MAKING A HIGH DENSITY, MIXED-USE NEIGHBORHOOD ENERGY NEUTRAL

With new urban building blocks and using renewable resources, in Western Europe

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ABSTRACT

This paper describes a set of guideline that will help architects, planners and policy makers in developing high-density, mixed-use neighborhoods that are energy neutral by firstly reducing the initial demand, combining functions to reuse and recycle waste streams and thirdly to use on-site renewable energy sources to meet the remaining demand. Lessons learned from doing multiple case studies are that the process, participating actors and goals set during the initial phase are crucial to the success and the (financial) feasibility of the project. Literature research will be done on both spatial and energetic aspects of urban building blocks to eventually form the guidelines and recommendations. Reducing and reusing can decrease the electricity demand up to 25% in general and heating and cooling energy by an astonishing 80%. Integrating both photovoltaic thermal hybrid solar collectors and photovoltaic panels into roof designs greatly increases its total area and annual yield. Together with a wind turbine in the close proximity it is demonstrated that a newly built neighborhood with a population density of 330 people per hectare in the Marine Area, Amsterdam can be totally energy neutral on a yearly basis. The intention of this paper is thus to demonstrate that urban neighborhoods as opposed to more commonly seen low density neighborhoods can be energy neutral and economically feasible by combining principles of urban 'cityplot' design, the new stepped strategy and an energy planning approach.

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1. INTRODUCTION

1.1. BACKGROUND & RELEVANCE

In the last few centuries the world population has grown almost exponentially and more and more people have moved from rural areas to live in urban areas. This development will continue in the coming decades when the total world population will increase at a staggering rate from 7.2 billion now to 9.6 billion by 2050 (Our World in Data, 2016). During this same period, the continued urbanization will lead to 69% of this populace living in urban areas (Shen, Jorge Ochoa, Shah & Zhang, 2011; Komeily & Srinivasan, 2015). And according to Suzuki, Dastur. Moffatt, Yabuki & Maruyama (2010) these two factors will definitely shape the future of 21st century cities. Because all these people not only require space to live, but also need energy, heating and cooling, food, (drinking) water and produce waste, which all in turn require even more space and increase the total human footprint. While these cities only occupy 2% of the earth's surface (Vartholomaios, 2015), they contribute more than 70% of global CO_2 emissions and are also responsible for the depletion of natural resources and, as mentioned before, agricultural lands (FAO, 2011). Greenhouse gas emissions are the result of a fossil fuel based society and have consequently lead to rising global average surface temperature and rising global mean sea level (IPCC, 2014). These fossil fuels reserves are furthermore not unlimited and are predicted to become depleted in the next century or more (Shafiee & Topal, 2009).

It must be clear that for the Netherlands, which will have a predicted population of 15.1 million to 20.3 million depending on different economic scenarios (CBS, 2015c; PBL, 2016), with an urbanization rate of around 90% (Niemans, 2016) and space as a scarcity, a new way of designing the living environment is needed. The city should be transformed from a place of consumption to a place of production by first reducing the demand, reusing existing flows and producing the residual demand in a sustainable way. In 2014 for example, only 5.6% of the energy production came from renewable resources whereas it should be 14% by 2020 according to European guidelines (CBS, 2015d). Households use approximately 14% of all the energy produced (Compendium voor de Leefomgeving, 2016) and according to Van den Dobbelsteen, Wisse, Doepel & Tillie (2012) buildings in total amount for 30% to 40% of all the energy consumed while cities with heavy industry lacking have a contribution of 50% or more. From this it must become clear that the city and especially the neighborhood and building block scale has great potential to change the city from being the problem to being the solution.

1.2. RESEARCH QUESTION & SIGN POSTING

The research question presented in this paper is therefore: ''How can a new, high density, mixed-use neighborhood with urban building blocks located in Western Europe be energy neutral using renewable resources?'' Both the mixed-use and the urban form of the building block are starting points which enable an efficient use of resources and the exchange of flows between different functions, which will both be major parts of the research. Sub questions will consequently be for the general aspect to firstly define what energy-neutral means, what renewable resources can be used in the built environment and what ambitions the governmental bodies have set. Secondly multiple case studies will be done of sustainable urban projects with special attention to their process, spatial principles and the implementation of electricity, heating and cooling. For the spatial aspects the choice of the urban form will be supported with arguments found in literature. As well as the utilization of mixed-use, the effect of both dwelling and population density and of course what functions can exchange what flows. This will then lead to the next topic of energy neutrality with question how the demand can be reduced, how residual waste streams can be reused and how the remaining demand can be solved with the use of sustainable energy sources like solar, wind, geothermal and biomass. With these sources comes to problem of intermittencies which will also be discussed. Aspects like food production, water retention and waste management will not be dealt with, but will be integrated in the coming design for which this research paper forms the starting point.

This research paper is the first out of two phases of my graduation at the chair of Architectural Engineering Intecture at Delft University of Technology and will form the basis for the second semester in which a design for the Marine Area in Amsterdam will be made with as objective to create added value by combining functions and exchanging their flows to reduce consumption. In a phasing flexible neighborhood made up from building blocks, creating a diverse, life-cycle proof and vibrant living environment and using architectural principles to be energy neutral, using renewable resources like solar, wind, geothermal heat and waste. Also integrating a greywater system in combination while at the same time contributing to the knowledge economy and providing education with homegrown food in local green-houses to create awareness about consumerism and actively reduce the human footprint.
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2. METHOD

2.1. WAY OF WORKING

In order to answer the main research questions and its sub questions a few steps have to be taken first. One of which is gathering information in the form of articles and books from literature databases. Articles and books will be selected by reading and identifying their abstracts and should be recently published in order for it to still be relevant. From this a solid base of background knowledge will be formed, which will even further increase by using the references from these articles and books.

The following case studies will be done, using both literature as well as other forms of media: Swedish neighborhoods BO01 in Malmö and Hammarby Sjöstad in Stockholm and Vauban in Freiburg, Germany. These projects were not only selected because of the geographical and climatic similarity, but also because of, as Fraker (2013) states: ''A similar kind of integrated, whole-systems approach to neighborhood design […] which has been in existence (in whole or part) long enough for performance data to have been collected […] and demonstrate the […] possible strategies for generating energy from local renewables – wind, solar, geothermal and biomass.''

Once all information has been gathered and sorted, including the data from the case studies the calculations can be made for the overall feasibility of the project. As a result of these calculations can be made on the energy demand and urban form with set parameters of density or total gross floor area, ratio of dwelling space versus other functions. The guidelines that will be the result of this research paper will only form the starting points and not the actual urban and architectural design. The building block typology, however is a chosen directive because of the advantages which will later in this paper be supported by arguments and is a worldwide used typology which can therefore be translated to any other location using different settings for the parameters.

2.2. DESCRIPTION OF CIRCUMSTANCES

For the circumstances used in this research the location of the Marine Area in Amsterdam has been chosen located near to the city center of Amsterdam, with a size of 12,6 hectares. Van Timmeren (2006) states that a small environment, such as a house, is 'easier' to make self-sustaining then a neighborhood or city because of the scale of implemented changes or the measurements needed. Energy neutrality in turn is obviously easier for a low density neighborhood, because of the large ratio of rooftops fit for solar panels versus the living spaces, in comparison to a high-density urban building block. But on the other hand, a higher density enables more different functions to exchange waste flows. Fong & Lee (2012) showed that the net-zero energy target is not possible for high-rise buildings in the subtropical climate of Hong Kong, which can most likely be directly translated to this not being possible for a Western European climate as well.


Aerial view of Marine Area, Amsterdam

The Marine Area has a moderate maritime climate, with cool summers and mild winters with typically high humidity. The average minimum and maximum temperature are 6,1 °C and 13,5 °C respectively. Annual rainfall amounts to 776 mm divided over 185 days and the sun shines for 1580 hours per year. (Climatedata.eu, 2016) With the sun at its highest peak on June 21 at 61,5 degrees and at its lowest point on December 21 at 14,5 degrees (Hermans, 2004).

The neighborhood will be totally newly build and serve as a showcase if high density, mixed-use neighborhoods can be energy neutral. The current buildings (except for one monument), infrastructure and other elements will be disregarded as not to lead to complications during the design process. Transformation of these to energy neutral buildings can be researched in future studies. In order to stay flexible and enable anticipation on changes in energy production procedures, the neighborhood will be connected to the existing electricity grid will be used in case of higher or lower production than consumption.

To be able to use all data and turn it into a calculation model, assumptions have to be made. For this a square plot of one hectare has been taken as a starting point on which 14.000 m^2 dwellings and 7.000 m^2 of other functions have to be build. These other functions are those generally found in a city ranging from offices, a sports hall, a nursing home, a primary school, a supermarket, retail and horeca. With 12,6 hectares of space on the Marine Area in Amsterdam and around 60% of this area being built upon, eight building blocks can be realized, which in total ads up to 112.000 m^2 for dwellings and 56.000 m^2 of other functions.

Four cities were taken as references because of their comparable similarities and being the four largest cities in the Randstad. Of all dwellings built since 2005 in Amsterdam and Rotterdam 85% and 68% are apartments and for The Hague and Utrecht these numbers are lower and around 50% and 49% respectively (CBS, 2013). Although Amsterdam has the lowest average dwelling size (usable floor area), knowing that sustainable neighborhoods are more popular with middle- to upper-middle-income groups the average gross floor area was set at 93 m^2. This amounts in total to around 150 dwellings per hectare and with an average household size of 2,2 this gives a population density of 330 people per hectare.

Floor area (m^2)	Amsterdam	Rotterdam	The Hague	Utrecht
15 – 50	20,3%	6,4%	7,3%	8,4%
50 – 75	40,8%	28,9%	32,0%	20,3%
75 – 100	24,4%	35,4%	28,5%	34,0%
100 – 150	11,7%	23,8%	22,3%	30,4%
150 – 250	2,4%	4,8%	8,1%	5,6%
250 – 000	0,4%	0,7%	1,8%	1,3%
Total	**100,0%**	**100,0%**	**100,0%**	**100,0%**

Dwelling size (CBS, 2012)

Floor area (m^2)	Amsterdam	Rotterdam	The Hague	Utrecht
Average	74	91	96	96
Reliability interval (95%)	72 – 76	89 – 93	93 – 98	93 – 98

Average usable floor area (CBS, 2016)

3. RESULTS

3.1. ENERGY NEUTRAL & SELF SUFFICIENT

Both renewable energy and sustainable development focus on lengthening the timeframe to come to an equilibrium between production and consumption, but instead of only lengthening the timeframe closing cycles also affects and lengthens the usability of the energy source (Van Timmeren, 2006). Based on Van den Dobbelsteen's (2008) new step strategy which aims to reduce the human footprint by creating cycles the first step is to reduce demand, second is reusing waste streams, third is solving the remaining demand using sustainable energy sources and last use waste as food or reuse this waste. This is similar to nature's way of creating balance within life-, material- and energy-cycles (Yanovshtchinsky, Huijbers & Van den Dobbelsteen, 2012).

Self-sufficiency or self-sustainability are based on the same principles and mean being able to maintain oneself or itself without outside aid or capable of providing for one's own needs (Merriam-Webster, n.d.a; Merriam-Webster, n.d.b.). On a national scale, a totally self-sufficient economy that does not trade with the outside world is called an autarky. Self-sufficiency on a building block or neighborhood scale means that everything consumed is equal to everything produced on site on an annual basis. Energy and heat neutrality or (net) zero-energy basically means the same, but only for electricity, heating and cooling. In the case of most developed countries an existing grid can be used to store overproduction or can be used in case of shortages.

