Rakesh Paul

Redevelopment of Skotfossbruk into an energy efficient neighbourhood considering the principles of circularity and energy exchange

Graduate thesis in M. Sc. Sustainable Architecture
Supervisor: Neil Alperstein
May 2022

Graduate thesis

NTNU
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Kunnskap for en bedre verden

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ABSTRACT

Skotfossbruk, once the largest paper mill in North Europe and having distributed paper products globally had to close after more than 70 years of successful operation. Started in the year 1892 it used to manufacture a variety of products such as wrapping paper to newsprint for the New York Times. The newly constructed Telemark Canal, regarded as the 8th wonder of the world by Europeans located near the mill brought in raw materials from the nearby Telemark Forest and served as an important route for transporting people, goods, and farm animals. It is situated in Skien municipality next to lake Norsjø which after the construction of a hydroelectric power plant meant the industry was sitting over its power source. A failing market meant the closure of the industry with the last produce ending in 1986. Today the industry is part of a cultural trail that tells stories about the glorious past. This paper aims at redeveloping the paper mill to a neighbourhood that can attract people from all over the world. By redesigning remains of the old industry to proposing new buildings it can brings communities together and promote the idea of a sustainable redevelopment. Promoting walkable infrastructure and improving the spatial qualities it provides a space for various activities. The neighbourhood achieves on becoming a net zero energy neighbourhood through local production of energy through renewables. Since little hydropower will be coming in Norway in the future, it is important to demonstrate self-sufficiency in projects of this nature that can become a testing ground for other neighbourhood projects. Circularity in the food system has been a critical part of this neighbourhood, as it generates a certain amount of energy to fulfil the energy demand. Localisation of food production in this neighbourhood also meant that people are aware of the food they are consuming bridging the gap between production and supply. The neighbourhood demonstrated internal energy exchange to fulfil the energy demand of its building first and then exchanging the surplus energy outside the neighbourhood. Through careful designing and selection of right building systems the neighbourhood was able to reduce the overall energy load and through self-production it was able to cover its energy needs demonstrating a successful development of the project.

Keywords: neighbourhood, redevelopment, circularity, energy exchange, localisation

ACKNOWLEDGEMENT

I would like to express my gratitude towards my supervisor Neil Alperstein for guiding me throughout the project with his valuable comments and insights. He let me realise the potential of this project by bringing in new perspectives that helped me shape the design of this neighbourhood. I would also like to appreciate Knut Hovland who introduced me to this project and providing me with the required information for the successful completion of the work.

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ABBREVIATIONS

CSC	Collective Self Consumption
DCV	Demand Control Ventilation
DHW	Domestic Hot Water
GHG	Greenhouse Gas
ISC	Individual Self Consumption
MGC	Microgrid Controller
PPA	Power Purchase Agreement
PV	Photo Voltaic
UFS	Urban Food Systems
ZEN	Zero Emission Neighbourhood

1. INTRODUCTION

1.1 Background

With its inception in 1892, Skotfossbruk became Northern Europe's most modern and largest paper mill lasting for more than 70 years. It used to produce several different paper products and shipped globally, ranging from newsprint being exported to the New York Times, to wrapping paper, book paper and so on. The settlement of Skotfoss was a place built under industrial influence in contrast to the many other settlements in this country which were built around a water course or the fjord [1] [2]. The mill had housing arrangement for the workers which was located on the slope of the hill east of the factory and the population rapidly grew from 1500 in 1905 to 2400 by 1920. With the operation of the Skotfossk hydropower plant in 1953, it meant the industry was literally sitting over its own power source, though owned by Akershus energi, a different company. The powerplant was built with a power capacity of 24MW and has an annual production of 150GWh. With the development of these infrastructures this place provided an opportunity for work, growth, and development.

16th century at Skotfoss saw the increase of sawmill operation and with this the floating of timber along the watercourse from the Telemark forests also increased. Due to the destructive force of the current, the first major water regulation was brought into the country with the construction of a large dam by Master Anders in 1578. With the finishing of the Løveid locks in 1861, this meant the timber could be floated more gently. After putting a wood grinding mill, Løveid Tresliperi into operation in 1872 and merging with the Union in 1890 it established the cornerstone Skotfossbruk. The watercourse which brought the raw material was also used for the transportation of the finished products. Løveid locks at Skotfoss which consists of three locks and has a lifting height of 10.3m is part of an eighteen-lock chamber Telemark Canal and was fully operational in the beginning of the year 1892, the same as Skotfossbruk. It was called as the 8th wonder of the world by Europeans and became an important route between upper and lower Telemark. It connected Skien to Dalen, the national romantic village and had a total route of 105km and ascending a total of 72meters [3]. Currently, this place attracts tourists from all over the world to have an experience of the unique waterway which is kept authentic in its original form with the lock gates still opened and closed manually.

After almost a hundred years of successful operation, a failing market meant the owners Union Co. had to shut down the paper mill in 1986. With huge responsibility in maintaining the building premise without any active usage after its closure, portion of the building complex was demolished and as of today, it is a part of a 3.7km cultural trail starting at Løveid locks that brings the reminiscent of a once flourishing industrial heritage [4]. Presently there is an approach to redevelop the site into an energy efficient neighbourhood that aims to bring in technology tourists from all over the world showcasing Norwegian Innovation with responsible construction and sustainable energy consumption. Once a popular industrial site, this project can become a demo centre for environmental rebuilding and bring in contributors globally to participate in this project with their expertise for further innovation.

Figure 1 Skotfossbruk paper mill at the time of operation

Figure 2 Present condition of Skotfossbruk

Figure 3 Visualisation of redeveloped Skotfossbruk

2. MOTIVATION

Skotfossbruk, once an established paper mill is inactive with minimal activities going on at present. There is a potential to regain its glory and turn this place into something vibrant and exciting to bring in people from all age groups and create a hub for learning, working, living and visiting for both locals and the tourists. Benefitting from its status and location, through redesigning with considerations of circularity and energy exchange this place can demonstrate the efficient use of resources for the present and can as well as become a flagship for showcasing sustainable design practices for the future. Through design and research, this paper will critically demonstrate the process, proposals, and findings in order to achieve the goals of this project.

3. AIM AND OBJECTIVES

The aim of this project would be to redevelop Skotfossbruk into a climate friendly and energy efficient neighbourhood, creating attractive spaces and activities to draw in technology tourists from all over the world. The neighbourhood will also aim at becoming a model and a testing ground for future developments that can be expanded into a larger urban scale. Following are the objectives that will be covered in the project listed below:

i. Careful planning to minimise greenhouse gas (GHG) emissions throughout its life cycle by means of energy efficient design.
ii. Achieve a Zero Energy Neighbourhood (ZEN) by producing its own energy on site through a high share of renewables to compensate for the emissions from operations (O-Eq) during its lifecycle.
iii. Demonstrate a shift from a linear to a circular economy.
iv. Energy exchanges within and between buildings in the neighbourhood with potential for surrounding neighbourhood energy exchange.
v. Strengthening the walkable infrastructure and promoting sustainable transport in the neighbourhood.
vi. Promoting sustainable social environments through careful planning and the creation of neighbourhoods with good qualities and attractive urban spaces.

4. CHALLENGES

There were certain challenges that were faced while working on the project, these are addressed below:

i. Although this building is not listed as a heritage building, I believe that it is important to give careful considerations to its heritage value.
ii. The site of Skotfossbruk is divided between different owners which meant only a portion of the site could be considered for redevelopment.

5. LIMITATIONS

This project will limit itself to certain key areas mentioned below:

i. Broadly discuss the planning and architecture of the site without detailed investigation and design of the architectural spaces of individual buildings, limiting itself to volumetric study.
ii. Circularity in the food system in a neighbourhood will be explained in detail while the other areas of circularity will be covered in general.

6. METHODOLOGY

The following steps are to be followed for this project::

i. Talk to key persons involved with this project for data collection and understanding the project brief.
ii. Literature study to gain insights on projects of this nature and to have a brief understanding of the theories applicable.
iii. Use digital tools such as Arc GIS to map and study site context, grasshopper for energy analysis and performance check and Revit for BIM modelling.
iv. Propose design concept based on energy efficient design of individual buildings.
v. Analyse the performance of proposed buildings and comparing the results.
vi. Discussion and concluding with remarks to achieve the objectives as stated above
vii. Possible further investigation.

7. THEORY

This section will involve a comprehensive study of the theories involved that will be a base for the project development. Key areas related to achieving a ZEN target, applying the principles of circularity and energy exchanges will be discussed in detail in this section.

7.1 Zero Emission Neighbourhood (ZEN)

A neighbourhood can be defined as a geographical localised social community within a larger area such as a town or a city [5]. A zero-emission neighbourhood aims to reduce the amount of GHG emissions directly or indirectly involved to zero over the life cycle of the neighbourhood within the chosen ambition level [6]. The words emissions and energy can be interchanged depending on the ambition level. Since the ambition level for this neighbourhood is to achieve zero by compensating for the operational use (O-Eq) throughout its lifetime. Here, the ZEN target will be to achieve net zero energy considering operations. Following are the points that shall be considered in this project to achieve a ZEN target which will have a direct consequence on the energy and emissions:

i. There should be a huge focus on minimising the GHG emissions starting from the planning, designing to operations of the buildings in the neighbourhood. The first step is to reduce the energy demand for individual buildings and the smart use of energy in a neighbourhood scale.
ii. A ZEN neighbourhood should be able to meet its own energy requirements through a high share of renewables that will be able to compensate for GHG emissions it emits in its lifetime. Since there will be a little growth in Norway in the next years with respect to hydro power capacity, local generation of electricity in ZEN through renewables can contribute to clean exports of energy [5].
iii. It should be able to exchange energies within and between buildings and with the surroundings in a flexible way. The energy exchange part which is a crucial part of this project will be discussed more in detail in Section 7.3.
iv. Considerations to achieve economic sustainability by reducing the total life cycle costs and life cycle system costs [5].
v. Encouraging sustainable behaviour through planning and locating amenities in the neighbourhood and provide ambient spatial qualities [5].

7.2 Circularity

Neighbourhoods can be a powerful entry point for inspiring the role of circularity in a city scale. The scale allows for the design and operation of a living lab which can represent community behaviour and their interactions within an urban system. For implementing the concept of sustainable development, circularity can be a concrete response to create a shift from a linear economy. City level action is essential for accelerating the circular economy transition but a community-initiated activity such as a neighbourhood can be an impelling starting point. There are various means by which circularity can be achieved in a neighbourhood. This paper however will be discussing about three vital areas of circularity i.e., circular construction, servitisation and circular food systems which can effectively accelerate circular economy transition in a neighbourhood. Out of these three areas, the circular food system will be discussed in detail with calculations to show the potential of energy generation in the neighbourhood.

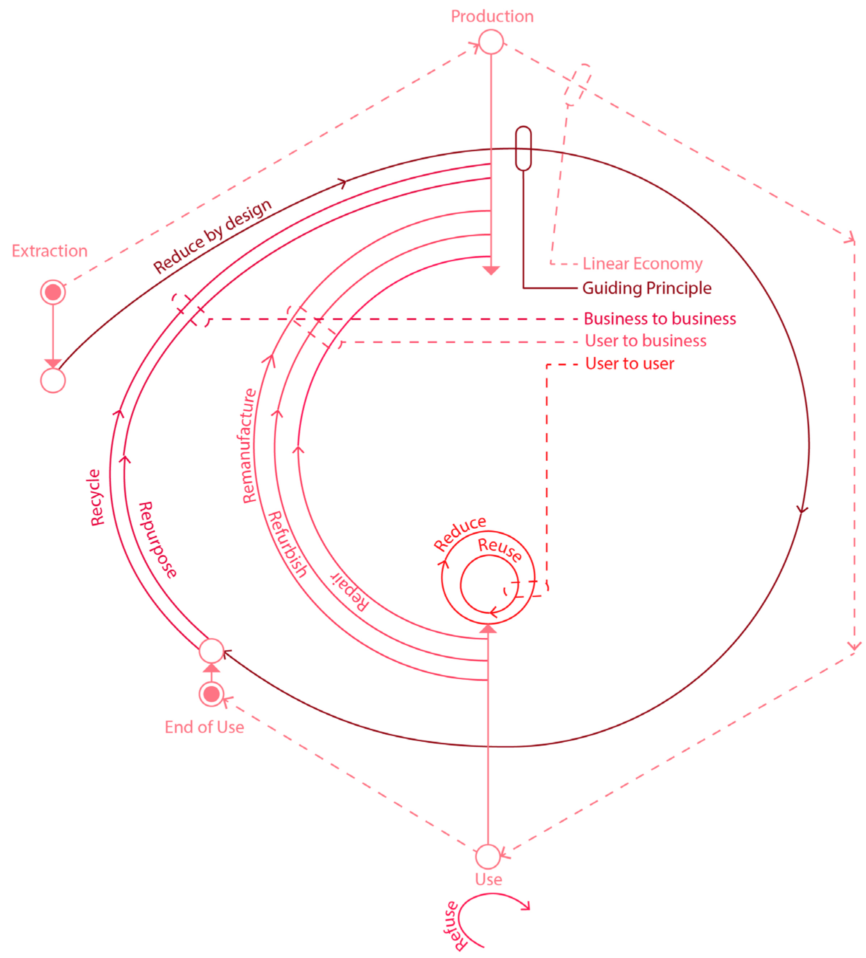


Figure 4 Circularity in principle

7.2.1 Circular construction

The construction sector is responsible for one third of global material consumption and waste generation and as per current trends it is expected to grow by 85 percent by 2030 [6]. Technologies in present use rely on materials and methods in this sector that emits directly or indirectly 40 percent of the greenhouse gases in cities [6]. With the introduction of circularity into the construction industry, it has reinstated vernacular architecture in its interest where choice of local materials and environmental benefits were considered out of necessity. Traditional architecture had addressed local climatic challenges like heating and cooling for comfort through design and construction techniques because of the unavailability of electricity. It may seem simple to bridge traditional and modern building techniques to achieve circularity and resource efficiency but there are several existing and potential dilemmas: easy disassembly versus structural resistance, longevity versus flexibility, simple versus composite products, renovations versus new build, etc [7].

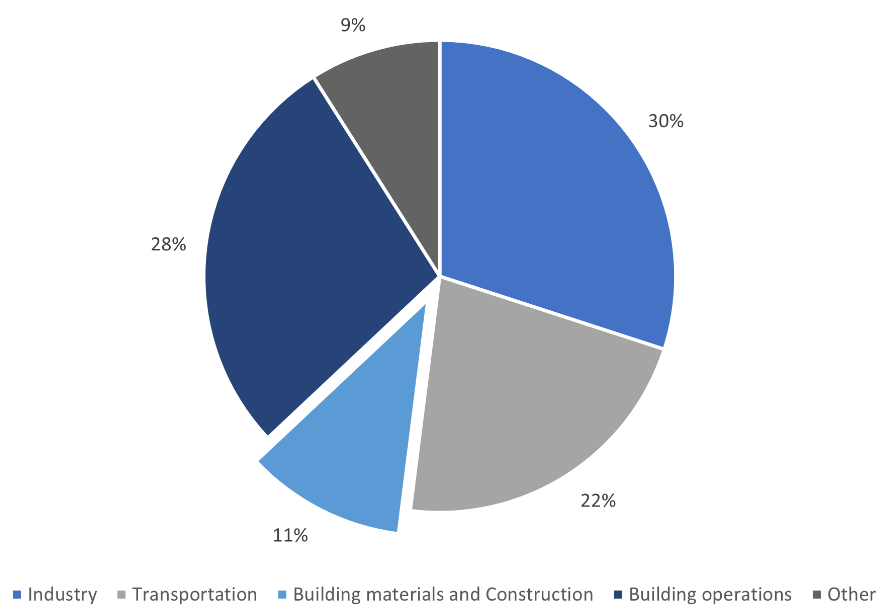


Figure 5 Sector wise contribution of global emissions

Neighbourhoods can be a testing environment to support development of micro solutions where the good practices can be scaled and replicated in an urban setting. It can include exploring local materials to shorten the supply chain and that can be responsive to the local environmental and socio-economic needs [6]. The aim should also be to reduce the material consumption for a new build or else refuse for a new build altogether. Buildings can be conceived as a material bank in a circular construction by extending the end-of-life use of materials and building components, where possible reuse the entire building. New building design should consider design for disassembly and recoverability, considering local technological and biological circular material flows making them easier for repair, refurbish and reuse [6] [8]. Material banks have the opportunity to shorten supply chain, revitalise traditional building practices and strengthen repair networks [6].

7.2.2 Servitisation

Servitisation or product-as-a-service is a concept where a consumer accesses a service, an output or an outcome instead of having to invest in the equipment generating it. The consumer pays per unit of consumption whereas the asset stays under the solution provider. Servitisation can improve the resource and energy efficiency while reducing the overall costs which can be implemented at a household or a neighbourhood level. Consumers can access state of the art energy efficient appliances without worrying about the investment and the maintenance and repair costs. It also makes consumers more aware of their consumption which makes them behave more sustainably [6]. In a servitisation, circularity stays in the model itself as the ownership is under the technical provider which makes them to manufacture goods with longer durability and extend products life through repair, remanufacturing and resource efficiency throughout the products life cycle [9]. A well-known example is the photovoltaic industry, where customers pay per kilowatt of consumption instead of buying the solar panels through a power purchase agreement (PPA). Here, the ownership, operation and maintenance remain a responsibility of the solution provider [6].

7.2.3 Circular food systems

Due to the increase in the global food supply chain and food market, it has changed the neighbourhood food systems which was a vital part of local communities [10]. Lately, urban food systems (UFS) got disconnected between the city's food source and its immediate vicinity, which resulted in an increasing reliance over industrial supply chains [6]. Consumers are less aware about their food origin leading to the unsustainability of the UFS with regards to the social, ecological and economic components [11].
As per estimates, on average around 44 percent of municipal solid waste is organic wastes which is mostly composed of food waste [6]. While anaerobic digestion is a favourable scheme towards a circular transition, it is important to minimise food waste if not eliminate it. Globally, one third of all food produced has been estimated to go to waste which was meant for human consumption [12]. There should be an intervention at the community level to design/test to target food waste eligible for a circular economy transition [6].

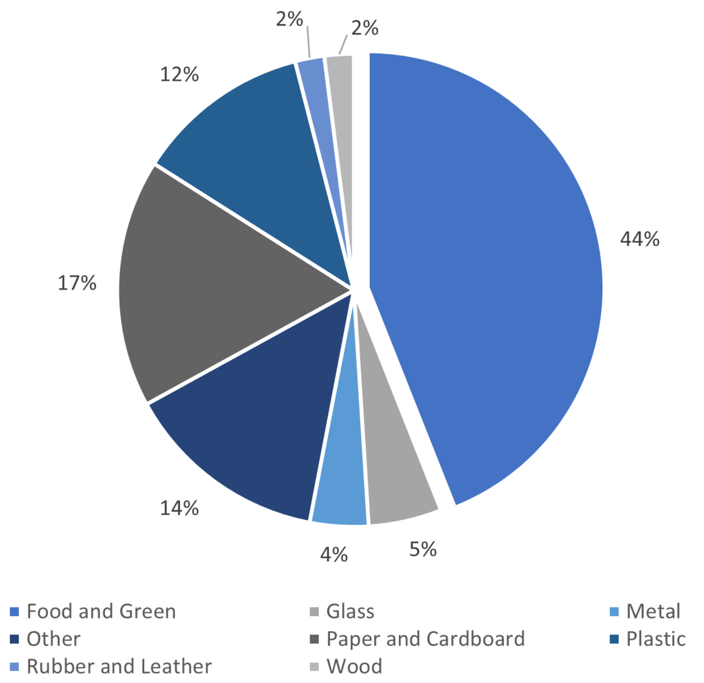


Figure 6 Composition of municipal solid waste

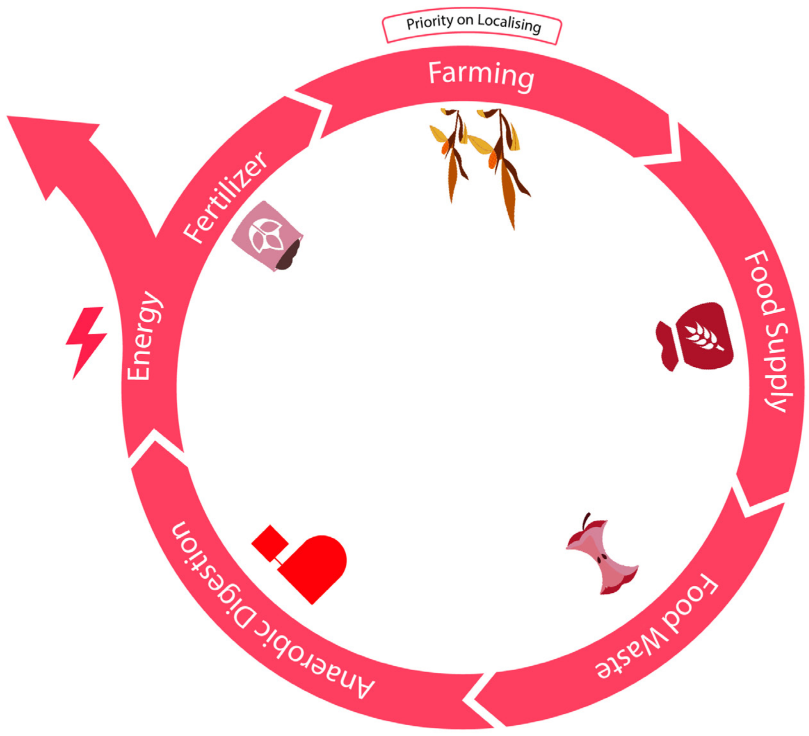


Figure 7 Circularity in the food system

There is a possible solution to shore up urban food security and resilience by localising the food supply chains and nutrient cycle [13]. This is due to the fact that industrialisation of the food systems has resulted in a shift from regenerative sustainable agricultural practices, which on the other hand depletes the natural resources and affects the quality of life both within the city and the regions that produces it [14]. Urban gardens can be used as a testing in a neighbourhood to run experiments to shorten the food supply chain and implement regenerative production. This could also lead to job creation and economic diversification at the neighbourhood level [6].
Green open spaces can create an impact on the users of a neighbourhood in the way they use land and their connection with nature. Though this is less prominent in the discourse of circularity, but this can be taken onto the next level with the implementation of urban gardening which builds up people's appreciation of a circular mindset towards food systems and nature [6]. Localised food supply chain in a neighbourhood could therefore become a learning environment and provide development opportunities for both children and adults.
The three areas introduced above are good starting points for introducing circularity in a neighbourhood which can be scaled up to an urban level. This can help extend a products life, regard waste as a resource and change the consumption pattern to reduce the overall material consumption and enact a circular thinking [6].

