Chapter 14

Achieving Zero Carbon in Sustainable Communities

Malgorzata Jacewicz and Herbert Robinson

1. Introduction

Contemporary urban lifestyle emphasises green living and encourages people to estimate their environmental impact and to reduce their carbon footprint. It is important that carbon footprint of users and their demand is quantifiable and measured to create scenarios for design of buildings in various neighbourhoods forming clusters. This chapter presents an alternative approach for developing sustainable communities using activity-based design principles to quantify the energy demand per activity performed on a daily basis by members of various communities rather than making assumptions on space requirements using the traditional functional-based design approach. It starts with an overview of the key concepts and a set of principles for the development of sustainable communities based on achieving an equilibrium between local renewable resources (e.g. wind, water, solar) and users demand for alternative energy. Making smart use of renewable energy sources (e.g. solar, wind, water and utility grid) is becoming increasingly critical as the cost of electricity from conventional sources continues to rise sharply over the next years due to increase in global demand for energy and economic growth. The chapter discusses how energy demand consumption analysis per person based on different activities is used in evaluating overall energy need, space and land requirements in the community**.**

2. Key Principles and Concepts

The project was established through collaboration between the Department of Architecture at London South Bank University and Hyperbody Research Group at the Technical University of Delft in the Netherlands. The project outlines a set of principles and provide tools to capture the relationship between renewable energy supply within the local environment and the demand from communities to achieve a balance.

First, sustainability is at the heart of the approach as changes in social behaviours through life/work balance, sharing of common public spaces, reducing the reliance and dependency on conventional energy sources to minimise both economic and environmental costs is a core principle in the design of sustainable communities. Second, the approach is based on the concept of energy gradients, setting out planning principles allowing for the generation of decentralised energy systems using local renewable energy sources such as wind, water and solar. Third, the approach focuses on activity-based design principle capturing user energy needs based on a set of daily activities for optimum space planning rather than traditional functional-based design to reduce fossil fuel dependency and the capital and life cycle costs associated with it.

Energy availability per m2 is captured from meteorological water, wind and sun data provided by national meteorological institutes. Such data can be used for urban planning and to facilitate the distribution of infrastructure across any country. The goal is to influence development of new urban areas and to ensure efficient use of gradients energy capacity through energy trading markets to capture, use and share the surplus in demand for energy.
Similarly, energy usage or consumption is calculated based on certain factors. Table 1 is an example showing the breakdown of consumption of energy resources per person to determine users demand for different sources of energy (water, wind or solar) for specific activities with or without using various types of appliances.

Table 1. Breakdown of consumption of resources per person

available renewable energy resources	=	users demand
rain - water		water - personal hygiene 45l / day - drinking and cooking 4-5l / day - toilet flushing 24-30l / day - dishwashing 30l / wash - washing clothes 40l / wash - other uses/cleanning, gardening 10-30l / use
wind - electricity		electricity appliances - kilowatt-hours - electronic equipment 4-8 kWh / year - clothes washers - 450kWh / year - dishwashers 440 kWh / year - fridge/freezer 500 kWh / year - electric boiler 3200 kWh / year - solar boiler 1,900 kWh / year - lightning
sun - heat - electricity		heat heating - 150 kWh m2 /year electricity - as above

Table 2 shows the wind classification and conversion to power densities. This example illustrates how different wind speeds are converted to energy. Similarly conversion for solar and water sources into energy can be determined based on a set of factors. Micro power generation tools such as solar panels, micro wind turbines and heat pumps take energy directly from the surroundings and convert it into electricity and heat. During this process no carbon dioxide (CO_2) is emitted. Such energy sources are inexhaustible and therefore truly renewable.

The decentralized energy generated locally from different sources is used for office buildings, warehouses, homes, apartment buildings or other facilities. The energy is consumed where it is being produced and thousands of units provide a small portion of the energy needed, instead of relying on a few power plants providing enormous amounts of energy.

Table 2: Wind energy conversion and classification

Class	Power	Wind Speed	Power Density
1		0.0 - 5.6 m/s	0 - 200 W/m2
2		5.6 - 6.4 m/s	200 - 300 W/m2
3		6.4 - 7.0 m/s	300 - 400 W/m2
4		7.0 - 7.5 m/s	400 - 500 W/m2
5		7.5 - 8.0 m/s	500 - 600 W/m2
6		8.0 - 8.8 m/s	600 - 800 W/m2
7		> 8.8 m/s	> 800 W/m2

The principles outlined above allow for the development of sustainable decentralized renewable energy systems for community buildings creating clusters where all buildings correspond with each other and are linked to the main utility grid. The creation of micro power trading energy clusters feeding into the main utility grid through local energy networks helps to secure sustainable and clean energy almost entirely harnessed from local renewable sources providing energy security for the future.

Decentralised renewable energy systems are also efficient. In the traditional centralised energy-infrastructure, almost 60% of the energy is lost during conversions, transmission, distribution, overproduction and transport of fuel from various global sources. This means that only 40% of the energy that is stored in the fuel is used. With decentralized energy systems, less conversions are required and virtually no transportation is needed which makes the system very efficient and reliable.

In a decentralized energy system, thousands of units are generating electricity so massive power outages can be avoided. When a unit fails, surrounding units will take over and bear the load of the failing unit. Decentralised energy systems also allow for better cost control as most energy is generated locally from renewable sources reducing the dependency on ever increasing oil prices. Oil price is based on supply and demand determined in the global markets with political influences resulting in strong fluctuations, uncertainty in price levels, leading to high oil prices in most cases.