Among others Santorni & Hestnes (2007) conclude form their analysis of sixty case studies on normal and low energy dwellings that operating energy represents a 54% to 62% of energy demand in a building during its lifetime (Thormark, 2002; Treloar, Fay, Love & Iyer-Raniga, 2000). Adalberth (1997) furthermore states "that as much as 85% of the total energy consumption during construction, use and demolition of a single unit dwelling with a service life of 50 years occurs in the operational phase." In addition to this Blom, Itard & Meijer (2011) researched the environmental impact of building-related and user-related energy consumption in dwellings and came to the conclusion that "when the average gas and electricity consumption of all households in all dwelling types are compared, gas consumption contributes most to the environmental impact categories of abiotic depletion, global warming and human toxicity." Reducing this consumption by 23% leads up to 13% less environmental impact and 47% less electricity consumption leads to a 9% to 45% reduction. They furthermore state that with increasing electricity consumption the environmental effects may be better reduced by producing 100% from sustainable resources to reach 90% less environmental impact.

In relation to energy neutrality it is important to consider the types of energy used in the lifetime of a building and whether or not including them in this balance. Building related energy for example includes heating, cooling, ventilation, hot water and other technical service systems. User related energy is for cooking, the use of appliances and lighting and last construction related energy is energy "embodied in building materials and installations and energy use for building construction, maintenance, renovation and demolition." (Strategic Research Centre for Zero Energy Buildings, n.d.) For this research only building- and user related energy will be taken into account.

3.2. RENEWABLE RESOURCES

Renewable (energy) resources are, as opposed to non-renewable or finite resources, any natural resource that can replenish itself naturally over time to overcome usage and consumption through either naturally reoccurring processes or biological reproduction (International Energy Agency, 2002a). Examples of renewable resources are biomass, geothermal, hydropower, solar and wind which are all part of nature or as Stead & Stead (2009) state the earth's natural environment and the largest components of its ecosphere. It furthermore provides energy in electricity generation, air and water heating or cooling, transportation and off-grid energy services (REN21, 2014). Renewable energy sources are furthermore available almost everywhere where there are human settlements in contrast to oil, coal and gas sources which are concentrated in a limited number of countries. Another advantage of renewable energy is that it is also suited for rural and remote areas as well as developing countries and it is also applicable on a large scale or integrated in the urban context (World Energy Assessment, 2000).

Great increase in energy efficiency and cost reduction have led to rising popularity together with energy security, climate change mitigation and also economic benefits (IEA, 2012). Renewables now contribute 19% of the global energy consumption, divided as 9% traditional biomass, 4.2 % heat energy, 3.8% hydroelectricity and only 2% from wind, solar, geothermal and biomass (REN21, 2014). For the Netherlands these numbers are 12.2% in total of which 6% is biomass, 5.6% is wind energy, 0.5% solar and 0.1% hydroelectricity (CBS, 2015a). The four largest renewable energy resources for the Netherlands are briefly explained below and their applicability in the urban environment is discussed.

3.2.1. BIOMASS

Biomass is biological material derived from living or recently living organisms and is a renewable energy source because the energy saved in it comes from the sun and its replenishing rate or the time it takes to regrow is a relatively short period of time compared to the hundreds of millions of years it takes for fossil fuels to form. In short chlorophyll captures the sun's energy and through the process of photosynthesis converts carbon dioxide from the air and water from the ground into carbohydrates. (Union of Concerned Scientists, 2015) When these carbohydrates are burned they turn back into carbon dioxide and water and release the captured energy in the form of heat or can be indirectly converted to various forms of biofuel using thermal, chemical or biochemical methods.

Wood is still the largest biomass energy source today (National Renewable Energy Laboratory, 2014), but industrially grown biomass, or so called energy crops, are becoming more popular and are specifically grown for use as fuel that offer high mass output per hectare with low energy input. (Biomass Energy Centre, n.d.) Producing biomass on this scale however is not applicable for the built environment. Combustible waste, like urban agricultural remains for a cogeneration plant, sludge waste for a digestion plant and food waste are options that can be used. Since these waste flows are generated continuously by both the neighborhood itself and surrounding neighborhoods it can fill the gap in renewable energy supply that cannot be met by geothermal, solar or wind power. In this way waste ''can be rethought of as a first source of renewable energy supply. All forms of combustible waste can be a primary fuel source for cogeneration, and biogas digested from sludge, organic food waste, and green waste can be an additional fuel source for cogeneration and cooking. When waste is reconceived as a renewable energy source, it suddenly becomes a positive resource for cities rather than a significant cost burden for its removal and dumping.'' (Fraker, 2013)

Biomass power station in Moerdijk, Netherlands

A lot of controversy surrounds biomass as an energy source and its environmental risks need to be mitigated. The Union of Concerned Scientists (2015) state that ''If not managed and monitored carefully, biomass for energy can be harvested at unsustainable rates, damage ecosystems, produce harmful air pollution, consume large amounts of water, and produce net global warming emissions.'' It furthermore takes up space that otherwise could have been used for the production of food. Ladanai & Vinterback (2010) also state in their paper that bioenergy systems can be relatively complex and site- and scale-specific, while its environmental benefits can vary strongly.

3.2.2. GEOTHERMAL

Both high and low temperature geothermal energy use the heat stored in the earth and earth's crust as an alternative to fossil fuels. High temperature geothermal energy originates from the earth's core which is estimated to be 2.000 to 12.000 degrees Celsius and drives a continuous conduction of thermal energy in the form of heat from the core to the surface. Low temperature geothermal energy uses the stable temperature of the earth's outer crust which is heated by sunlight, especially during summer time. Through circulation of groundwater this form of heat can be spread up to several hundreds of meters below the surface. It can be used to reduce the heating and cooling load on a varying seasonal basis and also flattens the electric demand curve eliminating the extreme summer and winter peak electric supply requirements. (Milieu Centraal, n.d.a)

Geothermal heat pumps us the constant temperature as the exchange medium outside air temperature which allows such systems to reach much higher efficiencies during cold winter nights. Three of the four different types are closed-loop systems, namely: horizontal, vertical and pond/lake systems and circulate an antifreeze solution through a closed loop, usually made of plastic tubing, that is either buried in the ground or submerged under water. The horizontal installation is most cost-effective for residential uses but is only possible if sufficient land is available. Vertical system are more applied to large commercial buildings and schools or where the soil is too shallow for trenching, because they minimize the disturbance to existing landscapes. An open system uses a well or surface body water as the heat exchange fluid by circulating it through the system and subsequently pumping it back into the ground. (Energy.gov, n.d.)

Geothermal source in The Hague, Netherlands

Although in theory the Dutch earth's surface holds more than three times the energy demand, it is a sparsely used practice because it costs more money to extract this heat than its yields. The first reason for this is the high costs accompanying the construction of a geothermal power plant and the second reason is the fact that the soil composition in the Netherlands is not always suitable and thus expensive test drilling is required prior to construction. (Milieu Centraal, n.d.a)

3.2.3. SOLAR

Solar energy is radiant light and heat from the sun which is captured using a range of ever-evolving technologies which can be characterized as either active or passive solar technologies. Active technologies include photovoltaic systems, concentrated solar power and solar water heating. Passive solar techniques including building orientation, materials with favorable thermal mass or light dispersing properties and designing spaces that can ventilate naturally through heating up air. (International Energy Agency, 2011) For an urban environment photovoltaics are better applicable than concentrated solar power which uses a system of lenses or mirrors to focus a large area of sunlight into a small beam that heats up water to create steam that is thereafter converted into electricity by a turbine (Wald, 2013). Photovoltaics converts light into electric currents using photoelectric effect and can also be used on a small scale.

Because of the ever-evolving technologies, as previously stated, solar energy has now become cheaper than gas. Just outside of Dubai in the United Arab Emirates the Mohammed bin Rashid Al Maktoum solar park has recently changed history by producing energy for 2,99 US cents per kWh (Graves, 2016). Other countries like Australia, Chile, Italy, Jordan and the state of California have started up projects and reached the tipping point of producing energy cheaper than coal or gas as well. India has recently also reached this point and has even stopped the development of a coal power plant and use the same area for solar panels, because this was not only more sustainable but even cheaper. (VPRO Tegenlicht, 2016) "Investment bank Deutsche Bank is predicting that solar systems will be at grid parity in up to 80% of the global market within 2 years, and says the collapse in the oil price will do little to slow down the solar juggernaut." (Parkinson, 2015) If this trend continues the International Energy Agency (2014) predicts that solar power will be the largest source of electricity by 2050, contributing in total 27 percent to the global overall consumption.

Mohammed bin Rashid Al Maktoum Solar Park

Solar power, together with wind power are intermittent energy sources, meaning that both are not available continuously and should be either used immediately, transported to somewhere where it can be used or stored for later use. Storing can be done on a home-scale, using batteries like the Tesla Powerwall or on a grid scale using different forms such as compressed air, liquid air, rechargeable batteries (from electric cars), hydrogen, and hydroelectricity. Because many of these technologies are either too expensive or need certain geographical features, batteries seem to be the only solution for storing peak loads on a neighborhood scale in the Netherlands. Different companies are researching the possible use of electric cars for temporary storage in which plugged-in cars sell the electricity from their 20 to 50 kWh battery during peak hours and charge during the night or during off-peak hours (BBC, 2010).

Before the use of climate controlling installations architecture was influenced by the climate in the same way passive solar design uses both architectural and urban planning methods. Common features are orientation relative to the sun, compact proportions (low surface area to volume ratio), facade openings, selective shading (overhangs) and thermal mass (Schittich, 2003). On an urban scale Vartholomaios (2015) for example presents in his paper the Residential Solar Block (RSB) envelope which enables the development of compact residential urban block with high passive solar potential using solar geometry data deduced from energy simulations with respect to useful passive solar gains and local climatic needs.

3.2.4. WIND

The second intermittent energy source is wind power which uses air flow through wind turbines to mechanically power generators for electricity and just like solar energy does not produce greenhouse gasses during operation. So called wind farms consist of many wind turbines connected to the electrical power transmission network and produces consistent power year to year but which can fluctuate on a shorter time scale. Around 20 percent of all the renewable energy is generated by both offshore and onshore wind parks (CBS, 2015b). The advantage of onshore wind farms is their lower construction and maintenance costs, but its disadvantages in comparison to offshore wind turbines are the visual impact and less steady wind currents (Gipe, 1989).


Offshore wind park NoordzeeWind

These wind farms however cannot be built in urban areas due to numerous reasons, like regulations. Small-scale wind power has thus a higher potential for the urban environment and research has been done on both vertical axis wind turbines (Muller, Jentsch & Stoddart, 2008) as well as ducted turbines (Grant, Johnstone & Kelly, 2008; Hu & Cheng, 2008) to solve the largest, current disadvantage of this form of production, which are its relative high costs in comparison to yield, the unpredictability and availability of the wind, the noise created by the blades and the possible threat to wildlife.