7.3 Energy Exchange

Nature has been generous in Norway, and this has been exploited to self-satisfy the energy needs in this country. Hydropower has supplied clean energy in Norway since the end of the 1800s [15]. Even though hydropower is dominant in the energy production market of Norway, there have been a technological pioneering towards other sources of clean energy, including solar power, floating offshore wind and energy storage [15]. Data reveals that the beginning of 2021 saw the total installed capacity of 160 MW of solar power in Norway [16]. This proves beneficial to consumers as the cost of buying electricity from the energy providers declines. Generating and consuming all or part of self-produced energy from a local source (e.g., PV panels, windmills) is termed as individual self-consumption (ISC). However only 25% to 40% of this energy is consumed by the producer, there is also the opportunity to sell the excess energy to the grid [17]. This distribution of surplus energy provides an obstacle to the ISC as it can cause grid instability. There is also an additional cost incurred by the distributor operators from electricity transportation who must perform load balancing which is also less sustainable at a larger scale [18].

In this scenario the best solution would be to consume whole or part of the produced energy to overcome the challenges as mentioned above. Several solutions exist currently to intensify the development of self-consumed energy. One approach is with the installation of battery storage, which creates energy flexibility due to the higher level of uncertainties associated with the power generation from renewable energy sources [19]. The other approach which is an emerging concept is the use of neighbourhood energy exchange. Here, one participant's excess energy production may be transferred to another member's consumption needs providing flexibility in a decentralised neighbourhood energy grid [20], which is termed as collective self-consumption (CSC). The trade in a CSC can be performed by connecting all buildings in a given neighbourhood to a Microgrid Controller (MGC), which is responsible for taking care of the electricity routing and load balancing process [21]. In a neighbourhood exchange, from a physical point of view the energy distribution is continuous which is accomplished by the MGC but the resulting financial flows in CSC are performed at regular time steps on a contractual basis. The consumer of the excess energy can buy power through PPA under the servitisation model as discussed in Section 7.2.2. CSC operations can be set up in various ways adhering to the availability of production and storage, based on the contract and characteristics of the building energy use. Developing new CSC operations needs building owners, property developers, urban communities, energy providers and network operators to be informed about the consumption and exchange of renewable energy in a neighbourhood [22].

In a CSC, energy exchange can take different forms where two categories are generally distinguished: distributed energy exchange and centralized energy exchange. In a distributed energy exchange, there is no involvement of a third party, and the trading operations directly takes place between the

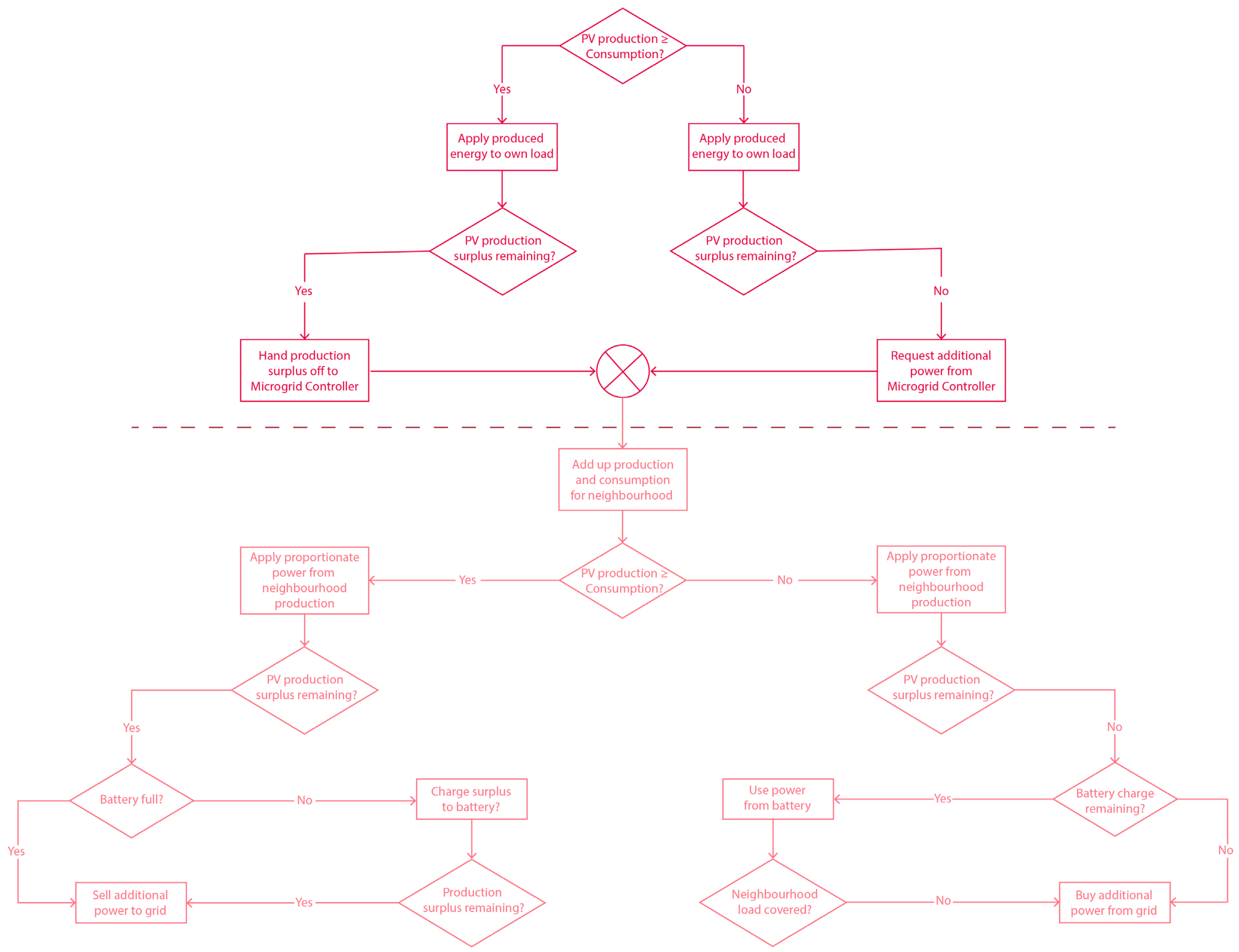


Figure 8 Flowchart demosntrating internal trade considering batter storage

producers and the consumers. Buildings that are involved in these operations transmits the necessary information to each other to exchange energy. Contrary to this, in a centralised energy exchange a third party is involved which is involved in some of the decision-making concerning energy exchange. The duty of the third party is to distribute energy between the building users according to precise rules [22].

It must be noted that an important distinction is made in a CSC between the physical and the contractual layer. The physical layer is responsible for the distribution of energy that actually transmits on the electricity network. The contractual layer however is however responsible for all the contractual and financial flows regarding energy exchanges in a neighbourhood [22]. In this paper, the physical layer of a CSC will be considered while making the simulations for the introduced neighbourhood project. Based on the above theory, a flowchart has been demonstrated (Fig. 1) to explain the working principle of a neighbourhood energy exchange considering self-production, storage, sale and purchase from the utility grid. The dotted line separates the components that are involved in decision making. The part above the dotted line is for the building to apply its production for self-usage. The part below is for the micro grid controller to handle further decisions.

8. DESIGN

This section will introduce to the design of the neighbourhood. It will start from the analysis of the site to the key proposals visioned to uplift the neighbourhood. It will be followed by research results to discuss on the findings as per the objectives of this project.

8.1 Analysis

Skotfossbruk lies approx. 6km from Skien Sentrum. Skien is the capital of Vestfold and Telemark County and happens to be the seventh largest by urban area in Norway. Skien is also one of Norway's eight medieval towns. Viking age, the middle age, industrial age is a strong identifying feature of this region which can be used for marketing the region [23]. This region possesses a rich cultural heritage and has a number of structures and buildings that are either protected or worthy of protection [23]. The case goes for Skotfossbruk which is not listed with the Cultural Monuments Act, but special consideration must be taken for its protection and in this case revival.

The Telemark Canal (Figure 9) which attracts tourists from all over the world, was built as an important route taking people, farm animals, timber and goods between upper and lower Telemark and has been an important link between the East and West in Norway [3]. The canal has two parts one which goes to Notodden and the other to Dalen. It connects to the sea via locks at Skotfoss and Skien. The Løveid locks at Skotfoss ferries many tourists and can be of a significance in attracting tourists to the redeveloped neighbourhood of Skotfoss by providing significant activities on site.

The region is characterised by having concentrated settlements in the urban areas, with short distances to access trades and services located centrally. The areas located outside the towns and cities have a scattered development with detached houses, agricultural and commercial areas [24]. The villages of Skotfoss on the north and Åfoss on the south can be connected with this project through infrastructure to facilitate localization of new functions (Figure 10). A conscious localization of homes and businesses means the area remain viable and be an attractive social meeting place [24]. It also brings communities closer and can facilitate an environment friendly transportation which is an important climate measure.

Transport and road network is an important infrastructure for a settlement and can play an important role for a sustainable development of a society. Road traffic accounted for 12% of total emissions being the second largest source in the county of Vestfold and Telemark [25]. Figure 12 shows that the transport infrastructure is quite friendly in the region with both road and ferry network. Attention will be paid to encourage people to use public transportation and upgrading of infrastructure to promote walking and cycling to access services on the site.

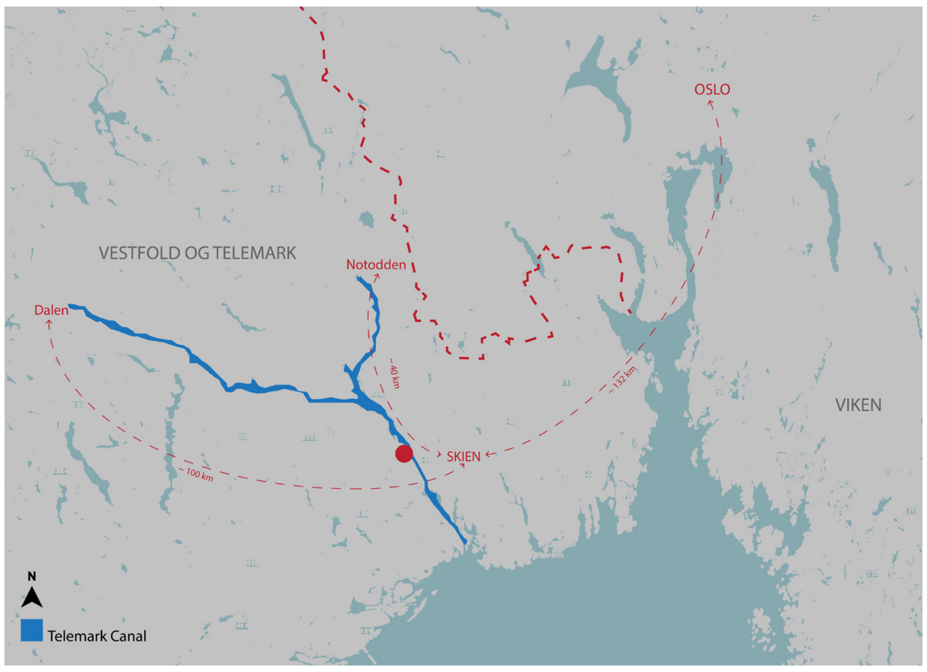


Figure 9 Location showing Skotfoss and the Telemark Canal

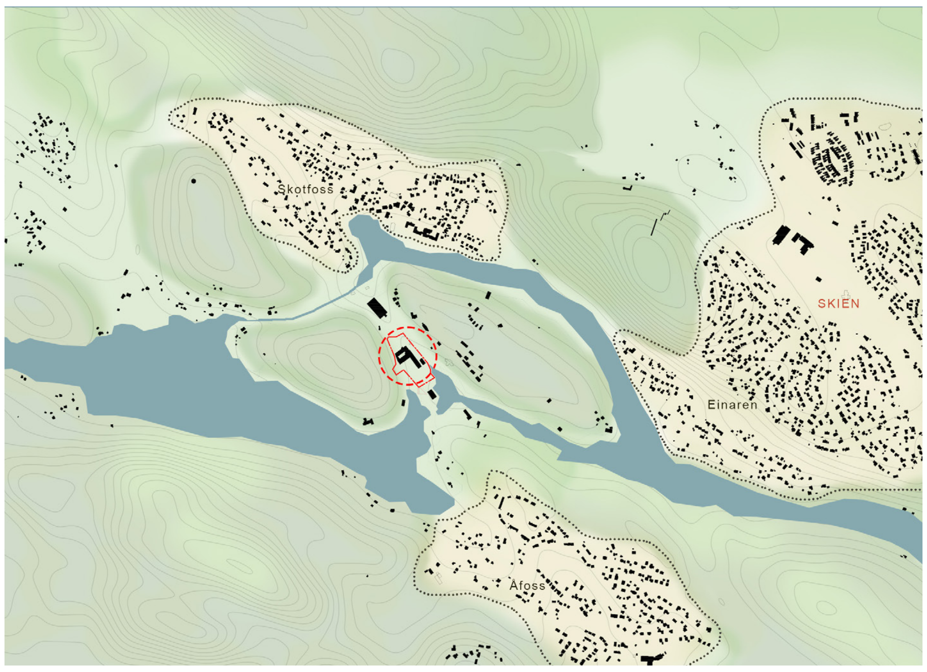


Figure 10 Bluegreen infrastructure and the settlement pattern

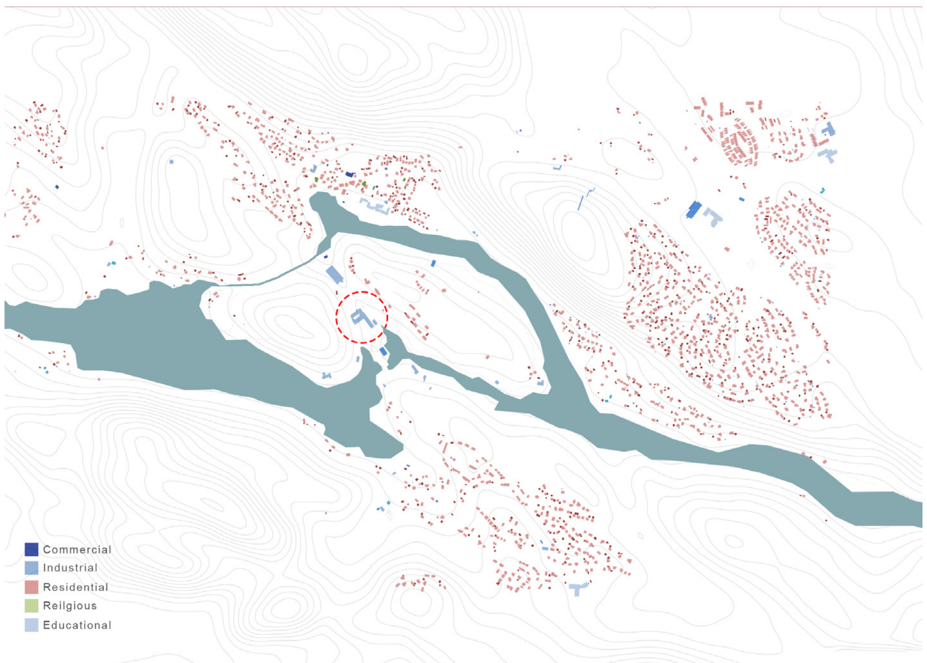


Figure 11 Building use in Skien

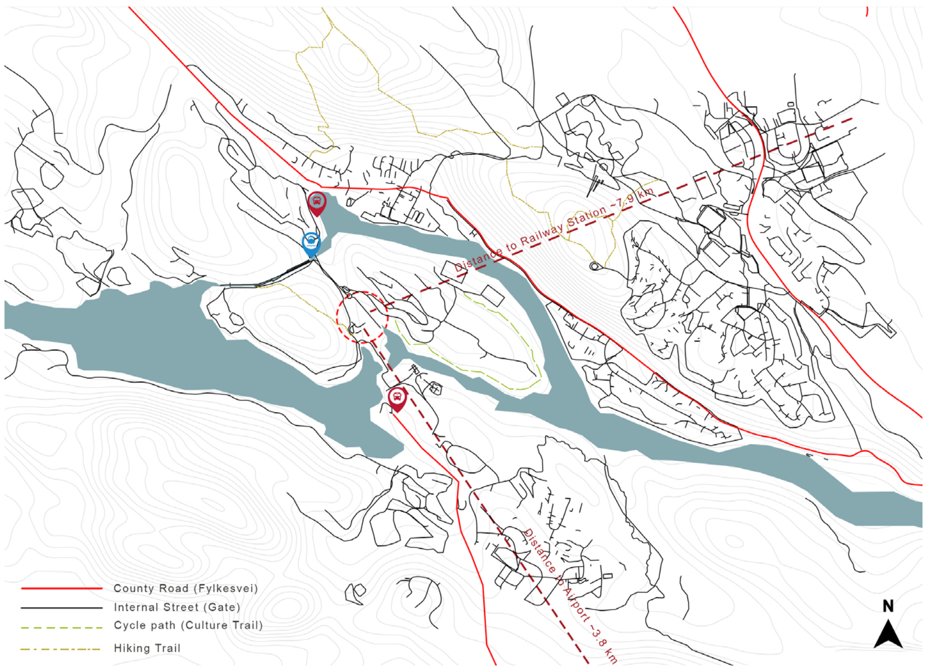
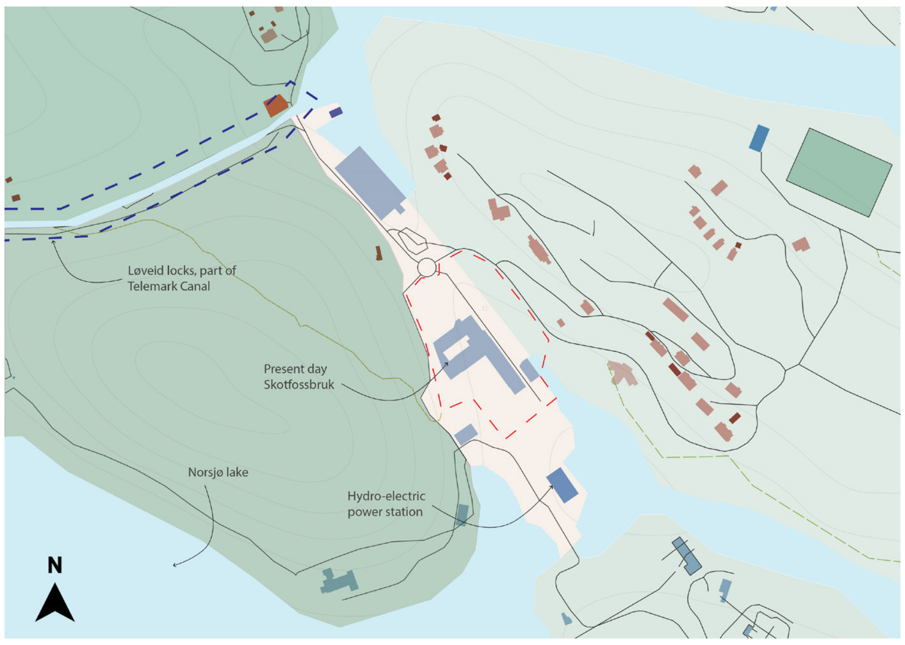
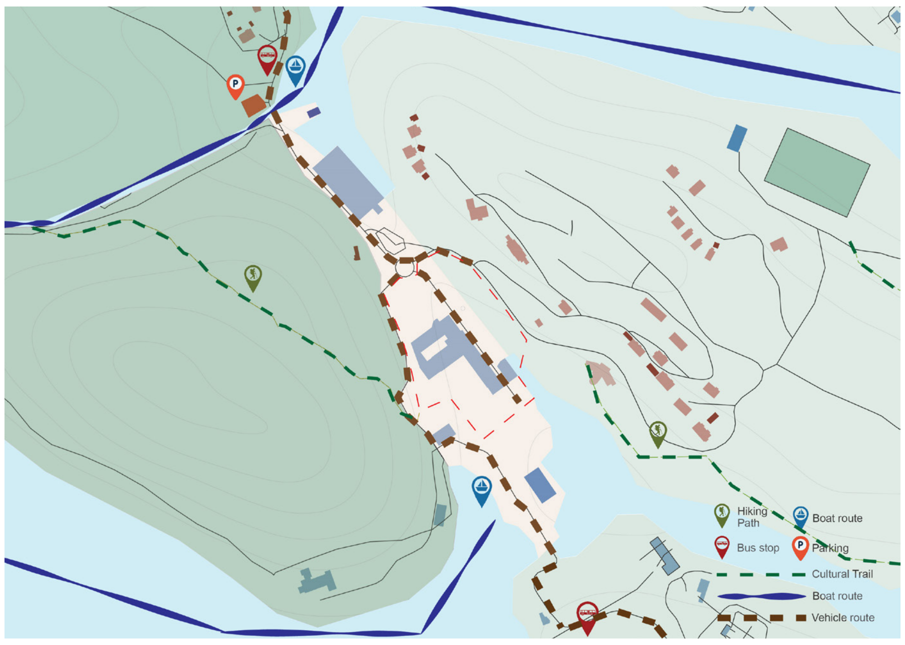


