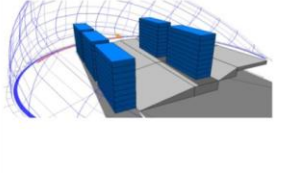
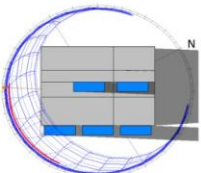
Time	Views	
21 st Jun	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

On Jun21st, the situation is the same as in site layout 1

Attachment 3: Site layout 3 solar access analyses

9-storey buildings

On **Dec. 21st** at 10:15, the first lane of 9-storey will receive morning sun, the second lane will be shade. From 12:30, only the building in second lane close to west is exposed to the sun. From 13:00 till 14:45, all the south facades will expose to the sun. But solar exposure hours for the first lane of 9-storey building is only 5 hours and for second lane is 2 hours.

Time	Views	9-storey buildings
21 st Dec	Perspective	Plan
10:15		
11:00		
12:00		
15:00		

Time	Views 9-storey buildings	
21 st Mar	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

On **21st of March**, south façade of first lane 9-storey buildings will receive morning sun from 7:00. Around 10:30, all the buildings in this model will expose to the morning sun. From 12:00 till 17:00, the open space is in good solar condition. From 14:30, the south façades of all the buildings start to be shaded. Total solar exposure hours for the first lane are 7 hours. Total solar exposure hours for the second lane are 3 hours

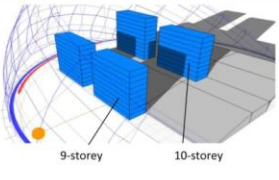
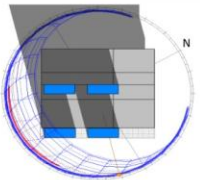
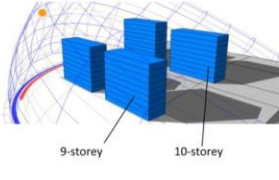
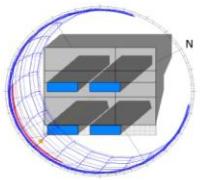
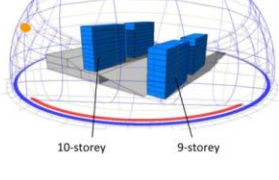
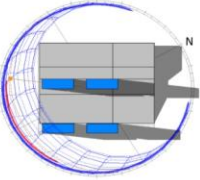
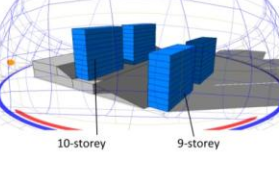
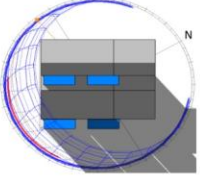
Time	Views 9-storey buildings	
21 st Jun	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

From sunrise at 3:45 till 14:00 on **Jun. 21st**, the first lane 9-storey buildings' south facades are exposed to the sun. From 7:15 till 14:00, the second lane 9-storey buildings' south facades are exposed to the sun. The open space is in a good solar condition from 11:00-16:00. Total hours of solar exposure of south facades in the first lane are 10 hours and in the second lane are 6 hours.

9-storey and 10-storey buildings

The model with 9-storey buildings on the first lane and 10-storey buildings on the second lane will be simulated here. From 10:15 till 14:45 on **Dec. 21st**, most of the south facades in the buildings are exposed to the sun. From first floor till fifth floor in 10-storey building against east start to be shaded from 10:15 till 13:00. Total solar exposure hours of 9-storey buildings are 5 hours 10-storey building against west have total solar exposure hours of 4 and the one against east have total solar exposure hours of 2.

Time	Views
21 st Dec	Perspective
10:15	Plan
10:15	
11:00	
12:00	
15:00	
10:15	
11:00	
12:00	
15:00	

Time	Views	
21 st Mar	Perspective	Plan
08:00		
12:00		
15:00		
18:00		

On **Mar.21st**, from 7:00 till 14:30, south facades of the first lane with 9-storey buildings are exposed to the sun. From 11:00 till 14:30, south facades of the second lane with 10-storey buildings are exposed to the sun. The open space has a good solar condition is from 12:00 till 16:00. Total south facades solar exposure hours for first lane are 7 hours. The Second lane has total south facades solar exposure of 3 hours.

Time	Views
21 st Jun	Perspective
08:00	Plan
12:00	Perspective
15:00	Plan
18:00	Perspective

On **Jun.21st**, from 3:45 till 14:00, south facades of 9-storey buildings are exposed to the sun. That is equal to approx. 10 hours solar exposure. From 10:00 till 15:00, open space is in a good condition. From 7:00 till 14:00, south facades in second lane are exposed to the sun. That is equal to approx. 7 hours.