3.3. AMBITIONS

The Dutch government has, by order of the European Commission, set guidelines that all newly build buildings should be *almost* energy-neutral by 2020 and al governmental buildings from 2018. Almost meaning that the EPC (energy performance coefficient) value should be close to zero for which zero is totally energy neutral. This includes building energy consumption under normal user- and climatic conditions. The energy can, but is not limited to being produced locally and renewable energy sources are appreciated. The net energy consumption is determined over a year. (Rijksdienst voor Ondernemend Nederland, 2015)

Other European climate targets are a 20% reduction in greenhouse gas emissions compared to 1990, 20% of the total energy consumption is from renewable energy sources and another 20% increase in energy efficiency (Renzenbrink, 2014). This will not only help the climate, but these policies will also yield many macroeconomic benefits and contribute to smart en sustainable growth. ''By increasing energy efficiency, supporting research, and developing and commercializing innovative green technologies, Member States can also boost their competitiveness and create jobs. Realizing the growth potential of the green economy will ensure that the European Union remains a competitive player in this growing global market. Fiscal consolidation can be supported through increased revenues from policies addressing energy and climate issues, for example by shifting taxation to energy and other environmental taxes.'' (European Commission, 2015)

The European Environment Agency has released a progress report stating that the European Union as a whole is on track to meet its 2020 climate and energy targets, but needs an even bigger push to achieve the 2030 goals. ''Even against the backdrop of economic recession in recent years, we can see that policies and measures are working and have played a key role in reaching this interim result.'' Says Hans Bruyninckx, EEA Executive Director. ''But there is no room for complacency. The analyses we are publishing today also highlight countries and sectors where progress has been slower than planned.'' (European Environment Agency, 2014a) The Netherlands for example, along with Belgium, France and Luxembourg are amongst the worst performing member states and are still not on track for two out of three objectives (European Environment Agency, 2014b,c). This is worrisome, knowing that the European Council has set new headline targets for 2030, reducing greenhouse gases emissions by at least 40% from 1990 levels, increasing renewable energy to make up at least 27% of final energy consumption and a minimum 27% reduction in energy consumption compared to the normal (European Council, 2014).

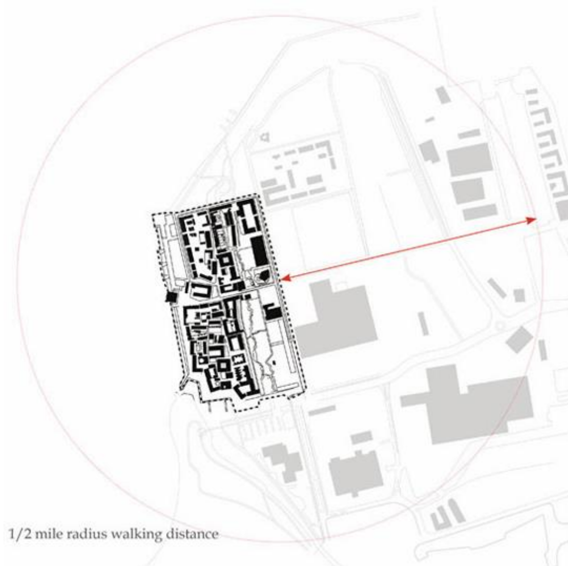
3.4. CASE STUDIES

Many precedents can be found of energy- and heat neutral buildings, because of its relatively less complexity and smaller investment risks involved in comparisons to neighborhoods (van Timmeren, 2006). But neighborhoods can become their own micro-utilities, generating all or most of their own energy demand on-site and reusing and recycling their water and waste while being easily integrated in the existing infrastructure. It should nonetheless be noted that the empirical demands of sustainability should not become ends in themselves, but the urban and architectural design should find a way to bring these together and form a compelling whole. The case studies in this respect show that sustainable communities need to be places where people want to live and which are accessible to all. The environmental benefits and sustainable interventions should be visible on all scales and has been proven to be critical in gaining support and investment. (Fraker, 2013)

The neighborhoods chosen for analysis were selected on a number of criteria. First of all the neighborhoods had to generate most or part of their energy from renewables and have an integrated planning process to achieve these goals. The neighborhoods should furthermore be large enough "to generate sufficient flows of energy, water, and waste to enable potential borrowing, balancing, and stealing among systems". (Fraker, 2013) A mixed-use enabling reasonable walking and biking distances and convenient public transport systems to reduce daily car trips and carbon dioxide emissions. Goals for energy, water and waste saving were optional, but all neighborhoods have paid attention to these while not being discussed in the case studies below.

3.4.1. BO01, MALMÖ

Area (ha)	200
Population	25,000
Number of units	11,000
Density (dwelling units/ha)	54
Parking Ratio	0.7
Coverage	
Buildings	15%
Roads and parking	8%
Green space	45%
Water	22%
Jobs (within 800 m)	5,193
Jobs/housing ratio	47%
Average energy consumption (kWh/m²/y)	154
From renewable sources	22%
From solar	0,5%
From wind	0%
From waste	21%



Plan of Bo01, Malmö

Bo01, as one of the first attempts to create a national example of sustainable design on a neighborhood scale, is overlooking the Öresund Strait between Copenhagen, Denmark, and Malmö, Sweden. According to Fraker (2013) it is also one of the most visited, toured, published, and cited examples of sustainable development with 100% renewable energy consumption. About one quarter of the total units were already completed for the opening of the European Millennium Housing Exposition of 2001 and the remaining units have been built since. The city of Malmö, being the primary landowner and 'horizontal developer', prepared a concept plan together with the Swedish National Board of Housing, Building and Planning for a compact, lively, sustainable city district with conditions for a high quality of life which "endeavored to exemplify a holistic approach but also gave criteria, detailed objectives and directions for more sustainable solutions, e.g. concerning energy efficiency, source separation of waste, greenery, biodiversity, and also for the more elusive quality of human sustainability". (Persson & Tanner, 2005)

Major contributors of the success of Bo01's urban form, remaking of qualities inherent in the historical European city, is the diversity, quality of the architectural expressions, compactness, high density, mixed-use, the integration of public with collective and private areas and its diverse fine-grained "network of streets, boulevards, promenades, paths, and alleys creating rich contrasts between legibility, mystery, and surprise"

(Fraker, 2013). While the city was responsible for planning and construction of all public spaces and infrastructure, private developers were responsible for all construction inside the many, small, individual plots (Persson & Tanner, 2005). These developers and architects were already involved in the earlier process and were also willing to meet the more detailed and strict design requirements including guideline for height, density, green points and such, while being free in architectural responses to site conditions (Fraker, 2013).

Aerial view of Bo01, Malmö

One of the quantitative requirements for the designs was the target of a maximum annual energy consumption of 105 kWh/m^2 gross floor area, which includes all property related produced and recovered energy (Persson & Tanner, 2005). To achieve this goal engineers had to work out the technical solutions using software to model the thermal performance of all building elements including walls, windows, ceilings, roofs, solar and internal gains, heating and cooling loads, ventilation, air infiltration and air-conditioning systems to make sure they met the requirements. The only downside being that actually achieving the calculated energy performance is very complicated, because small construction flaws can have big effects on air infiltration rates for example, which can overwhelm the thermal transmittance of the walls, windows, floors and roofs. Both air infiltration and thermal bridges were encountered and were likely the result of the rush to complete construction for the start of the expo. (Fraker, 2013)

With the target to produce all energy locally and from renewable sources the demand side of this equation was kept as low as possible. But the lack of education and real-time feedback on residents' behavior and for instance the impact of hot-water use and thermostat settings on the total domestic electricity consumption lead to much higher totals. All ten out of thirty-four monitored building units had higher observed total energy consumption than estimated, which represents an average 77% increase over the calculated estimate and a 60% increase over the target.

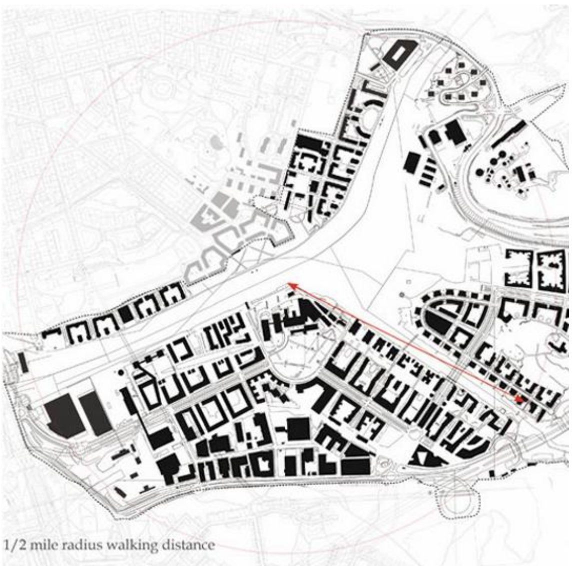
In order to meet this demand the good solar radiation, favorable average annual wind speed, the seawater and a groundwater aquifer, which act as heat sinks were used as natural energy resources. A 120 meter array of photovoltaic cells, located on buildings in the district and a two megawatt wind turbine, located one-and-a-half kilometers of the coast supply the dwellings with electricity and power the heat pumps. These large heat pumps use the local groundwater aquifer and seawater as a heat sink, providing seasonal storage. Heat and cold are furthermore extracted from the dwellings during summer and winter time and stored in the aquifer in addition to 1.400 m^2 of solar collectors, located on roofs and facades of buildings. These electric, heating and cooling supplies are also connected to the existing city grid and the city heating and cooling district systems in order to use this as storage when production exceeds consumption. When the local production is insufficient this energy can be received from this grid, but on an annual basis the system has been designed to be self-sufficient. (Fraker, 2013)

Street view of Bo01, Malmö

The city's goal of making the neighborhood 'at least as convenient, attractive and beautiful as the (so-called) unsustainable city' lead to the fact that sustainable strategies have not been at the expense of quality urban design. While many of these strategies are made visible, in ways of solar collectors, wind protection and open stormwater collection and retention for example, they are seamlessly integrated into the urban landscape and architecture and do not negatively affect it. This, and of course other indicators have proven that Bo01 has been a financial success for both the city of Malmö and the developers and has become very popular for middle- and upper-middle-income classes. Making low carbon and 100% renewable neighborhood projects a solid business model, which hopefully can also be extended to all income classes in the future.