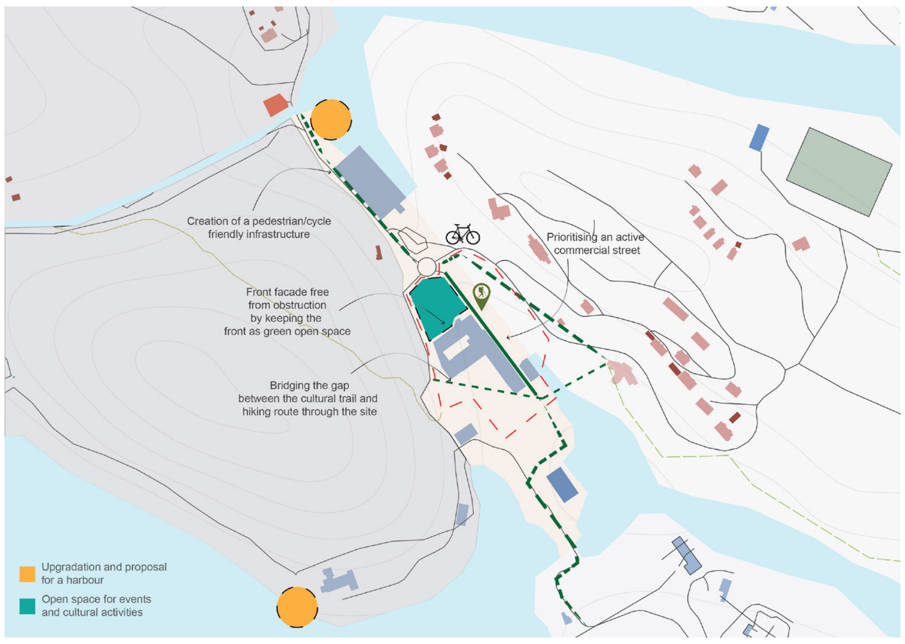
Figure 12 Road network in Skien



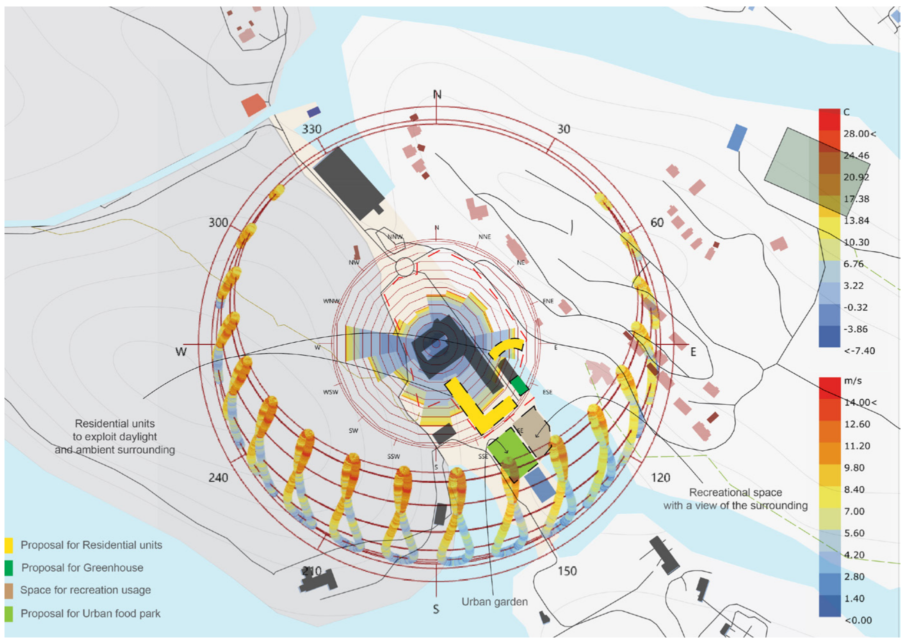
1. The site currently has only two buildings standing while the rest of it were demolished after its closure due to costly maintenance. The site is depicted by a red boundary and the area is 20000 sq. m. The Telemark Canal passes from the NW of the site and is importantly used for tourism now. The hydroelectric power plant is located on the south side at the end of the property.



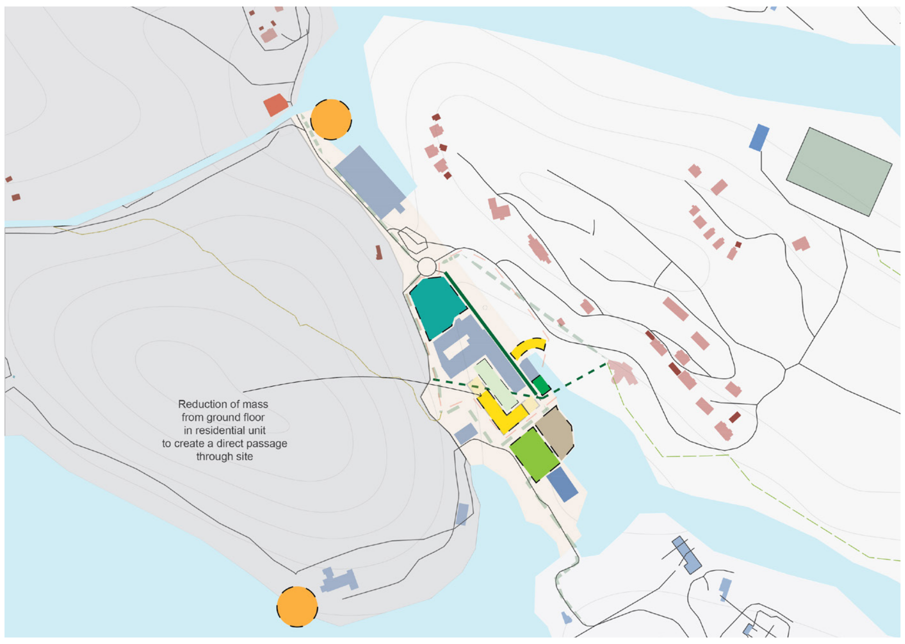
2. The access to the site is well connected by roads and waterways. There are bus stops and parking near its vicinity which will be a major benefit for the site access. The lake Norsjø edges its boundary along with the presence of the Telemark Canal which will be majorly used for boat traffic. The cultural trail starts at Løveid locks and passes through the site to complete a 3.5 km long trail.



3. The priority here is to create a walkable and cycle friendly neighborhood. To attract people onto the site, some of the spaces will be commercialized with a street serving mainly for this purpose. Creation of green open spaces will create, and healthy atmosphere and infrastructure will be further upgraded to suit people's needs better.

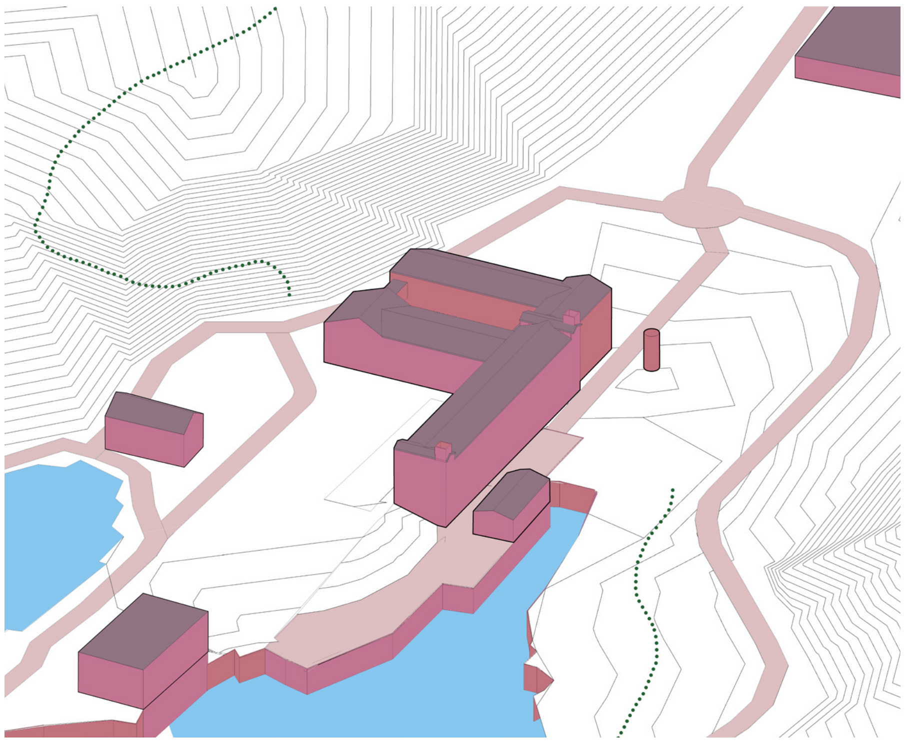


4. New buildings are proposed for residential usage that are located and oriented to gain maximum solar energy along with natural air flow through it without causing disturbances to the present buildings. A greenhouse will be built that will become an experimental and learning space for growing food locally and depict the circularity in the food industry.

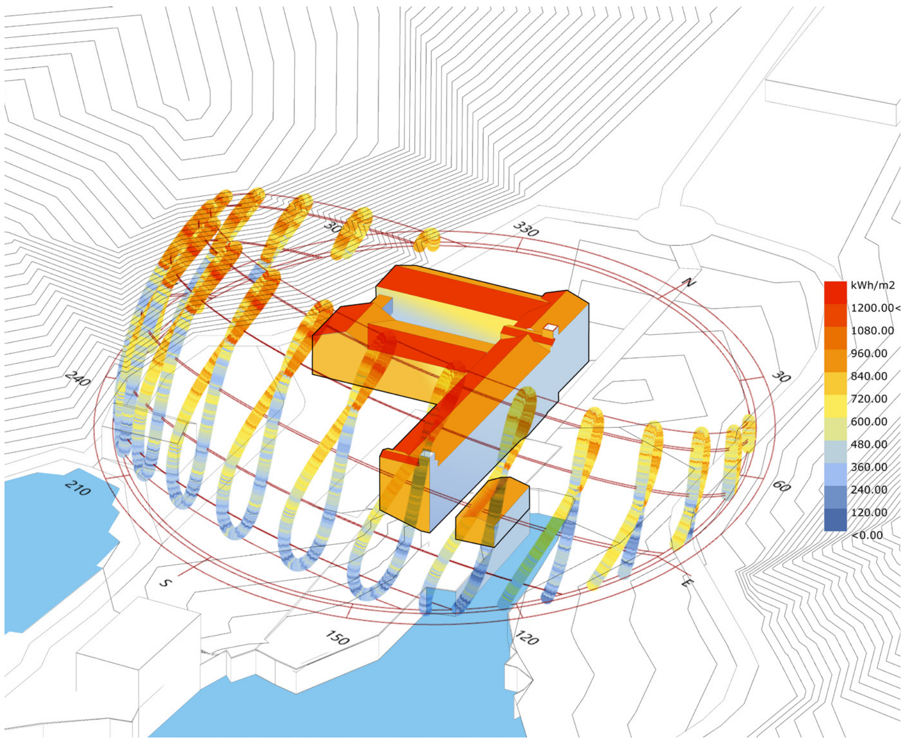


5. With new and upgraded infrastructure and creation of open and ambient spaces this place can become a hub for social learning and experiments which can be a model for future neighborhood projects.

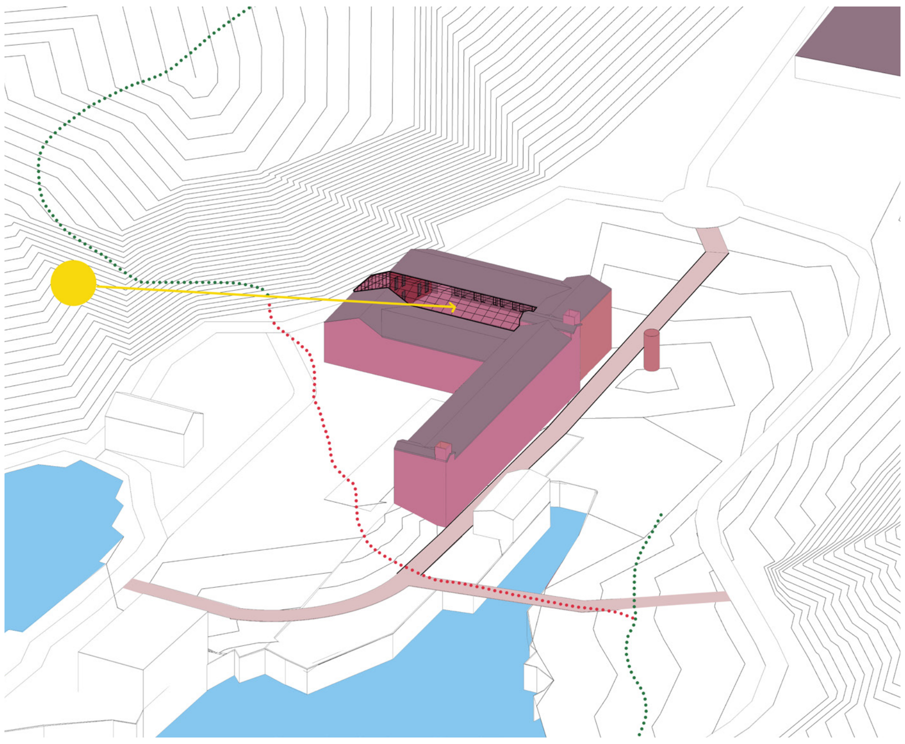
Figure 13 Site analysis with a view of the proposed development



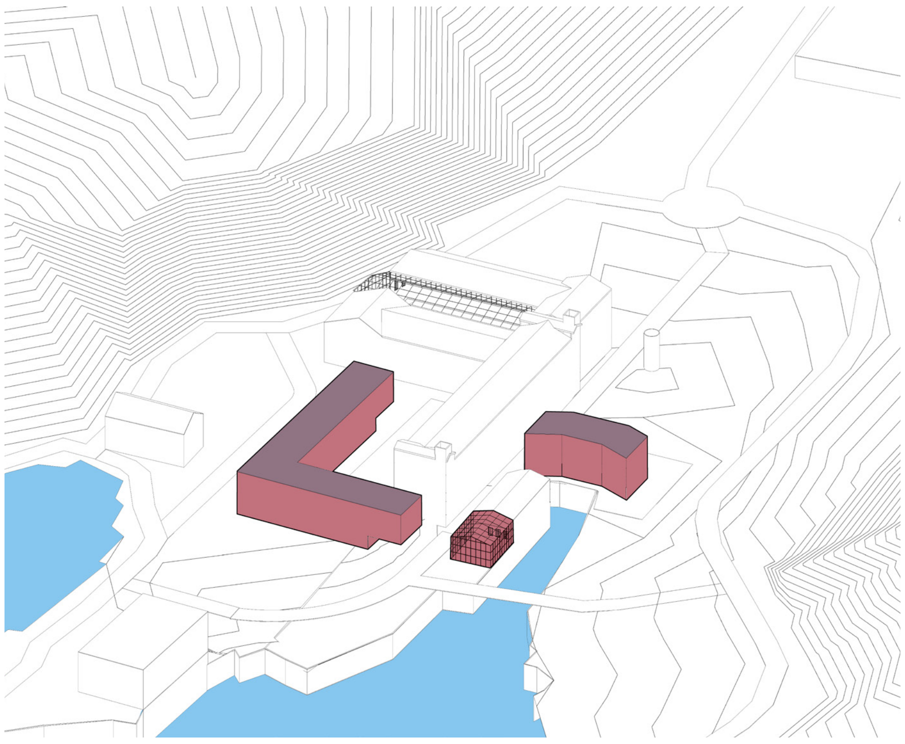
1. Analyzing the present built up conditions and road network on site.



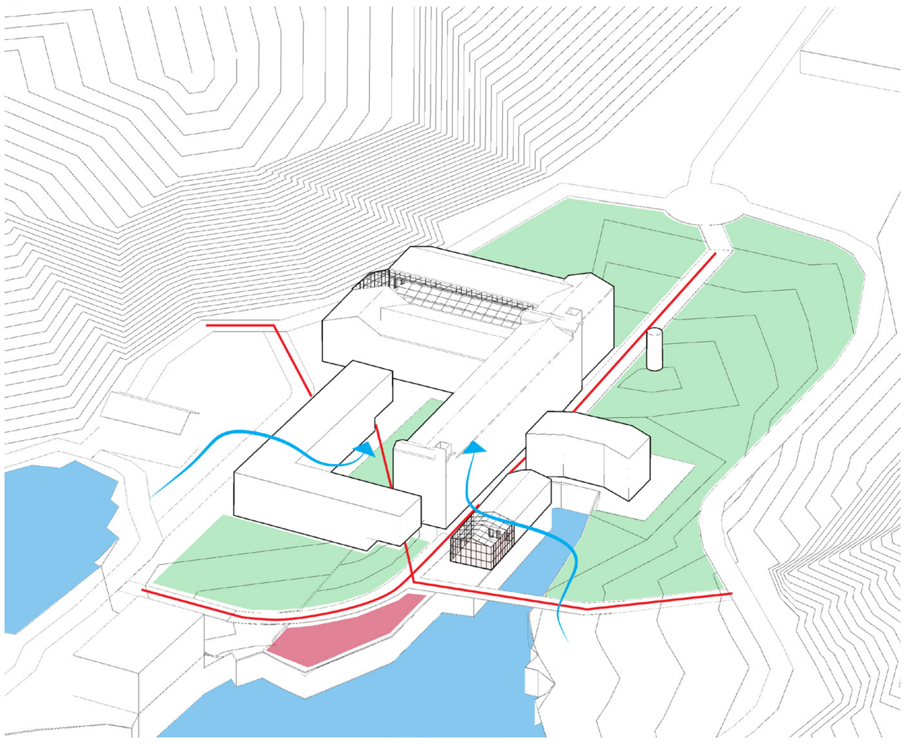
2. Solar radiation analysis to maximize heat gains in new and old buildings



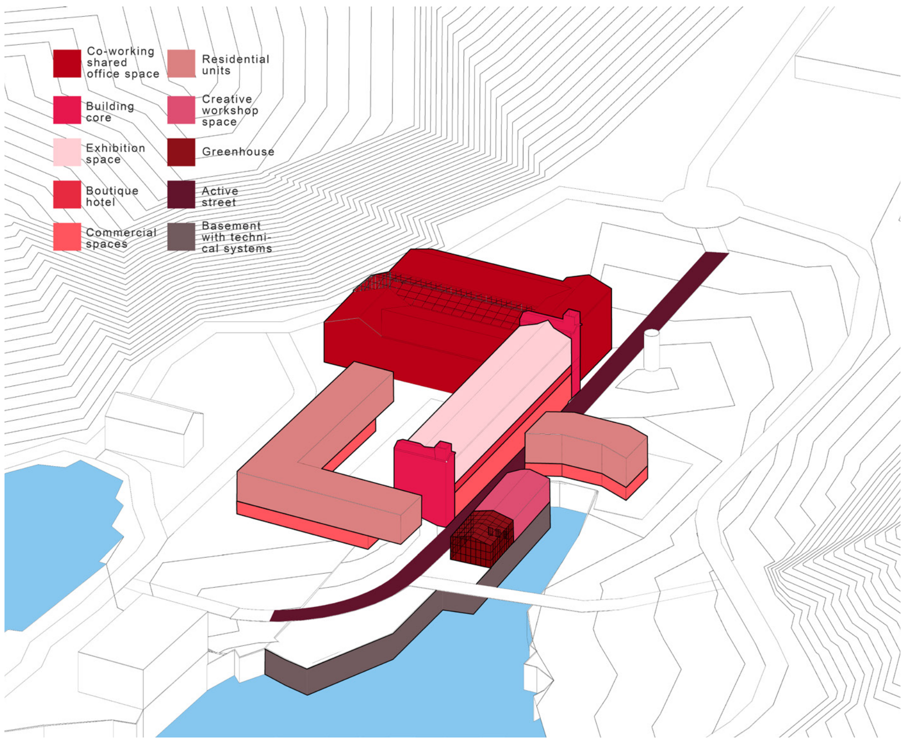
3. Upgrading the old block by putting an atrium for heat gains and create a dynamic indoor space. Creating a road connection to link the cultural trail on site and proposal of the commercial strip.



4. New residential buildings plus greenhouse based on location and solar conditions providing an ambient quality of life.