In a decentralized system, the dependency will diminish as energy costs become controllable. As a result, the focus will shift towards greater efficiency and innovation in extracting the energy from the environment through better solar panels and wind turbines etc. Decentralised local networks also allow for scalable infrastructure design compared to conventional power plants that are large with high tension networks and city heating systems that do not allow for gradual increments in size. Changes in conventional power plants are always massive, costly and are usually delivered or driven by large government schemes or government support requiring significant investment and risks. However, a decentralized energy system is easily scalable because the technical and investment requirements are far less demanding and provides for small incremental design site by site, building by building, if needed.

3. Key Features of Decentralised Energy Networks

Decentralised energy networks allow for generation of building design that embraces energy capturing through shape, form, location, and orientation. The nature of the design influences type of shared activities and community run services that will enable the creation of small local energy networks. Within the networks, which potentially will be mostly privately owned, members exchange energy to maximize the efficiency of the energy they produce. In a local energy network, multiple houses or office buildings are connected into a cluster where energy can be exchanged freely.

Decentralised energy grids can be connected to the main utility grid. A local energy network is basically a mini-grid that is connected to the utility grid through one connection of the cluster. Electricity can be exchanged within the cluster before surplus capacities are sold back to the grid. When the cluster as a whole is not producing enough energy, then additional energy will be brought in through the grid. Sharing energy with other members optimizes the efficiency of the system. For instance, at noon both solar panels and wind turbines are likely to be producing significant quantity of electricity. However, because cluster users are at work, normally appliances would not be used except those that can be programmed in advance and so the rest of the power would be sold back to the grid.

By using the differences in consumption profiles between members, surplus capacity for one member can address problems of shortages for other members. The overall approach is useful in dealing with surpluses and shortages to ensure that energy is not wasted and most of the gradient capacity is captured and used. The system would therefore allow for efficient management of power demand from various clusters and to distribute it accordingly over the whole day. Given the available renewable energy, local networks located and planned according to sustainable urban principles within energy gradients would develop energy trading opportunities and development of new markets.

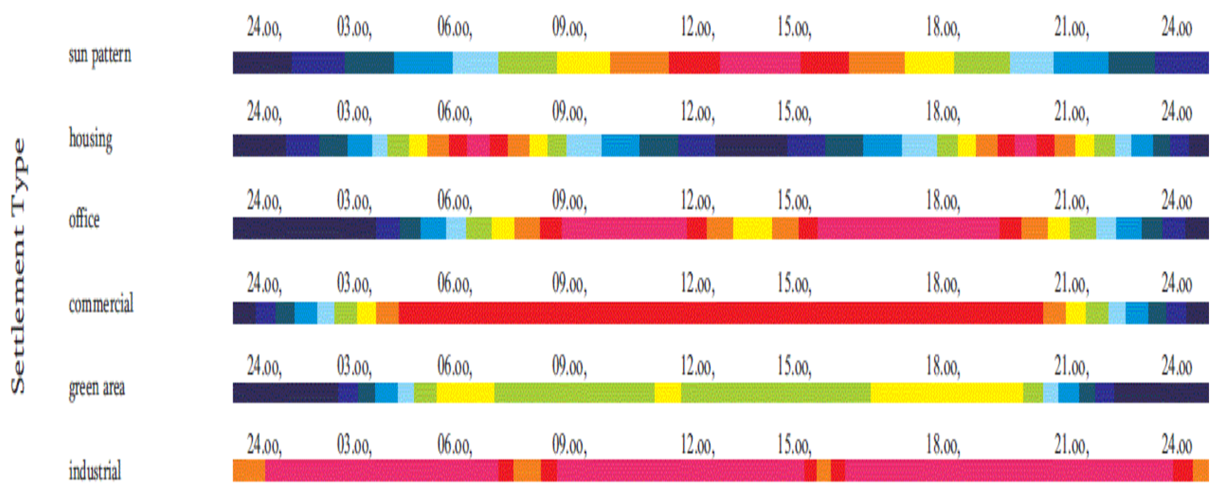
4. Activity-Based Design Approach

The activity-based design approach capture users' activities and quantify the energy demand per activity performed on a daily basis. Rather than making assumptions on space requirements, activity approach focuses on the activity of a user and the different space requirements. Moving away from traditional design based on function to activity-based design principle allows for space adjustments in terms of balancing energy demand per activity and required space to perform it. For example, activity such as cooking is not related to function of having generic size kitchen with generic appliances, but to optimize what is the minimum space required for a user to comfortably perform the activity. In design terms, the objective is to assess energy demand per activity driven by user's lifestyle. For example, two single people living on their own may have different needs. The person cooking every day will require higher energy demand then the other single person socialising outside of work and using basic cooking facilities to warm up food on daily basis.

4.1 Data and Information Requirements

For decentralised energy systems to work, urban planners need to understand environmental constraints of natural gradients and how to capture renewable energy through shape, form, orientation and the application of modern technologies. To gain the maximum of the gradient capacity, available energy will be quantified from information provided by national meteorological institutes. For instance, meteorological data will enable the quantification of the surface area required for any particular settlement with a given energy consumption pattern and to determine the size of the land to meet the demand. For example, figure 1 shows different settlement types and their consumption patterns.

Figure 1. Settlement types and their consumption peak times over 24H period (colour coding key?)



This can be measured using the equation below:

D = (x) C : (x) kWh

where D is total land required (in m2) to supply single user or cluster energy demand,

C is assessed consumption in kWh per person or cluster and kWh per m2 is the total amount of energy available in particular gradient.

For example, wind speed in the Netherlands on average is 15-20 m/s which is an equivalent of 600-800W per m2, solar energy is equivalent to circa 833 kWh/m2 in the North and 1199 kWh/m2 in the South per year. Use of the equation allows for development of balanced system were decentralised energy networks capture renewable energy and users can be encouraged to reduce their carbon footprint. Current types of settlements were compared for high peak energy demands with standard day sun energy availability pattern over 24 hours.