3.4.2. HAMMARBY SJÖSTAD, STOCKHOLM

Area (ha)	200
Population	25,000
Number of units	11,000
Density (dwelling units/ha)	54
Parking Ratio	0.7
Coverage	
Buildings	15%
Roads and parking	8%
Green space	45%
Water	22%
Jobs (within 800 m)	5,193
Jobs/housing ratio	47%
Average energy consumption (kWh/m²/y)	154
From renewable sources	22%
From solar	0,5%
From wind	0%
From waste	21%



Plan of Hammarby Sjöstad, Stockholm

Hammarby Sjöstad in Stockholm is one of the largest mixed-use housing developments and at the same time most financially successful ones. With low potentials for both wind en solar energy, due to its situation in a valley and low winter solar radiation, the former industrial area is still a very sustainable development due to the integrated approach of its infrastructure and the process of the waste flows. The master plan, as part of this integrated approach, was prepared by the project team, which was an organization within the Stockholm City Planning Administration established by the city. This master plan included "physical designs and specifications for the streets, blocks, parks, open space (including quays), land use designations, density, coverage, setbacks, height restrictions, and the like, to guide construction." (Fraker, 2013)

Just like the other described case studies the city played a major role in the development of Hammarby in close partnership with multiple developers and architects which each had to design individual plots. As part of the master plan the project team also set up a document with detailed design principles. Examples of these were using the Stockholm inner-city block form as a model combined with modern architecture, influenced by the natural environment. Other principles were mixed-use, density requirements, public space and the relationship to water. (Stockholm City Planning Administration, 2010) The project team also set goals for the environmental program including the restoring the lake and maintaining the local ecology, minimizing consumption of resources, including energy and water, utilizing sewage for energy generation and to generate knowledge, experience and technology to contribute to sustainable developments in other areas. (Gaffney, Huang, Maravilla & Soubotin, 2007)

Aerial view of Hammarby Sjöstad, Stockholm

As goes for urban form the project team also included requirements for energy efficiency en production. The total energy consumption was to be 105 kWh/m^2 per year, which was changed from 60 kWh/m^2 annually to meet the requirement that solutions should not increase costs. The eventual energy consumption was approximately 50% higher than the goal and has been attributed to several factors including urban design decisions and architectural principles to create larger glass areas to take advantage of lake views, which resulted in greater heat losses. Other causes were increased cooling load because of greater solar gain in the summer and the fact that not all residents purchased high-performance appliances and energy saving lighting fixtures. (Poldermans, 2005)

Hammarby Sjöstad is a prime example that achieving aggressive energy conservation goals is a critical factor in being able to supply a high percentage of energy from on-site sources, because the set goal to supply 50% of the total energy demand on-site has not been met. Due to the average consumption of 105 kWh/m^2 per year only 20% of the measured demand has been attained, but this would have been 54% if the original goal of 60 kWh/m^2 per year had been maintained and achieved. This energy supply comes from the district heating by a heat recovery plant that uses purified wastewater from the site as a heat source, combustible waste is burned, with additional biofuel obtained off-site by a cogeneration plant and biogas from wastewater sludge is used for city vehicles. Limited arrays of solar photovoltaic cells and solar hot water panels have furthermore been incorporated to demonstrate and test new technologies and thus do not significantly contribute to the local energy generation system. (Fraker, 2013)

Street view of Hammarby Sjöstad, Stockholm

Although the project didn't perform so well on energy efficiency and production, its pedestrian friendliness, mixed-use with local shopping and local jobs together with the integration in the local public transport have made it a very sustainable urban development. The neighborhood's configuration has, despite its relatively isolated location, reduced the dependency of the car and thus reduced carbon emissions. Its waste system is the closest any system has come to eliminating the concept of waste by collecting combustible solids to provide district heating and electricity. "Any toxic waste from combustion is captured in the flues, contained, and disposed of off-site. The sludge from sewage is converted to gas in an anaerobic digester and used for multiple purposes: it powers city buses, provides cooking gas for 1,000 homes, and generates some electricity. The organic garbage is composted. Heat is recovered from the treated sewage effluent before it is returned to the bay. All glass, metal, plastics, and newspapers are recycled. Only a small amount of toxic material (from television sets and other electronics) is collected and carefully disposed of." And by doing this, it closed the cycle of waste on a never before seen scale. (Fraker, 2013)

3.4.3. VAUBAN, FREIBURG

Area	34
Population	6,000
Number of units	1,793
Density (dwelling units/ha)	53
Parking Ratio	0.2

Coverage	
Buildings	19%
Roads and parking	11%
Green space	68%
Water	2%
Jobs	600
Jobs/housing ratio	33%
Average energy consumption (kWh/m²/y)	75
From renewable sources	85%
From solar	2%
From wind	0%
From waste	81%

Plan of Vauban, Freiburg

As was the case with Bo01 in Malmö the city of Freiburg was the landowner as well and bought the property of former French barracks from the federal authorities in 1993. Its main goal was to build a mixed-use neighborhood for different income groups, but what eventually emerged was one of the most unusual en enlightened examples of sustainable urban design (Fraker, 2013). As landowner the city was responsible for planning and development of the site and adopted a principle called 'learning while planning' intended to engage direct community participation (Scheuerer, n.d.). The city of Freiburg also set up a special committee to be the forum for discussion and to prepare recommendations for city council approval. At the same time the decision was made to divide the project into small plots, facilitating the sale of land directly to final owners rather than to intermediary developers. According to Fraker (2013) this, including the mindset to allow the development to change as a result of continuous learning and evolving standards, was part of the neighborhood's great success. "As goals and standards evolved, the city was able to incorporate them by putting new restrictions on builders in the sale contracts, thus controlling development."

The goals for Vauban's urban form were not explicitly reported, so the result was guided by concepts developed out of the open design competition and by the zoning guidelines of the city. The neighborhood is shaped around the two main streets or green spines, which could be thought of as a boulevard with the necessary two-way traffic and tramline, a linear green space and a storm water swale. The small plots are not built on with the more commonly seen perimeter blocks, but all adjacent buildings are built perpendicular to this green axis. Only their ends front this public space and contain commercial functions on the first three floors, reinforce the interpretation of a park-like setting. (Fraker, 2013)

Aerial view of Vauban, Freiburg

This park-like setting and relative low densities enabled low energy-standards. Policies, set by national and local governmental bodies encouraged energy efficiency (use redistribution) at the neighborhood scale, passively designed buildings and energy supply through district cogeneration systems and the use of renewable sources. Each assembly could set their own goals and strategies for achieving or exceeding these mandatory standards, to further reduce consumption costs, which led to more than hundred units meeting the passive house standard of 15 kWh/m² per year for heating and seventy-five units producing 15% more energy than what was needed. Due to this and other reasons the average total energy consumption was 80 kWh/m² annually, which was a staggering 24% below the approximated goal of 105 kWh/m^2 annually for heating, electricity and hot water.

This required energy was provided by a local high-efficiency cogeneration plant operating on wood chips and natural gas as fuel, which supplies 100% of the heating demand and 60% of the electricity demand. The hot water is supplied to all building by a district hot water system and electricity is fed through the city grid and comes from 450 m^2 of photovoltaic solar panels installed on the roofs of both dwellings and two parking garages. This in total leads to approximately 93% of the neighborhoods energy demand being supplied by renewable resources. (Fraker, 2013)

Street view of Vauban, Freiburg

Together with energy efficiency, passive solar design and natural ventilation on the buildings scale, Vauban demonstrates that successful whole-system performance is possible. Other key factors for its success were providing funding to support a forum and establishing it as the legally constituted representative of the citizens' groups and creating small lots and selling these directly to the homeowners' groups or so-called assemblies to make the housing more affordable by cutting out 'the middlemen' developers. ''The continuous participatory planning and design process 'learning while planning' was instrumental not only in achieving the goals, [...] but also in promoting the goals of a socially integrated living and working neighborhood that is friendly to families, children, and elderly residents.'' (Fraker, 2013)

3.4.4. LESSONS LEARNED

Out of the three examples, only Vauban was really developed because of a city's visionary environmental goals, the other two example were built because of the European Millennium Housing Exposition and an Olympic bid, leading to exemplary developments demonstrating a more sustainable and livable urban future. For this all three neighborhoods ''received considerable seed funding from their host cities, their federal governments, and the European Union to defray the added cost of initiating a more integrated, interagency, and interdisciplinary professional development process.'' (Fraker, 2013) And even though most projects do not have access to similar funds, it is also much more interesting to create a plan which is economically viable without these subsidies. The three case studies have an exemplary role of which a lot can be learned, from both the process as their energy approach.

Without a doubt the most important factor for all the neighborhoods' success is the role of the city as master horizontal developer, having the power and legal authority and taking all the risk in demanding a new integrated approach to sustainability. By creating special, interdisciplinary development committees, with representation from internal agencies, outside consultants and citizens' groups, which were given planning authority and leadership over the projects. These groups set specific goals and objectives as a benchmark for performance of sustainable neighborhoods to drive innovative planning and design. The city furthermore has also used its authority to charge responsible utilities of energy, waste, sewage and water with developing an integrated plan using internal expertise and outside consultants. The same approach was taken with developing the master plan, including all public spaces while outsourcing the development of all small building plots to architect-developer teams. Using this process the cities have made these projects financially sustainable and their role has paid off. (Fraker, 2013)

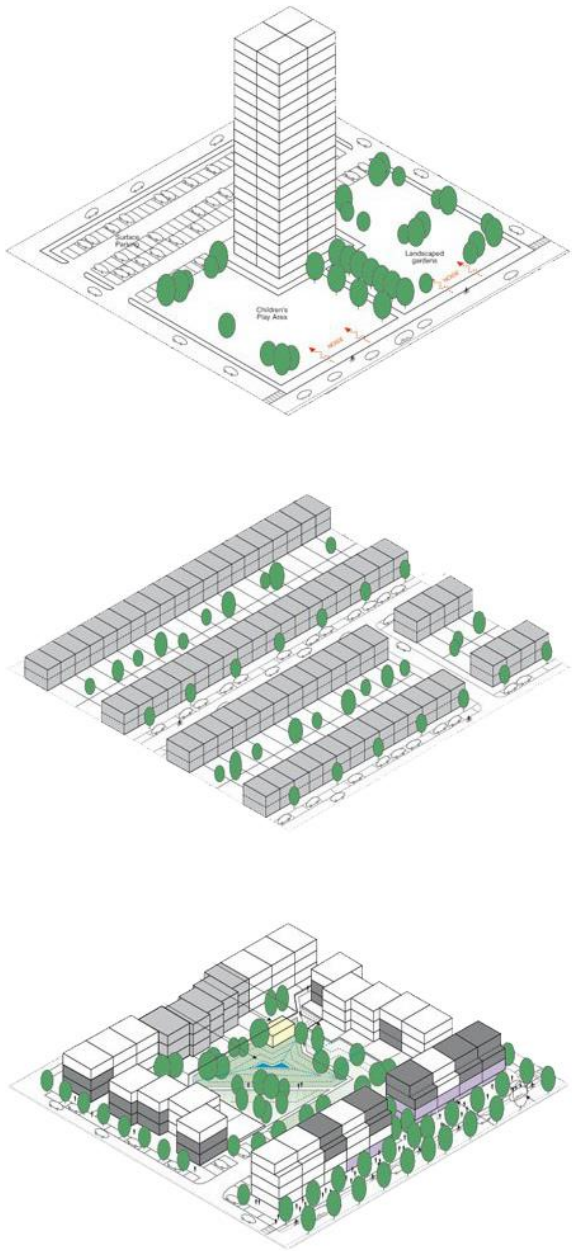
The three projects also show that reducing the energy demand is very important in order to meet this using renewable resources. But at the same time Bo01 shows that, even though it has the highest average energy demand of 167 kWh/m²/year it is the only neighborhood with a 100% renewable supply, because of abundant local resources. Because Bo01 gets 98% of all its energy from a 2 MW wind turbine located about 1,5 kilometers north of the site it could be argued that this is not on-site and thus not really self-sufficient. Vauban on the other hand provides the evidence that with large energy reductions up to an average of 75 kWh/m²/year, 81% of this can be generated from waste. Important to note is that this waste are actually wood chips and can thus not be used for the Marine Area in Amsterdam. Even though Hammarby Sjöstad only reaches a total of 22% from renewable resources, the use of waste water and solid human waste makes up for 21% of this total and in this method lays quite possibly the secret for filling the gap in renewable energy supply that cannot be met by solar, wind or geothermal power. ''Since waste flows are generated continuously by neighborhoods and cities, they can be rethought of as a first source of renewable energy supply. All forms of combustible waste can be a primary fuel source for cogeneration, and biogas digested from sludge, organic food waste, and green waste can be an additional fuel source for cogeneration and cooking. When waste is reconceived as a renewable energy source, it suddenly becomes a positive resource for cities rather than a significant cost burden for its removal and dumping.'' (Fraker, 2013)

3.5. SPATIAL

On the scale of the neighborhood Jabareen (2006) graded four different urban form design concepts and came to the conclusion that both the compact city and the eco-city scored the best on sustainability with density, compactness, sustainable transport, mixed land use, diversity, greening and passive solar design as criteria. He furthermore concluded that sustainable urban forms aim to achieve high scores on all these criteria and at the same time reduce waste, pollution and automobile dependency, preserve open space and sensitive ecosystems while creating livable community-oriented human environments.