5. Green open and recreational spaces to create a social and healthy neighborhood.

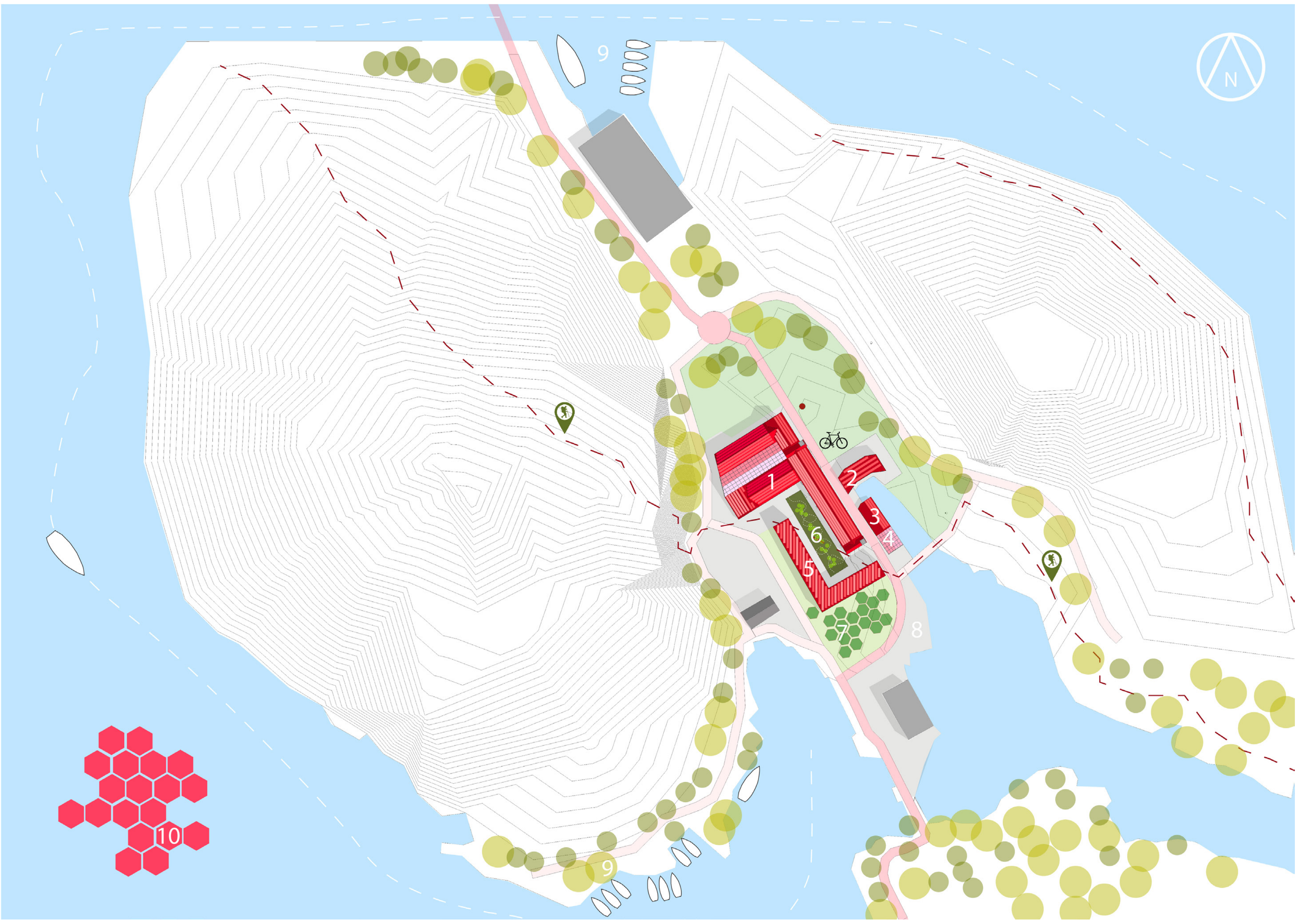


6. Programming of spaces to serve different purposes in the neighborhood.

Figure 14 Steps of the project development

8.2 Proposal

The site is proposed to be a self-sufficient neighbourhood with localisation of basic amenities. There are currently five buildings on site of which three will be newly constructed. Referring to Figure 15, block 1 which has the largest footprint on site will be mainly used for commercial and office usage. Block 3 which is located next to the water body will be transformed into a space for creative workshops. Attached to this will be the greenhouse (block 4) which will also be a place for learning and experimenting to grow foods locally. The two new residential blocks 2 & 5 will offer commercial spaces on the ground level and will offer three floors of residential units above it. The road on the east of the site passing through the green spaces will be used as a pedestrian/ cycle only zone. The other roads can be accessed by car, but the project will encourage people to only use public transportation and as a result there will be no private parking space available on the site. If needed people can use the parking located at the north end of the site near Løveid locks. Between blocks 1 and 5 three will be a green open space to offer a semi-public recreational space. When season permits, the green space in front of residential block 5 can be transformed into an urban farm increasing the local food production. The south-east of the site has an open space which will be used actively given its view towards the waterbody. Considering the needs of the future, a floating solar farm is proposed on lake Norsjø. The production capacity will however not be used for calculation in the neighbourhood's energy supply system.



1. Renovated Industrial Block
2. Residential Block 2
3. Creative Workshop Block
4. Greenhouse
5. Residential Block 1
6. Semi Public green space
7. Urban farming
8. Outodoor recreational space
9. Harbour
10. Floating solar farm (Future development)

Figure 15 Proposed Site Plan

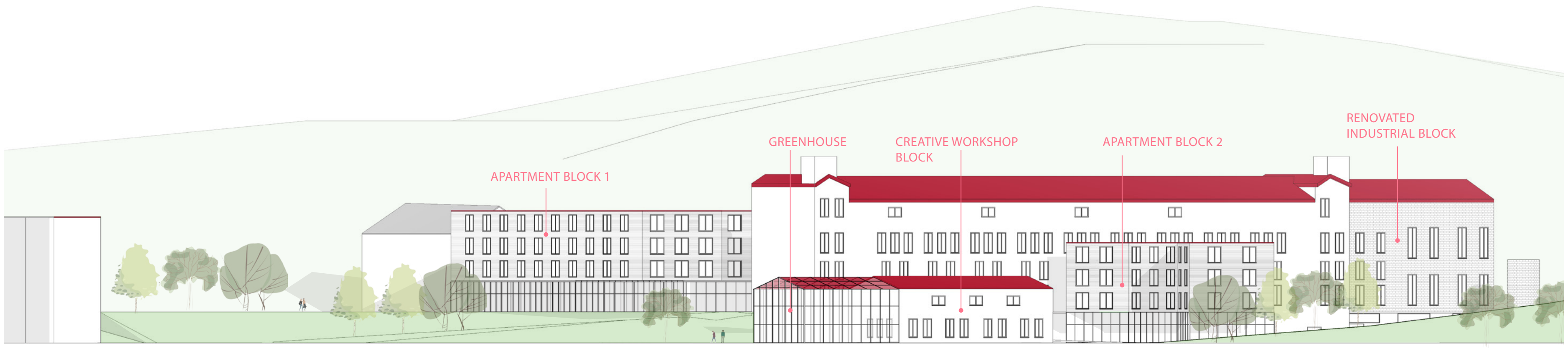


Figure 16 East Elevation

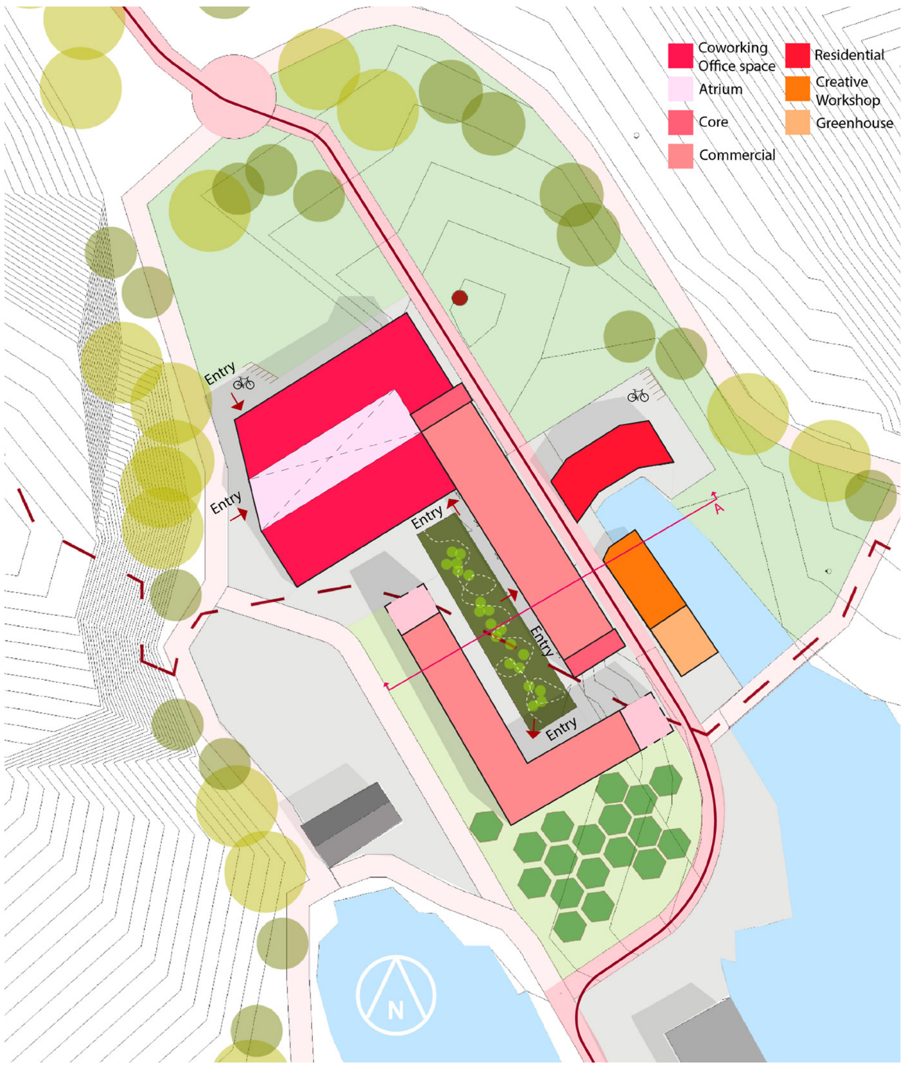


Figure 17 Level 1 zones

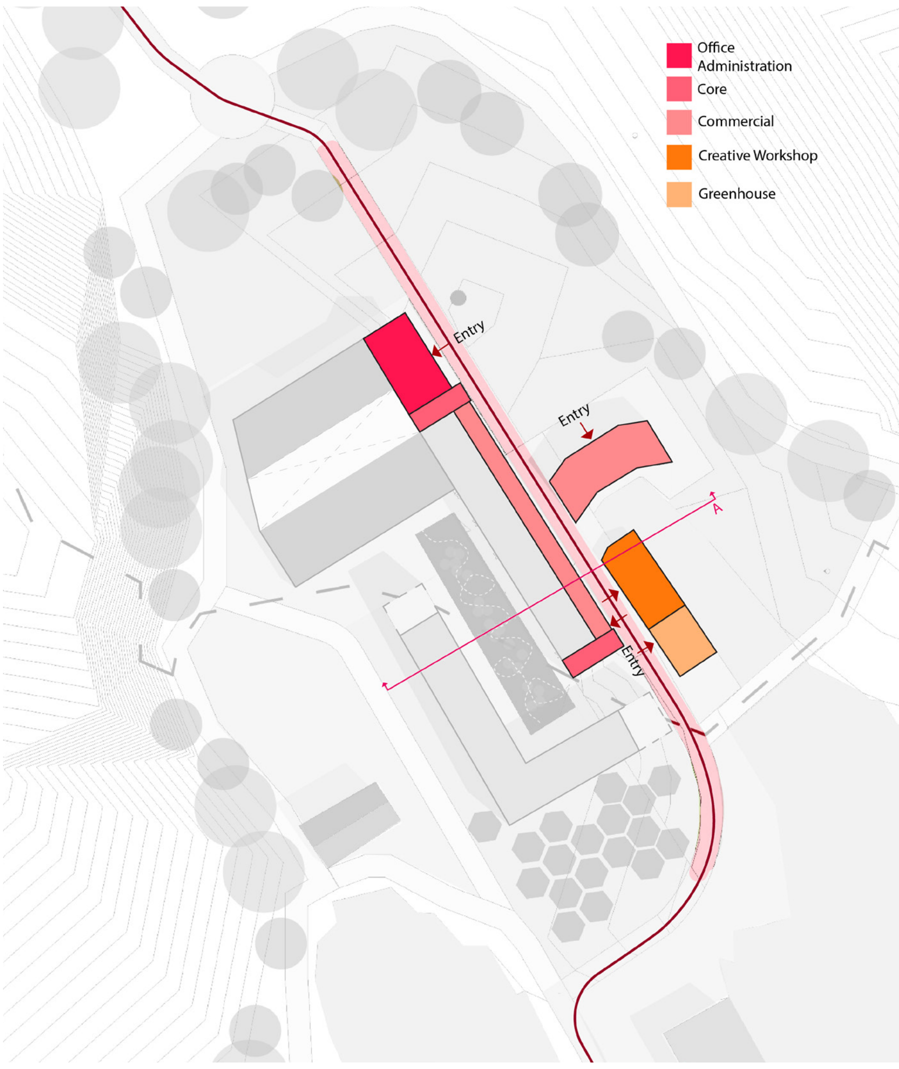


Figure 18 Level -1 zones

Figure 19 Site Section A

The buildings on the site functions as multi-use buildings. The renovated industrial block has a dedicated zone for co-working space while the rest is divided for commercial, hotels and exhibition spaces. This building can be accessed through two levels because of the topography of the site. Section A shows the height difference on the surface level along with the other programs of the building. The lower part of the site (Level -1) consists of the 'active street' (Figure 20) supported by commercial activities along the street and recreational spaces on both ends of it. Figure 17 and 18 demonstrates the two surface levels with the entrances to the buildings. On the upper layer of the site, the space between the residential and the renovated industrial block creates an ambient semi-public space. The building also has a large basement which will be a non-climatised zone consisting of the technical equipment for the functioning of the neighbourhood.

Figure 20 View of the active street

8.3 Results

This section will discuss in depth the findings of the neighbourhood's energy performance through energy simulations. A neighbourhood consists of a set of buildings catering to various functions. It will therefore analyse the performance of each building separately. Since the neighbourhood will produce its own energy, it will follow the CSC system to meet its own demand before exchanging energy with the surrounding neighbourhoods.

8.3.1 Individual Building Performance

The first building to be analysed is the old industrial block with the largest footprint. It has a total built up area of 10105 m2. The walls for the buildings are made of bricks which are 450mm thick. The roof of the building is a sloped roof with asbestos sheeting of 6mm thickness over a wooden roof truss. The building has single layered glass windows for light transmission. It was however found out that the SW façade of this building had very less windows. An energy simulation was run through grasshopper by modelling this building. The results showed that the highest amount of energy was consumed to heat the building followed by equipment load and lighting. The heating load for the building stood at 141.7 kwh/m2 (Figure 21) which is quite high compared to current standard. Therefore, it was necessary to retrofit and redesign the building to serve the present needs and also fulfil the objectives of this project.

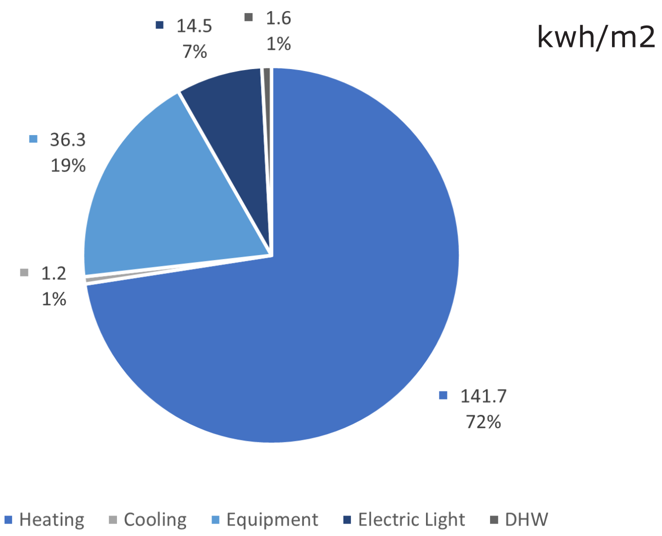


Figure 21 Energy consumption of the old industrial block (Without Renovation)

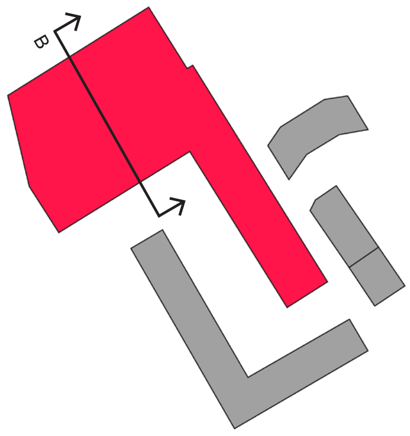


Figure 22 Old Industrial Block marked in red

This is one of the two buildings that is standing today and is a reminder of the once flourishing industrial complex. This building is proposed to be used as a coworking space along with certain other commercial activities and exhibition space. The northwest façade is kept free for modification and obstruction by keeping the space in front as a green open space as this will be the face of the neighbourhood. However, to create a dynamic working environment, the internal walls of this block will be demolished and covered with a glass atrium to create an exciting and open working environment and also for heat gains. Solar radiation analysis shows that the SW façade which is not covered with any glazing receives huge solar gains. Therefore, considering the principles of circular construction, the materials collected from demolition will be used back in this project. The brick from the wall will be used in the groundwork of this project. The scavenged window will be used in the SW façade to maximise solar gains and maintain the old aesthetics of the building. Figure 24 shows the part that will be demolished in the building and the way the material will be reused back into the project.