Figure 3. Present energy consumption peak times

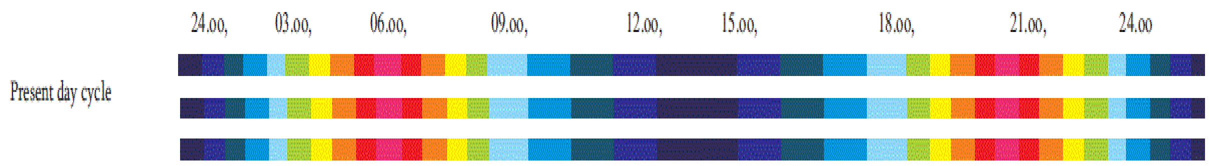
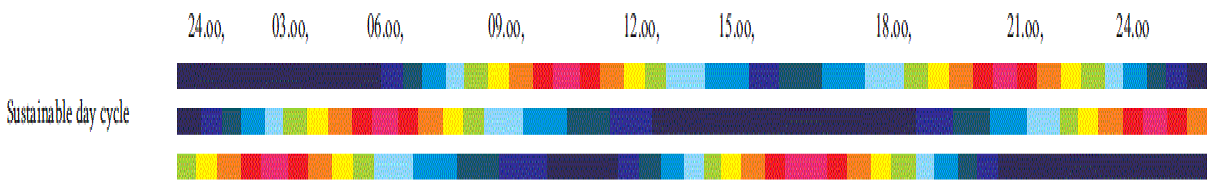


Figure 4. Potential sustainable energy day cycle



4.2 Type of Settlements and Location Decisions

The initial analysis of various types of settlements generated system of rules applied to optimise and develop design principles to explore gradients efficiency and propose sustainable energy day cycle for decentralised energy networks. The analysis looks at energy consumption and its dependency on lifestyle to compare it with available energy within the gradient to distribute settlements accordingly. For example, depending on the settlement type it might be an advantage to locate high energy depended cluster within the costal gradient to take advantage of wind and sun to generate power to the settlement. For clusters of units with low power consumption but with high water demand it may be suitable to locate them within appropriate gradient deeper inland. The rationale is to increase and maximise the efficiency of renewable energy for decentralised networks. The cluster type shall achieve the following: have assessed demand within a reason and therefore be located in appropriate gradient. Further, the gradient shall be explored to avoid peaks and troughs within the cluster.

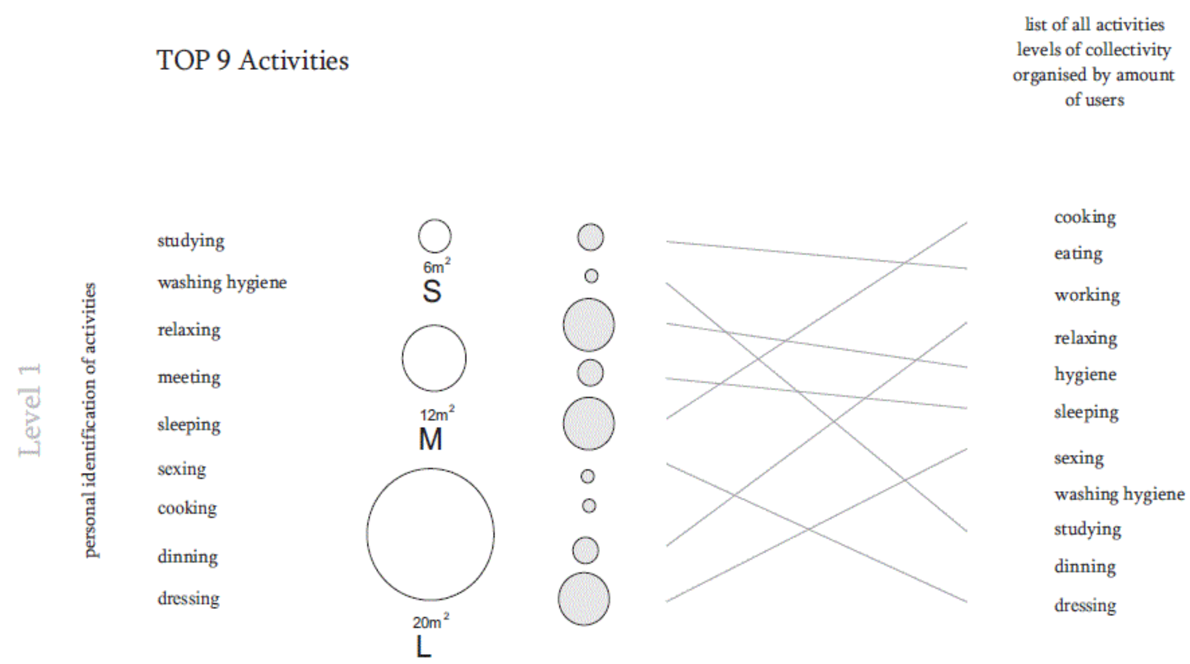
5. Design Solutions

Design approach for the distributed energy network is to assess the energy demand and locate the cluster within the relevant gradient. The key is to understand the balance between work and lifestyle on the user level. Research was carried out using a group of young people who intended to live and work together in delivering community and art services. The group of eight gathered over a one-day workshop to design their sustainable living and work environment using a system of rules to reduce their carbon footprint. Every participant had to declare from the start their willingness to share activities and compromise personal needs for a shared benefit to reduce demand for energy and associated building costs. The initial research explored assessment of individual demand for energy and space.