Urban density is not just related to population per unit of area, the number of dwellings per unit of area or even the building floor area to total urban area ratio, but according to Khodabakhshi (2013) it is also closely related to integrity and uniformity of the urban structure and optimum usage of the city's potential. ''The lack of balance and proportion between different factors that form a compact sustainable city sometimes results in excessive density. This, in a similar way to having low density, can make the city unsustainable because of environmental issues.'' It is thus important to find a balance between density and compactness, as density has several dimensions such as form which is the most important one, social and functionality (Jenks, 2000). Elkin, McLaren & Hillman (1991) defined the compact city as ''a city that must have a form and scale appropriate for walking, cycling, and have efficient public transportation with a compactness that encourages social interaction.''

This same compactness of the urban form has influence on the usage of motorized vehicle or traffic and transport in total, which amounts for 14% of the overall energy consumption (Compendium voor de Leefomgeving, n.d.a) and emits the vast majority of greenhouse gasses for the traffic and transport sector in the Netherlands (Compendium voor de Leefomgeving, n.d.b). Other undesirable effects are, road congestion, pollution as well as road safety, health and severance effects (European Commission, 2007). Another advantage for high density and also for mixed-use in comparison to low density, single-use developments is the decreased dependence of the car as the sole form of transport to access other everyday activities instead of more sustainable forms of transport, such as walking, cycling and the use of public transport. (Ferguson & Woods, 2010)

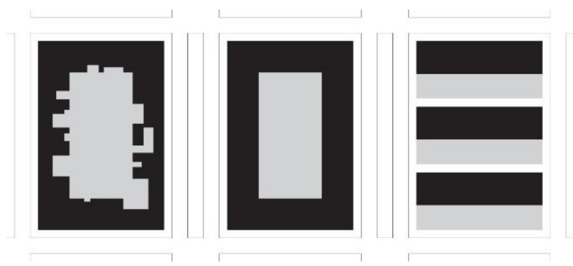


Density in relation to compactness and use

Mixed-use development or mixed land use, as part of diversity is a type of urban or architectural development that blends residential, commercial, cultural, institutional and industrial uses, integrated both physically and practically on either the scale of a single building, a city block or an entire neighborhood (Thrall, 2002). Its benefits have, according to Beyer (2012) a lot in common with sustainable urban forms as Jabareen (2006) described them and include land use synergy, walkable/bikeable neighborhoods, increased transit opportunities, affordable- and life-cycle housing, access to amenities and destinations and a sense of place. From the case studies it became clear that similar neighborhoods are most popular with middle- and upper-middle-income groups. A bigger diversity in housing types and size for example will leads to other forms of diversity such as income, occupation, cultural background, race/ethnicity, household composition and age (Day, 2009).

This diversity can also be found, as stated before, in functions but also in the variation in built en urban open spaces like well-designed streets, plazas, squares and parks. Especially green areas have a lot of benefits, like increase of biodiversity, better air quality and it also improves the natural water cycle through infiltration and retention. Green furthermore increases land and property values and can lead to economic growth and investments. It also causes higher mitigation and reduces the urban heat island effect, something which in turn will save energy by reducing the cooling load. This last aspect is thus part of the formerly mentioned passive solar design techniques. (Pötz & Bleuzé, 2012)

As the main research question stated the mixed-use neighborhood is composed of urban building blocks. Historically speaking Hildebrand (1999) states that most cities in the world have been planned instead of developing gradually over a long period of time as was the case in for example medieval cities in Europe. Instead of an organic development, streets are typically laid out on a grid plan with square or rectangular shapes, and building entrances facing the streets with courtyards in the rear of the buildings to provide social interaction among people. This configuration has its advantages and disadvantages both spatially and related to energy consumption.



Historic significance of the building block

Especially when taking into account the principles presented by Studio Nine Dots (2012) for their Cityplots concept the most disadvantages are solved by way of urban and architectural design. Instead of using one developing team to design and build one large development, they suggest using multiple design teams to enable a more diverse, flexible and gradually phased project. "Advocates of the perimeter urban block (Jacobs, 1961; Bentley, Alcock, Murrain, McGlynn & Smith, 1985; Krier, 1990; Carmona, Tiesdell, Heath & Oc, 2010) argue that it promotes compact development, urban vitality and resilience, variety of uses and experiences, as well as permeability and legibility of the urban fabric" (Vartholomaios, 2015). Another problem with a high density neighborhood is the relatively small ratio of available roof area for solar panels to floor area. Studio Nine Dots partially solves this problem by decreasing the average building height but maintaining the density by adding buildings inside the central courtyard. This also has the advantage that new relations between public and private are made.

Impression of the Cityplots concept

When applied to an urban building block Vartholomaios (2015) states that passive solar heating favors east-west oriented building rows with sufficient distance between them in the north-south axis. "Yet, its biggest limitation is the creation of a visually monotonous housing monoculture that is difficult to adapt to the underlying natural landscape and regular street patterns." as Okeil (2010) also confirms in his research. The challenge thus lays in a multi-story building blocks in a high density urban environment, because the urban building block might not be as efficient in terms of passive solar utilization. "Some of its sides inevitably have unfavorable orientations and generate mutual overshadowing, while solar irradiation of the facades is not uniformly distributed." (Okeil, 2010)

3.6. ENERGY

3.6.1. NEIGHBORHOOD SCALE

It has been proven that zero energy is feasible with small or large residential buildings or even office buildings (Voss & Musall, 2012) and many built examples of this can be found (New Building Institute, n.d.; Batchgeo.com, n.d.). Studies or reports and especially completed projects on the neighborhood scale however are much fewer in number according to Marique & Reiter (2014). Van den Dobbelsteen, Doepel & Tillie (2009) state that reducing, reusing and producing from renewable resources on a building scale will undoubtedly generate a more sustainable building, but great potential lies in the exchange or reuse of waste streams between different functions within the urban environment. "A better idea is to consider a cluster of buildings and to determine whether energy can be exchanged, stored or cascaded (see schematic diagram). In other words, if at individual building level all the waste heat has been recycled, the remaining demand for heat or cooling can probably be solved by buildings with a different pattern of energy requirements, buildings with an excess of the required energy or which produce waste heat (or cold)." In addition to this the researchers suggest energetic implants, which is basically adding a function to complete missing links in the energy supply chain. This can be for example an ice rink that needs cold or a swimming pool that requires heat.

3.6.2. ADVANTAGES & DISADVANTAGES

Being energy neutral or zero-energy on the building scale, just like on the neighborhood or urban building block scale has its advantages and disadvantages. With the increased insulation and reduced energy demand, users are much more future proof and independent of rising energy prices, especially when using local, renewable resources. This will also mean that these buildings will not lose its value when the (nearly) zero-energy rules go into effect at the end of

2020. The advantages are not only financial, these interventions also increase the living comfort during both the summer and winter months and of course, just as importantly drastically reduce the environmental impact. (Rijksdienst voor Ondernemend Nederland, 2015)

Disadvantages however keep these principles from being implemented on a large scale because of several reasons. Probably most importantly is the initial costs, which are around 8% more upfront than conventional buildings in Germany (International; Passive House Association, n.d.a) or around 10-15% for other (less experienced) countries (Zero Energy Buildings, 2016). Secondly is the lack of knowledge and skill for designers and constructors (Spiegel, 2008). And thirdly is the increased popularity of renewable resources, which might sound contradicting, but with rapidly falling prices for photovoltaic solar cells and possible future decline in electricity prices due to large (solar) power plants capital investments can turn out to be unprofitable. Together with distributed generation of electricity and energy neutrality on a yearly basis, this means that when possible peak loads occur the grid has to provide this demand, which prevents a reduction of power plant capacities.

3.6.3. DISTRIBUTED GENERATION

Since the emergence of the AC grid, which allowed electricity to be transported over longer distances, power plants have been large, centralized units (Alanne & Saari, 2006). This in turn resulted into increased convenience en lower costs per unit, but new technological innovations, a changing economic and regulatory environment have led to renewed interest for distributed generation. (Pepermans, Driesen, Haeseldonckx, Belmans & D'haeseleer, 2005) This is furthermore confirmed by the International Energy Agency (2002b) who name "development in distributed generation technologies, constraints on the construction of new transmission lines, increased customer demand for highly reliable electricity, the electricity market liberalization and concerns about climate change" as major factors to contribute to this evolution.

Although there seems to be no consensus among researchers on the definition of a distributed or decentralized energy system, which was also confirmed by CIRED (1999) on the basis of a survey among member countries. Ackermann, Andersson & Söder (2001) state that it should be based on the purpose, the location, the power scale, the power delivery, the technology, the environmental impact, the mode of operation, the ownership and the penetration of distributed generation. Pepermans, Driesen, Haeseldonckx, Belmans & D'haeseleer (2005) define it as "an electric power generation source that is connected directly to the distribution network or on the customer side of the meter". In this case distributed generation can be defined as electricity generation of the neighborhood scale with a connection to the existing grid while taking into account the former mentioned factors.

A decentralized system has both its advantages and disadvantages in comparison to a conventional, centralized system on aspects like reliability, flexibility, local and global well-being of humans, the environment and the utilization of local (renewable) resources and networks. About a centralized system much more knowledge and expertise exists and in terms of decision making or management this system is more beneficial. Also because of its uniformity and the few educated people need to run it. A decentralized system on the other hand is not as vulnerable to external risks and decreases the chance of wide electricity blackouts, because of the independency on electricity distribution. (Alanne & Saari, 2006)

For the aspect of flexibility a centralized system does not require new laws, but such systems are large en inflexible and require large investments. In comparison, changes in electricity or heat demand can be much more easily met by a decentralized system, which can also use different, locally available resources because of versatile technologies. This will in turn lead to changing market conditions (Pepermans et al., 2005) with job creation, new local market opportunities and competition, giving people the feeling of independence and self-control. Alanne & Saari (2006) also state that: "in addition, distributed energy generation provides even private real estate owners with an opportunity to receive income by selling surplus electricity. This may positively affect their energy consumption behavior, thus improving the efficient use of energy in the whole society."

Further benefits from this type of system are the absence of transmission lines, large power plants and fuel storage, which according to the same researchers, deteriorated the landscape. And without large distances between production and consumption large transmission losses are eliminated. A new infrastructure however, which would be needed at the beginning does create a small local distribution of emissions, but this can be easily solved by using renewable resources. (Alanne & Saari, 2006)

3.6.4. REDUCE

As was concluded from the case studies and confirmed by Fraker (2013) it is pivotal to reduce the energy demand to achieve a high percentage of energy supply from renewable resources and become energy neutral. Especially when these sources are not abundant, as is the case in a high dense urban environment, which can be done, as stated before, by focusing on building form and orientation, high-performance envelope, minimizing heating and cooling loads, maximized day lighting opportunities and efficient mechanical systems can be greatly downsized to meet remaining loads. According to Harvey (2009) "this generates cost savings that can offset the additional cost of a high-performance envelope and the additional cost of installing premium (high efficiency) equipment throughout the building. These steps alone can usually achieve energy savings on the order of 35–50% for a new commercial building, compared to standard practice, while utilization of more advanced or less conventional approaches has often achieved savings on the order of 50–80%." To reduce the demand many low-energy building techniques and technologies can be combined.