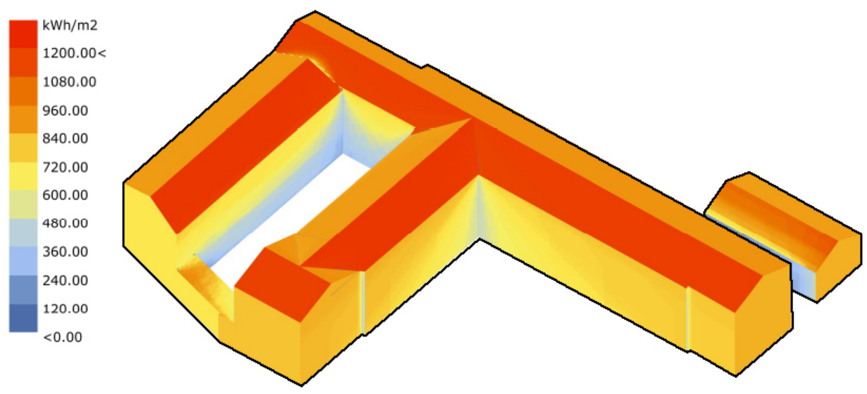


Figure 23 Solar radiation analysis

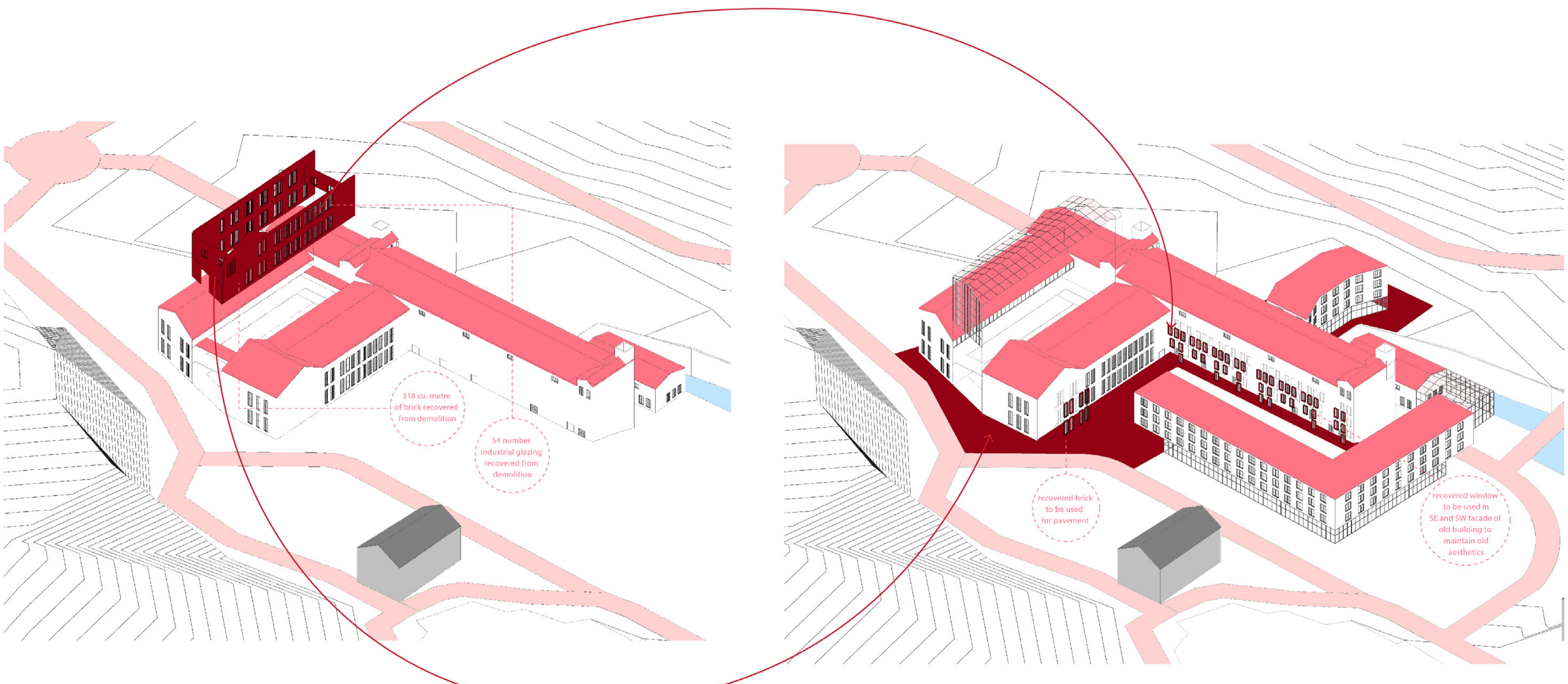


Figure 24 Image showing the reuse of materials in new development

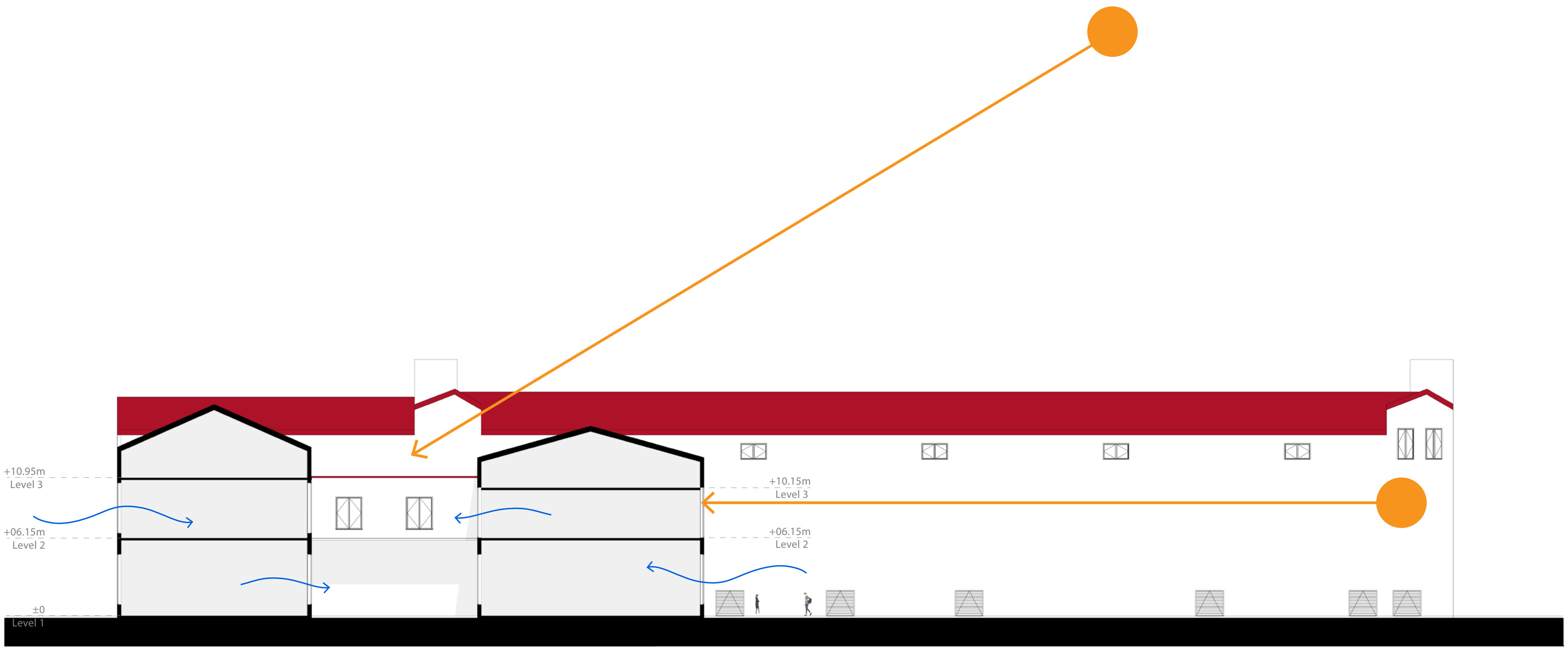


Figure 25 Section B (Current condition)

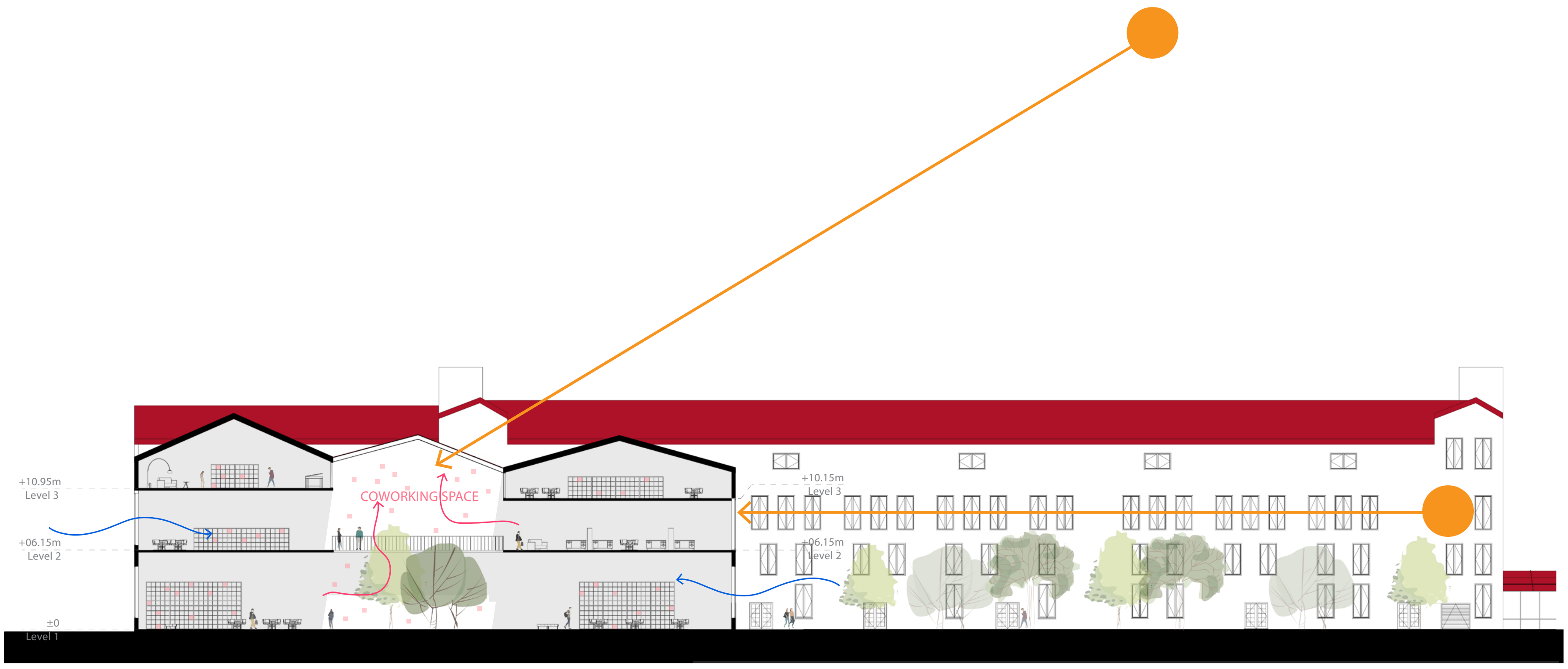


Figure 26 Section B (After Redevelopment)

Figure 27 View of the north facade of old industrial block

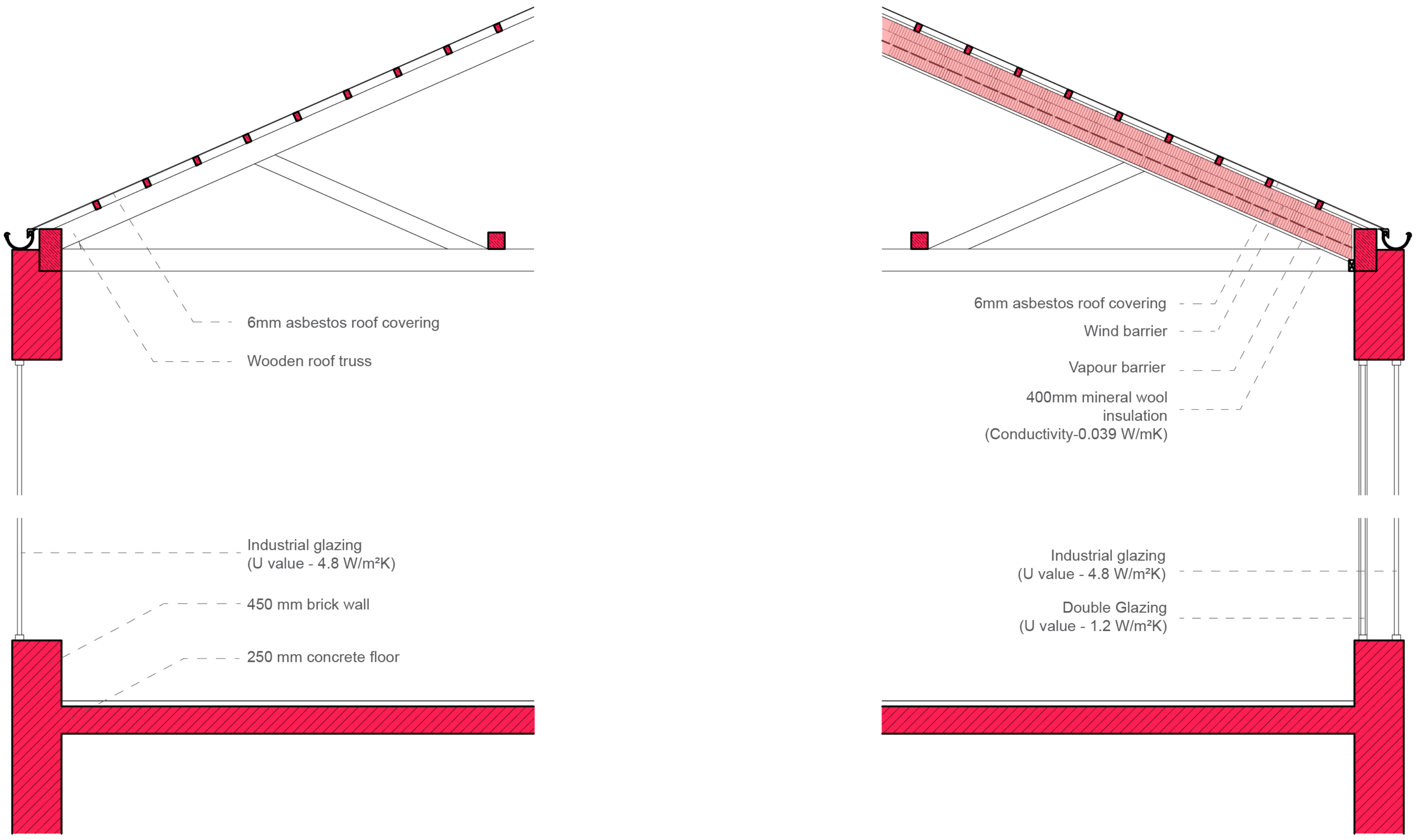


Figure 28 Wall section of old industrial block (before and after retrofitting)

After the design changes upgrades were made to minimize the heat losses through this building. The roof of the building was insulated with 400mm mineral wool insulation which brought the u-value of the roof down from 13.33 W/m2k to 0.08 W/m2K. Figure 28 shows the changes in the wall section with the necessary retrofits. The u-value of the glazing was also improved. The use of single layered industrial glazing had a u-value of 4.8 W/m2K. Since, the motive was to keep the aesthetics of the building intact, double layered glazing was installed on the inside of the wall which improved the u-value to 0.08 W/m2K. The floor was also insulated with 300mm mineral wool insulation, and the u-value changed from 10 to 0.08 W/m2K. The wall was kept intact without any physical changes. A simulation was run to check the performance after the design changes and retrofitting.

U value (W/m2K)	NS 3701 Standard	Without Renovation	Renovation	Additional wall insulation
Wall	0.15	1.11	1.11	0.12
Windows and Door	0.8	4.8	0.8	
Roof	0.13	13.33	0.08	
Ground Floor	0.15	10	0.08	

Table 1 U value of the old industrial block

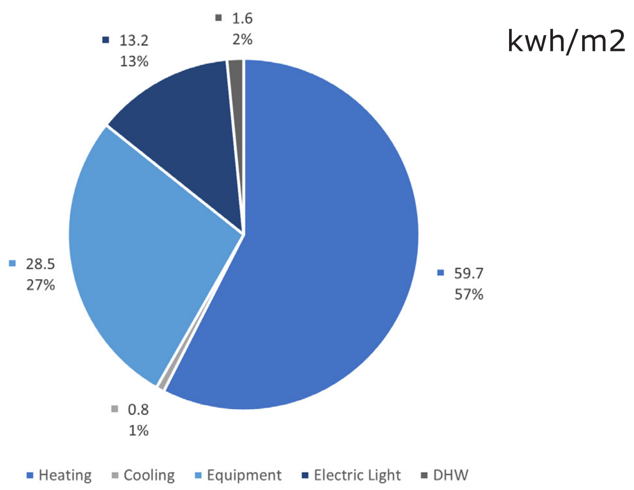


Figure 29 Energy consumption of the old industrial block (After Renovation)

There was an increase in the buildings footprint with the total being 10876 sq. m. now. The new results showed that there was a huge improvement in the energy performance of the building. The heating load dropped by a great extent and stood at 59.7kwh/m2 (Figure 29). There were also changes made in the input with respect to equipment loads in the simulation and the equipment load dropped to 28.5 kwh/m2. The lighting energy consumption also improved though there was only a small gap here. These three areas managed to consume the highest share of loads in the building's energy performance.

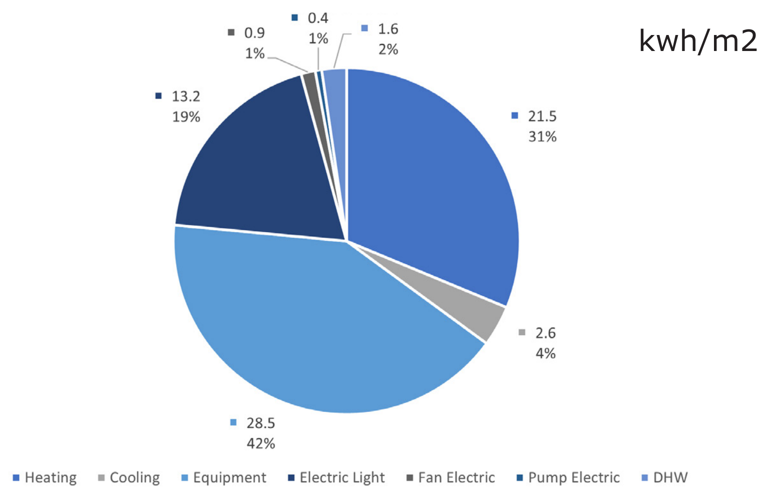


Figure 30 Energy consumption of the old industrial block (After Renovation with heat pump + DCV)

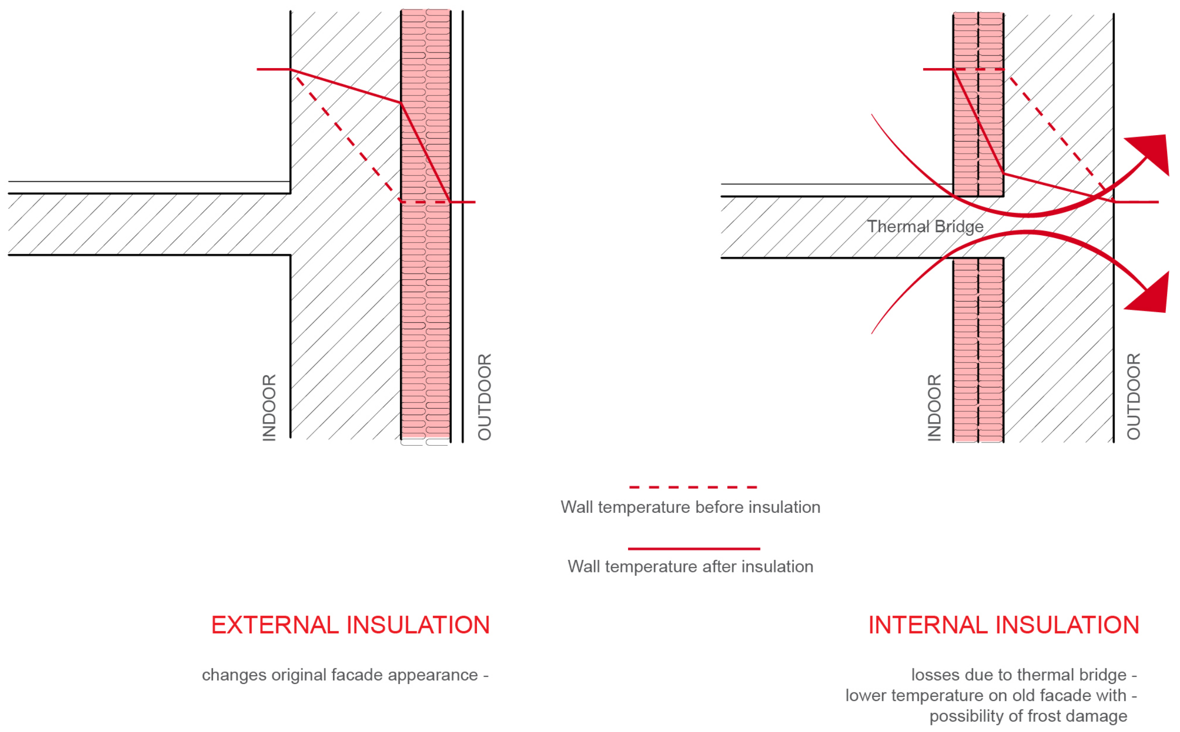


Figure 31 Wall section showing insulation types

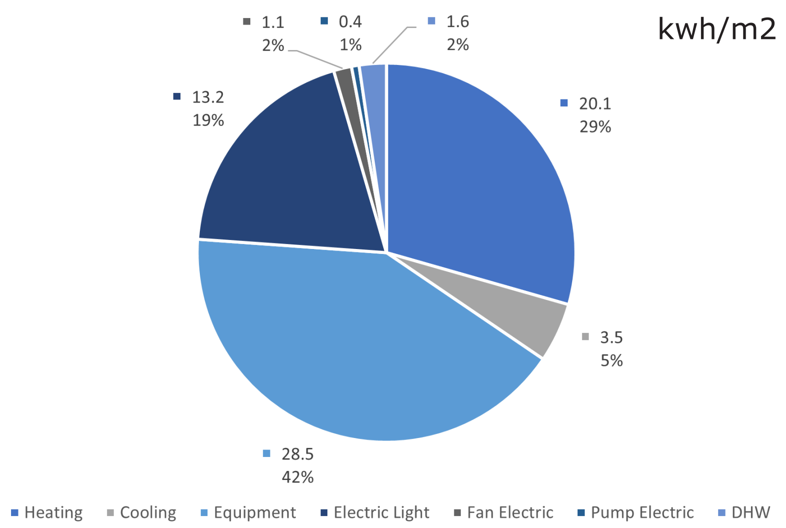


Figure 32 Energy consumption of the old industrial block (Additional wall insulation)

With 250 mm mineral wool insulation added, the u value of the wall improved to 0.12 W/m2K from 1.11 W/m2K. The simulation results showed the heating load to be 20.1 kwh/m2 which is not a significant improvement from the previous results. The cooling load also slightly increased in this case. Though it was expected to show further improvements in the heating loads but going with this result and the challenges faced with both external and internal insulation it was decided to not insulate the wall.

A final comparison has been made to show the improvement in the performance of the building. With the design changes to maximise the heat gains in the buildings plus retrofitting to minimise the heat losses and with the right technical systems the energy performance improved by 64% from its current condition.