Level 1 – Identify key activities

The design criteria of Level 1 allowed for every individual to specify the top nine (9) activities they perform on a daily basis. Once this has been achieved, each individual is assigned the space needed for their activity. A choice of three space dimensions was used - Small (6m2), Medium (12m2) and Large (20m2) assigned to each of the top nine (9) activities.

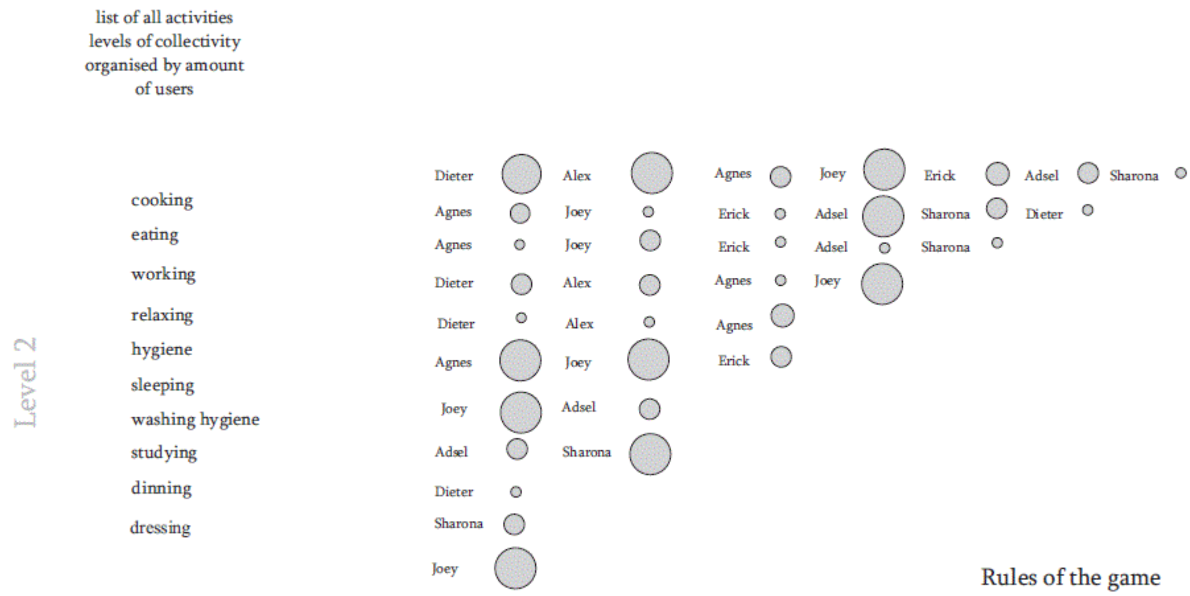
Figure 8. Design process - Level 1



Level 2 – Establish all activities performed in the community

Level 2 involves establishing a list of all activities to be performed across the settlement.

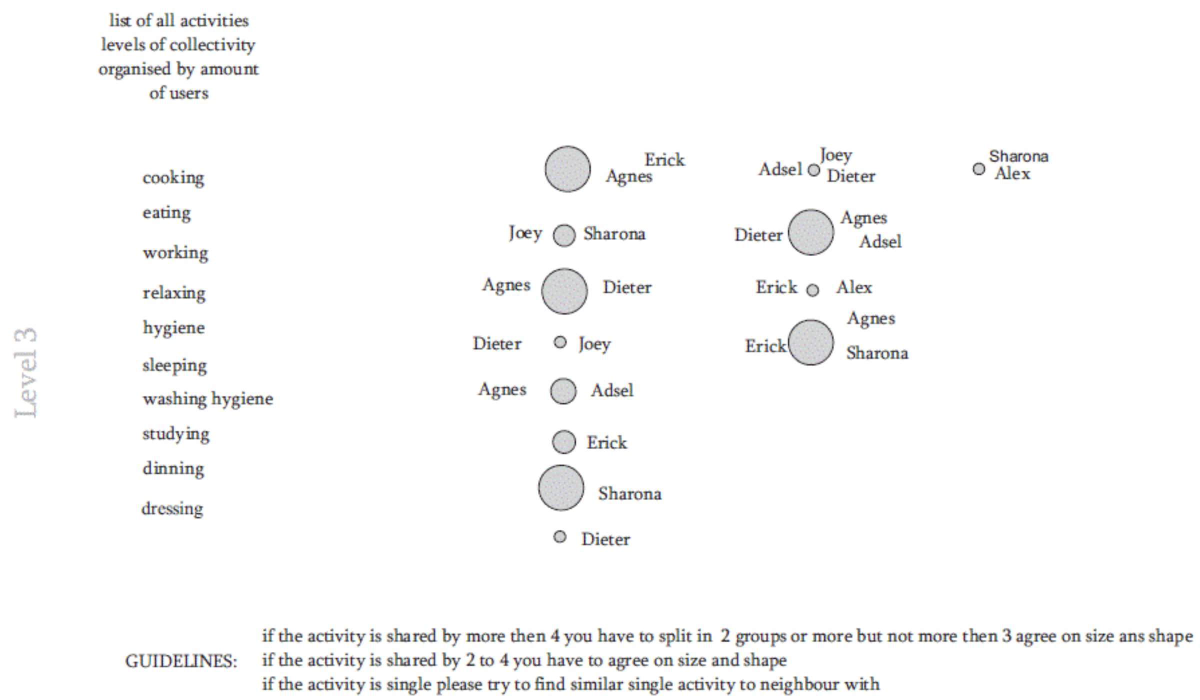
Figure 9. Design process - Level 2



Level 3 – Defining collectivism and rules to reduce space demand

Level 3 defined collectivism within the group and procedures to follow up a set of rules to reduce space demand. The objective of Level 3 is to reduce personal space if the activity was performed by more than 4 other users. For instance, in case of cooking that each one of them performed up to various grades, they had to split into two groups and agree common space dimension for that particular activity. Some of them were keen on cooking and some were more orientated towards take away. On this basis, two cooking areas were required, one with full cooking facility with dining area where the assigned group would cook together or take turns to cook for each other. Also, a small kitchenette was included for those who do not intend to cook. As a result, there were two areas serving the same activity with different energy and space requirements. Similar scenario to other activities.