Harvey (2009) also states that key decisions – usually made by the architect or urban planner – can greatly influence opportunities to reduce the demand. Because this research involves urban building blocks, not all buildings are oriented efficiently facing the south, but in order to reduce this, building blocks should be rectangular with the long sides on the east-west axis and the short sides on the north-south axis, as Vartholomaios (2015) suggested. Using passive solar techniques, the building block should be compact to reduce the surface area to volume ratio (Gelekta & Sedlakova, 2012) and height to floor area ratio. Integrating energy-efficient landscaping is important to support this as well, including planting trees to provide shade, together with green roofs and certain paving types and reduce the cooling load.

As part of the building envelope window to wall area ratios, insulation levels of walls, ceilings and other buildings parts, the thermal properties of windows and doors and the use of thermal mass are all influential factors in reducing the demand. If designed and built adequately the heat losses can be offset by internal heat gain from people, lighting and appliances and passive solar heat gain using passive house guidelines. (Harvey, 2009) For this the required heating is not more than 15 kWh/m^2/year, which can typically be achieved by reducing the heat loss to about 45 kWh/m^2/year with one third of the heat loss offset by internal heat gains and one third by passive solar heat gains.

To reduce the cooling load, something which is only necessary for approximately 64 degree days in comparison to 3013 heating degree days in the Netherlands (BPIE, 2011) several different methods can be applied. Orientation to minimize facades facing east or west, which are the directions most difficult to shade from the sun. Providing fixed or adjustable shading, which in case of lamellas should be vertical on the east and west facade and horizontal on the south side, because of the relative position of the sun. Increased insulation. Windows and other facade openings should transmit a relatively small fraction of the total incident solar energy while permitting a larger fraction of the visible radiation to enter for day lighting purposes. Harvey (2009) furthermore adds "utilizing thermal mass to minimize daytime interior temperature peaks; utilizing nighttime ventilation to remove daytime heat; and minimizing internal heat gains by using efficient lighting and appliances.''

Another requirement for passive house design is that the building must not leak more air than 0,6 times the total volume per hour (Passive House Institute, 2015a) which requires in turn an extremely airtight construction. Occupants can open windows whenever they want, but because of the ventilation system, fresh air is supplied continuously and much more consistently using fine filters to keep dirt and pollen out (International Passive House Association, n.d.b). This controlled ventilation furthermore uses a heat-exchanger to minimize heat loss or gain depending on the climate, so air leaks are best avoided (Gröndahl & Gates, 2010). The insulation also requires a careful management of moisture and dew points, which is achieved through air barriers, sealing construction joints and service penetration points (Herb, 2010).

When thermal loads are reduced in such a way several passive cooling and ventilation techniques are available, which reduces the need for mechanical cooling by directly removing warm air when incoming air is cooler than the outgoing air, also reducing the perceived temperature due to air motion and psychological adaption when occupants have control of operable windows. (Harvey, 2009) Design features, such as courtyards, atria, wind towers, solar chimneys (Holford & Hunt, 2003; Forster & Hawkes, 2002) or solar facades (Bronsema, 2014) can create thermal driving forces or utilize wind effects for this and can improve air quality and create a connection with outside. ''In buildings with good thermal mass exposed to the interior air, passive ventilation can continue right through the night, sometimes more vigorously than during the day due to the greater temperature difference between the internal and external air. Nighttime ventilation, in turn, serves to reduce the cooling load by making use of cool ambient air to remove heat.'' (Harvey, 2009) By precooling the air through buried air ducts, so called earth-pipe cooling, the ratio of cooling obtained to fan energy required to move air through this system is according to Eiker, Huber, Seeberger & Vorschulze (2006) 30-50% lower, and thus can be used to further reduce the energy demand.

Because of passive solar gain and heat from internal sources conventional central heating systems are mostly unnecessary (Passive House Insitute, 2015b). Low temperature heating and cooling systems can be applied if necessary (Keller, 1997) and can be combined with geothermal pumps. Using hydronic systems with either floor, wall or ceiling heating of cooling systems are always better, but if these systems together with passive ventilation is either not possible or adequate a heating, ventilation and air-conditioning (HVAC) system is needed. Harvey (2009) suggests a number of changes in the design of these systems to achieve dramatic savings in energy use including using variable air volume system with variable speed fans, to minimize simultaneous heating and cooling of air and reduce energy use. This can be further improved by separating the ventilation from the heating and cooling functions and using heat exchangers to recover heat or coldness from waste streams. Airflows and temperature should furthermore change with building occupancy and seasonal changes. And ultimately when designed properly all components should have the correct sizing.

Heating, cooling and ventilation amount for 35% for housing (Energieloket, 2013) and 50% for offices (Agentschap NL, n.d.) of the total energy demand. The remaining part is used for other functions like lighting, electrical appliances and information technologies. Strategies to reduce lighting energy use focusses on optimal use of day lighting and efficient lighting systems. Harvey (2009) names ''an example of an efficient lighting system would be one with separate controls for different lighting zones and use of task or ambient lighting (relatively low background light levels where appropriate, supplemented with greater lighting when and where needed).'' With this around 30-50% can be saved on electricity, while this can exceed to 70-75% with considerable effort (Harvey, 2006).

Commissioned by the 'Rijksdienst voor Ondernemend Nederland' Meijer & Verweij (2009) did research on the energy consumption of different functions. This data has been subdivided in three different categories, just like Van den Dobbelsteen, Doepel & Tillie (2009) did. Electricity includes horeca, IT-centralized, IT-decentralized, lighting (emergency), lighting (exterior), lighting (interior), miscellaneous, moistening, product preparation, pumps, transport and finally ventilation. Heating includes space heating and hot water. Last is cooling, which includes cooling itself and product cooling. The totals of this are shown in the table below in kWh/m²/year and are rounded to multiples of five.

Function	Electricity	Heating	Cooling	Area	Electricity	Heating	Cooling
Housing	25	120	0	112.000	2.800.000	13.440.000	
Offices	180	140	20	40.000	7.200.000	5.600.000	800.000
Swimming pool	660	525	0				
Sports hall	140	140	0	2.000	280.000	280.000	
Nursing home	160	210	5	2.000	320.000	420.000	10.000
Hospital	260	230	35				
Primary school	50	115	0	2.000	100.000	230.000	
High school	80	115	0				
University	165	105	5				
Car company	110	70	5				
Wholesale	55	45	5				
Supermarket	375	140	610	2.000	750.000	280.000	1.220.000
Retail	155	125	15	4.000	620.000	500.000	60.000
Horeca	225	175	70	4.000	900.000	700.000	280.000
Total				**168.000**	**12.970.000**	**21.450.000**	**2.370.000**

Conventional energy demand (Meijer & Verweij, 2009)

This shows that there is an electricity demand of 12.970.000 kWh/year, an enormous heat demand of 21.450.000 kWh/year and a cooling demand of 2.370.000 kWh/year. As a first step this demand must be reduced using the formerly mentioned principles. The case studies showed that 60 to 65 kWh/m²/year for heating is much more feasible than the passive house design standard of 15 kWh/m²/year. Hamada, Nakamura, Ochifuji, Yokoyama & Nagano (2003) evaluated energy savings for 66 houses in 17 different countries and concluded that a super insulated and airtight home with both solar collectors and a photovoltaic system save on average 75% on purchased energy demand (around 50% for the three examined Dutch houses) in comparison to the same houses built according to conventional standards. The only problem with these results is that the available data lacks any architectural form. So for the sake of convenience the new heating demand will be reduced by 50%, to enable architectural freedom during the design phase in for example the floor plans and facade opening

Torcellini & Crawley (2006) state that for commercial buildings the average energy demand is 266 kWh/m²/year for different buildings located in a range of climates in the US, which is comparable to the data found by Meijer & Verweij (2009) and can be reduced up to 65% with improved electrical lighting, daylight implementation, solar shading and elongation of along the east-west axis. Important to note is that all these building are free-standing and not obstructed by other structures, which would decrease the formerly mentioned value. Taking into account the unpredictability of users and that lighting takes up around 22% of the total energy demand for offices (Agentschap NL, n.d.) 25% reduction thus seems more reasonable.

Function	Electricity	Heating	Cooling	Area	Electricity	Heating	Cooling
Housing	20	60	0	112.000	2.240.000	6.720.000	
Offices	135	70	20	40.000	5.400.000	2.800.000	800.000
Swimming pool	495	265	0				
Sports hall	105	70	0	2.000	210.000	140.000	
Nursing home	120	105	5	2.000	240.000	210.000	10.000
Hospital	195	115	35				
Primary school	40	60	0	2.000	80.000	120.000	

High school	60	60	0				
University	125	55	5				
Car company	85	35	5				
Wholesale	45	25	5				
Supermarket	285	70	610	2.000	570.000	140.000	1.220.000
Retail	120	65	15	4.000	480.000	260.000	60.000
Horeca	170	90	70	4.000	680.000	360.000	280.000
Total	- 25%	- 50%	- 0%	168.000	9.900.000	10.750.000	2.370.000

Energy demand after reduction

3.6.5. REUSE

The table above shows that by implementing adjustments of solar passive design the electricity and heat demand is improved by 25% and 50% respectively and the total energy demand is reduced by almost 60%. Continuing on this the energy flow within buildings or functions can be exchanged to further reduce this demand. This process is either called energy recycling or reusing and can be done in different ways, from waste heat recovery, combined heat and power and other enabling technologies and has the potential to mitigate global warming profitably (McKibben, 2007) by reducing greenhouse gasses while simultaneously reducing the energy consumption and thus the costs (Inderscience Publishers, 2009).

Waste heat recovery is a process by which a heat exchanger recovers heat from streams with high energy content and converts in into steam which in turn powers a turbine that creates electricity or returns this energy in the form of (pre)heated air, water or other liquids. This process is similar to that of fired boilers but instead of a traditional flame waste heat is used as source and is typically used on large scale industrial production plants where this waste heat recovery can be very effective (McKibben, 2007). It has both direct benefits as named earlier and indirect advantages, but also some disadvantages including the capital cost of implementing a waste heat recovery system, increased maintenance because of the additional equipment and the low quality of waste heat.

Another form of energy recycling is the so called combined heat and power (CHP) or cogeneration and uses the same principles by reusing the nearly two-thirds of the energy used to generate electricity in the form of heat which would otherwise be discharged to the atmosphere. In this way CHP can achieve efficiencies of over 80% in comparison to conventional technologies which reach up to 50% efficiency (US Environmental Protection Agency, 2015a). Besides its efficiency, economic and environmental benefit of reducing emissions and greenhouse gasses by needing less fuel to produce a unit over energy output, reducing its costs and because of the avoided transmission losses it also has very important reliability benefits. According to the US Environmental Protection Agency (2015b) ''CHP is an onsite generation resource and can be designed to support continued operations in the event of a disaster or grid disruption by continuing to provide reliable electricity.''