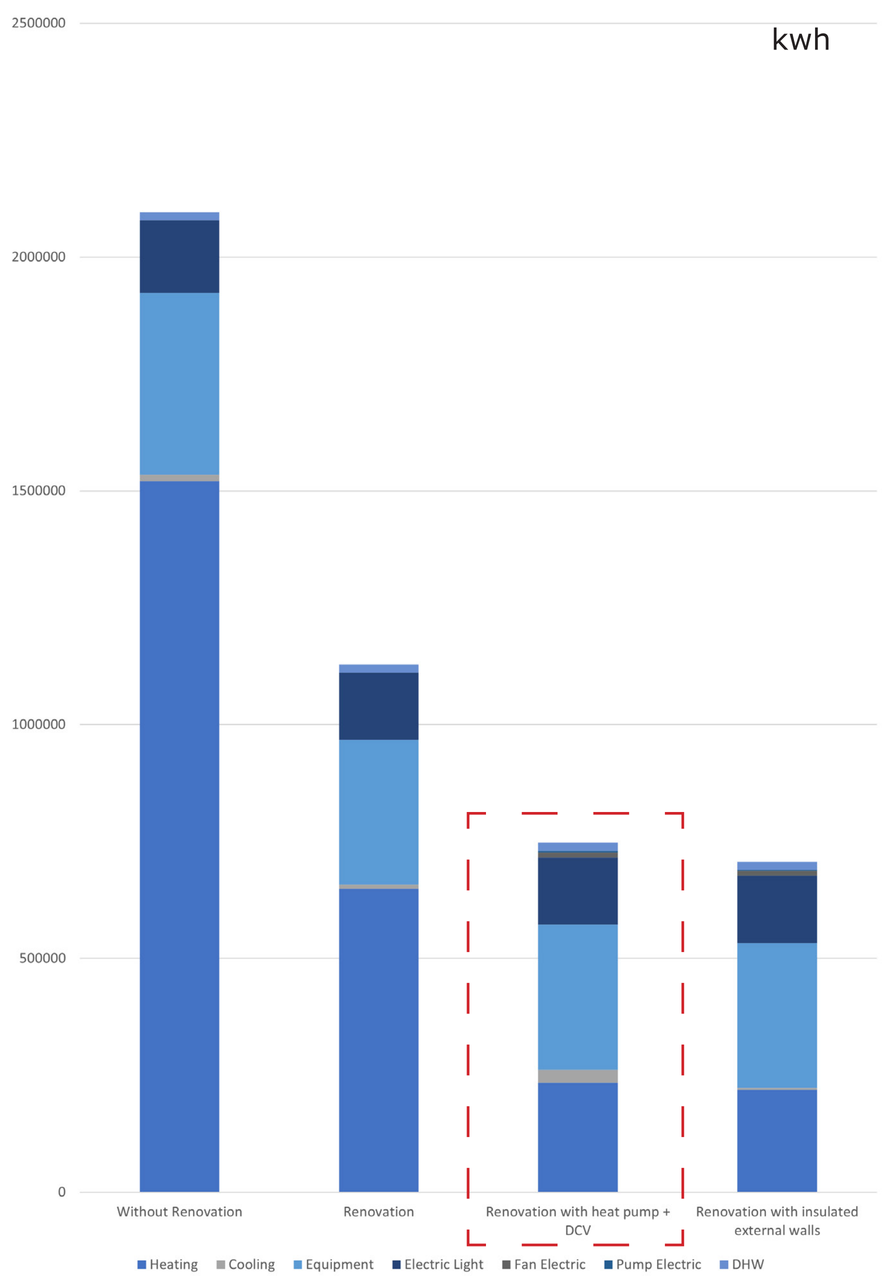


Figure 33 Comparison of energy consumption with respect to considered strategies

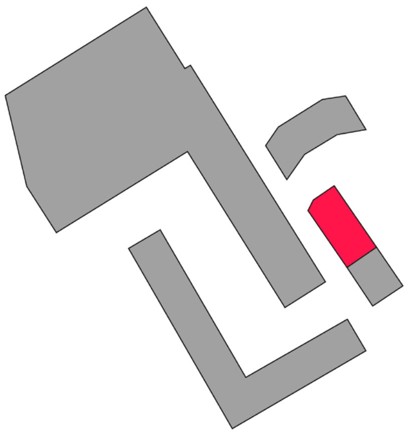


Figure 34 Creative Workshop Block marked in red

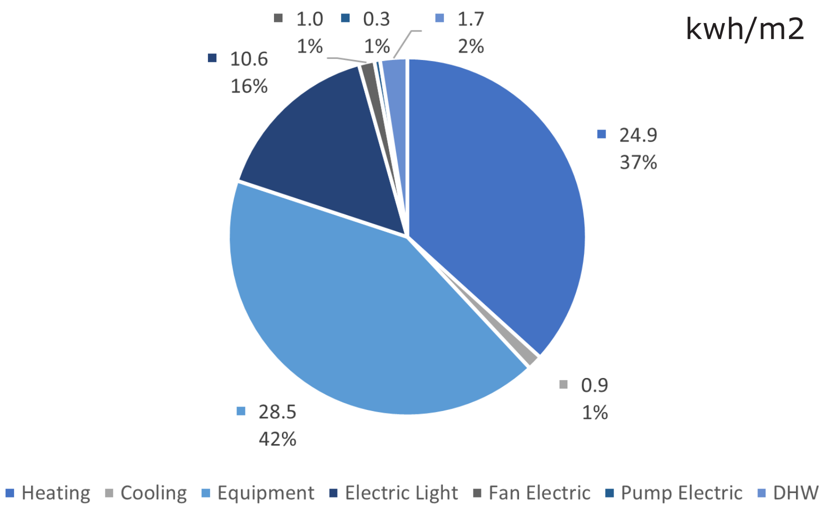


Figure 35 Energy consumption of creative workshop block

The next building to be analyzed is the creative workshop block part of the old industrial complex. This building is relatively small compared to its counterpart with the total built up area being 625 sq. m. spread in two levels. The building is located next to the water body and was designated as a creative workshop space. On one side it overlooked the active street whereas on the other it offered serene view. The building was retrofitted as the same as the previous building. The simulation results showed that the heating load consumed 24.9 kwh/m2 of energy which is more compared to the results from the previous building. The equipment and lighting load were 28.5 kwh/m2 and 10.6 kwh/m2 which with the heating load are the three highest source of energy consumption for the entire building. Upon investigating about the reason for higher amount of heat load, it can be seen from the radiation analysis (Figure 23) that the bigger building shaded the SW façade of this building lowering the amount of heat transmitted.

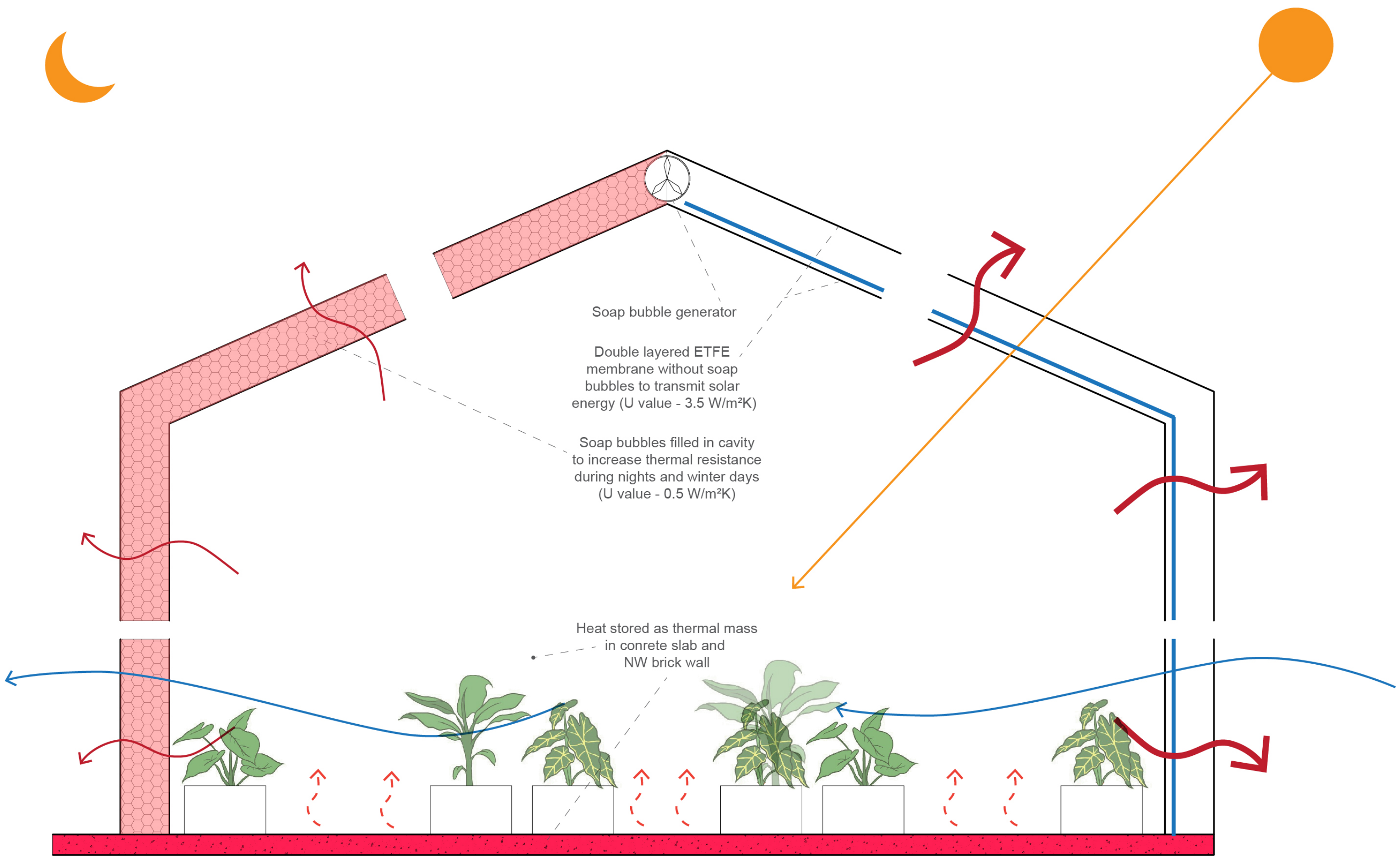


Figure 36 Wall section through greenhouse

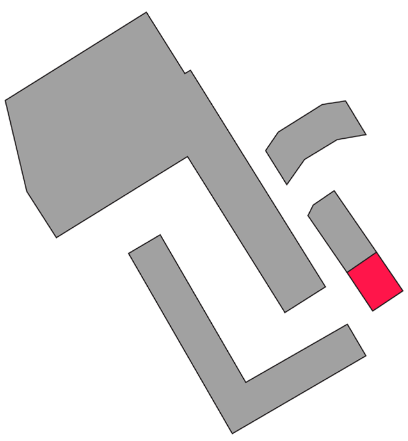


Figure 37 Greenhouse marked in red

A greenhouse will be built on the site to learn and experiment with growing foods locally and demonstrate the principle of the circular food system. The greenhouse will be attached to the SW façade of the creative workshop block which can benefit from the thermal mass of this brick wall. The greenhouse is proposed to be built by an innovative method which uses soap bubbles for dynamic insulation. Bubbles from liquid soap solution provides a better insulation than air alone offering low maintenance flexibility since the bubbles dissipate over time [26]. The bubbles are injected inside an enclosed double layered ETFE envelope through a soap bubble generator. During night or on cloudy days it reduces the energy

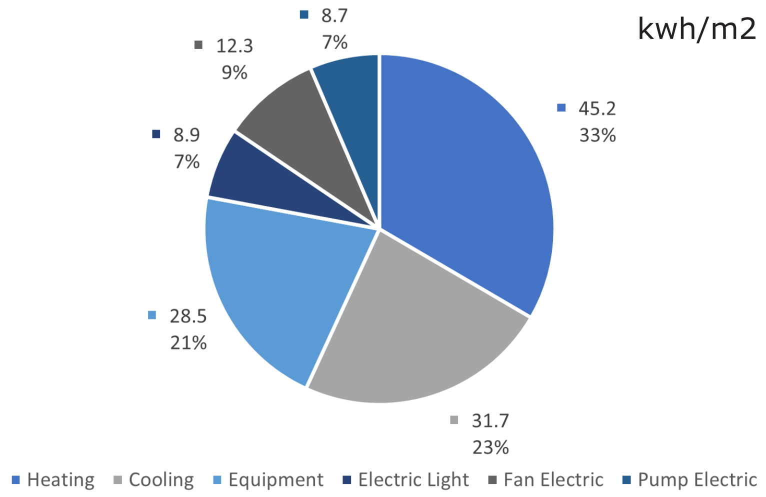


Figure 38 Energy consumption of greenhouse

U value (W/m2K)	NS 3701 Standard	Residential Units	Greenhouse
Wall	0.15	0.11	0.5
Windows and Door	0.8	0.8	0.8
Roof	0.13	0.08	0.5
Ground Floor	0.15	0.08	0.08

Table 2 U value of the building (Residential/ Greenhouse)

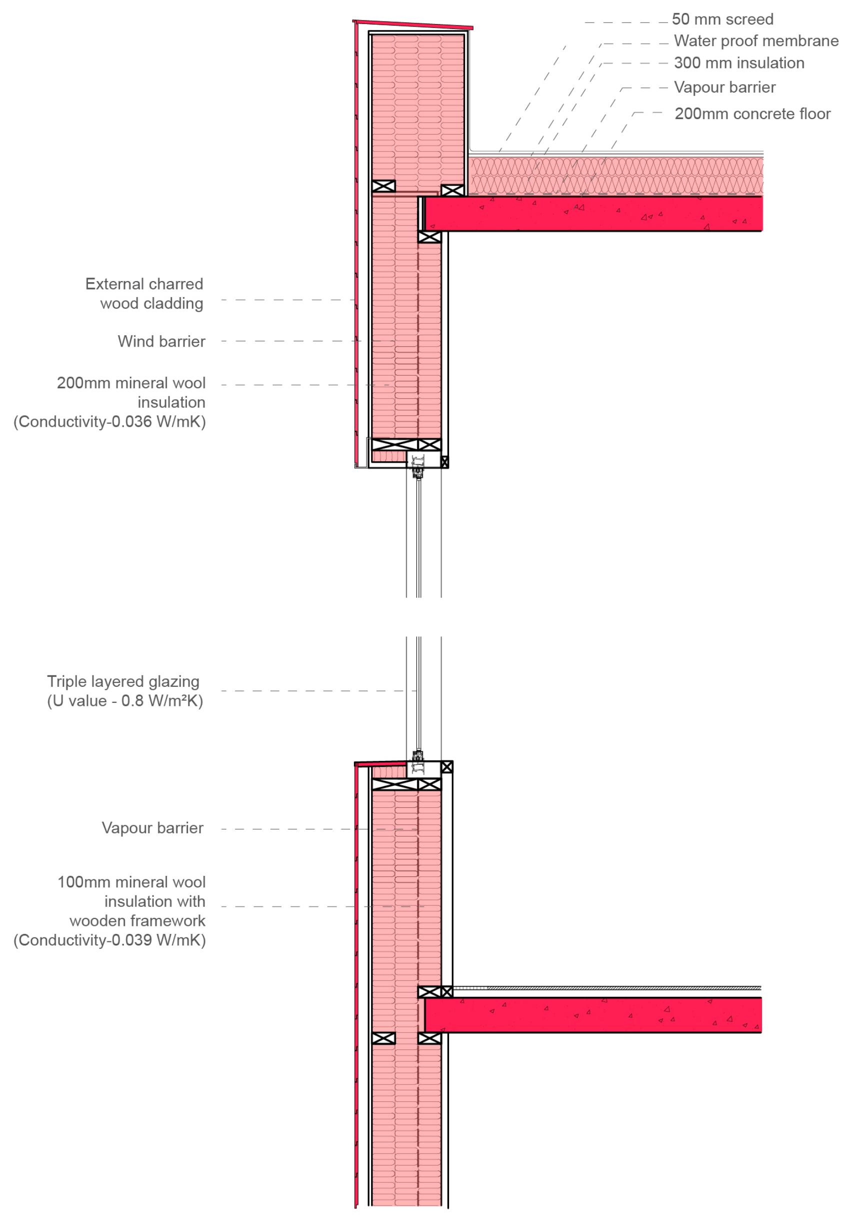


Figure 39 Wall section through residential block

losses offering a U-value of 0.5 W/m2K. The soap bubbles dissipate in the morning to allow solar radiation to penetrate through the envelope and store heat in form of thermal mass in the brick wall and concrete floor (Figure 36). Offering dynamic insulation to lower heat losses and higher heat gains, it reduces the overall energy consumption. With this type of envelope, it reduces the amount of structural load minimising materials used for construction.

The greenhouse will have the smallest footprint out of all the buildings in the neighbourhood covering an area of 189 sq. m. The results from the energy simulation showed that the greenhouse consumed a high amount of energy both for heating and cooling at 45.2 kwh/m2 and 31.7 kwh/m2 respectively. Energy systems in a greenhouse must run all day unlike an office building where it is adjusted with the occupancy. The greenhouse has the highest amount of transparent surface and hence that was the reason for its high heat gains and losses. The total energy consumed by this greenhouse was 135.3 kwh/m2 whereas a typical double polycarbonate greenhouse has a total energy consumption of 583 kwh/m2 [27]. This showed an improvement of 76% of total energy consumption comparatively.

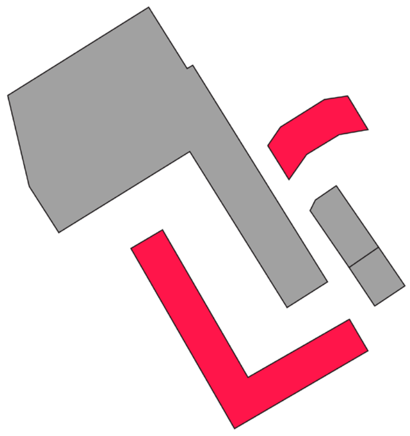


Figure 40 Residential blocks marked in red

The remaining buildings to be analysed are the residential units. The residential units are four level high with the ground floor designated for commercial spaces. The commercial space is 4 meters high while the residential units are 3 meters for each level. Both the residential units have been designed to have a good indoor environment. The residential block 1 has a total built up area of 4700 sq. m. and that of residential block 2 being 1450 sq. m. Block 1 will have 12 units of 100 sq. m. each on every level and for block 2 it will be 4 units of 80 sq. m. each. The structure (columns and floor slabs) of the building will be built with concrete. Concrete floors slabs can benefit from the thermal mass by storing heat. Because of the thermal lag it can maintain an even temperature throughout the day requiring less time for reheating the building up. Walls will be made of wood with external insulation to lower the effects of thermal bridges. Simulations have been run to check the performance of these buildings individually.

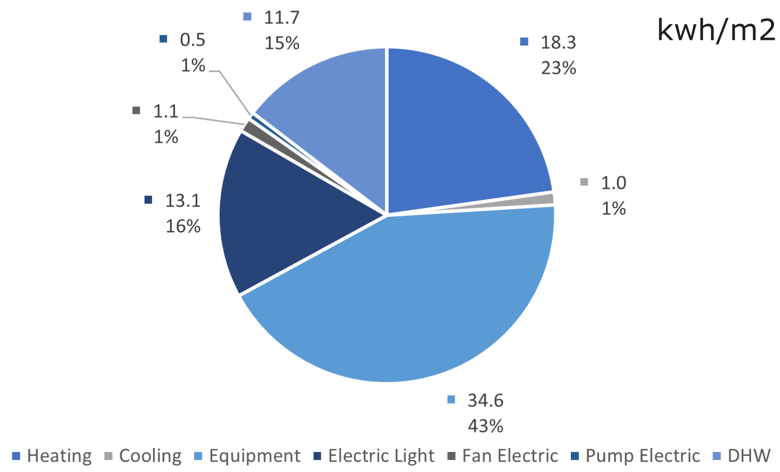


Figure 41 Energy consumption of residential block 1

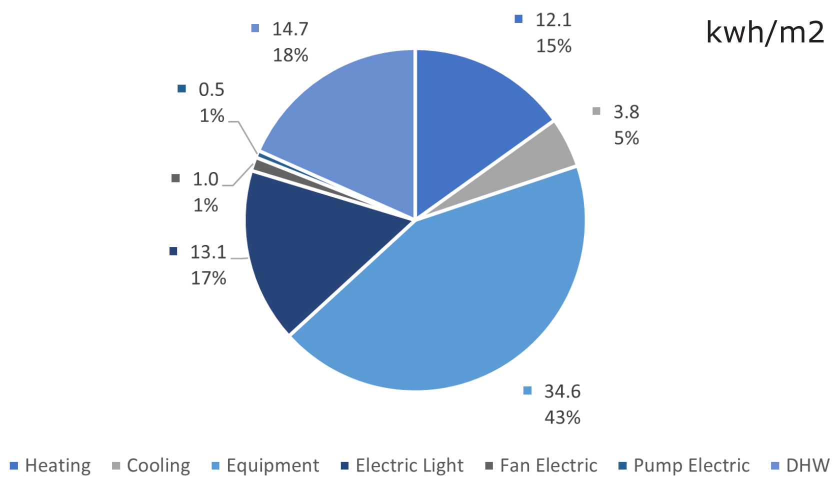


Figure 42 Energy consumption of residential block 2

For both the residential buildings equipment loads had the highest share of electricity consumption. Heating loads for residential block 1 was more than that of residential block 2 amounting to 18.3 kwh/m2 and 12.1 kwh/m2. Cooling load was more for block 2 than block 1 at 3.8 kwh/m2 and 1.0 kwh/m2 respectively. Though a residential building operates throughout the week and must maintain comfort throughout the night it consumes less energy compared to a building for office usage. Load for electric lighting was 13.1 kwh/m2 for the both the buildings. It was also important to note that for a residential building the energy required for domestic hot water (DHW) is the highest among the rest. It was at 11.7 kwh/m2 and 14.7 kwh/m2 for the residential block 1 and 2 respectively. Though the site will have a centralised DHW supply supported by a heat pump, the differences in the result was because the buildings were simulated separately.