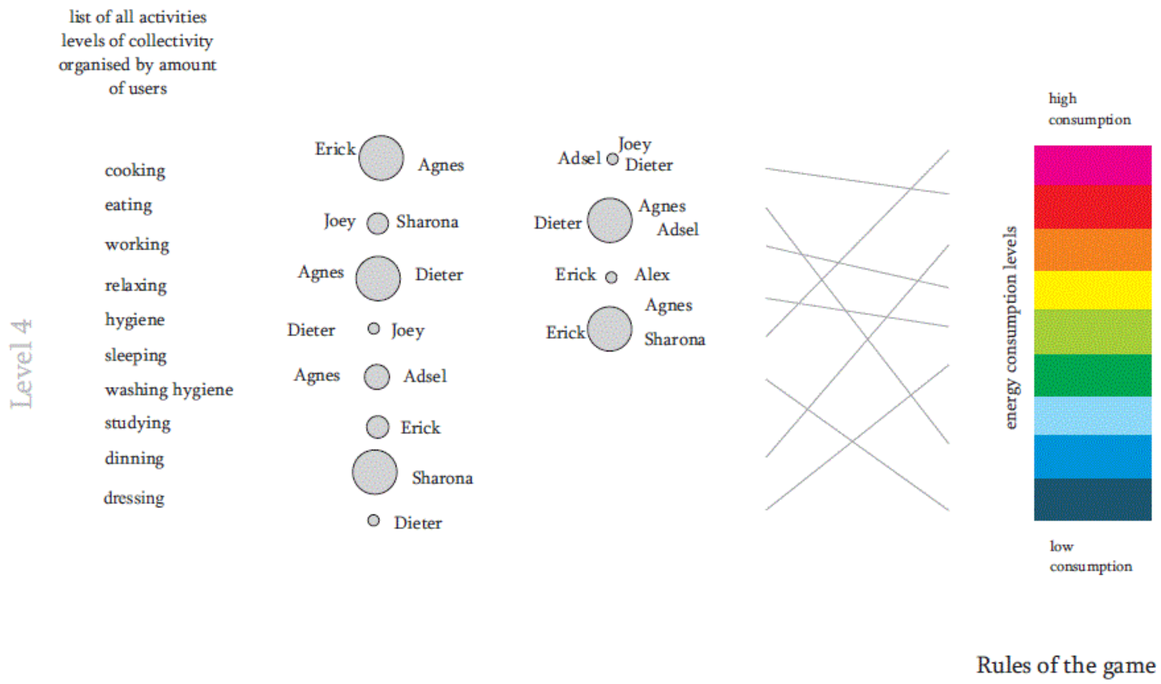
Figure 10. Design process - Level 3



Level 4 – Re-assessing energy consumption of activities

Once Level 3 has been agreed, Level 4 involves re-assessing the energy consumption per common activities using manufacturers' guidelines on energy consumption of equipment or appliances to be purchased for the house for shared activities in common areas or in private areas. The power requirements of the items on the required list were quantified per kWh and multiplied by the number of times to be used in a yearly cycle to determine energy demand. As the project was experimental, relevant location was chosen after the quantification of the users energy demand. This allowed for a proposal of various locations for the group to decide on the land price within their reach. The electricity demand for the group was circa 48,000 kWh a year. The value is largely influenced by type of appliances and initial capital expenditure for the building. For example, a 3-phase electric boiler would consume 3,200kWh a year. A 2-phase solar boiler would reduce this value to circa 1,800kWh a year. Similar situation applies to lighting within the house. Depending on the design if the lights in all areas would be energy efficient or preferably LED's the consumption could be covered by 12V solar panels and run of batteries (UPS system). This would allow for direct electric current transmission straight from the renewable source.

Figure 11. Design process - Level 4



The design process was further explored to assign to each activity an energy value depending on its consumption and percentage (%) split out of the total 100%.

Level 5 – Identify areas with high energy consumption

Level 5 was designed to identify areas with high percentage (%) of energy consumption and allocate certain activities based on high energy availability pattern during sustainable day cycle. All activities have been colour coded in order to allocate them in further design stages in appropriate zones.