Besides heat exchangers other technologies that enable the reuse or recycling of energy that would otherwise be inaccessible due to a temperature that is too low for utilization or because of intermittencies (a time lag between when the energy is produced and when there is a demand for it) are heat pumps and thermal energy storage.

Heat pumps invert the spontaneous flows from warmer to colder places while using a small amount of external energy. By this process electrically powered heat pumps can transfer heat that is three to even nine times larger than the electrical power consumed which is called coefficient of performance (COP) rather than efficiency. When temperatures differences between the cold and warm area are larger the coefficient of performance decreases. The heat can be transported through air, but this quickly becomes impractical due to the small amounts of heat it can carry so therefore liquids, like refrigerant or water are used more often. Water, sometimes mixed with antifreeze, is used when large amounts of heat have to be transported to decrease the risk of expensive refrigerant leakage. (Lowe, 2011)

Ground-source or geothermal heat pumps use shallow underground heat exchangers as a heat source and water as the heat transport medium because the temperature at around ten meters deep is relatively constant across the seasons at 10 °C (Geologie van Nederland, n.d.). Horizontal (closed) systems are buried around 70 to 150 centimeters underground and need around three times the heated area for space. Together with the low yield during winter months and the fact that no deep-rooted plants can be placed above the collector makes that this system is not applicable for the densely built environment. Vertical (closed) systems on the other hand have the advantage that during winter warm groundwater can be pumped up to preheat buildings and then be pumped back into another reservoir in the ground. This cold water can then be used during summer to cool buildings. (Duurzaam Thuis, n.d.) Because heat exchangers require drilling for some heat pumps to be efficient they are also expensive and are thus in a disadvantage when it comes to initial investments but annual running costs are lower. According to the Building Services Research and Information Association (2010) legislative measures on minimum efficiency standards and declining electricity rates will positively increase the attractiveness of heat pumps.

The formerly mentioned disadvantage of the low quality of waste heat can be nullified by making a distinction between high-caloric (90 °C) and low-caloric (40 °C) heat, as Van den Dobbelsteen, Wisse, Doepel & Tillie (2012) describe. The high-caloric heat for example can be used for the hot water demand of all functions and is produced by a bio-cogeneration plant after which it can still be used as low-caloric energy to reduce the space heating demand.

CHP	90 °C →	Hot water + PVT Panels	40 °C →	Space heating	30 °C →	Storage

Energy cascading from high-caloric heat to low-caloric heat

This high-caloric energy can be produced by a cogeneration or combined heat and power (CHP) plant as was shown in the case study of Hammarby Sjöstad. In this example 450 kg of combustible municipal solid waste per person per year is used to produce 886 kWh/y of heat and 202 kWh/y of electricity. Combustible municipal solid waste is all trash or garbage that can be burned and includes paper, wood, scrap, rubber and leather (Solid Waste Management, n.d.) and can include textiles, bedding, yard trimmings and leaves, but also other recyclable and hazardous materials like paints and plastics (Code Publishing, 2016). The question can be asked if combusting instead of recycling these materials is the best way to use this waste. So by reusing the high-caloric energy of hot water for space heating the energy demand becomes even lower, as is shown in the diagram below.

Van den Dobbelsteen, et al. (2009) suggested a better idea than just applying the 'reduce, reuse and produce' principle on a single building while solving the remaining demand for heating. By exchanging these flows between buildings with different functions and thus a different pattern of energy requirements the excess of the required energy or produced waste heat or cold can be used by another building. Examples of this are the combinations of a supermarket, which needs continued cooling and houses, which need frequent heating or another example is modern offices which start cooling as soon as outdoor temperatures exceed 12 °C while at these temperatures houses still require to be heated. Another method is energy storage at cluster level when heat and cold are only available in excess when there is a small demand. This basically means that during winter most functions require heating, while cold is in excess and during summer it is the other way around and therefor energy should be stored for later use. The last and third method is enabling cascading by enabling a heat exchanger to use residual heat from for example a greenhouse to heat dwellings, using low temperature heating systems. This low temperature heating systems (40 °C) are possible for buildings with high-quality insulation, double glass windows and underfloor heating according to Van den Dobbelsteen, et al. (2011).

In addition to these three methods so-called energetic implants can be used to complete missing links in the energy supply chain. Van den Dobbelsteen, et al. (2009) explains that once the amenities have been optimally tuned to each other there can be a residual demand for either heat or cold. In this case would be a larger supermarket of around 17.500 m² gross floor area, which is not desirable for non-energetic aspects or an ice rink to even the balance.

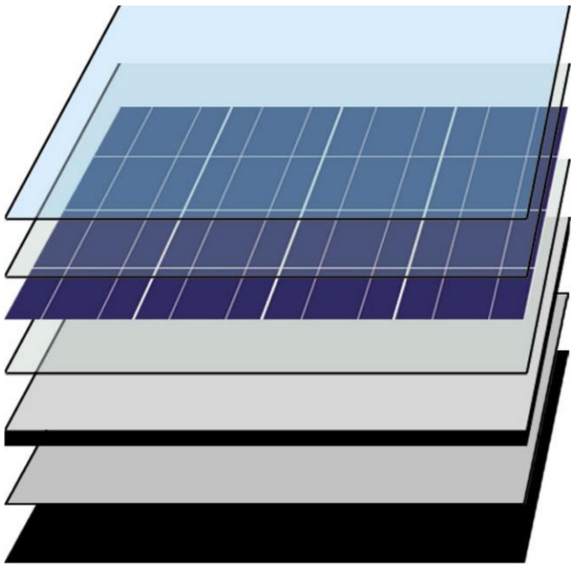
Function	Electricity	Heating	Hot water	Cooling	Difference
Housing	2.240.000	5.040.000	1.680.000	-	3.360.000
Offices	5.400.000	2.600.000	200.000	800.000	1.600.000
Sports hall	210.000	110.000	30.000	-	80.000
Nursing home	240.000	190.000	20.000	10.000	160.000
Primary school	80.000	110.000	10.000	-	100.000
Supermarket	570.000	130.000	10.000	1.220.000	-1.100.000
Retail	480.000	240.000	20.000	60.000	160.000
Horeca	680.000	300.000	60.000	280.000	-40.000
Subtotal	**9.900.000**	**8.720.000**	**2.030.000**	**2.370.000**	**4.320.000**

Reduced energy demand by cascading

3.6.6. PRODUCE

The final and third phase of the 'new stepped strategy' is to produce the remaining reduced electricity demand of 9.900.000 kWh/year and double reduced heating demand of 4.320.000 kWh/year demand with renewable resources. As was stated earlier a cogeneration plant is used to produce electricity and high-caloric heat from waste of the 2.640 inhabitants of the neighborhood throughout the year so no heat exchangers which use additional electricity are needed for this process. The residual heat demand is produced by 10.000 m² PVT panels generating 500 kWh/m² of heat and 125 kWh/m² of electricity making the neighborhood heating and cooling neutral.

These PVT panels or photovoltaic thermal hybrid solar collectors in full produce in total more energy than PV panels or solar thermal panels because of their higher exergy. By using water to extract heat from the PV cells and thereby cooling these the resistance is lowered and the overall efficiency increased, while on the other hand, the thermal component generates less energy than a solar thermal collector because of this. (Mojiri, Taylor, Thomsen & Rosengarten, 2013) In the image below the seven different layers are shown and are from bottom to top: insulation, heat exchangers, back sheet protection, encapsulating film, solar collectors, another encapsulating film and last tempered glass (SmartClima, n.d.)



Schematic of a PVT solar collector

With the heating and cooling demand being provided by the cogeneration plant from the waste of the neighborhood's inhabitants, the PVT panels on the roof and the underground thermal storage with heat pumps the remaining electricity demand has to be provided by PV panels. Wind turbines unfortunately are much harder to integrate into the built environment because of obstructive regulations and of the high initial purchase costs the investment does not earn itself back within the technical life (Milieu Centraal, n.d.b).

Groenewoud (2013) concluded from his research that when using a hybrid system of solar panels and wind turbines the total storage capacity is decreased as opposed to using only one source. This is needed because renewable energy sources are intermittent dependent on external variables such as the weather, which causes differences between the supply and demand. Instead of using the existing grid, the electrical energy can also be stored (partially) on-site. Only demand response backup generation of the cogeneration plant is not sufficient for the neighborhood making storage in batteries or other mediums necessary. The potential of electrical cars (VPRO Tegenlicht, 2016) or rechargeable lithium-ion batteries such as the Tesla Powerwall are gaining more and more popularity, but on the other hand are also called toys for rich green people (Helman, 2015)

A very important factor in the feasibility of meeting the remaining electricity demand is available roof space or rather the floor area to roof area ratio as Harvey (2006) also describes. An energy neutral high-rise building, as mentioned earlier, is therefore not possible (Fong & Lee, 2012) and it is thus for a high-density neighborhood crucial to have compact buildings and a higher FSI while maintaining the GSI (Urban Knowledge, 2004).

Another major aspect is the ratio of solar panel area to roof area or so called ground coverage ratio (Culligan & Botkin, 2007). ''Traditional practice in Europe has focused on maximizing output at the module level, which dictates tilting at or close to 30 degrees depending on latitude.'' But when increasing the tilt angle the ground coverage ratio decreases, leading to higher costs as well as smaller systems. A 30 degree system has a ground coverage ratio of 50%, while a 5 degree system reaches 85%. According to the same authors a lightweight system with a lower tilt angle will therefore provide the best economic return. An even better approach would be when integrating the solar panels into the design as can be seen in the street view image of Vauban, Freiburg.

Taking into account exterior influences around 70% of all roof area can be fitted with solar panels, in total that would be 30.000 m^2 of which one third is used for the formerly mentioned PVT panels. When adding up all these numbers almost 70% of the electricity can be generated on-site. Possibly using a 1,5 MW wind turbine in the close proximity of the Marine Area in Amsterdam could then be used to be 100% energy neutral.

A total overview for both a summer and winter situation of all energy flows can be seen in the appendix.

Function				Electricity	Hot water	Heating
Demand				9.900.000	2.030.000	4.320.000
Waste	200	800	kWh/person	528.000	2.323.200	
PVT Panels	125	500	kWh/m^2	1.250.000		5.000.000
PV Panels	250		kWh/m^2	5.000.000		
Total	**Electricity**	**Heat**		**3.122.000**	**-293.200**	**-680.000**

Production of energy from renewable on-site sources

4. CONCLUSION & DISCUSSION

4.1. CONCLUSION

From this research paper it becomes clear that when designing an energy neutral neighborhood many parameters have to be taken into account and the best results are achieved when designing through and incorporating the different scales of the building, the urban block, the neighborhood and the environment. In this way many aspects can be used to create added value and a better overall living and working environment.

The first and maybe most crucial step of achieving energy neutrality is by reducing the demand, as was also shown by both Swedish and German case studies. Only when renewable resources are not in abundance, which is not the case for most cities, minimizing this demand is not only economical in the long run but also benefits the environment by reducing greenhouse gas emissions and fossil fuel dependency. Paramount to its success are the dedication and collaboration of governmental parties (preferably with long term visions), designers, builders and end-users before, during and after the design process. Although requiring large investment costs, it has also been proven that similar projects are economically viable, paving the way for large scale or small scale developments by private parties. Attention to detail, execution and quality assurance are furthermore important to realize intended measures and prevent construction flaws. Electricity demand can in this way be easily reduced by 25% and heating demand by 50%.