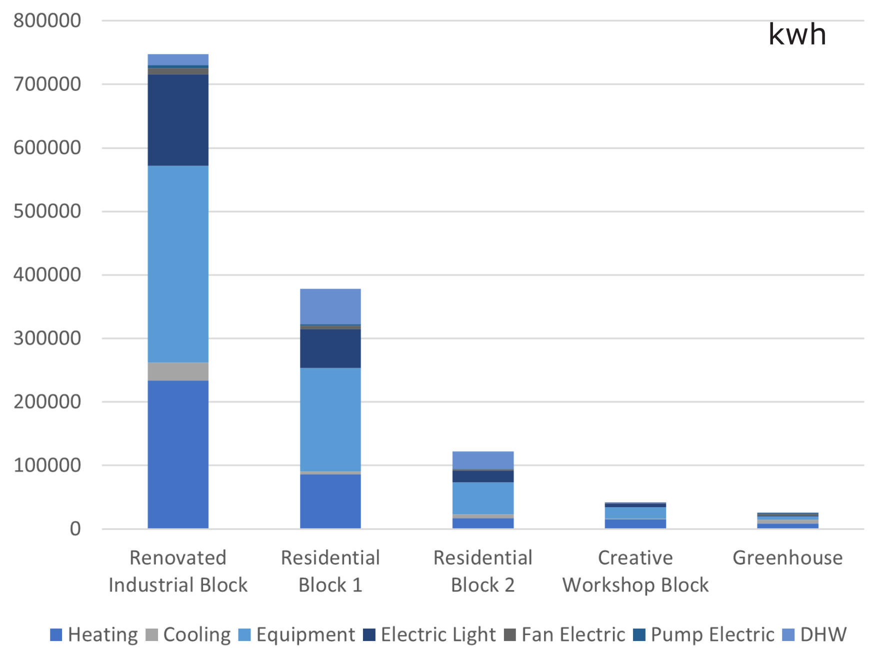


Figure 43 Comparison of energy consumption between different buildings (kWh)

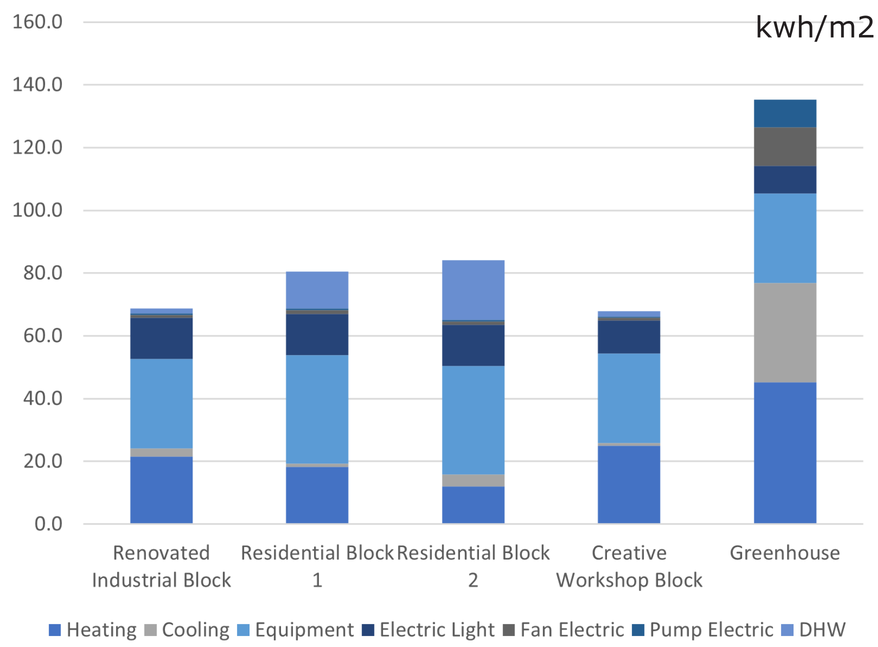


Figure 44 Comparison of energy consumption between different buildings with respect to built up area (kWh/m2)

Finally, a comparison was made to check the energy performance of all the buildings in the neighbourhood. The highest energy was consumed by the buildings with the largest built-up area which is obvious. But it was interesting to check the energy performance per square meter of built-up area. Surprisingly the building with the lowest built-up area consumed the highest amount of load per square meter which is the greenhouse. The reason for this was already discussed above. The residential units were at the second highest number with almost similar amount of energy consumption per square meter. The renovated industrial block and the creative workshop block comparatively had the least consumption. This can be explained with the usage of the building and its occupancy. A residential building and a greenhouse must maintain comfort level for maximum hours compared to an office building or other building meant for public use. The graphs at Figures 43 and 44 briefly compares the energy consumption of the buildings in this neighbourhood.

8.3.2 Energy Production

For a neighbourhood to be a ZEN, locally produced energy (considering a large percentage by renewables) must compensate for the emissions/ energy consumed in its life cycle depending on the ambition level. This neighbourhood produces energy through two ways. One through roof top PVs installed over each building and the other through an anaerobic digester installed at the basement of the building. Monocrystalline solar panels have been used for the energy generation installed at the roof of each building. This panels have the highest solar to electric energy conversion compared to its counterparts and exhibit a lifetime of up to 30 years. The efficiency was set at 20 percent for the simulation.

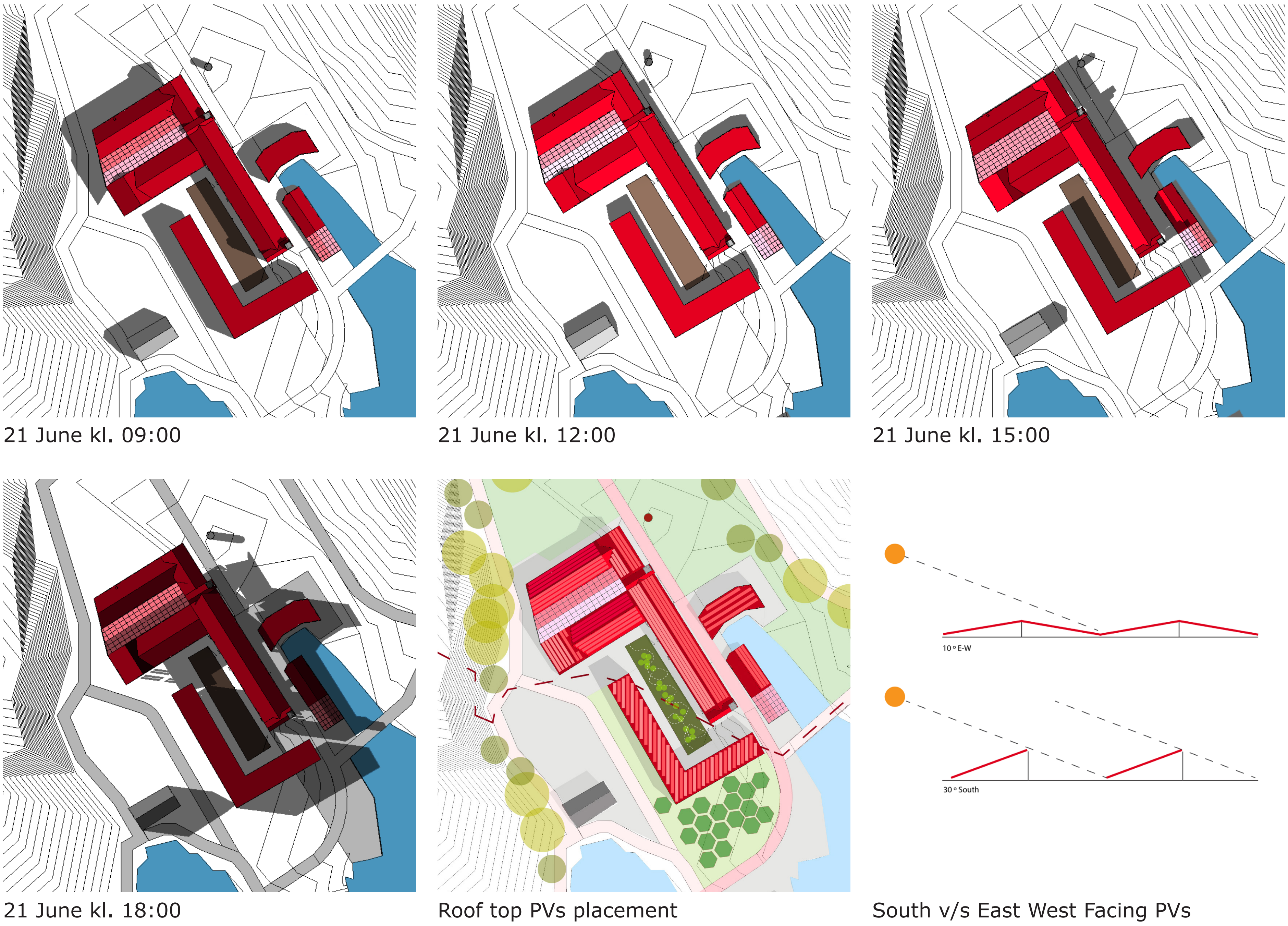


Figure 45 Shadow analysis for PV placement

PVs were installed on the roofs of the buildings optimised by performing a shadow analysis. The roof of the renovated industrial block was completely covered with PVs but this block also shaded the creative workshop block and the residential block when the sun is oriented towards the west in the evening. It meant the PVs couldn't be oriented on the roof facing on the west side in these buildings. The residential block 2 had PVs oriented towards the SW direction to maximise gains without being shaded. The residential block 1 has PVs placed in an E-W orientation. While a south facing PV produces more energy, with E-W orientation it is possible to install more amount of PVs per square meter of roof area. There were no PVs installed over the greenhouse as this would block the heat gains through its roof.

	Installed PV Surface Area (m2)	PV Orientation	Energy Production (Kwh)	Energy Production per m2 of installed PV(Kwh/m2)
Renovated Industrial Block	2444	Roof Integrated	335196	137.2
Residential Block 1	1000	10° E-W	161722	161.7
Residential Block 2	200	30° S-E	34233	171.2
Creative Workshop Block	173	Roof Integrated	19165	110.8

Table 3 PV energy production from different buildings

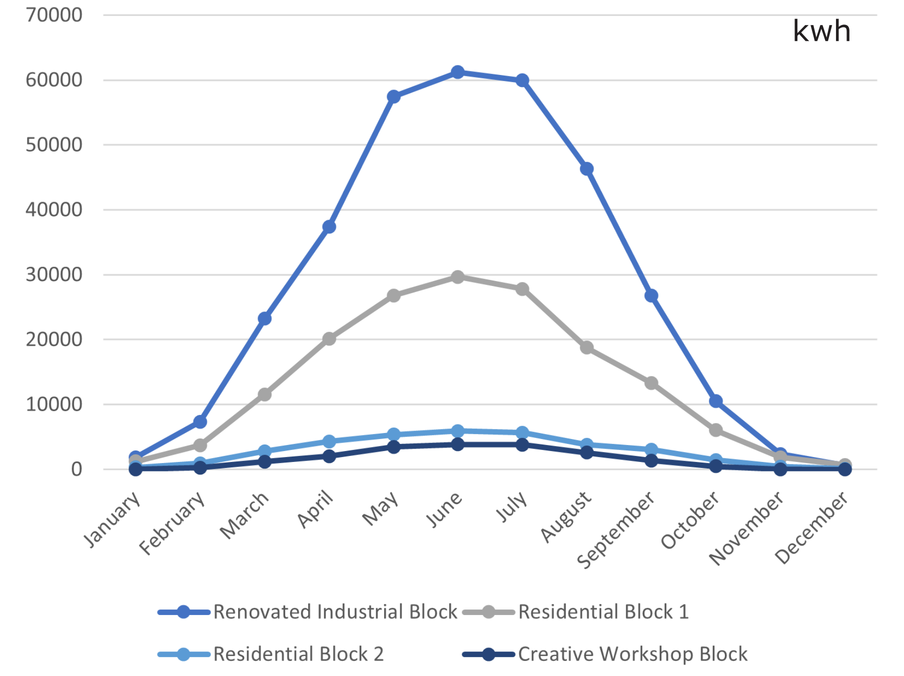


Figure 46 Comparison of PV production from different buildings throughout the year

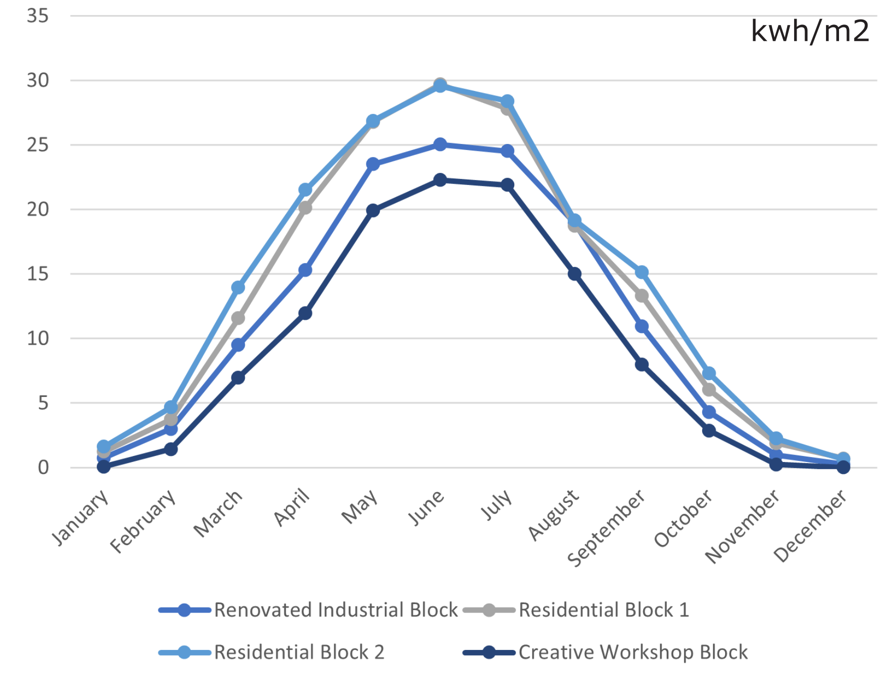


Figure 47 Comparison of PV production from different buildings throughout the year with respect to installed surface area

The results showed that the energy production was at its peak during the summer while lowest during the winters (Figure 46). The renovated industrial block produced the highest amount of electricity as it had the highest amount of PV installed on its roof. Comparing the results of the energy produced per sq. m. of installed PVs, residential block 2 with S-E orientation has the highest generation while the creative workshop block at the lowest. During the summer season both the residential blocks produced almost equal amount of energy per sq. m. of installed PVs though both had different PV orientation (Figure 47).

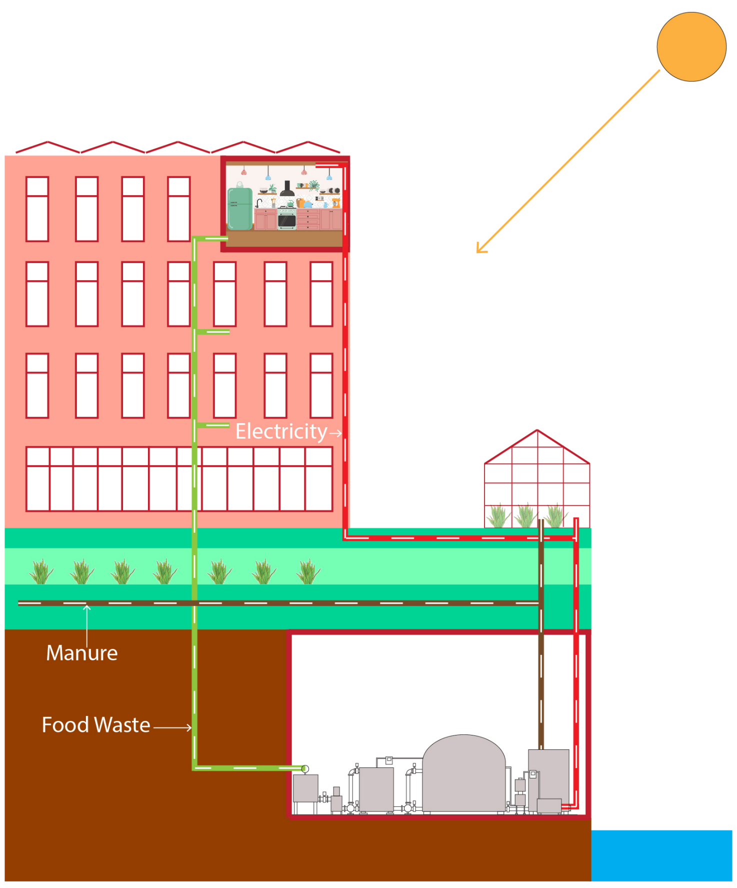


Figure 48 Demonstration of circular food system in the neighborhood

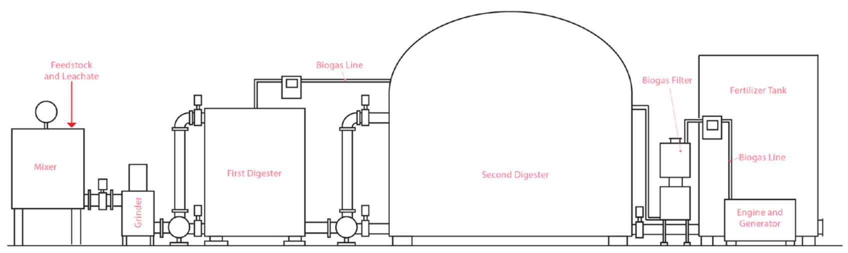


Figure 49 Setup of a biogas powerplant

The second source of energy production in the neighbourhood is through anaerobic digestion of food waste. For conversion of waste to energy, where the constituent materials have a higher percentage of organic bio-degradable matter with a high level of moisture/water content a bio-chemical process is involved. This aids a microbial activity, and the main technological operation falls under the category of Anaerobic Digestion which can also be referred to as Biomethanantion [28].

The parameters determining the energy recovery potential from wastes are the quantity and the quality (physical and chemical attributes) of the waste. With considerations of these two parameters, the actual production of energy will depend upon the specific treatment process employed [28], in this case anaerobic digestion. The neighbourhood will be promoting sustainable behaviour such as segregation of food waste from solid waste before the waste is discarded.

Anaerobic Digestion involves a process where the organic waste is fed to a biogas digestor. Here, the organic waste undergoes bio degradation to produce biogas (rich in methane) and sludge under anaerobic conditions. This biogas can be used for cooking, heating or converted to electricity using steam turbines. The sludge after stabilisation can be used as manure for agriculture which is rich in nitrogen since it is not lost by oxidation [28].

The energy generation potential from food waste in line with Circular Food System (Section 7.2.3) for the neighbourhood of Skotfossbruk is calculated in the next page:

Total waste generated in kg (TW)= P

Total Organic/Volatile Solids (VS) = ~50% of TW = 0.5P

Food Waste/ Organic bio-degradable fraction (FW) = ~60% of VS = 0.3P

Typical digestion efficiency = 60%

Typical bio-gas yield (B) = 0.8 m3/kg of VS destroyed

= (0.8 * 0.6 * 0.3 P) m3

= 0.144 P m3

Calorific value of bio-gas = 5000 kcal/m3

(Calorific value is a direct indication of the energy available for the production of steam [29].

1 calorie = 860 kWh)

Typical Conversion Efficiency = 30%

Energy Recovery Potential = (B * 5000/860 * 0.3) kWh/yr

= **0.25 P kWh/yr** (Eq. 1)

Household waste per capita for Norway in kg = 449 [30]

Total waste generated for the designed neighbourhood considering 500 people (P1) = 224 500

Energy Recovery Potential for the neighbourhood = **56 125 kWh/yr**

Additional waste collected from the village of Skostfoss and Åfoss assuming 45% of the population agrees to send waste into the site numbering 1700 people (P2) = 763 300

Additional Energy Recovery Potential for the neighbourhood = **190 825 kWh/yr**

Total Energy Recovered = 246 950 kWh/yr

Total Power Generated = (246 950/ 24) kW/yr

= 10 289 kW (10.2MW)

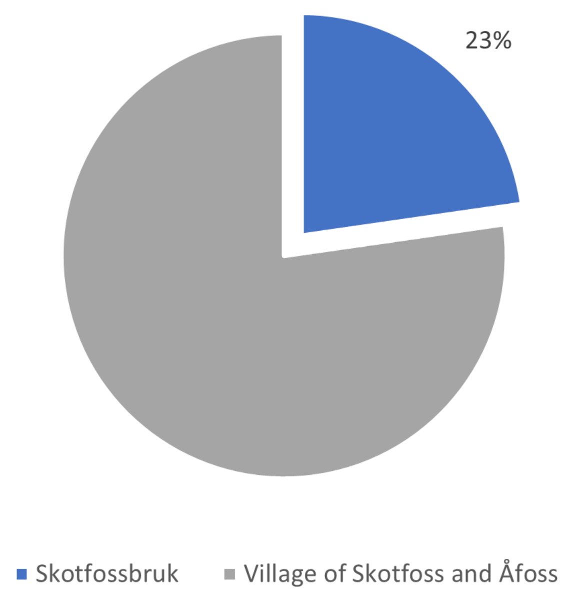


Figure 50 Percentage contribution of energy generated from collection of waste in the neighborhood

The total energy recovered after anaerobic digestion was 246 950 kWh with a power output of 10.2 MW. The neighbourhood of Skotfossbruk contributed to 23 percent of the total energy generation with an assumption that waste can be collected from the neighbourhood villages.

8.3.3 Energy Exchange

After having calculated the operational energy needs of the building along with local energy generation, the project will aim at CSC model of self-consumption. The first objective is to cover the demand of the neighbourhood by exchanging surplus energy in between the buildings and once the energy demand is met the rest of the energy can be exchanged with the villages of Skostfoss and Åfoss under a PPA scheme. Battery storage will not be used in this neighbourhood as priority is to use all the energy at the time of production. The scheme proposed here is that food waste will be collected from these villages in exchange for energy offered at discounted rates. This will still be higher than the rates one receives if energy is sold back to the grid. The villages using this energy will come under the servitisation model of circularity where they can access clean energy without having to invest on the required energy system.