Figure 12.Design process - Level 5

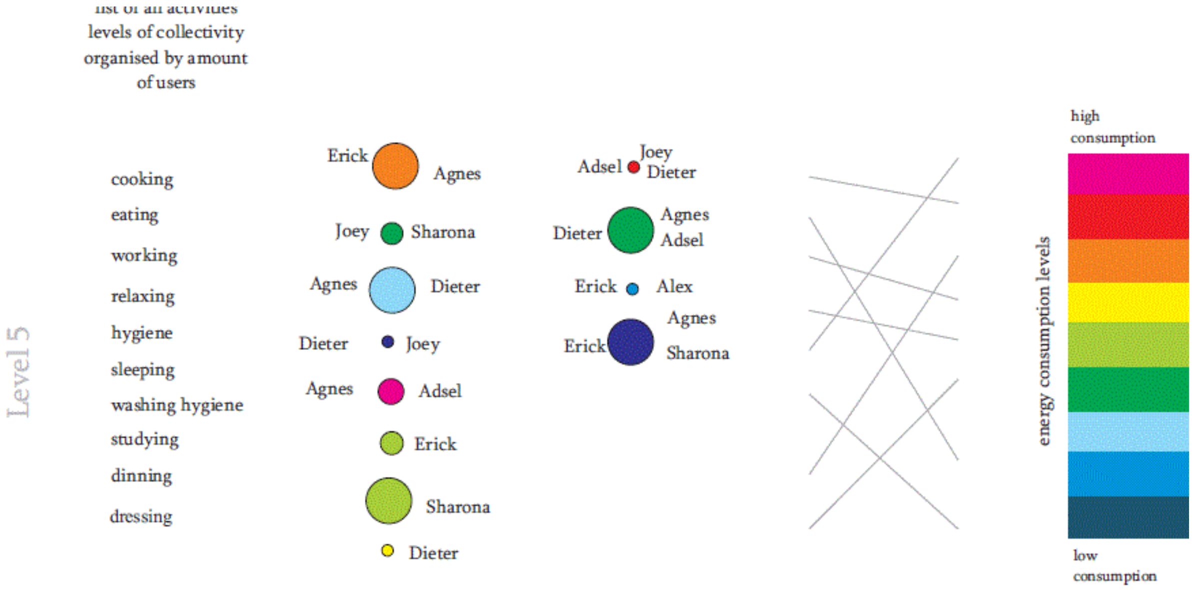
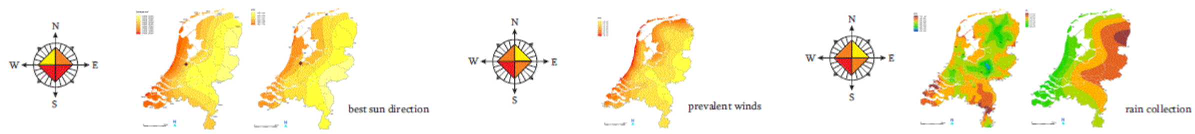


Figure 13. Zoning proposal based on users self-organisation

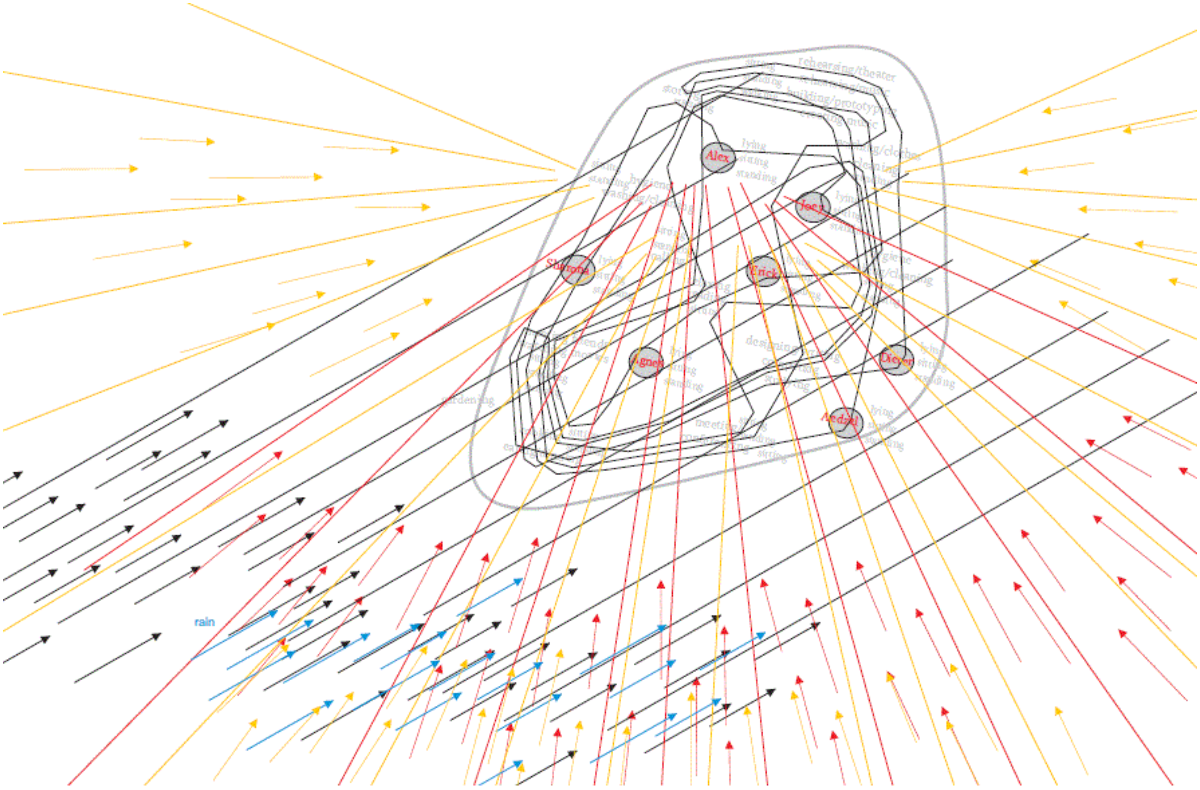
As the quality of working environment is critical, the requirement was to have access to day light for as long as possible. This zone of activities was allocated as a central part of the building on the south facing side together with main cooking and dining area.