Design principles should be derived from the passive house standard including window placement and size, thermal insulation, thermal mass, shading and incorporating landscape design. A highly dense neighborhood can furthermore only achieve energy neutrality by building compact and increase roof area for solar panels. A mix of uses or functions not only contributes to a greater diversity in housing and social demography, better access to everyday amenities, a stronger sense of place or character, but also enable the exchange of energy waste streams. Houses for example need heating throughout most of the year, while offices need cooling. By reusing and exchanging these flows the overall demand is further reduced by another 50%. So-called energetic implants, in this case a large supermarket, can be used to bring the heating and cooling load in an even better balance.

The residual demand, which is 75% for electricity and only 20% for heating of the initial demand, can be produced from on-site renewable energy sources and stored or returned on the existing energy grid. While generating electricity, a cogeneration plant using waste from the inhabitants of the neighborhood provides all hot water together with PVT panels producing the remaining energy used for space heating and cooling. Integrating these PVT panels together with PV panels into the design on roofs increases the total area and delivers 70% of the total energy demand. And finally by building a wind turbine in the close proximity of the neighborhood it becomes totally energy neutral on an annual basis.

4.2. DISCUSSION

Although a 1,5 MW wind turbine produces renewable energy, it however does not produce this really on-site. In order to develop an energy neutral neighborhood without it a few options are possible. First of which is decreasing the total floor area and thus reducing the electricity demand. Having a lower population density does also help, but at the same time the municipal solid waste produced decreases as well. The best option would be to either increase the total area of photovoltaic solar panels (possibly by decreasing the total area of PVT panels) or further explore methods to reduce electricity demand by better day lighting, more energy efficient appliances and lifestyle behavior. Continuing, this energy balance is on a yearly basis, but monthly, daily and even hourly balances should also be studied according to the same definitions to better understand the intermittencies between energy consumption and production by renewable sources.

Another question that can be asked is how this method of designing can be applied to existing neighborhoods. Renovating and transforming buildings to better suit the energy balance can be radical and very costly, because of the intensive infrastructure needed among other things. Certain urban structures and probably even people will not permit such thorough changes. It would therefore be maybe better to reduce the demand in these neighborhoods and produce as much locally from renewable resources, but leave out the second step of reusing and recycling waste streams between functions. Creating awareness and education on the other hand should be an intermediate part of this.

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5.2. IMAGES

Aerial view of Bo01, Malmö: http://www.msaudcolumbia.org/summer/wp-content/uploads/2014/07/aerial1.jpg

Aerial view of Hammarby Sjöstad, Stockholm: https://sweden.se/wp-content/uploads/2013/06/Hammarby-Sjostad.jpg

Aerial view of Marine Area, Amsterdam: http://marineterrein.nl/wp-content/uploads/2014/01/MAT_1024_luchtfoto.png

Aerial view of Vauban, Freiburg: http://www.freiburg.de/pb/site/Freiburg/get/documents_E-1562355727/freiburg/daten/bauen/vauban/Luftbilder_Download/Luftbild_2009.jpg

Biomass power station in Moerdijk, Netherlands: http://www.gelderlander.nl/polopoly_fs/1.3069217.1350933273!/image/image.JPG_gen/derivatives/landscape_800_600/image-3069217.JPG

Density in relation to compactness and use: http://sagacitymovie.org/admin/wp-content/uploads/2011/02/2832_N30_w-562x412.jpg

Geothermal source in The Hague, Netherlands: http://www.groenblauwenetwerken.com/uploads/Aardwarmtecentrale1-630x630.jpg

Impression of the Cityplots concept: http://static.wixstatic.com/media/5f9de3_55dc12226df142d3bd6770c10bebc7a6.jpg/v1/fill/w_784,h_492,al_c,q_90,usm_0.66_1.00_0.01/5f9de3_55dc12226df142d3bd6770c10bebc7a6.jpg

Mohammed bin Rashid Al Maktoum Solar Park: http://www.constructionweekonline.com/pictures/FSPhase1web2.jpg

Offshore wind park NoordzeeWind: http://nlintheusa.com/wp-content/uploads/2015/11/noordzeewind-windmills-north-sea.jpg

Plan of Bo01, Malmö: Fraker, H. (2013). *The hidden potential of sustainable neighborhoods*. Island Press. ISBN 9781610914079

Plan of Hammarby Sjöstad, Stockholm: Fraker, H. (2013). *The hidden potential of sustainable neighborhoods*. Island Press. ISBN 9781610914079

Plan of Vauban, Freiburg: Fraker, H. (2013). *The hidden potential of sustainable neighborhoods*. Island Press. ISBN 9781610914079

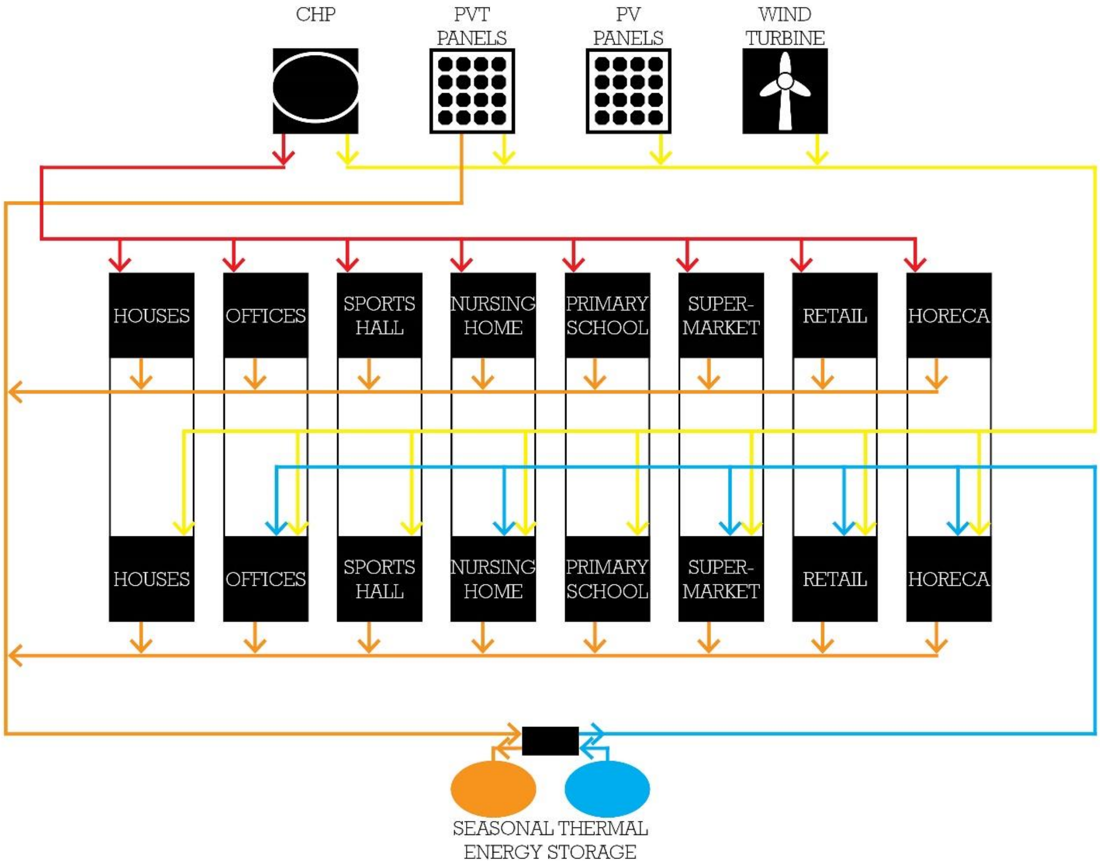
Schematic of a PVT solar collector: http://www.smartclima.com/wp-content/uploads/2013/08/solar-PVT-Panel-structure-6.jpg

Street view of Bo01, Malmö: https://eau123go.files.wordpress.com/2011/10/vastrahammen_002.jpg

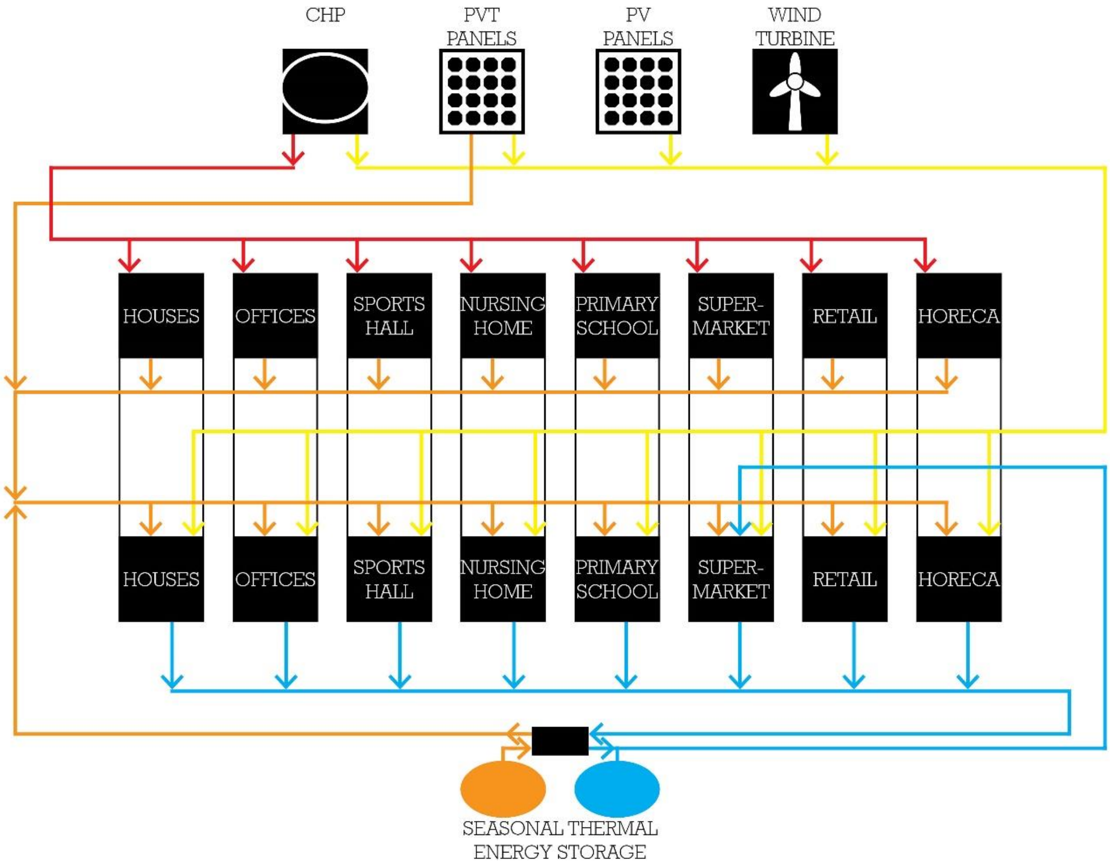
Street view of Hammarby Sjöstad, Stockholm: http://www.fabege.se/ScaledImages/546x340x2/Documents-Vara%20marknader%20och%20fastigheter-Vara%20marknader-Hammarby%20Sjostad-Hammarbycafe-1092x680.png

Street view of Vauban, Freiburg: http://ais.badische-zeitung.de/piece/00/e4/ec/2e/15002670.jpg

6. APPENDIX



Energy flow diagram in summer situation



Energy flow diagram in winter situation