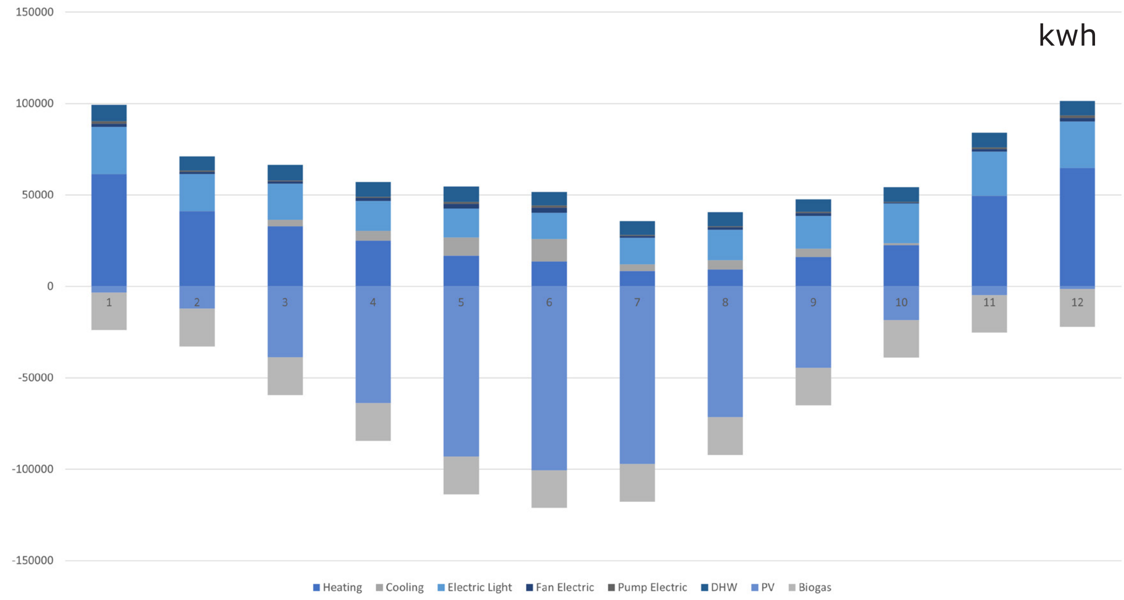


Figure 51 Total energy demand and production throughout the year

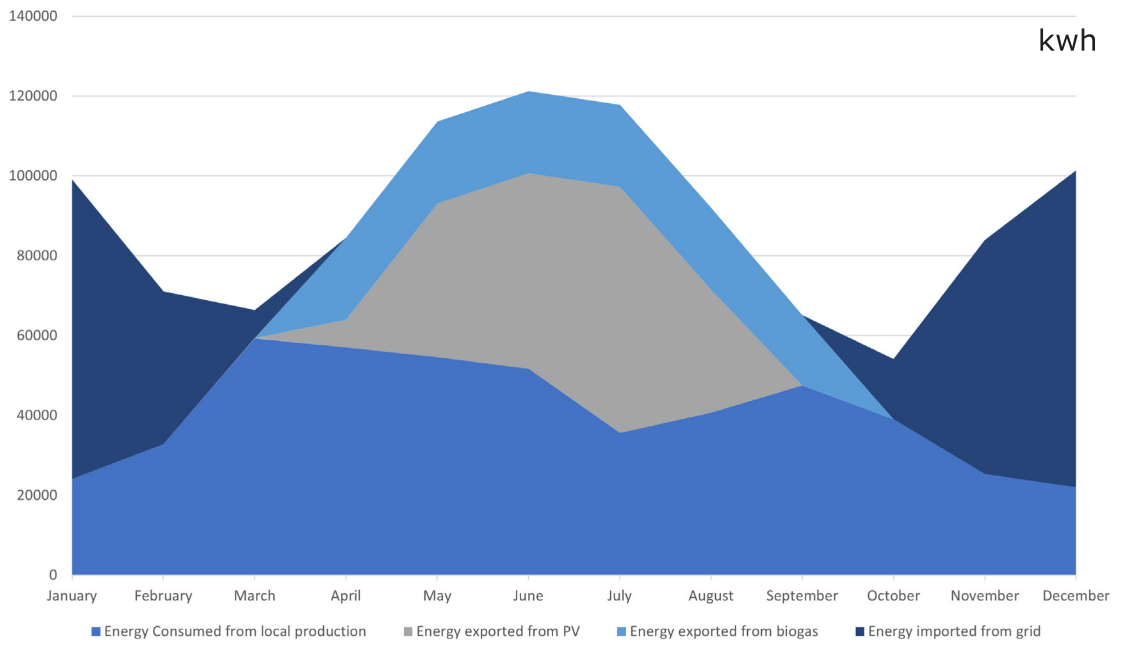


Figure 52 Energy consumption, import and export throughout the year

Figure 51 shows the energy balance graph with energy demand and production for the neighbourhood throughout the year. As per the ambitions level for a ZEN, operational energy need has been excluded from the calculations. The months producing the highest amount of energy are the ones that requires less energy for that period. While energy from the PV have a dynamic profile throughout the year peaking during the summer, energy from the biogas production has a linear profile and can contribute to the energy demand during winters as well. Therefore, the energy exchange outside the neighbourhood will take place only on the summer whereas the priority would be to use maximum self-produced energy within. Figure 52 shows the load distribution through the year. A detailed flow of energy in the neighbourhood has been shown in Figure 53. While the buildings which have PVs installed on the rooftop could fulfil its energy demand at the time of production. The greenhouse which has no PVs installed uses the surplus provided by the other buildings exchanged through a micro grid. While residential block 2 has PVs installed on its roof, it was found that the amount of electricity generated was not sufficient for its total use comparatively and required extra electricity from the micro grid. The total energy demand for the neighbourhood stood at 763520 kWh (42.8 kWh/m2) where 490135 kWh (27.5 kWh/m2) of energy was covered from on site energy production. 307130 kWh (17.1 kWh/m2) of energy was exchanged outside the neighbourhood while energy imported from the grid was 273384 kWh (15.3 kWh/m2).

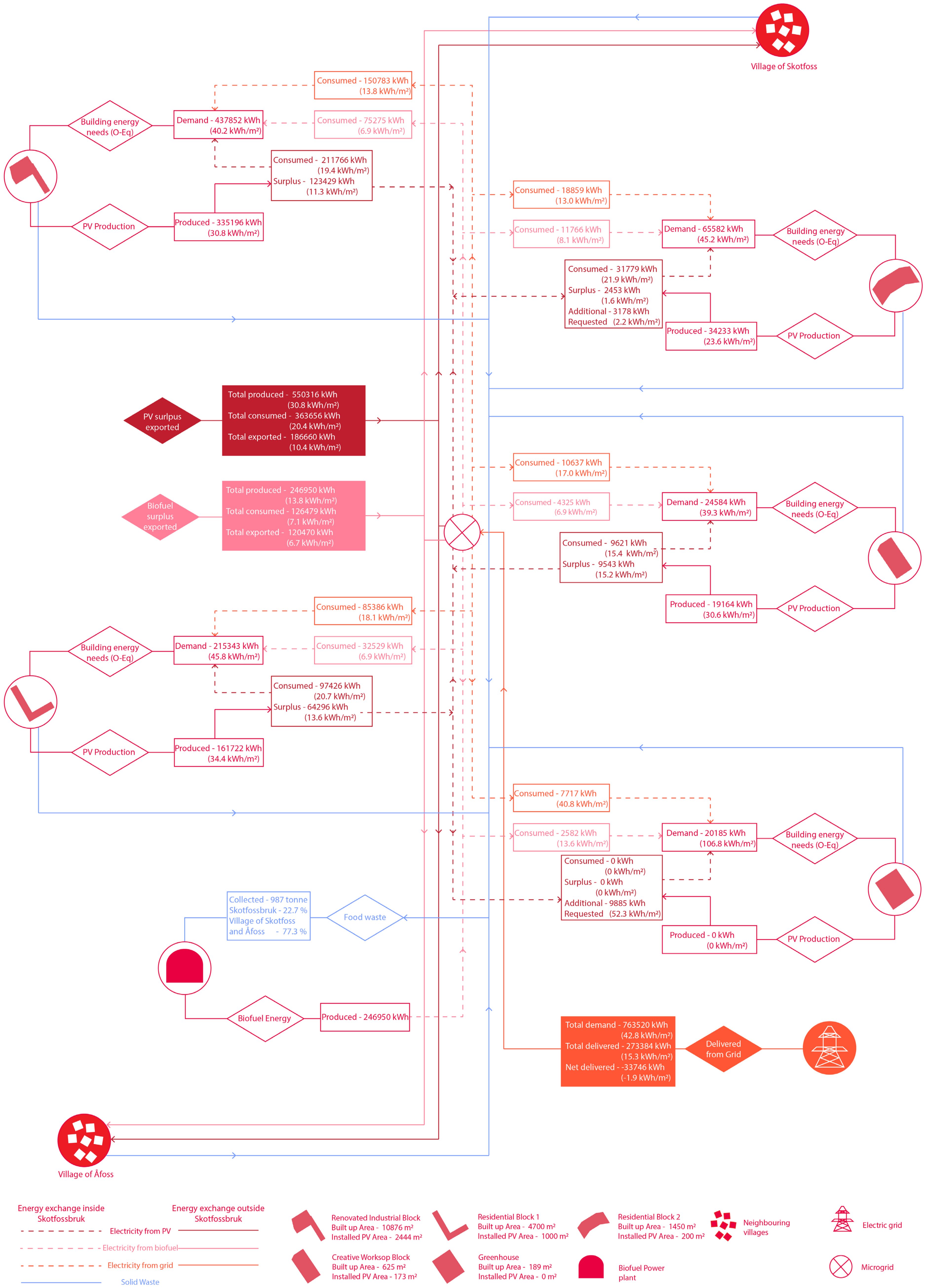


Figure 53 Flowchart showing energy exchange inside the neighborhood

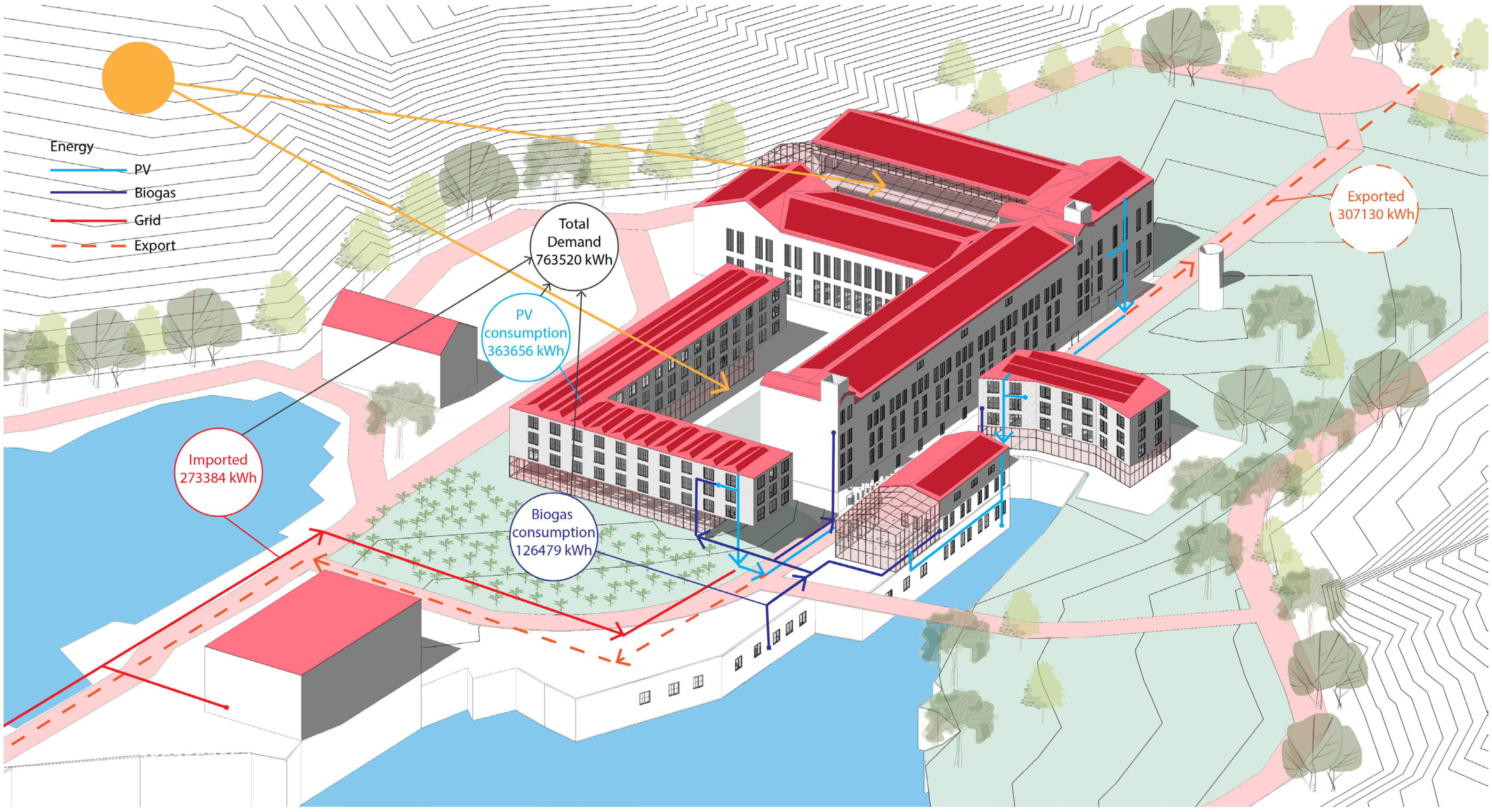


Figure 54 Illustration of energy exchange in the neighborhood

8.3.4 ZEN

Achieving a zero-energy neighborhood was the objective of this project. By successfully reducing energy consumption through energy efficient design and through production of local energy it was able to achieve net zero energy. Demonstrating the principle of circularity in the food system to produce energy from waste, it contributed to 31 percent of total energy produced. For achieving the nZEN the equipment load was deducted from the balance and to compensate for the total operational use more electricity has to be produced on site either through installing more PVs or improving the production capacity of the biogas power plant.

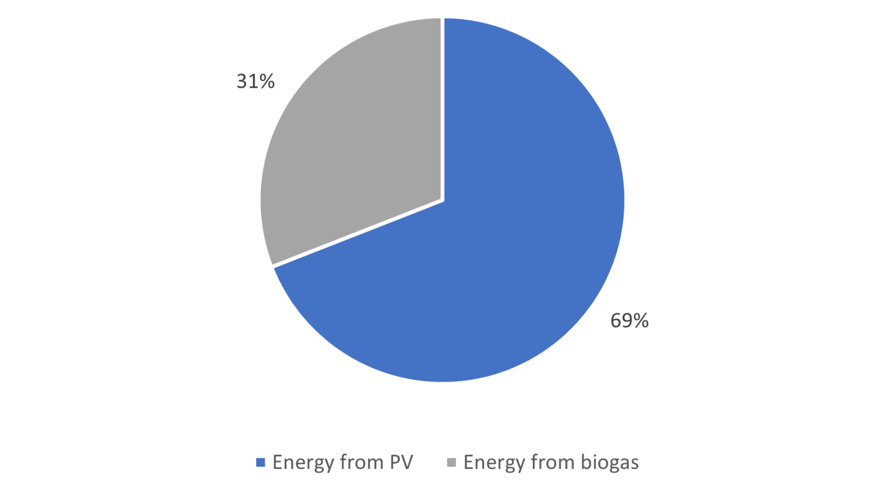


Figure 56 Energy production contribution chart

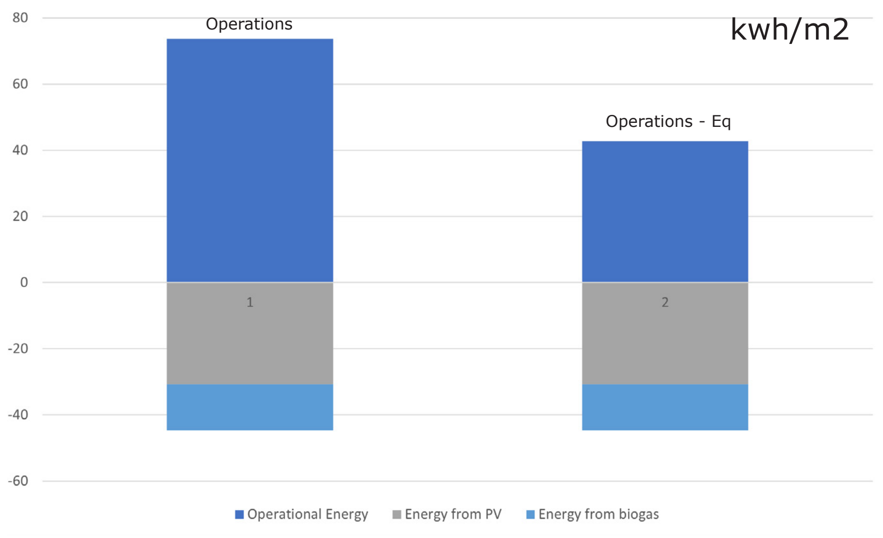


Figure 55 Energy balance for achieving ZEN

9. CONCLUSION

The project has demonstrated how a once flourishing industrial complex which was lying inactive for many years can be transformed into an attractive neighbourhood able to draw people in it. Analysing the context to provide good spatial qualities to the project where people can come, live, work, and learn this project can become a flagship how neighbourhoods can be redeveloped to suit the present needs and be ready for the future. The project not only aimed at becoming an energy efficient neighbourhood but also tried to create a social hub for people of all age groups. Thoughts were put in this project to make this a lively neighbourhood promoting walking and cycling routes through the site and strengthening the already existing infrastructure.

Energy efficiency in the design was achieved by careful redesigning of the remaining buildings and proposing new buildings that takes in consideration the social and environmental actors. Using the right building systems such as DCV and heat pumps it has achieved to reduce the energy to a great extent.

Through active participation this project aims that people learn how to grow foods locally bridging the gap between production and supply. This will also let people know the way food is grown without the use of chemicals. Promoting sustainable behaviour in the neighbourhood to segregate food waste from solid waste will create an efficient use of waste in the circular food system. Circularity in the food system has played an important role in minimising the overall energy demand in this project. While the use of PVs in the building system generates more electricity comparatively, it is important to note that energy from PVs have an uncertain generation profile minimising the generation during winters and bad weathers. The energy generated from biofuel has a linear profile and can contribute equally to the energy generation throughout the year. The energy generation capacity can also be increased just by importing more waste from the surrounding neighbourhood.

This project has also shown the use of energy exchange inside and outside the neighbourhood. By satisfying the needs of the buildings in the neighbourhood it exported the remaining electricity outside the neighbourhood for a discounted rate. Exporting electricity back to the grid can cause instability and hence it is better to consume the energy generated during that time by exchanging with the neighbourhood. Battery storage is also an option, but it brings in additional investment costs.

Further development of this project lies in respect with developing the individual buildings proposed on the site and to increase the ambition level required in reaching a ZEN. Local energy can further be generated from the introduced solar farm on the waterbody near the site.

Figure 57 View of the urban food park in front of residential block 1

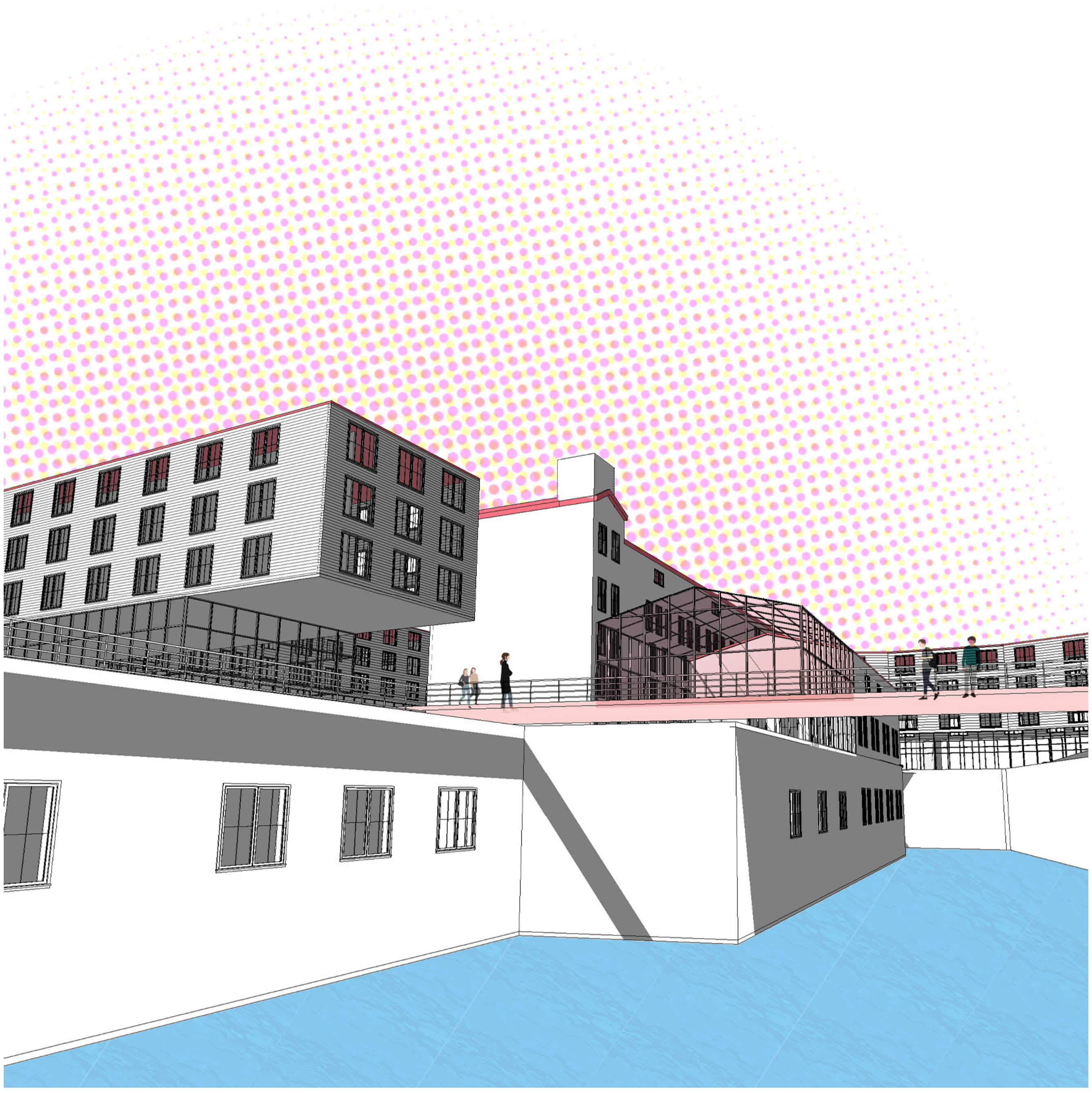


Figure 58 View of the neighbourhood from the waterbody on SE side

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