Figure 14. Design forces – wind, rain sun and their prevalent directions



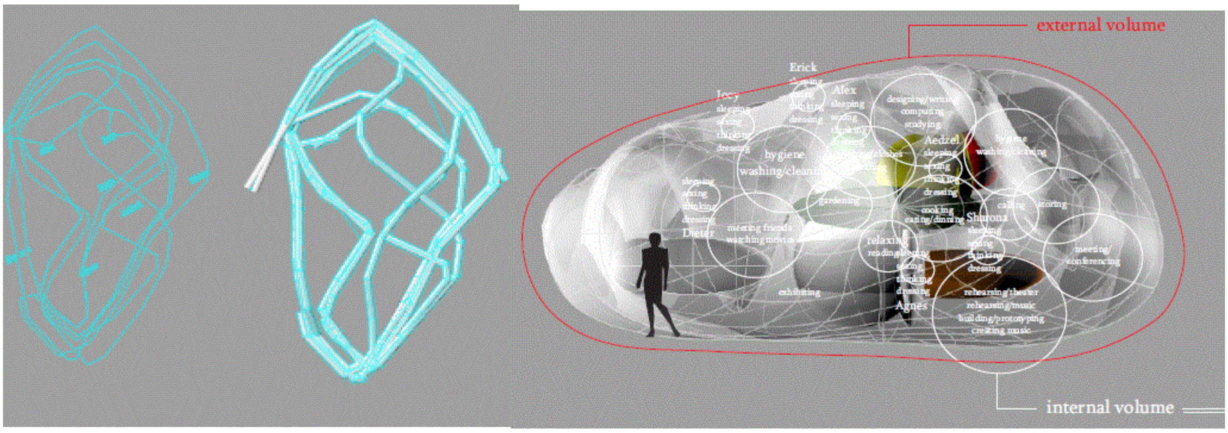
Prevalent directions of wind, sun and water defined the relationship between internal communication layout and allocation of activities carried throughout the day.

Figure 15. Form finding using application of design forces as per figure 14.



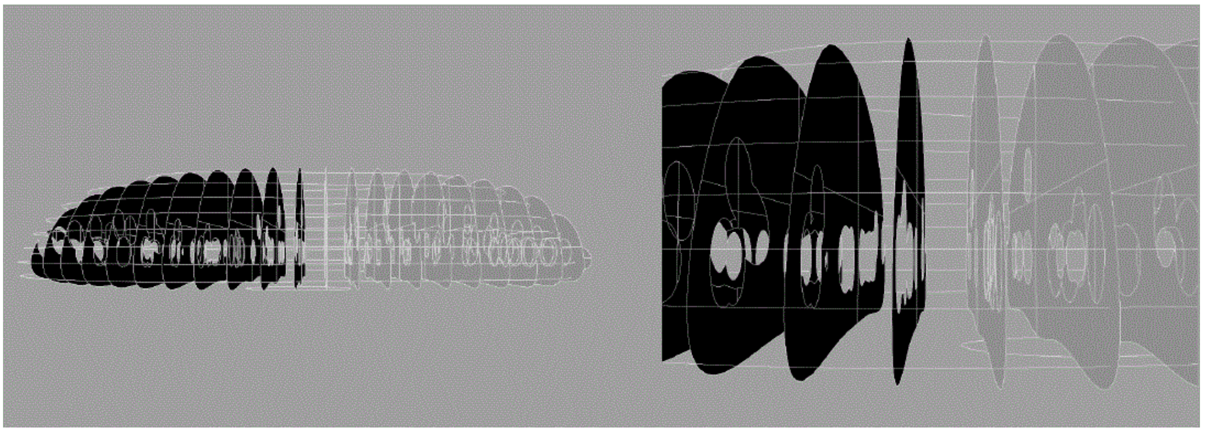
Level 5 of the design process allowed the group to organise their space in relationship to the external environment and to achieve the most efficient layout in relationship with external design forces. Various zones have been allocated and therefore generated building form; most appropriate structure allowing for community living and renewable energy absorption.

Figure 16a &b. Design solution stage 1: zoning and connection via communication paths



The internal layout approach was to connect all activities zones with continuous communication channels. Interior layout has been designed to optimise space and communication areas being continuous loop overlapping and crossing activity zones.

Figure 17. Design solution stage 2: structural approach form division by structural ribs



Further design decisions were taken to optimise the interior space and generate structural design approach. By dividing the joined zones of activities and communication paths into equal sections/ribs, structural integrity has been provided between interior and exterior.

Figure 18.Longitudinal section showing volumes of communication and zoning areas from the external volumes

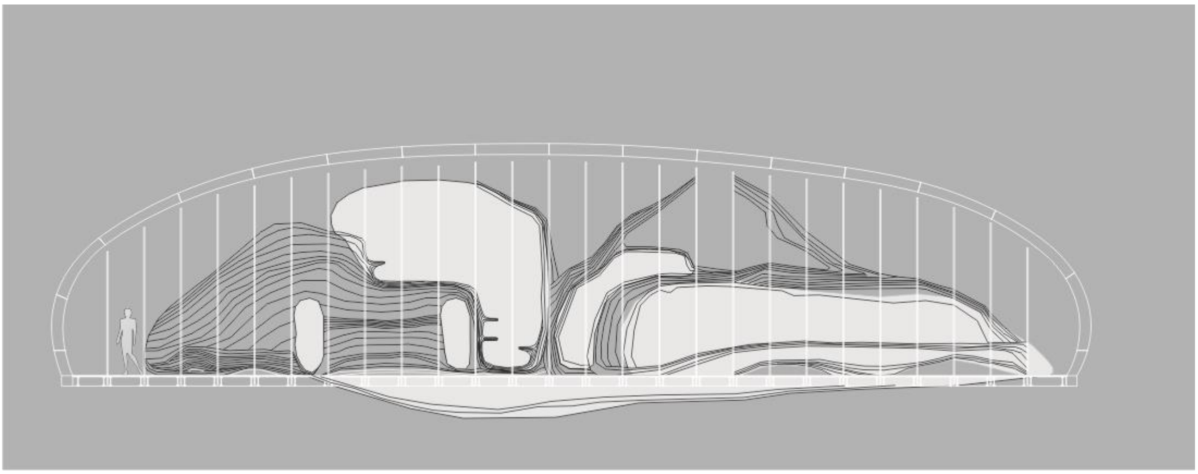
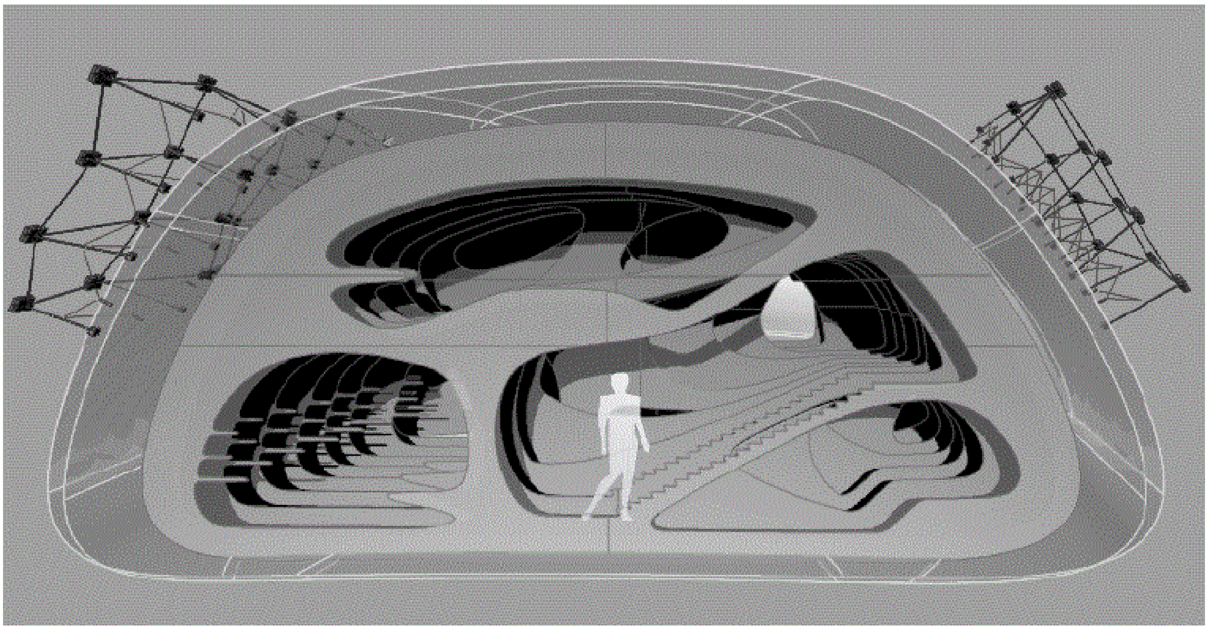


Figure 19. Cross section image of subtracted communication and zoning volumes from the external volumes



The internal layout space is therefore curved out of the external shell and ribs as per zones and communication paths. The building structure is designed as a set of ribs joined by the interior compartments and covered over with mixture of transparent and semi translucent cladding. The building design makes use of available space by overlapping activities and using the structural frame as a part of the interior design generating partitions and space continuity throughout the building. The structural frame is the main space division creating enclosure for user's privacy and opening up in areas of common activities.

6. Evaluating Energy, Space and Land Requirements

Once the energy demand is calculated, layout and space dimensions are assigned to activities and location chosen. The required land (in m2) can be estimated to support a community and their work-life environment. By developing a breakdown of activities performed and their estimated energy consumption, a suitable location can be chosen and supply and demand relationship managed. The activity-based design approach is based on the analysis of meteorological data and quantification of the surface area. Gradients may be defined and their maximum and average values assessed.

The approach allows for flexible assessment of how much land is required to power certain type of settlements to guarantee reduction in fossil fuels and replacement of it over time with full energy supply from renewable sources. Once the demand is calculated per person, proposals of energy reduction can be introduced. The objective is to decrease human impact on the environment by revisiting concepts of common spaces and generate socially vibrant environments whilst cutting down on fossil fuel dependency. Achieving equilibrium will allow for the development of decentralised energy systems.

The disadvantage of this system is that densities and gradient capacity cannot be increased without technological innovation which requires funding for improved energy absorption. Once the limit of the gradient is reached, the area would not be explored any further. Higher densities would require higher start-up capital expenditure and space allowance for power generation, which might become critical for buildings to interact closely within clusters as energy generating devices. The savings gained from the environmental impact reduction can therefore be invested in renewable energy absorption devices which are currently costly technology. This scenario potentially will influence technological progress in facade development and whole areas being designed for the purpose of energy absorption.

The decentralised energy networks explores the relationship between energy supply and demand resulting in the application of a framework underpinned by a system of rules for energy absorption driven building design. The design rules influence reduction in human environmental impact and encourage a planning approach to gain the maximum available renewable energy. Areas within energy gradients will become energy independent trading units based on local micro power generation leading to energy security for communities. The use of renewable sources also creates opportunities to feed into power grid.

7. Concluding Remarks

This approach is not only driven by local environmental factors but globally to respond to current demand for energy efficiency and better quality of life. There is a need to adopt activity-based rather than the traditional functional-based design principles to address the actual needs of communities in terms of land and energy needs to decrease the environmental impact on the planet. The proposed approach takes into account the social, environmental and economic aspects to develop sustainable communities of globally aware citizens who are prepared to reduce their carbon footprint without compromising on their core activities. As prices of fossil fuel and their exploitation from other countries becomes far more unpredictable, gaining energy independence at a reasonable cost is critical to the present and future development of sustainable communities.